GNU Awk

GAWK: Effective AWK Programming

A User's Guide for GNU Awk
Edition 5.4
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Arnold D. Robbins

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To my parents, for their love, and for the wonderful example they set for me.

To my wife, Miriam, for making me complete. Thank you for building your life together with me.

To our children, Chana, Rivka, Nachum, and Malka, for enrichening our lives in innumerable ways.

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Foreword to the Third Edition

Arnold Robbins and I are good friends. We were introduced in 1990 by circumstances—and our favorite programming language, AWK. The circumstances started a couple of years earlier. I was working at a new job and noticed an unplugged Unix computer sitting in the corner. No one knew how to use it, and neither did I. However, a couple of days later, it was running, and I was `root` and the one-and-only user. That day, I began the transition from statistician to Unix programmer.

On one of many trips to the library or bookstore in search of books on Unix, I found the gray AWK book, a.k.a. Alfred V. Aho, Brian W. Kernighan, and Peter J. Weinberger's *The AWK Programming Language* (Addison-Wesley, 1988). `awk`'s simple programming paradigm—find a pattern in the input and then perform an action—often reduced complex or tedious data manipulations to a few lines of code. I was excited to try my hand at programming in AWK.

Alas, the `awk` on my computer was a limited version of the language described in the gray book. I discovered that my computer had "old `awk`" and the book described "new `awk`." I learned that this was typical; the old version refused to step aside or relinquish its name. If a system had a new `awk`, it was invariably called `nawk`, and few systems had it. The best way to get a new `awk` was to `ftp` the source code for `gawk` from `prep.ai.mit.edu`. `gawk` was a version of new `awk` written by David Trueman and Arnold, and available under the GNU General Public License.

(Incidentally, it's no longer difficult to find a new `awk`. `gawk` ships with GNU/Linux, and you can download binaries or source code for almost any system; my wife uses `gawk` on her VMS box.)

My Unix system started out unplugged from the wall; it certainly was not plugged into a network. So, oblivious to the existence of `gawk` and the Unix community in general, and desiring a new `awk`, I wrote my own, called `mawk`. Before I was finished, I knew about `gawk`, but it was too late to stop, so I eventually posted to a `comp.sources` newsgroup.

A few days after my posting, I got a friendly email from Arnold introducing himself. He suggested we share design and algorithms and attached a draft of the POSIX standard so that I could update `mawk` to support language extensions added after publication of *The AWK Programming Language*.

Frankly, if our roles had been reversed, I would not have been so open and we probably would have never met. I'm glad we did meet. He is an AWK expert's AWK expert and a genuinely nice person. Arnold contributes significant amounts of his expertise and time to the Free Software Foundation.

This book is the `gawk` reference manual, but at its core it is a book about AWK programming that will appeal to a wide audience. It is a definitive reference to the AWK language as defined by the 1987 Bell Laboratories release and codified in the 1992 POSIX Utilities standard.

On the other hand, the novice AWK programmer can study a wealth of practical programs that emphasize the power of AWK's basic idioms: data-driven control flow, pattern matching with regular expressions, and associative arrays. Those looking for something new can try out `gawk`'s interface to network protocols via special `/inet` files.

The programs in this book make clear that an AWK program is typically much smaller and faster to develop than a counterpart written in C. Consequently, there is often a payoff to prototyping an algorithm or design in AWK to get it running quickly and expose problems early. Often, the interpreted performance is adequate and the AWK prototype becomes the product.

The new `pgawk` (profiling `gawk`), produces program execution counts. I recently experimented with an algorithm that for n lines of input, exhibited $\sim Cn^2$ performance, while theory predicted $\sim Cn \log n$ behavior. A few minutes poring over the `awkprof.out` profile pinpointed the problem to a single line of code. `pgawk` is a welcome addition to my programmer's toolbox.

Arnold has distilled over a decade of experience writing and using AWK programs, and developing `gawk`, into this book. If you use AWK or want to learn how, then read this book.

Michael Brennan
Author of `mawk`
March 2001

Foreword to the Fourth Edition

Some things don't change. Thirteen years ago I wrote: "If you use AWK or want to learn how, then read this book." True then, and still true today.

Learning to use a programming language is about more than mastering the syntax. One needs to acquire an understanding of how to use the features of the language to solve practical programming problems. A focus of this book is many examples that show how to use AWK.

Some things do change. Our computers are much faster and have more memory. Consequently, speed and storage inefficiencies of a high-level language matter less. Prototyping in AWK and then rewriting in C for performance reasons happens less, because more often the prototype is fast enough.

Of course, there are computing operations that are best done in C or C++. With `gawk` 4.1 and later, you do not have to choose between writing your program in AWK or in C/C++. You can write most of your program in AWK and the aspects that require C/C++ capabilities can be written in C/C++, and then the pieces glued together when the `gawk` module loads the C/C++ module as a dynamic plug-in. Chapter 17 [Writing Extensions for `gawk`], page 415, has all the details, and, as expected, many examples to help you learn the ins and outs.

I enjoy programming in AWK and had fun (re)reading this book. I think you will too.

Michael Brennan
Author of `mawk`
October 2014

Preface

Several kinds of tasks occur repeatedly when working with text files. You might want to extract certain lines and discard the rest. Or you may need to make changes wherever certain patterns appear, but leave the rest of the file alone. Such jobs are often easy with `awk`. The `awk` utility interprets a special-purpose programming language that makes it easy to handle simple data-reformatting jobs.

The GNU implementation of `awk` is called `gawk`; if you invoke it with the proper options or environment variables, it is fully compatible with the POSIX[1] specification of the `awk` language and with the Unix version of `awk` maintained by Brian Kernighan. This means that all properly written `awk` programs should work with `gawk`. So most of the time, we don't distinguish between `gawk` and other `awk` implementations.

Using `awk` you can:

- Manage small, personal databases
- Generate reports
- Validate data
- Produce indexes and perform other document-preparation tasks
- Experiment with algorithms that you can adapt later to other computer languages

In addition, `gawk` provides facilities that make it easy to:

- Extract bits and pieces of data for processing
- Sort data
- Perform simple network communications
- Profile and debug `awk` programs
- Extend the language with functions written in C or C++

This book teaches you about the `awk` language and how you can use it effectively. You should already be familiar with basic system commands, such as `cat` and `ls`,[2] as well as basic shell facilities, such as input/output (I/O) redirection and pipes.

Implementations of the `awk` language are available for many different computing environments. This book, while describing the `awk` language in general, also describes the particular implementation of `awk` called `gawk` (which stands for "GNU `awk`"). `gawk` runs on a broad range of Unix systems, ranging from Intel-architecture PC-based computers up through large-scale systems. `gawk` has also been ported to macOS, z/OS, Microsoft Windows (all versions), and OpenVMS.[3]

---

[1] The 2018 POSIX standard is accessible online at https://pubs.opengroup.org/onlinepubs/9699919799/.

[2] These utilities are available on POSIX-compliant systems, as well as on traditional Unix-based systems. If you are using some other operating system, you still need to be familiar with the ideas of I/O redirection and pipes.

[3] Some other, obsolete systems to which `gawk` was once ported are no longer supported and the code for those systems has been removed.

History of awk and gawk

Recipe for a Programming Language

1 part `egrep`	1 part `snobol`
2 parts `ed`	3 parts C

Blend all parts well using `lex` and `yacc`. Document minimally and release.

After eight years, add another part `egrep` and two more parts C. Document very well and release.

After 35 more years, add Unicode and CSV support, sprinkle lightly with a few choice features from `gawk`, document very well again, and release.

The name `awk` comes from the initials of its designers: Alfred V. Aho, Peter J. Weinberger, and Brian W. Kernighan. The original version of `awk` was written in 1977 at AT&T Bell Laboratories. In 1985, a new version made the programming language more powerful, introducing user-defined functions, multiple input streams, and computed regular expressions. This new version became widely available with Unix System V Release 3.1 (1987). The version in System V Release 4 (1989) added some new features and cleaned up the behavior in some of the "dark corners" of the language. The specification for `awk` in the POSIX Command Language and Utilities standard further clarified the language. Both the `gawk` designers and the original `awk` designers at Bell Laboratories provided feedback for the POSIX specification.

Paul Rubin wrote `gawk` in 1986. Jay Fenlason completed it, with advice from Richard Stallman. John Woods contributed parts of the code as well. In 1988 and 1989, David Trueman, with help from me, thoroughly reworked `gawk` for compatibility with the newer `awk`. Circa 1994, I became the primary maintainer. Current development focuses on bug fixes, performance improvements, standards compliance, and, occasionally, new features.

In May 1997, Jürgen Kahrs felt the need for network access from `awk`, and with a little help from me, set about adding features to do this for `gawk`. At that time, he also wrote the bulk of *TCP/IP Internetworking with* `gawk` (a separate document, available as part of the `gawk` distribution). His code finally became part of the main `gawk` distribution with `gawk` version 3.1.

John Haque rewrote the `gawk` internals, in the process providing an `awk`-level debugger. This version became available as `gawk` version 4.0 in 2011.

See Section A.9 [Major Contributors to gawk], page 498, for a full list of those who have made important contributions to `gawk`.

A Rose by Any Other Name

The `awk` language has evolved over the years. Full details are provided in Appendix A [The Evolution of the awk Language], page 483. The language described in this book is often referred to as "new `awk`." By analogy, the original version of `awk` is referred to as "old `awk`."

On most current systems, when you run the `awk` utility you get some version of new `awk`.[4] If your system's standard `awk` is the old one, you will see something like this if you try the following test program:

```
$ awk 1 /dev/null
error  awk: syntax error near line 1
error  awk: bailing out near line 1
```

In this case, you should find a version of new `awk`, or just install `gawk`!

Throughout this book, whenever we refer to a language feature that should be available in any complete implementation of POSIX `awk`, we simply use the term `awk`. When referring to a feature that is specific to the GNU implementation, we use the term `gawk`.

Using This Book

The term `awk` refers to a particular program as well as to the language you use to tell this program what to do. When we need to be careful, we call the language "the `awk` language," and the program "the `awk` utility." This book explains both how to write programs in the `awk` language and how to run the `awk` utility. The term "`awk` program" refers to a program written by you in the `awk` programming language.

Primarily, this book explains the features of `awk` as defined in the POSIX standard. It does so in the context of the `gawk` implementation. While doing so, it also attempts to describe important differences between `gawk` and other `awk` implementations.[5] Finally, it notes any `gawk` features that are not in the POSIX standard for `awk`.

This book has the difficult task of being both a tutorial and a reference. If you are a novice, feel free to skip over details that seem too complex. You should also ignore the many cross-references; they are for the expert user and for the Info and HTML versions of the book.

There are sidebars scattered throughout the book. They add a more complete explanation of points that are relevant, but not likely to be of interest on first reading. All appear in the index, under the heading "sidebar."

Most of the time, the examples use complete `awk` programs. Some of the more advanced sections show only the part of the `awk` program that illustrates the concept being described.

Although this book is aimed principally at people who have not been exposed to `awk`, there is a lot of information here that even the `awk` expert should find useful. In particular, the description of POSIX `awk` and the example programs in Chapter 10 [A Library of `awk` Functions], page 247, and in Chapter 11 [Practical `awk` Programs], page 285, should be of interest.

This book is split into several parts, as follows:

- Part I describes the `awk` language and the `gawk` program in detail. It starts with the basics, and continues through all of the features of `awk`. It contains the following chapters:
  - Chapter 1 [Getting Started with `awk`], page 17, provides the essentials you need to know to begin using `awk`.

[4] Only Solaris systems still use an old `awk` for the default `awk` utility. A more modern `awk` lives in `/usr/xpg6/bin` on these systems.

[5] All such differences appear in the index under the entry "differences in `awk` and `gawk`."

- Chapter 2 [Running awk and gawk], page 33, describes how to run gawk, the meaning of its command-line options, and how it finds awk program source files.
- Chapter 3 [Regular Expressions], page 51, introduces regular expressions in general, and in particular the flavors supported by POSIX awk and gawk.
- Chapter 4 [Reading Input Files], page 69, describes how awk reads your data. It introduces the concepts of records and fields, as well as the getline function. I/O redirection is first described here. Network I/O is also briefly introduced here.
- Chapter 5 [Printing Output], page 103, describes how awk programs can produce output with print and printf.
- Chapter 6 [Expressions], page 123, describes expressions, which are the basic building blocks for getting most things done in a program.
- Chapter 7 [Patterns, Actions, and Variables], page 151, describes how to write patterns for matching records, actions for doing something when a record is matched, and the predefined variables awk and gawk use.
- Chapter 8 [Arrays in awk], page 181, covers awk's one-and-only data structure: the associative array. Deleting array elements and whole arrays is described, as well as sorting arrays in gawk. The chapter also describes how gawk provides arrays of arrays.
- Chapter 9 [Functions], page 197, describes the built-in functions awk and gawk provide, as well as how to define your own functions. It also discusses how gawk lets you call functions indirectly.

- Part II shows how to use awk and gawk for problem solving. There is lots of code here for you to read and learn from. This part contains the following chapters:
  - Chapter 10 [A Library of awk Functions], page 247, provides a number of functions meant to be used from main awk programs.
  - Chapter 11 [Practical awk Programs], page 285, provides many sample awk programs.

  Reading these two chapters allows you to see awk solving real problems.
- Part III focuses on features specific to gawk. It contains the following chapters:
  - Chapter 12 [Advanced Features of gawk], page 343, describes a number of advanced features. Of particular note are the abilities to control the order of array traversal, have two-way communications with another process, perform TCP/IP networking, and profile your awk programs.
  - Chapter 13 [Internationalization with gawk], page 365, describes special features for translating program messages into different languages at runtime.
  - Chapter 14 [Debugging awk Programs], page 375, describes the gawk debugger.
  - Chapter 15 [Namespaces in gawk], page 391, describes how gawk allows variables and/or functions of the same name to be in different namespaces.
  - Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399, describes advanced arithmetic facilities.
  - Chapter 17 [Writing Extensions for gawk], page 415, describes how to add new variables and functions to gawk by writing extensions in C or C++.

- Part IV provides the appendices, the Glossary, and two licenses that cover the `gawk` source code and this book, respectively. It contains the following appendices:
  - Appendix A [The Evolution of the `awk` Language], page 483, describes how the `awk` language has evolved since its first release to the present. It also describes how `gawk` has acquired features over time.
  - Appendix B [Installing `gawk`], page 503, describes how to get `gawk`, how to compile it on POSIX-compatible systems, and how to compile and use it on different non-POSIX systems. It also describes how to report bugs in `gawk` and where to get other freely available `awk` implementations.
  - Appendix C [Implementation Notes], page 529, describes how to disable `gawk`'s extensions, as well as how to contribute new code to `gawk`, and some possible future directions for `gawk` development.
  - Appendix D [Basic Programming Concepts], page 539, provides some very cursory background material for those who are completely unfamiliar with computer programming.
  - The [Glossary], page 543, defines most, if not all, of the significant terms used throughout the book. If you find terms that you aren't familiar with, try looking them up here.
  - [GNU General Public License], page 557, and [GNU Free Documentation License], page 569, present the licenses that cover the `gawk` source code and this book, respectively.

Typographical Conventions

This book is written in Texinfo, the GNU documentation formatting language. A single Texinfo source file is used to produce both the printed and online versions of the documentation. Because of this, the typographical conventions are slightly different than in other books you may have read.

Examples you would type at the command line are preceded by the common shell primary and secondary prompts, '`$`' and '`>`', respectively. Input that you type is shown *`like this`*. Output from the command is preceded by the glyph "⊣". This typically represents the command's standard output. Error messages and other output on the command's standard error are preceded by the glyph " error ". For example:

```
$ echo hi on stdout
⊣ hi on stdout
$ echo hello on stderr 1>&2
error  hello on stderr
```

In the text, almost anything related to programming, such as command names, variable and function names, and string, numeric and regexp constants appear in `this font`. Code fragments appear in the same font and quoted, '`like this`'. Things that are replaced by the user or programmer appear in *this font*. Options look like this: `-f`. File names are indicated like this: `/path/to/ourfile`. Some things are emphasized *like this*, and if a point needs to be made strongly, it is done **like this**. The first occurrence of a new term is usually its *definition* and appears in the same font as the previous occurrence of "definition" in this sentence.

Characters that you type at the keyboard look *like this*. In particular, there are special characters called "control characters." These are characters that you type by holding down both the *CONTROL* key and another key, at the same time. For example, a *Ctrl-d* is typed by first pressing and holding the *CONTROL* key, next pressing the *d* key, and finally releasing both keys.

For the sake of brevity, throughout this book, we refer to Brian Kernighan's version of `awk` as "BWK `awk`." (See Section B.5 [Other Freely Available `awk` Implementations], page 523, for information on his and other versions.)

Dark Corners

> *Dark corners are basically fractal—no matter how much you illuminate, there's always a smaller but darker one.*
>
> —*Brian Kernighan*

Until the POSIX standard (and *GAWK: Effective AWK Programming*), many features of `awk` were either poorly documented or not documented at all. Descriptions of such features (often called "dark corners") are noted in this book with the picture of a flashlight in the margin, as shown here. They also appear in the index under the heading "dark corner."

But, as noted by the opening quote, any coverage of dark corners is by definition incomplete.

Extensions to the standard `awk` language that are supported by more than one `awk` implementation are marked "(c.e.)," and listed in the index under "common extensions" and "extensions, common."

The GNU Project and This Book

The Free Software Foundation (FSF) is a nonprofit organization dedicated to the production and distribution of freely distributable software. It was founded by Richard M. Stallman, the author of the original Emacs editor. GNU Emacs is the most widely used version of Emacs today.

The GNU[6] Project is an ongoing effort on the part of the Free Software Foundation to create a complete, freely distributable, POSIX-compliant computing environment. The FSF uses the GNU General Public License (GPL) to ensure that its software's source code is always available to the end user. A copy of the GPL is included in this book for your reference (see [GNU General Public License], page 557). The GPL applies to the C language source code for `gawk`. To find out more about the FSF and the GNU Project online, see the GNU Project's home page. This book may also be read from GNU's website.

A shell, an editor (Emacs), highly portable optimizing C, C++, and Objective-C compilers, a symbolic debugger and dozens of large and small utilities (such as `gawk`), have all been completed and are freely available. The GNU operating system kernel (the HURD), has been released but remains in an early stage of development.

Until the GNU operating system is more fully developed, you should consider using GNU/Linux, a freely distributable, Unix-like operating system for Intel, Power Architecture,

[6] GNU stands for "GNU's Not Unix."

Sun SPARC, IBM S/390, and other systems.[7] Many GNU/Linux distributions are available for download from the Internet.

The book you are reading is actually free—at least, the information in it is free to anyone. The machine-readable source code for the book comes with `gawk`. (Take a moment to check the Free Documentation License in [GNU Free Documentation License], page 569.)

The book itself has gone through multiple previous editions. Paul Rubin wrote the very first draft of *The GAWK Manual*; it was around 40 pages long. Diane Close and Richard Stallman improved it, yielding a version that was around 90 pages and barely described the original, "old" version of `awk`.

I started working with that version in the fall of 1988. As work on it progressed, the FSF published several preliminary versions (numbered 0.*x*). In 1996, edition 1.0 was released with `gawk` 3.0.0. The FSF published the first two editions under the title *The GNU Awk User's Guide*.

This edition maintains the basic structure of the previous editions. For FSF edition 4.0, the content was thoroughly reviewed and updated. All references to `gawk` versions prior to 4.0 were removed. Of significant note for that edition was the addition of Chapter 14 [Debugging `awk` Programs], page 375.

For FSF edition 5.0, the content has been reorganized into parts, and the major new additions are Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with `gawk`], page 399, and Chapter 17 [Writing Extensions for `gawk`], page 415.

This book will undoubtedly continue to evolve. If you find an error in the book, please report it! See Section B.4 [Reporting Problems and Bugs], page 518, for information on submitting problem reports electronically.

How to Contribute

As the maintainer of GNU `awk`, I once thought that I would be able to manage a collection of publicly available `awk` programs and I even solicited contributions. Making things available on the Internet helps keep the `gawk` distribution down to manageable size.

The initial collection of material, such as it is, is still available at `ftp://ftp.freefriends.org/arnold/Awkstuff`.

In the hopes of doing something broader, I acquired the `awklang.org` domain. Late in 2017, a volunteer took on the task of managing it.

If you have written an interesting `awk` program that you would like to share with the rest of the world, please see `http://www.awklang.org` and use the "Contact" link.

If you have written a `gawk` extension, please see Section 17.8 [The `gawkextlib` Project], page 478.

Acknowledgments

The initial draft of *The GAWK Manual* had the following acknowledgments:

> Many people need to be thanked for their assistance in producing this manual. Jay Fenlason contributed many ideas and sample programs. Richard Mlynarik

[7] The terminology "GNU/Linux" is explained in the [Glossary], page 543.

and Robert Chassell gave helpful comments on drafts of this manual. The paper *A Supplemental Document for AWK* by John W. Pierce of the Chemistry Department at UC San Diego, pinpointed several issues relevant both to `awk` implementation and to this manual, that would otherwise have escaped us.

I would like to acknowledge Richard M. Stallman, for his vision of a better world and for his courage in founding the FSF and starting the GNU Project.

Earlier editions of this book had the following acknowledgements:

The following people (in alphabetical order) provided helpful comments on various versions of this book: Rick Adams, Dr. Nelson H.F. Beebe, Karl Berry, Dr. Michael Brennan, Rich Burridge, Claire Cloutier, Diane Close, Scott Deifik, Christopher ("Topher") Eliot, Jeffrey Friedl, Dr. Darrel Hankerson, Michal Jaegermann, Dr. Richard J. LeBlanc, Michael Lijewski, Pat Rankin, Miriam Robbins, Mary Sheehan, and Chuck Toporek.

Robert J. Chassell provided much valuable advice on the use of Texinfo. He also deserves special thanks for convincing me *not* to title this book *How to Gawk Politely*. Karl Berry helped significantly with the TEX part of Texinfo.

I would like to thank Marshall and Elaine Hartholz of Seattle and Dr. Bert and Rita Schreiber of Detroit for large amounts of quiet vacation time in their homes, which allowed me to make significant progress on this book and on `gawk` itself.

Phil Hughes of SSC contributed in a very important way by loaning me his laptop GNU/Linux system, not once, but twice, which allowed me to do a lot of work while away from home.

David Trueman deserves special credit; he has done a yeoman job of evolving `gawk` so that it performs well and without bugs. Although he is no longer involved with `gawk`, working with him on this project was a significant pleasure.

The intrepid members of the GNITS mailing list, and most notably Ulrich Drepper, provided invaluable help and feedback for the design of the internationalization features.

Chuck Toporek, Mary Sheehan, and Claire Cloutier of O'Reilly & Associates contributed significant editorial help for this book for the 3.1 release of `gawk`.

Dr. Nelson Beebe, Andreas Buening, Dr. Manuel Collado, Antonio Colombo, Stephen Davies, Scott Deifik, Akim Demaille, Daniel Richard G., Juan Manuel Guerrero, Darrel Hankerson, Michal Jaegermann, Jürgen Kahrs, Stepan Kasal, John Malmberg, Chet Ramey, Pat Rankin, Andrew Schorr, Corinna Vinschen, and Eli Zaretskii (in alphabetical order) make up the current `gawk` "crack portability team." Without their hard work and help, `gawk` would not be nearly the robust, portable program it is today. It has been and continues to be a pleasure working with this team of fine people.

Notable code and documentation contributions were made by a number of people. See Section A.9 [Major Contributors to `gawk`], page 498, for the full list.

Thanks to Michael Brennan for the Forewords.

Thanks to Patrice Dumas for the new `makeinfo` program. Thanks to Karl Berry for his past work on Texinfo, and to Gavin Smith, who continues to work to improve the Texinfo markup language.

Robert P.J. Day, Michael Brennan, and Brian Kernighan kindly acted as reviewers for the 2015 edition of this book. Their feedback helped improve the final work.

I would also like to thank Brian Kernighan for his invaluable assistance during the testing and debugging of `gawk`, and for his ongoing help and advice in clarifying numerous points about the language. We could not have done nearly as good a job on either `gawk` or its documentation without his help.

Brian is in a class by himself as a programmer and technical author. I have to thank him (yet again) for his ongoing friendship and for being a role model to me for over 30 years! Having him as a reviewer is an exciting privilege. It has also been extremely humbling. . .

I must thank my wonderful wife, Miriam, for her patience through the many versions of this project, for her proofreading, and for sharing me with the computer. I would like to thank my parents for their love, and for the grace with which they raised and educated me. Finally, I also must acknowledge my gratitude to G-d, for the many opportunities He has sent my way, as well as for the gifts He has given me with which to take advantage of those opportunities.

Arnold Robbins
Nof Ayalon
Israel
March, 2020

Part I:
The `awk` Language

1 Getting Started with awk

The basic function of awk is to search files for lines (or other units of text) that contain certain patterns. When a line matches one of the patterns, awk performs specified actions on that line. awk continues to process input lines in this way until it reaches the end of the input files.

Programs in awk are different from programs in most other languages, because awk programs are *data driven* (i.e., you describe the data you want to work with and then what to do when you find it). Most other languages are *procedural*; you have to describe, in great detail, every step the program should take. When working with procedural languages, it is usually much harder to clearly describe the data your program will process. For this reason, awk programs are often refreshingly easy to read and write.

When you run awk, you specify an awk *program* that tells awk what to do. The program consists of a series of *rules* (it may also contain *function definitions*, an advanced feature that we will ignore for now; see Section 9.2 [User-Defined Functions], page 225). Each rule specifies one pattern to search for and one action to perform upon finding the pattern.

Syntactically, a rule consists of a *pattern* followed by an *action*. The action is enclosed in braces to separate it from the pattern. Newlines usually separate rules. Therefore, an awk program looks like this:

```
pattern { action }
pattern { action }
...
```

1.1 How to Run awk Programs

There are several ways to run an awk program. If the program is short, it is easiest to include it in the command that runs awk, like this:

```
awk 'program' input-file1 input-file2 ...
```

When the program is long, it is usually more convenient to put it in a file and run it with a command like this:

```
awk -f program-file input-file1 input-file2 ...
```

This section discusses both mechanisms, along with several variations of each.

1.1.1 One-Shot Throwaway awk Programs

Once you are familiar with awk, you will often type in simple programs the moment you want to use them. Then you can write the program as the first argument of the awk command, like this:

```
awk 'program' input-file1 input-file2 ...
```

where *program* consists of a series of patterns and actions, as described earlier.

This command format instructs the *shell*, or command interpreter, to start awk and use the *program* to process records in the input file(s). There are single quotes around *program* so the shell won't interpret any awk characters as special shell characters. The quotes also cause the shell to treat all of *program* as a single argument for awk, and allow *program* to be more than one line long.

This format is also useful for running short or medium-sized `awk` programs from shell scripts, because it avoids the need for a separate file for the `awk` program. A self-contained shell script is more reliable because there are no other files to misplace.

Later in this chapter, in Section 1.3 [Some Simple Examples], page 25, we'll see examples of several short, self-contained programs.

1.1.2 Running `awk` Without Input Files

You can also run `awk` without any input files. If you type the following command line:

```
awk 'program'
```

`awk` applies the *program* to the *standard input*, which usually means whatever you type on the keyboard. This continues until you indicate end-of-file by typing *Ctrl-d*. (On non-POSIX operating systems, the end-of-file character may be different.)

As an example, the following program prints a friendly piece of advice (from Douglas Adams's *The Hitchhiker's Guide to the Galaxy*), to keep you from worrying about the complexities of computer programming:

```
$ awk 'BEGIN { print "Don\47t Panic!" }'
⊣ Don't Panic!
```

`awk` executes statements associated with `BEGIN` before reading any input. If there are no other statements in your program, as is the case here, `awk` just stops, instead of trying to read input it doesn't know how to process. The '`\47`' is a magic way (explained later) of getting a single quote into the program, without having to engage in ugly shell quoting tricks.

> **NOTE:** If you use Bash as your shell, you should execute the command '`set +H`' before running this program interactively, to disable the C shell-style command history, which treats '`!`' as a special character. We recommend putting this command into your personal startup file.

This next simple `awk` program emulates the `cat` utility; it copies whatever you type on the keyboard to its standard output (why this works is explained shortly):

```
$ awk '{ print }'
Now is the time for all good men
⊣ Now is the time for all good men
to come to the aid of their country.
⊣ to come to the aid of their country.
Four score and seven years ago, ...
⊣ Four score and seven years ago, ...
What, me worry?
⊣ What, me worry?
Ctrl-d
```

1.1.3 Running Long Programs

Sometimes `awk` programs are very long. In these cases, it is more convenient to put the program into a separate file. In order to tell `awk` to use that file for its program, you type:

```
awk -f source-file input-file1 input-file2 ...
```

The -f instructs the awk utility to get the awk program from the file *source-file* (see Section 2.2 [Command-Line Options], page 33). Any file name can be used for *source-file*. For example, you could put the program:

```
BEGIN { print "Don't Panic!" }
```

into the file advice. Then this command:

```
awk -f advice
```

does the same thing as this one:

```
awk 'BEGIN { print "Don\47t Panic!" }'
```

This was explained earlier (see Section 1.1.2 [Running awk Without Input Files], page 18). Note that you don't usually need single quotes around the file name that you specify with -f, because most file names don't contain any of the shell's special characters. (If your file names have spaces in them, then you will need the single quotes.) Notice that in advice, the awk program did not have single quotes around it. The quotes are only needed for programs that are provided on the awk command line. (Also, placing the program in a file allows us to use a literal single quote in the program text, instead of the magic '\47'.)

If you want to clearly identify an awk program file as such, you can add the extension .awk to the file name. This doesn't affect the execution of the awk program but it does make "housekeeping" easier.

1.1.4 Executable awk Programs

Once you have learned awk, you may want to write self-contained awk scripts, using the '#!' script mechanism. You can do this on many systems.[1] For example, you could update the file advice to look like this:

```
#! /bin/awk -f

BEGIN { print "Don't Panic!" }
```

After making this file executable (with the chmod utility), simply type 'advice' at the shell and the system arranges to run awk as if you had typed 'awk -f advice':

```
$ chmod +x advice
$ ./advice
⊣ Don't Panic!
```

Self-contained awk scripts are useful when you want to write a program that users can invoke without their having to know that the program is written in awk.

[1] The '#!' mechanism works on GNU/Linux systems, BSD-based systems, and commercial Unix systems.

Understanding '#!'

`awk` is an *interpreted* language. This means that the `awk` utility reads your program and then processes your data according to the instructions in your program. (This is different from a *compiled* language such as C, where your program is first compiled into machine code that is executed directly by your system's processor.) The `awk` utility is thus termed an *interpreter*. Many modern languages are interpreted.

The line beginning with '`#!`' lists the full file name of an interpreter to run and a single optional initial command-line argument to pass to that interpreter. The operating system then runs the interpreter with the given argument and the full argument list of the executed program. The first argument in the list is the full file name of the `awk` program. The rest of the argument list contains either options to `awk`, or data files, or both. (Note that on many systems `awk` is found in `/usr/bin` instead of in `/bin`.)

Some systems limit the length of the interpreter name to 32 characters. Often, this can be dealt with by using a symbolic link.

You should not put more than one argument on the '`#!`' line after the path to `awk`. It does not work. The operating system treats the rest of the line as a single argument and passes it to `awk`. Doing this leads to confusing behavior—most likely a usage diagnostic of some sort from `awk`.

Finally, the value of `ARGV[0]` (see Section 7.5 [Predefined Variables], page 167) varies depending upon your operating system. Some systems put '`awk`' there, some put the full pathname of `awk` (such as `/bin/awk`), and some put the name of your script ('`advice`'). Don't rely on the value of `ARGV[0]` to provide your script name.

1.1.5 Comments in `awk` Programs

A *comment* is some text that is included in a program for the sake of human readers; it is not really an executable part of the program. Comments can explain what the program does and how it works. Nearly all programming languages have provisions for comments, as programs are typically hard to understand without them.

In the `awk` language, a comment starts with the number sign character ('`#`') and continues to the end of the line. The '`#`' does not have to be the first character on the line. The `awk` language ignores the rest of a line following a number sign. For example, we could have put the following into `advice`:

```
# This program prints a nice, friendly message.  It helps
# keep novice users from being afraid of the computer.
BEGIN    { print "Don't Panic!" }
```

You can put comment lines into keyboard-composed throwaway `awk` programs, but this usually isn't very useful; the purpose of a comment is to help you or another person understand the program when reading it at a later time.

CAUTION: As mentioned in Section 1.1.1 [One-Shot Throwaway `awk` Programs], page 17, you can enclose short to medium-sized programs in single quotes, in order to keep your shell scripts self-contained. When doing so, *don't* put an apostrophe (i.e., a single quote) into a comment (or anywhere else in your program). The shell interprets the quote as the closing quote for the en-

tire program. As a result, usually the shell prints a message about mismatched quotes, and if `awk` actually runs, it will probably print strange messages about syntax errors. For example, look at the following:

```
$ awk 'BEGIN { print "hello" } # let's be cute'
>
```

The shell sees that the first two quotes match, and that a new quoted object begins at the end of the command line. It therefore prompts with the secondary prompt, waiting for more input. With BWK `awk`, closing the quoted string produces this result:

```
$ nawk '{ print "hello" } # let's be cute'
> '
error  awk: can't open file be
error   source line number 1
```

Putting a backslash before the single quote in '`let's`' wouldn't help, because backslashes are not special inside single quotes. The next subsection describes the shell's quoting rules.

1.1.6 Shell Quoting Issues

For short to medium-length `awk` programs, it is most convenient to enter the program on the `awk` command line. This is best done by enclosing the entire program in single quotes. This is true whether you are entering the program interactively at the shell prompt, or writing it as part of a larger shell script:

```
awk 'program text' input-file1 input-file2 ...
```

Once you are working with the shell, it is helpful to have a basic knowledge of shell quoting rules. The following rules apply only to POSIX-compliant, Bourne-style shells (such as Bash, the GNU Bourne-Again Shell). If you use the C shell, you're on your own.

Before diving into the rules, we introduce a concept that appears throughout this book, which is that of the *null*, or empty, string.

The null string is character data that has no value. In other words, it is empty. It is written in `awk` programs like this: `""`. In the shell, it can be written using single or double quotes: `''` or `""`. Although the null string has no characters in it, it does exist. For example, consider this command:

```
$ echo ""
```

Here, the `echo` utility receives a single argument, even though that argument has no characters in it. In the rest of this book, we use the terms *null string* and *empty string* interchangeably. Now, on to the quoting rules:

- Quoted items can be concatenated with nonquoted items as well as with other quoted items. The shell turns everything into one argument for the command.
- Preceding any single character with a backslash ('\') quotes that character. The shell removes the backslash and passes the quoted character on to the command.
- Single quotes protect everything between the opening and closing quotes. The shell does no interpretation of the quoted text, passing it on verbatim to the command. It is *impossible* to embed a single quote inside single-quoted text. Refer back to Section 1.1.5 [Comments in awk Programs], page 20, for an example of what happens if you try.

- Double quotes protect most things between the opening and closing quotes. The shell does at least variable and command substitution on the quoted text. Different shells may do additional kinds of processing on double-quoted text.

  Because certain characters within double-quoted text are processed by the shell, they must be *escaped* within the text. Of note are the characters '`$`', '`` ` ``', '`\`', and '`"`', all of which must be preceded by a backslash within double-quoted text if they are to be passed on literally to the program. (The shell strips the leading backslash first.) Thus, the example seen previously in Section 1.1.2 [Running `awk` Without Input Files], page 18:

  ```
  awk 'BEGIN { print "Don\47t Panic!" }'
  ```

  could instead be written this way:

  ```
  $ awk "BEGIN { print \"Don't Panic!\" }"
  ⊣ Don't Panic!
  ```

  Note that the single quote is not special within double quotes.

- Null strings are removed when they occur as part of a non-null command-line argument, while explicit null objects are kept. For example, to specify that the field separator `FS` should be set to the null string, use:

  ```
  awk -F "" 'program' files # correct
  ```

  Don't use this:

  ```
  awk -F"" 'program' files  # wrong!
  ```

  In the second case, `awk` attempts to use the text of the program as the value of `FS`, and the first file name as the text of the program! This results in syntax errors at best, and confusing behavior at worst.

Mixing single and double quotes is difficult. You have to resort to shell quoting tricks, like this:

```
$ awk 'BEGIN { print "Here is a single quote <'"'"'>" }'
⊣ Here is a single quote <'>
```

This program consists of three concatenated quoted strings. The first and the third are single-quoted, and the second is double-quoted.

This can be "simplified" to:

```
$ awk 'BEGIN { print "Here is a single quote <'\''>" }'
⊣ Here is a single quote <'>
```

Judge for yourself which of these two is the more readable.

Another option is to use double quotes, escaping the embedded, `awk`-level double quotes:

```
$ awk "BEGIN { print \"Here is a single quote <'>\" }"
⊣ Here is a single quote <'>
```

This option is also painful, because double quotes, backslashes, and dollar signs are very common in more advanced `awk` programs.

A third option is to use the octal escape sequence equivalents (see Section 3.2 [Escape Sequences], page 52) for the single- and double-quote characters, like so:

```
$ awk 'BEGIN { print "Here is a single quote <\47>" }'
⊣ Here is a single quote <'>
$ awk 'BEGIN { print "Here is a double quote <\42>" }'
⊣ Here is a double quote <">
```

This works nicely, but you should comment clearly what the escape sequences mean.

A fourth option is to use command-line variable assignment, like this:

```
$ awk -v sq="'" 'BEGIN { print "Here is a single quote <" sq ">" }'
⊣ Here is a single quote <'>
```

(Here, the two string constants and the value of `sq` are concatenated into a single string that is printed by `print`.)

If you really need both single and double quotes in your `awk` program, it is probably best to move it into a separate file, where the shell won't be part of the picture and you can say what you mean.

1.1.6.1 Quoting in MS-Windows Batch Files

Although this book generally only worries about POSIX systems and the POSIX shell, the following issue arises often enough for many users that it is worth addressing.

The "shells" on Microsoft Windows systems use the double-quote character for quoting, and make it difficult or impossible to include an escaped double quote character in a command-line script. The following example, courtesy of Jeroen Brink, shows how to escape the double quotes from this one liner script that prints all lines in a file surrounded by double quotes:

```
{ print "\"" $0 "\"" }
```

In an MS-Windows command-line the one-liner script above may be passed as follows:

```
gawk "{ print \"\042\" $0 \"\042\" }" file
```

In this example the '`\042`' is the octal code for a double quote; `gawk` converts it into a real double-quote for output by the `print` statement.

In MS-Windows escaping double quotes is a little tricky because you use backslashes to escape double quotes, but backslashes themselves are not escaped in the usual way; indeed they are either duplicated or not, depending upon whether there is a subsequent double quote. The MS-Windows rule for double-quoting a string is the following:

1. For each double quote in the original string, let N be the number of backslash(es) before it, N might be zero. Replace these N backslash(es) by $2 \times N + 1$ backslash(es)
2. Let N be the number of backslash(es) tailing the original string, N might be zero. Replace these N backslash(es) by $2 \times N$ backslash(es)
3. Surround the resulting string by double quotes.

So to double-quote the one-liner script '`{ print "\"" $0 "\"" }`' from the previous example you would do it this way:

```
gawk "{ print \"\\\"\" $0 \"\\\"\" }" file
```

However, the use of '`\042`' instead of '`\\\"`' is also possible and easier to read, because backslashes that are not followed by a double quote don't need duplication.

1.2 Data files for the Examples

Many of the examples in this book take their input from two sample data files. The first, `mail-list`, represents a list of peoples' names together with their email addresses and information about those people. The second data file, called `inventory-shipped`, contains information about monthly shipments. In both files, each line is considered to be one *record*.

In `mail-list`, each record contains the name of a person, his/her phone number, his/her email address, and a code for his/her relationship with the author of the list. The columns are aligned using spaces. An '`A`' in the last column means that the person is an acquaintance. An '`F`' in the last column means that the person is a friend. An '`R`' means that the person is a relative:

```
Amelia       555-5553     amelia.zodiacusque@gmail.com    F
Anthony      555-3412     anthony.asserturo@hotmail.com   A
Becky        555-7685     becky.algebrarum@gmail.com      A
Bill         555-1675     bill.drowning@hotmail.com       A
Broderick    555-0542     broderick.aliquotiens@yahoo.com R
Camilla      555-2912     camilla.infusarum@skynet.be     R
Fabius       555-1234     fabius.undevicesimus@ucb.edu    F
Julie        555-6699     julie.perscrutabor@skeeve.com   F
Martin       555-6480     martin.codicibus@hotmail.com    A
Samuel       555-3430     samuel.lanceolis@shu.edu        A
Jean-Paul    555-2127     jeanpaul.campanorum@nyu.edu     R
```

The data file `inventory-shipped` represents information about shipments during the year. Each record contains the month, the number of green crates shipped, the number of red boxes shipped, the number of orange bags shipped, and the number of blue packages shipped, respectively. There are 16 entries, covering the 12 months of last year and the first four months of the current year. An empty line separates the data for the two years:

```
Jan  13  25  15 115
Feb  15  32  24 226
Mar  15  24  34 228
Apr  31  52  63 420
May  16  34  29 208
Jun  31  42  75 492
Jul  24  34  67 436
Aug  15  34  47 316
Sep  13  55  37 277
Oct  29  54  68 525
Nov  20  87  82 577
Dec  17  35  61 401

Jan  21  36  64 620
Feb  26  58  80 652
Mar  24  75  70 495
Apr  21  70  74 514
```

The sample files are included in the `gawk` distribution, in the directory `awklib/eg/data`.

1.3 Some Simple Examples

The following command runs a simple `awk` program that searches the input file `mail-list` for the character string '`li`' (a grouping of characters is usually called a *string*; the term *string* is based on similar usage in English, such as "a string of pearls" or "a string of cars in a train"):

```
awk '/li/ { print $0 }' mail-list
```

When lines containing '`li`' are found, they are printed because '`print $0`' means print the current line. (Just '`print`' by itself means the same thing, so we could have written that instead.)

You will notice that slashes ('`/`') surround the string '`li`' in the `awk` program. The slashes indicate that '`li`' is the pattern to search for. This type of pattern is called a *regular expression*, which is covered in more detail later (see Chapter 3 [Regular Expressions], page 51). The pattern is allowed to match parts of words. There are single quotes around the `awk` program so that the shell won't interpret any of it as special shell characters.

Here is what this program prints:

```
$ awk '/li/ { print $0 }' mail-list
⊣ Amelia       555-5553     amelia.zodiacusque@gmail.com    F
⊣ Broderick    555-0542     broderick.aliquotiens@yahoo.com R
⊣ Julie        555-6699     julie.perscrutabor@skeeve.com   F
⊣ Samuel       555-3430     samuel.lanceolis@shu.edu        A
```

In an `awk` rule, either the pattern or the action can be omitted, but not both. If the pattern is omitted, then the action is performed for *every* input line. If the action is omitted, the default action is to print all lines that match the pattern.

Thus, we could leave out the action (the `print` statement and the braces) in the previous example and the result would be the same: `awk` prints all lines matching the pattern '`li`'. By comparison, omitting the `print` statement but retaining the braces makes an empty action that does nothing (i.e., no lines are printed).

Many practical `awk` programs are just a line or two long. Following is a collection of useful, short programs to get you started. Some of these programs contain constructs that haven't been covered yet. (The description of the program will give you a good idea of what is going on, but you'll need to read the rest of the book to become an `awk` expert!) Most of the examples use a data file named `data`. This is just a placeholder; if you use these programs yourself, substitute your own file names for `data`.

Some of the following examples use the output of '`ls -l`' as input. `ls` is a system command that gives you a listing of the files in a directory. With the `-l` option, this listing includes each file's size and the date the file was last modified. Its output looks like this:

```
-rw-r--r--  1 arnold   user   1933 Nov  7 13:05 Makefile
-rw-r--r--  1 arnold   user  10809 Nov  7 13:03 awk.h
-rw-r--r--  1 arnold   user    983 Apr 13 12:14 awk.tab.h
-rw-r--r--  1 arnold   user  31869 Jun 15 12:20 awkgram.y
-rw-r--r--  1 arnold   user  22414 Nov  7 13:03 awk1.c
-rw-r--r--  1 arnold   user  37455 Nov  7 13:03 awk2.c
-rw-r--r--  1 arnold   user  27511 Dec  9 13:07 awk3.c
-rw-r--r--  1 arnold   user   7989 Nov  7 13:03 awk4.c
```

The first field contains read-write permissions, the second field contains the number of links to the file, and the third field identifies the file's owner. The fourth field identifies the file's group. The fifth field contains the file's size in bytes. The sixth, seventh, and eighth fields contain the month, day, and time, respectively, that the file was last modified. Finally, the ninth field contains the file name.

For future reference, note that there is often more than one way to do things in `awk`. At some point, you may want to look back at these examples and see if you can come up with different ways to do the same things shown here:

- Print every line that is longer than 80 characters:

  ```
  awk 'length($0) > 80' data
  ```

  The sole rule has a relational expression as its pattern and has no action—so it uses the default action, printing the record.

- Print the length of the longest input line:

  ```
  awk '{ if (length($0) > max) max = length($0) }
       END { print max }' data
  ```

  The code associated with `END` executes after all input has been read; it's the other side of the coin to `BEGIN`.

- Print the length of the longest line in `data`:

  ```
  expand data | awk '{ if (x < length($0)) x = length($0) }
                       END { print "maximum line length is " x }'
  ```

  This example differs slightly from the previous one: the input is processed by the `expand` utility to change TABs into spaces, so the widths compared are actually the right-margin columns, as opposed to the number of input characters on each line.

- Print every line that has at least one field:

  ```
  awk 'NF > 0' data
  ```

  This is an easy way to delete blank lines from a file (or rather, to create a new file similar to the old file but from which the blank lines have been removed).

- Print seven random numbers from 0 to 100, inclusive:

  ```
  awk 'BEGIN { for (i = 1; i <= 7; i++)
                     print int(101 * rand()) }'
  ```

- Print the total number of bytes used by *files*:

  ```
  ls -l files | awk '{ x += $5 }
                       END { print "total bytes: " x }'
  ```

- Print the total number of kilobytes used by *files*:

  ```
  ls -l files | awk '{ x += $5 }
     END { print "total K-bytes:", x / 1024 }'
  ```

- Print a sorted list of the login names of all users:

  ```
  awk -F: '{ print $1 }' /etc/passwd | sort
  ```

- Count the lines in a file:

  ```
  awk 'END { print NR }' data
  ```

- Print the even-numbered lines in the data file:

  ```
  awk 'NR % 2 == 0' data
  ```

If you used the expression 'NR % 2 == 1' instead, the program would print the odd-numbered lines.

1.4 An Example with Two Rules

The awk utility reads the input files one line at a time. For each line, awk tries the patterns of each rule. If several patterns match, then several actions execute in the order in which they appear in the awk program. If no patterns match, then no actions run.

After processing all the rules that match the line (and perhaps there are none), awk reads the next line. (However, see Section 7.4.8 [The next Statement], page 164, and also see Section 7.4.9 [The nextfile Statement], page 165.) This continues until the program reaches the end of the file. For example, the following awk program contains two rules:

```
/12/  { print $0 }
/21/  { print $0 }
```

The first rule has the string '12' as the pattern and 'print $0' as the action. The second rule has the string '21' as the pattern and also has 'print $0' as the action. Each rule's action is enclosed in its own pair of braces.

This program prints every line that contains the string '12' *or* the string '21'. If a line contains both strings, it is printed twice, once by each rule.

This is what happens if we run this program on our two sample data files, mail-list and inventory-shipped:

```
$ awk '/12/ { print $0 }
>      /21/ { print $0 }' mail-list inventory-shipped
⊣ Anthony      555-3412     anthony.asserturo@hotmail.com   A
⊣ Camilla      555-2912     camilla.infusarum@skynet.be     R
⊣ Fabius       555-1234     fabius.undevicesimus@ucb.edu    F
⊣ Jean-Paul    555-2127     jeanpaul.campanorum@nyu.edu     R
⊣ Jean-Paul    555-2127     jeanpaul.campanorum@nyu.edu     R
⊣ Jan  21  36  64 620
⊣ Apr  21  70  74 514
```

Note how the line beginning with 'Jean-Paul' in mail-list was printed twice, once for each rule.

1.5 A More Complex Example

Now that we've mastered some simple tasks, let's look at what typical awk programs do. This example shows how awk can be used to summarize, select, and rearrange the output of another utility. It uses features that haven't been covered yet, so don't worry if you don't understand all the details:

```
ls -l | awk '$6 == "Nov" { sum += $5 }
             END { print sum }'
```

This command prints the total number of bytes in all the files in the current directory that were last modified in November (of any year).

As a reminder, the output of 'ls -l' gives you a listing of the files in a directory, including each file's size and the date the file was last modified. The first field contains read-write

permissions, the second field contains the number of links to the file, and the third field identifies the file's owner. The fourth field identifies the file's group. The fifth field contains the file's size in bytes. The sixth, seventh, and eighth fields contain the month, day, and time, respectively, that the file was last modified. Finally, the ninth field contains the file name.

The '`$6 == "Nov"`' in our `awk` program is an expression that tests whether the sixth field of the output from '`ls -l`' matches the string '`Nov`'. Each time a line has the string '`Nov`' for its sixth field, `awk` performs the action '`sum += $5`'. This adds the fifth field (the file's size) to the variable `sum`. As a result, when `awk` has finished reading all the input lines, `sum` is the total of the sizes of the files whose lines matched the pattern. (This works because `awk` variables are automatically initialized to zero.)

After the last line of output from `ls` has been processed, the `END` rule executes and prints the value of `sum`. In this example, the value of `sum` is 80600.

These more advanced `awk` techniques are covered in later sections (see Section 7.3 [Actions], page 157). Before you can move on to more advanced `awk` programming, you have to know how `awk` interprets your input and displays your output. By manipulating fields and using `print` statements, you can produce some very useful and impressive-looking reports.

1.6 `awk` Statements Versus Lines

Most often, each line in an `awk` program is a separate statement or separate rule, like this:

```
awk '/12/  { print $0 }
     /21/  { print $0 }' mail-list inventory-shipped
```

However, `gawk` ignores newlines after any of the following symbols and keywords:

```
,    {    ?    :    ||    &&    do    else
```

A newline at any other point is considered the end of the statement.[2]

If you would like to split a single statement into two lines at a point where a newline would terminate it, you can *continue* it by ending the first line with a backslash character ('\'). The backslash must be the final character on the line in order to be recognized as a continuation character. A backslash followed by a newline is allowed anywhere in the statement, even in the middle of a string or regular expression. For example:

```
awk '/This regular expression is too long, so continue it\
 on the next line/ { print $1 }'
```

We have generally not used backslash continuation in our sample programs. `gawk` places no limit on the length of a line, so backslash continuation is never strictly necessary; it just makes programs more readable. For this same reason, as well as for clarity, we have kept most statements short in the programs presented throughout the book.

Backslash continuation is most useful when your `awk` program is in a separate source file instead of entered from the command line. You should also note that many `awk` implementations are more particular about where you may use backslash continuation. For example, they may not allow you to split a string constant using backslash continuation. Thus, for

[2] The '`?`' and '`:`' referred to here is the three-operand conditional expression described in Section 6.3.4 [Conditional Expressions], page 145. Splitting lines after '`?`' and '`:`' is a minor `gawk` extension; if `--posix` is specified (see Section 2.2 [Command-Line Options], page 33), then this extension is disabled.

maximum portability of your `awk` programs, it is best not to split your lines in the middle of a regular expression or a string.

> **CAUTION:** *Backslash continuation does not work as described with the C shell.* It works for `awk` programs in files and for one-shot programs, *provided* you are using a POSIX-compliant shell, such as the Unix Bourne shell or Bash. But the C shell behaves differently! There you must use two backslashes in a row, followed by a newline. Note also that when using the C shell, *every* newline in your `awk` program must be escaped with a backslash. To illustrate:
>
> ```
> % awk 'BEGIN { \
> ?     print \\
> ?             "hello, world" \
> ? }'
> ⊣ hello, world
> ```
>
> Here, the '`%`' and '`?`' are the C shell's primary and secondary prompts, analogous to the standard shell's '`$`' and '`>`'.
>
> Compare the previous example to how it is done with a POSIX-compliant shell:
>
> ```
> $ awk 'BEGIN {
> >   print \
> >       "hello, world"
> > }'
> ⊣ hello, world
> ```

`awk` is a line-oriented language. Each rule's action has to begin on the same line as the pattern. To have the pattern and action on separate lines, you *must* use backslash continuation; there is no other option.

Another thing to keep in mind is that backslash continuation and comments do not mix. As soon as `awk` sees the '`#`' that starts a comment, it ignores *everything* on the rest of the line. For example:

```
$ gawk 'BEGIN { print "don\47t panic" # a friendly \
>                                     BEGIN rule
> }'
error  gawk: cmd. line:2:                BEGIN rule
error  gawk: cmd. line:2:                ^ syntax error
```

In this case, it looks like the backslash would continue the comment onto the next line. However, the backslash-newline combination is never even noticed because it is "hidden" inside the comment. Thus, the `BEGIN` is noted as a syntax error.

Backslash continuation comes into play in an additional, unexpected situation. Consider:

```
gawk -F'\
a' '...'
```

This command line assigns a value to `FS`. But what value? There are several possibilities, and in fact different versions of `awk` do different things. `gawk` treats this as if it were written:

```
BEGIN { FS = "\
a"
}
...
```

In short, the backslash and newline are removed, assigning `"a"` to `FS`. This same treatment applies to variable assignments made with the `-v` option (see Section 2.2 [Command-Line Options], page 33) and to regular command-line variable assignments (see Section 6.1.3.2 [Assigning Variables on the Command Line], page 129).

If you're interested, see `https://lists.gnu.org/archive/html/bug-gawk/2022-10/msg00025.html` for a source code patch that allows lines to be continued when inside parentheses. This patch was not added to `gawk` since it would quietly decrease the portability of `awk` programs.

When `awk` statements within one rule are short, you might want to put more than one of them on a line. This is accomplished by separating the statements with a semicolon (';'). This also applies to the rules themselves. Thus, the program shown at the start of this section could also be written this way:

```
/12/ { print $0 } ; /21/ { print $0 }
```

NOTE: The requirement that states that rules on the same line must be separated with a semicolon was not in the original `awk` language; it was added for consistency with the treatment of statements within an action.

1.7 Other Features of `awk`

The `awk` language provides a number of predefined, or *built-in*, variables that your programs can use to get information from `awk`. There are other variables your program can set as well to control how `awk` processes your data.

In addition, `awk` provides a number of built-in functions for doing common computational and string-related operations. `gawk` provides built-in functions for working with timestamps, performing bit manipulation, for runtime string translation (internationalization), determining the type of a variable, and array sorting.

As we develop our presentation of the `awk` language, we will introduce most of the variables and many of the functions. They are described systematically in Section 7.5 [Predefined Variables], page 167, and in Section 9.1 [Built-in Functions], page 197.

1.8 When to Use `awk`

Now that you've seen some of what `awk` can do, you might wonder how `awk` could be useful for you. By using utility programs, advanced patterns, field separators, arithmetic statements, and other selection criteria, you can produce much more complex output. The `awk` language is very useful for producing reports from large amounts of raw data, such as summarizing information from the output of other utility programs like `ls`. (See Section 1.5 [A More Complex Example], page 27.)

Programs written with `awk` are usually much smaller than they would be in other languages. This makes `awk` programs easy to compose and use. Often, `awk` programs can be quickly composed at your keyboard, used once, and thrown away. Because `awk` programs are interpreted, you can avoid the (usually lengthy) compilation part of the typical edit-compile-test-debug cycle of software development.

Complex programs have been written in `awk`, including a complete retargetable assembler for eight-bit microprocessors (see [Glossary], page 543, for more information), and a

microcode assembler for a special-purpose Prolog computer. The original `awk`'s capabilities were strained by tasks of such complexity, but modern versions are more capable.

If you find yourself writing `awk` scripts of more than, say, a few hundred lines, you might consider using a different programming language. The shell is good at string and pattern matching; in addition, it allows powerful use of the system utilities. Python offers a nice balance between high-level ease of programming and access to system facilities.[3]

1.9 Summary

- Programs in `awk` consist of *pattern–action* pairs.
- An *action* without a *pattern* always runs. The default *action* for a pattern without one is '`{ print $0 }`'.
- Use either '`awk '`*`program`*`' `*`files`*' or '`awk -f `*`program-file files`*' to run `awk`.
- You may use the special '`#!`' header line to create `awk` programs that are directly executable.
- Comments in `awk` programs start with '`#`' and continue to the end of the same line.
- Be aware of quoting issues when writing `awk` programs as part of a larger shell script (or MS-Windows batch file).
- You may use backslash continuation to continue a source line. Lines are automatically continued after a comma, open brace, question mark, colon, '`||`', '`&&`', `do`, and `else`.

[3] Other popular scripting languages include Ruby and Perl.

2 Running awk and gawk

This chapter covers how to run **awk**, both POSIX-standard and **gawk**-specific command-line options, and what **awk** and **gawk** do with nonoption arguments. It then proceeds to cover how **gawk** searches for source files, reading standard input along with other files, **gawk**'s environment variables, **gawk**'s exit status, using include files, and obsolete and undocumented options and/or features.

Many of the options and features described here are discussed in more detail later in the book; feel free to skip over things in this chapter that don't interest you right now.

2.1 Invoking awk

There are two ways to run **awk**—with an explicit program or with one or more program files. Here are templates for both of them; items enclosed in [...] in these templates are optional:

awk [*options*] **-f** *progfile* [**--**] *file* ...
awk [*options*] [**--**] '*program*' *file* ...

In addition to traditional one-letter POSIX-style options, **gawk** also supports GNU long options.

It is possible to invoke **awk** with an empty program:

```
awk '' datafile1 datafile2
```

Doing so makes little sense, though; **awk** exits silently when given an empty program. If **--lint** has been specified on the command line, **gawk** issues a warning that the program is empty.

2.2 Command-Line Options

Options begin with a dash and consist of a single character. GNU-style long options consist of two dashes and a keyword. The keyword can be abbreviated, as long as the abbreviation allows the option to be uniquely identified. If the option takes an argument, either the keyword is immediately followed by an equals sign ('**=**') and the argument's value, or the keyword and the argument's value are separated by whitespace (spaces or TABs). If a particular option with a value is given more than once, it is (usually) the last value that counts.

Each long option for **gawk** has a corresponding POSIX-style short option. The long and short options are interchangeable in all contexts. The following list describes options mandated by the POSIX standard:

-F *fs*
--field-separator *fs*
: Set the **FS** variable to *fs* (see Section 4.5 [Specifying How Fields Are Separated], page 77).

-f *source-file*
--file *source-file*
: Read the **awk** program source from *source-file* instead of in the first nonoption argument. This option may be given multiple times; the **awk** program consists of the concatenation of the contents of each specified *source-file*.

Files named with `-f` are treated as if they had '`@namespace "awk"`' at their beginning. See Section 15.4 [Changing The Namespace], page 392, for more information on this advanced feature.

`-v` *var*`=`*val*
`--assign` *var*`=`*val*
: Set the variable *var* to the value *val* *before* execution of the program begins. Such variable values are available inside the `BEGIN` rule (see Section 2.3 [Other Command-Line Arguments], page 40).

  The `-v` option can only set one variable, but it can be used more than once, setting another variable each time, like this: '`awk -v foo=1 -v bar=2 ...`'.

  > **CAUTION:** Using `-v` to set the values of the built-in variables may lead to surprising results. `awk` will reset the values of those variables as it needs to, possibly ignoring any initial value you may have given.

`-W` *gawk-opt*
: Provide an implementation-specific option. This is the POSIX convention for providing implementation-specific options. These options also have corresponding GNU-style long options. Note that the long options may be abbreviated, as long as the abbreviations remain unique. The full list of `gawk`-specific options is provided next.

`--`
: Signal the end of the command-line options. The following arguments are not treated as options even if they begin with '`-`'. This interpretation of `--` follows the POSIX argument parsing conventions.

  This is useful if you have file names that start with '`-`', or in shell scripts, if you have file names that will be specified by the user that could start with '`-`'. It is also useful for passing options on to the `awk` program; see Section 10.4 [Processing Command-Line Options], page 266.

The following list describes `gawk`-specific options:

`-b`
`--characters-as-bytes`
: Cause `gawk` to treat all input data as single-byte characters. In addition, all output written with `print` or `printf` is treated as single-byte characters.

  Normally, `gawk` follows the POSIX standard and attempts to process its input data according to the current locale (see Section 6.6 [Where You Are Makes a Difference], page 149). This can often involve converting multibyte characters into wide characters (internally), and can lead to problems or confusion if the input data does not contain valid multibyte characters. This option is an easy way to tell `gawk`, "Hands off my data!"

`-c`
`--traditional`
: Specify *compatibility mode*, in which the GNU extensions to the `awk` language are disabled, so that `gawk` behaves just like BWK `awk`. See Section A.5 [Extensions in `gawk` Not in POSIX `awk`], page 485, which summarizes the extensions. Also see Section C.1 [Downward Compatibility and Debugging], page 529.

`-C`
`--copyright`
: Print the short version of the General Public License and then exit.

`-d`[*file*]
`--dump-variables`[=*file*]
: Print a sorted list of global variables, their types, and final values to *file*. If no *file* is provided, print this list to a file named `awkvars.out` in the current directory. No space is allowed between the `-d` and *file*, if *file* is supplied.

  Having a list of all global variables is a good way to look for typographical errors in your programs. You would also use this option if you have a large program with a lot of functions, and you want to be sure that your functions don't inadvertently use global variables that you meant to be local. (This is a particularly easy mistake to make with simple variable names like `i`, `j`, etc.)

`-D`[*file*]
`--debug`[=*file*]
: Enable debugging of `awk` programs (see Section 14.1 [Introduction to the `gawk` Debugger], page 375). By default, the debugger reads commands interactively from the keyboard (standard input). The optional *file* argument allows you to specify a file with a list of commands for the debugger to execute noninteractively. No space is allowed between the `-D` and *file*, if *file* is supplied.

`-e` *program-text*
`--source` *program-text*
: Provide program source code in the *program-text*. This option allows you to mix source code in files with source code that you enter on the command line. This is particularly useful when you have library functions that you want to use from your command-line programs (see Section 2.5.1 [The `AWKPATH` Environment Variable], page 42).

  Note that `gawk` treats each string as if it ended with a newline character (even if it doesn't). This makes building the total program easier.

  CAUTION: Prior to version 5.0, there was no requirement that each *program-text* be a full syntactic unit. I.e., the following worked:

  ```
  $ gawk -e 'BEGIN { a = 5 ;' -e 'print a }'
  ⊣ 5
  ```

  However, this is no longer true. If you have any scripts that rely upon this feature, you should revise them.

  This is because each *program-text* is treated as if it had '`@namespace "awk"`' at its beginning. See Section 15.4 [Changing The Namespace], page 392, for more information.

`-E` *file*
`--exec` *file*
: Similar to `-f`, read `awk` program text from *file*. There are two differences from `-f`:

  - This option terminates option processing; anything else on the command line is passed on directly to the `awk` program.

- Command-line variable assignments of the form '*var=value*' are disallowed.

This option is particularly necessary for World Wide Web CGI applications that pass arguments through the URL; using this option prevents a malicious (or other) user from passing in options, assignments, or `awk` source code (via `-e`) to the CGI application.[1] This option should be used with '`#!`' scripts (see Section 1.1.4 [Executable `awk` Programs], page 19), like so:

```
#! /usr/local/bin/gawk -E

awk program here ...
```

`-g`
`--gen-pot`
: Analyze the source program and generate a GNU `gettext` portable object template file on standard output for all string constants that have been marked for translation. See Chapter 13 [Internationalization with `gawk`], page 365, for information about this option.

`-h`
`--help`
: Print a "usage" message summarizing the short- and long-style options that `gawk` accepts and then exit.

`-i` *source-file*
`--include` *source-file*
: Read an `awk` source library from *source-file*. This option is completely equivalent to using the `@include` directive inside your program. It is very similar to the `-f` option, but there are two important differences. First, when `-i` is used, the program source is not loaded if it has been previously loaded, whereas with `-f`, `gawk` always loads the file. Second, because this option is intended to be used with code libraries, `gawk` does not recognize such files as constituting main program input. Thus, after processing an `-i` argument, `gawk` still expects to find the main source code via the `-f` option or on the command line.

  Files named with `-i` are treated as if they had '`@namespace "awk"`' at their beginning. See Section 15.4 [Changing The Namespace], page 392, for more information.

`-I`
`--trace`
: Print the internal byte code names as they are executed when running the program. The trace is printed to standard error. Each "op code" is preceded by a `+` sign in the output.

`-k`
`--csv`
: Enable special processing for files with comma separated values (CSV). See Section 4.5.4 [Working With Comma Separated Value Files], page 80. This option cannot be used with `--posix`. Attempting to do causes a fatal error.

[1] For more detail, please see Section 4.4 of RFC 3875. Also see the explanatory note sent to the `gawk` bug mailing list.

`-l` *ext*
`--load` *ext*

Load a dynamic extension named *ext*. Extensions are stored as system shared libraries. This option searches for the library using the `AWKLIBPATH` environment variable. The correct library suffix for your platform will be supplied by default, so it need not be specified in the extension name. The extension initialization routine should be named `dl_load()`. An alternative is to use the `@load` directive inside the program to load a shared library. This advanced feature is described in detail in Chapter 17 [Writing Extensions for gawk], page 415.

`-L`[*value*]
`--lint`[`=`*value*]

Warn about constructs that are dubious or nonportable to other `awk` implementations. No space is allowed between the `-L` and *value*, if *value* is supplied. Some warnings are issued when `gawk` first reads your program. Others are issued at runtime, as your program executes. The optional argument may be one of the following:

`fatal` Cause lint warnings become fatal errors. This may be drastic, but its use will certainly encourage the development of cleaner `awk` programs.

`invalid` Only issue warnings about things that are actually invalid are issued. (This is not fully implemented yet.)

`no-ext` Disable warnings about `gawk` extensions.

Some warnings are only printed once, even if the dubious constructs they warn about occur multiple times in your `awk` program. Thus, when eliminating problems pointed out by `--lint`, you should take care to search for all occurrences of each inappropriate construct. As `awk` programs are usually short, doing so is not burdensome.

`-M`
`--bignum` Select arbitrary-precision arithmetic on numbers. This option has no effect if `gawk` is not compiled to use the GNU MPFR and MP libraries (see Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399).

As of version 5.2, the arbitrary precision arithmetic features in `gawk` are "on parole." The primary maintainer is no longer willing to support this feature, but another member of the development team has stepped up to take it over. As long as this situation remains stable, MPFR will be supported. If it changes, the MPFR support will be removed from `gawk`.

`-n`
`--non-decimal-data`

Enable automatic interpretation of octal and hexadecimal values in input data (see Section 12.1 [Allowing Nondecimal Input Data], page 343).

> **CAUTION:** This option can severely break old programs. Use with care.

`-N`
`--use-lc-numeric`
: Force the use of the locale's decimal point character when parsing numeric input data (see Section 6.6 [Where You Are Makes a Difference], page 149).

`-o`[*file*]
`--pretty-print`[=*file*]
: Enable pretty-printing of `awk` programs. Implies `--no-optimize`. By default, the output program is created in a file named `awkprof.out` (see Section 12.6 [Profiling Your `awk` Programs], page 356). The optional *file* argument allows you to specify a different file name for the output. No space is allowed between the `-o` and *file*, if *file* is supplied.

  NOTE: In the past, this option would also execute your program. This is no longer the case.

`-O`
`--optimize`
: Enable `gawk`'s default optimizations on the internal representation of the program. At the moment, this includes just simple constant folding.

  Optimization is enabled by default. This option remains primarily for backwards compatibility. However, it may be used to cancel the effect of an earlier `-s` option (see later in this list).

`-p`[*file*]
`--profile`[=*file*]
: Enable profiling of `awk` programs (see Section 12.6 [Profiling Your `awk` Programs], page 356). Implies `--no-optimize`. By default, profiles are created in a file named `awkprof.out`. The optional *file* argument allows you to specify a different file name for the profile file. No space is allowed between the `-p` and *file*, if *file* is supplied.

  The profile contains execution counts for each statement in the program in the left margin, and function call counts for each function.

`-P`
`--posix`
: Operate in strict POSIX mode. This disables all `gawk` extensions (just like `--traditional`) and disables all extensions not allowed by POSIX. See Section A.7 [Common Extensions Summary], page 496, for a summary of the extensions in `gawk` that are disabled by this option. Also, the following additional restrictions apply:

  - Newlines are not allowed after '`?`' or '`:`' (see Section 6.3.4 [Conditional Expressions], page 145).
  - Specifying '`-Ft`' on the command line does not set the value of `FS` to be a single TAB character (see Section 4.5 [Specifying How Fields Are Separated], page 77).
  - The locale's decimal point character is used for parsing input data (see Section 6.6 [Where You Are Makes a Difference], page 149).

  If you supply both `--traditional` and `--posix` on the command line, `--posix` takes precedence. `gawk` issues a warning if both options are supplied.

`-r`
`--re-interval`
: Allow interval expressions (see Section 3.3 [Regular Expression Operators], page 54) in regexps. This is now `gawk`'s default behavior. Nevertheless, this option remains for backward compatibility.

`-s`
`--no-optimize`
: Disable `gawk`'s default optimizations on the internal representation of the program.

`-S`
`--sandbox`
: Disable the `system()` function, input redirections with `getline`, output redirections with `print` and `printf`, and dynamic extensions. Also, disallow adding file names to `ARGV` that were not there when `gawk` started running. This is particularly useful when you want to run `awk` scripts from questionable sources and need to make sure the scripts can't access your system (other than the specified input data files).

`-t`
`--lint-old`
: Warn about constructs that are not available in the original version of `awk` from Version 7 Unix (see Section A.1 [Major Changes Between V7 and SVR3.1], page 483).

`-V`
`--version`
: Print version information for this particular copy of `gawk`. This allows you to determine if your copy of `gawk` is up to date with respect to whatever the Free Software Foundation is currently distributing. It is also useful for bug reports (see Section B.4 [Reporting Problems and Bugs], page 518).

`--`
: Mark the end of all options. Any command-line arguments following `--` are placed in `ARGV`, even if they start with a minus sign.

In compatibility mode, as long as program text has been supplied, any other options are flagged as invalid with a warning message but are otherwise ignored.

In compatibility mode, as a special case, if the value of *fs* supplied to the `-F` option is '`t`', then `FS` is set to the TAB character (`"\t"`). This is true only for `--traditional` and not for `--posix` (see Section 4.5 [Specifying How Fields Are Separated], page 77).

The `-f` option may be used more than once on the command line. If it is, `awk` reads its program source from all of the named files, as if they had been concatenated together into one big file. This is useful for creating libraries of `awk` functions. These functions can be written once and then retrieved from a standard place, instead of having to be included in each individual program. The `-i` option is similar in this regard. (As mentioned in Section 9.2.1 [Function Definition Syntax], page 225, function names must be unique.)

With standard `awk`, library functions can still be used, even if the program is entered at the keyboard, by specifying '`-f /dev/tty`'. After typing your program, type *`Ctrl-d`* (the end-of-file character) to terminate it. (You may also use '`-f -`' to read program source from

the standard input, but then you will not be able to also use the standard input as a source of data.)

Because it is clumsy using the standard `awk` mechanisms to mix source file and command-line `awk` programs, `gawk` provides the `-e` option. This does not require you to preempt the standard input for your source code, and it allows you to easily mix command-line and library source code (see Section 2.5.1 [The `AWKPATH` Environment Variable], page 42). As with `-f`, the `-e` and `-i` options may also be used multiple times on the command line.

If no `-f` option (or `-e` option for `gawk`) is specified, then `awk` uses the first nonoption command-line argument as the text of the program source code. Arguments on the command line that follow the program text are entered into the `ARGV` array; `awk` does *not* continue to parse the command line looking for options.

If the environment variable `POSIXLY_CORRECT` exists, then `gawk` behaves in strict POSIX mode, exactly as if you had supplied `--posix`. Many GNU programs look for this environment variable to suppress extensions that conflict with POSIX, but `gawk` behaves differently: it suppresses all extensions, even those that do not conflict with POSIX, and behaves in strict POSIX mode. If `--lint` is supplied on the command line and `gawk` turns on POSIX mode because of `POSIXLY_CORRECT`, then it issues a warning message indicating that POSIX mode is in effect. You would typically set this variable in your shell's startup file. For a Bourne-compatible shell (such as Bash), you would add these lines to the `.profile` file in your home directory:

```
POSIXLY_CORRECT=true
export POSIXLY_CORRECT
```

For a C shell-compatible shell,[2] you would add this line to the `.login` file in your home directory:

```
setenv POSIXLY_CORRECT true
```

Having `POSIXLY_CORRECT` set is not recommended for daily use, but it is good for testing the portability of your programs to other environments.

2.3 Other Command-Line Arguments

Any additional arguments on the command line are normally treated as input files to be processed in the order specified. However, an argument that has the form *`var=value`*, assigns the value *value* to the variable *var*—it does not specify a file at all. (See Section 6.1.3.2 [Assigning Variables on the Command Line], page 129.) In the following example, '`count=1`' is a variable assignment, not a file name:

```
awk -f program.awk file1 count=1 file2
```

As a side point, should you really need to have `awk` process a file named `count=1` (or any file whose name looks like a variable assignment), precede the file name with '`./`', like so:

```
awk -f program.awk file1 ./count=1 file2
```

All the command-line arguments are made available to your `awk` program in the `ARGV` array (see Section 7.5 [Predefined Variables], page 167). Command-line options and the program text (if present) are omitted from `ARGV`. All other arguments, including variable assignments, are included. As each element of `ARGV` is processed, `gawk` sets `ARGIND` to the

[2] Not recommended.

index in ARGV of the current element. (gawk makes the full command line, including program text and options, available in PROCINFO["argv"]; see Section 7.5.2 [Built-in Variables That Convey Information], page 169.)

Changing ARGC and ARGV in your awk program lets you control how awk processes the input files; this is described in more detail in Section 7.5.3 [Using ARGC and ARGV], page 177.

The distinction between file name arguments and variable-assignment arguments is made when awk is about to open the next input file. At that point in execution, it checks the file name to see whether it is really a variable assignment; if so, awk sets the variable instead of reading a file.

Therefore, the variables actually receive the given values after all previously specified files have been read. In particular, the values of variables assigned in this fashion are *not* available inside a BEGIN rule (see Section 7.1.4 [The BEGIN and END Special Patterns], page 154), because such rules are run before awk begins scanning the argument list.

The variable values given on the command line are processed for escape sequences (see Section 3.2 [Escape Sequences], page 52).

In some very early implementations of awk, when a variable assignment occurred before any file names, the assignment would happen *before* the BEGIN rule was executed. awk's behavior was thus inconsistent; some command-line assignments were available inside the BEGIN rule, while others were not. Unfortunately, some applications came to depend upon this "feature." When awk was changed to be more consistent, the -v option was added to accommodate applications that depended upon the old behavior.

The variable assignment feature is most useful for assigning to variables such as RS, OFS, and ORS, which control input and output formats, before scanning the data files. It is also useful for controlling state if multiple passes are needed over a data file. For example:

```
awk 'pass == 1  { pass 1 stuff }
     pass == 2  { pass 2 stuff }' pass=1 mydata pass=2 mydata
```

Given the variable assignment feature, the -F option for setting the value of FS is not strictly necessary. It remains for historical compatibility.

Quoting Shell Variables On The `awk` Command Line

Small `awk` programs are often embedded in larger shell scripts, so it's worthwhile to understand some shell basics. Consider the following:

```
f=""
awk '{ print("hi") }' $f
```

In this case, `awk` reads from standard input instead of trying to open any command line files. To the unwary, this looks like `awk` is hanging.

However `awk` doesn't see an explicit empty string. When a variable expansion is the null string, *and* it's not quoted, the shell simply removes it from the command line. To demonstrate:

```
$ f=""
$ awk 'BEGIN { print ARGC }' $f
⊣ 1
$ awk 'BEGIN { print ARGC }' "$f"
⊣ 2
```

2.4 Naming Standard Input

Often, you may wish to read standard input together with other files. For example, you may wish to read one file, read standard input coming from a pipe, and then read another file.

The way to name the standard input, with all versions of `awk`, is to use a single, stand-alone minus sign or dash, '`-`'. For example:

```
some_command | awk -f myprog.awk file1 - file2
```

Here, `awk` first reads `file1`, then it reads the output of *some_command*, and finally it reads `file2`.

You may also use `"-"` to name standard input when reading files with `getline` (see Section 4.10.3 [Using `getline` from a File], page 95). And, you can even use `"-"` with the `-f` option to read program source code from standard input (see Section 2.2 [Command-Line Options], page 33).

In addition, `gawk` allows you to specify the special file name `/dev/stdin`, both on the command line and with `getline`. Some other versions of `awk` also support this, but it is not standard. (Some operating systems provide a `/dev/stdin` file in the filesystem; however, `gawk` always processes this file name itself.)

2.5 The Environment Variables `gawk` Uses

A number of environment variables influence how `gawk` behaves.

2.5.1 The `AWKPATH` Environment Variable

In most `awk` implementations, you must supply a precise pathname for each program file, unless the file is in the current directory. But with `gawk`, if the file name supplied to the `-f` or `-i` options does not contain a directory separator '`/`', then `gawk` searches a list of directories (called the *search path*) one by one, looking for a file with the specified name.

The search path is a string consisting of directory names separated by colons.[3] gawk gets its search path from the AWKPATH environment variable. If that variable does not exist, or if it has an empty value, gawk uses a default path (described shortly).

The search path feature is particularly helpful for building libraries of useful awk functions. The library files can be placed in a standard directory in the default path and then specified on the command line with a short file name. Otherwise, you would have to type the full file name for each file.

By using the -i or -f options, your command-line awk programs can use facilities in awk library files (see Chapter 10 [A Library of awk Functions], page 247). Path searching is always done, even if gawk is in compatibility mode. This is true for both --traditional and --posix. See Section 2.2 [Command-Line Options], page 33.

If the source code file is not found after the initial search, the path is searched again after adding the suffix '.awk' to the file name.

gawk's path search mechanism is similar to the shell's. (See *The Bourne-Again SHell manual*.) It treats a null entry in the path as indicating the current directory. (A null entry is indicated by starting or ending the path with a colon or by placing two colons next to each other ['::'].)

> **NOTE:** To include the current directory in the path, either place . as an entry in the path or write a null entry in the path.
>
> Different past versions of gawk would also look explicitly in the current directory, either before or after the path search. As of version 4.1.2, this no longer happens; if you wish to look in the current directory, you must include . either as a separate entry or as a null entry in the search path.

The default value for AWKPATH is '.:/usr/local/share/awk'.[4] Since . is included at the beginning, gawk searches first in the current directory and then in /usr/local/share/awk. In practice, this means that you will rarely need to change the value of AWKPATH.

See Section B.2.2 [Shell Startup Files], page 508, for information on functions that help to manipulate the AWKPATH variable.

gawk places the value of the search path that it used into ENVIRON["AWKPATH"]. This provides access to the actual search path value from within an awk program.

Although you can change ENVIRON["AWKPATH"] within your awk program, this has no effect on the running program's behavior. This makes sense: the AWKPATH environment variable is used to find the program source files. Once your program is running, all the files have been found, and gawk no longer needs to use AWKPATH.

2.5.2 The AWKLIBPATH Environment Variable

The AWKLIBPATH environment variable is similar to the AWKPATH variable, but it is used to search for loadable extensions (stored as system shared libraries) specified with the -l option rather than for source files. If the extension is not found, the path is searched again after

[3] Semicolons on MS-Windows.

[4] Your version of gawk may use a different directory; it will depend upon how gawk was built and installed. The actual directory is the value of $(pkgdatadir) generated when gawk was configured. (For more detail, see the INSTALL file in the source distribution, and see Section B.2.1 [Compiling gawk for Unix-Like Systems], page 507. You probably don't need to worry about this, though.)

adding the appropriate shared library suffix for the platform. For example, on GNU/Linux systems, the suffix '`.so`' is used. The search path specified is also used for extensions loaded via the `@load` directive (see Section 2.8 [Loading Dynamic Extensions into Your Program], page 47).

If `AWKLIBPATH` does not exist in the environment, or if it has an empty value, `gawk` uses a default path; this is typically '`/usr/local/lib/gawk`', although it can vary depending upon how `gawk` was built.[5]

See Section B.2.2 [Shell Startup Files], page 508, for information on functions that help to manipulate the `AWKLIBPATH` variable.

`gawk` places the value of the search path that it used into `ENVIRON["AWKLIBPATH"]`. This provides access to the actual search path value from within an `awk` program.

Although you can change `ENVIRON["AWKLIBPATH"]` within your `awk` program, this has no effect on the running program's behavior. This makes sense: the `AWKLIBPATH` environment variable is used to find any requested extensions, and they are loaded before the program starts to run. Once your program is running, all the extensions have been found, and `gawk` no longer needs to use `AWKLIBPATH`.

2.5.3 Other Environment Variables

A number of other environment variables affect `gawk`'s behavior, but they are more specialized. Those in the following list are meant to be used by regular users:

`GAWK_MSEC_SLEEP`
: Specifies the interval between connection retries, in milliseconds. On systems that do not support the `usleep()` system call, the value is rounded up to an integral number of seconds.

`GAWK_PERSIST_FILE`
: Specifies the backing file to use for persistent storage of `gawk`'s variables and arrays. See Section 12.7 [Preserving Data Between Runs], page 360.

`GAWK_READ_TIMEOUT`
: Specifies the time, in milliseconds, for `gawk` to wait for input before returning with an error. See Section 4.11 [Reading Input with a Timeout], page 99.

`GAWK_SOCK_RETRIES`
: Controls the number of times `gawk` attempts to retry a two-way TCP/IP (socket) connection before giving up. See Section 12.5 [Using `gawk` for Network Programming], page 354. Note that when nonfatal I/O is enabled (see Section 5.11 [Enabling Nonfatal Output], page 120), `gawk` only tries to open a TCP/IP socket once.

`PMA_VERBOSITY`
: Controls the verbosity of the persistent memory allocator. See Section 12.7 [Preserving Data Between Runs], page 360.

[5] Your version of `gawk` may use a different directory; it will depend upon how `gawk` was built and installed. The actual directory is the value of `$(pkgextensiondir)` generated when `gawk` was configured. (For more detail, see the `INSTALL` file in the source distribution, and see Section B.2.1 [Compiling `gawk` for Unix-Like Systems], page 507. You probably don't need to worry about this, though.)

`POSIXLY_CORRECT`
: Causes `gawk` to switch to POSIX-compatibility mode, disabling all traditional and GNU extensions. See Section 2.2 [Command-Line Options], page 33.

The environment variables in the following list are meant for use by the `gawk` developers for testing and tuning. They are subject to change. The variables are:

`AWKBUFSIZE`
: This variable only affects `gawk` on POSIX-compliant systems. With a value of '`exact`', `gawk` uses the size of each input file as the size of the memory buffer to allocate for I/O. Otherwise, the value should be a number, and `gawk` uses that number as the size of the buffer to allocate. (When this variable is not set, `gawk` uses the smaller of the file's size and the "default" blocksize, which is usually the filesystem's I/O blocksize.)

`AWK_HASH`
: If this variable exists with a value of '`gst`', `gawk` switches to using the hash function from GNU Smalltalk for managing arrays. With a value of '`fnv1a`', `gawk` uses the FNV1-A hash function. These functions may be marginally faster than the standard function.

`AWKREADFUNC`
: If this variable exists, `gawk` switches to reading source files one line at a time, instead of reading in blocks. This exists for debugging problems on filesystems on non-POSIX operating systems where I/O is performed in records, not in blocks.

`GAWK_MSG_SRC`
: If this variable exists, `gawk` includes the file name and line number within the `gawk` source code from which warning and/or fatal messages are generated. Its purpose is to help isolate the source of a message, as there are multiple places that produce the same warning or error message.

`GAWK_LOCALE_DIR`
: Specifies the location of compiled message object files for `gawk` itself. This is passed to the `bindtextdomain()` function when `gawk` starts up.

`GAWK_NO_DFA`
: If this variable exists, `gawk` does not use the DFA regexp matcher for "does it match" kinds of tests. This can cause `gawk` to be slower. Its purpose is to help isolate differences between the two regexp matchers that `gawk` uses internally. (There aren't supposed to be differences, but occasionally theory and practice don't coordinate with each other.)

`GAWK_STACKSIZE`
: This specifies the amount by which `gawk` should grow its internal evaluation stack, when needed.

`INT_CHAIN_MAX`
: This specifies intended maximum number of items `gawk` will maintain on a hash chain for managing arrays indexed by integers.

`STR_CHAIN_MAX`
: This specifies intended maximum number of items `gawk` will maintain on a hash chain for managing arrays indexed by strings.

`TIDYMEM`
: If this variable exists, `gawk` uses the `mtrace()` library calls from the GNU C library to help track down possible memory leaks. This cannot be used together with the persistent memory allocator.

2.6 gawk's Exit Status

If the `exit` statement is used with a value (see Section 7.4.10 [The `exit` Statement], page 166), then `gawk` exits with the numeric value given to it.

Otherwise, if there were no problems during execution, `gawk` exits with the value of the C constant `EXIT_SUCCESS`. This is usually zero.

If an error occurs, `gawk` exits with the value of the C constant `EXIT_FAILURE`. This is usually one.

If `gawk` exits because of a fatal error, the exit status is two. On non-POSIX systems, this value may be mapped to `EXIT_FAILURE`.

2.7 Including Other Files into Your Program

This section describes a feature that is specific to `gawk`. It discusses how one source file may include another.

The `@include` directive can be used to read external `awk` source files. This gives you the ability to split large `awk` source files into smaller, more manageable pieces, and also lets you reuse common `awk` code from various `awk` scripts. In other words, you can group together `awk` functions used to carry out specific tasks into external files. These files can be used just like function libraries, using the `@include` directive in conjunction with the `AWKPATH` environment variable. Note that source files may also be included using the `-i` option.

Let's see an example. We'll start with two (trivial) `awk` scripts, namely `test1` and `test2`. Here is the `test1` script:

```
BEGIN {
    print "This is script test1."
}
```

and here is `test2`:

```
@include "test1"
BEGIN {
    print "This is script test2."
}
```

Running `gawk` with `test2` produces the following result:

```
$ gawk -f test2
⊣ This is script test1.
⊣ This is script test2.
```

`gawk` runs the `test2` script, which includes `test1` using the `@include` directive. So, to include external `awk` source files, you just use `@include` followed by the name of the file to be included, enclosed in double quotes.

NOTE: Keep in mind that this is a language construct and the file name cannot be a string variable, but rather just a literal string constant in double quotes.

The files to be included may be nested; e.g., given a third script, namely `test3`:

```
@include "test2"
BEGIN {
    print "This is script test3."
}
```

Running `gawk` with the `test3` script produces the following results:

```
$ gawk -f test3
⊣ This is script test1.
⊣ This is script test2.
⊣ This is script test3.
```

The file name can, of course, be a pathname. For example:

```
@include "../io_funcs"
```

and:

```
@include "/usr/awklib/network"
```

are both valid. The `AWKPATH` environment variable can be of great value when using `@include`. The same rules for the use of the `AWKPATH` variable in command-line file searches (see Section 2.5.1 [The AWKPATH Environment Variable], page 42) apply to `@include` also.

This is very helpful in constructing `gawk` function libraries. If you have a large script with useful, general-purpose `awk` functions, you can break it down into library files and put those files in a special directory. You can then include those "libraries," either by using the full pathnames of the files, or by setting the `AWKPATH` environment variable accordingly and then using `@include` with just the file part of the full pathname. Of course, you can keep library files in more than one directory; the more complex the working environment is, the more directories you may need to organize the files to be included.

Given the ability to specify multiple `-f` options, the `@include` mechanism is not strictly necessary. However, the `@include` directive can help you in constructing self-contained `gawk` programs, thus reducing the need for writing complex and tedious command lines. In particular, `@include` is very useful for writing CGI scripts to be run from web pages.

The `@include` directive and the `-i`/`--include` command line option are completely equivalent. An included program source is not loaded if it has been previously loaded.

The rules for finding a source file described in Section 2.5.1 [The AWKPATH Environment Variable], page 42, also apply to files loaded with `@include`.

Finally, files included with `@include` are treated as if they had '`@namespace "awk"`' at their beginning. See Section 15.4 [Changing The Namespace], page 392, for more information. However, there is a separate `@nsinclude` command which does not change the namespace; see Section 15.8 [Including A File Without Changing The Namespace], page 395.

2.8 Loading Dynamic Extensions into Your Program

This section describes a feature that is specific to `gawk`.

The `@load` directive can be used to read external `awk` extensions (stored as system shared libraries). This allows you to link in compiled code that may offer superior performance

and/or give you access to extended capabilities not supported by the `awk` language. The `AWKLIBPATH` variable is used to search for the extension. Using `@load` is completely equivalent to using the `-l` command-line option.

If the extension is not initially found in `AWKLIBPATH`, another search is conducted after appending the platform's default shared library suffix to the file name. For example, on GNU/Linux systems, the suffix '`.so`' is used:

```
$ gawk '@load "ordchr"; BEGIN {print chr(65)}'
⊣ A
```

This is equivalent to the following example:

```
$ gawk -lordchr 'BEGIN {print chr(65)}'
⊣ A
```

For command-line usage, the `-l` option is more convenient, but `@load` is useful for embedding inside an `awk` source file that requires access to an extension.

Chapter 17 [Writing Extensions for gawk], page 415, describes how to write extensions (in C or C++) that can be loaded with either `@load` or the `-l` option. It also describes the `ordchr` extension.

2.9 Obsolete Options and/or Features

This section describes features and/or command-line options from previous releases of `gawk` that either are not available in the current version or are still supported but deprecated (meaning that they will *not* be in a future release).

As of `gawk` version 5.2, the arbitrary precision arithmetic feature is "on parole." This feature is now being supported by a volunteer in the development team and not by the primary maintainer. If this situation changes, then the feature will be removed. For more information see Section 16.3.1 [Arbitrary Precision Arithmetic is On Parole!], page 402.

2.10 Undocumented Options and Features

Use the Source, Luke!
—*Obi-Wan*

This section intentionally left blank.

2.11 Summary

- `gawk` parses arguments on the command line, left to right, to determine if they should be treated as options or as non-option arguments.
- `gawk` recognizes several options which control its operation, as described in Section 2.2 [Command-Line Options], page 33. All options begin with '`-`'.
- Any argument that is not recognized as an option is treated as a non-option argument, even if it begins with '`-`'.
  - However, when an option itself requires an argument, and the option is separated from that argument on the command line by at least one space, the space is ignored, and the argument is considered to be related to the option. Thus, in the invocation, '`gawk -F x`', the '`x`' is treated as belonging to the `-F` option, not as a separate non-option argument.

- Once gawk finds a non-option argument, it stops looking for options. Therefore, all following arguments are also non-option arguments, even if they resemble recognized options.
- If no -e or -f options are present, gawk expects the program text to be in the first non-option argument.
- All non-option arguments, except program text provided in the first non-option argument, are placed in ARGV as explained in Section 7.5.3 [Using ARGC and ARGV], page 177, and are processed as described in Section 2.3 [Other Command-Line Arguments], page 40. Adjusting ARGC and ARGV affects how awk processes input.
- The three standard options for all versions of awk are -f, -F, and -v. gawk supplies these and many others, as well as corresponding GNU-style long options.
- Nonoption command-line arguments are usually treated as file names, unless they have the form '*var=value*', in which case they are taken as variable assignments to be performed at that point in processing the input.
- You can use a single minus sign ('-') to refer to standard input on the command line. gawk also lets you use the special file name /dev/stdin.
- gawk pays attention to a number of environment variables. AWKPATH, AWKLIBPATH, and POSIXLY_CORRECT are the most important ones.
- gawk's exit status conveys information to the program that invoked it. Use the exit statement from within an awk program to set the exit status.
- gawk allows you to include other awk source files into your program using the @include directive and/or the -i and -f command-line options.
- gawk allows you to load additional functions written in C or C++ using the @load directive and/or the -l option. (This advanced feature is described later, in Chapter 17 [Writing Extensions for gawk], page 415.)

3 Regular Expressions

A *regular expression*, or *regexp*, is a way of describing a set of strings. Because regular expressions are such a fundamental part of `awk` programming, their format and use deserve a separate chapter.

A regular expression enclosed in slashes (‘`/`’) is an `awk` pattern that matches every input record whose text belongs to that set. The simplest regular expression is a sequence of letters, numbers, or both. Such a regexp matches any string that contains that sequence. Thus, the regexp ‘`foo`’ matches any string containing ‘`foo`’. Thus, the pattern `/foo/` matches any input record containing the three adjacent characters ‘`foo`’ *anywhere* in the record. Other kinds of regexps let you specify more complicated classes of strings.

Initially, the examples in this chapter are simple. As we explain more about how regular expressions work, we present more complicated instances.

3.1 How to Use Regular Expressions

A regular expression can be used as a pattern by enclosing it in slashes. Then the regular expression is tested against the entire text of each record. (Normally, it only needs to match some part of the text in order to succeed.) For example, the following prints the second field of each record where the string ‘`li`’ appears anywhere in the record:

```
$ awk '/li/ { print $2 }' mail-list
⊣ 555-5553
⊣ 555-0542
⊣ 555-6699
⊣ 555-3430
```

Regular expressions can also be used in matching expressions. These expressions allow you to specify the string to match against; it need not be the entire current input record. The two operators ‘`~`’ and ‘`!~`’ perform regular expression comparisons. Expressions using these operators can be used as patterns, or in `if`, `while`, `for`, and `do` statements. (See Section 7.4 [Control Statements in Actions], page 158.) For example, the following is true if the expression *exp* (taken as a string) matches *regexp*:

```
exp ~ /regexp/
```

This example matches, or selects, all input records with the uppercase letter ‘`J`’ somewhere in the first field:

```
$ awk '$1 ~ /J/' inventory-shipped
⊣ Jan  13  25  15 115
⊣ Jun  31  42  75 492
⊣ Jul  24  34  67 436
⊣ Jan  21  36  64 620
```

So does this:

```
awk '{ if ($1 ~ /J/) print }' inventory-shipped
```

This next example is true if the expression *exp* (taken as a character string) does *not* match *regexp*:

```
exp !~ /regexp/
```

The following example matches, or selects, all input records whose first field *does not* contain the uppercase letter 'J':

```
$ awk '$1 !~ /J/' inventory-shipped
⊣ Feb  15  32  24 226
⊣ Mar  15  24  34 228
⊣ Apr  31  52  63 420
⊣ May  16  34  29 208
...
```

When a regexp is enclosed in slashes, such as `/foo/`, we call it a *regexp constant*, much like `5.27` is a numeric constant and `"foo"` is a string constant.

3.2 Escape Sequences

Some characters cannot be included literally in string constants (`"foo"`) or regexp constants (`/foo/`). Instead, they should be represented with *escape sequences*, which are character sequences beginning with a backslash ('\'). One use of an escape sequence is to include a double quote character in a string constant. Because a plain double quote ends the string, you must use '`\"`' to represent an actual double quote character as a part of the string. For example:

```
$ awk 'BEGIN { print "He said \"hi!\" to her." }'
⊣ He said "hi!" to her.
```

The backslash character itself is another character that cannot be included normally; you must write '`\\`' to put one backslash in the string or regexp. Thus, the string whose contents are the two characters '`"`' and '`\`' must be written `"\"\\"`.

Other escape sequences represent unprintable characters such as TAB or newline. There is nothing to stop you from entering most unprintable characters directly in a string constant or regexp constant, but they may look ugly.

The following list presents all the escape sequences used in `awk` and what they represent. Unless noted otherwise, all these escape sequences apply to both string constants and regexp constants:

`\\` A literal backslash, '\'.

`\a` The "alert" character, *`Ctrl-g`*, ASCII code 7 (BEL). (This often makes some sort of audible noise.)

`\b` Backspace, *`Ctrl-h`*, ASCII code 8 (BS).

`\f` Formfeed, *`Ctrl-l`*, ASCII code 12 (FF).

`\n` Newline, *`Ctrl-j`*, ASCII code 10 (LF).

`\r` Carriage return, *`Ctrl-m`*, ASCII code 13 (CR).

`\t` Horizontal TAB, *`Ctrl-i`*, ASCII code 9 (HT).

`\v` Vertical TAB, *`Ctrl-k`*, ASCII code 11 (VT).

`\`*`nnn`* The octal value *nnn*, where *nnn* stands for 1 to 3 digits between '`0`' and '`7`'. For example, the code for the ASCII ESC (escape) character is '`\033`'.

`\x`*hh*`...` The hexadecimal value *hh*, where *hh* stands for a sequence of hexadecimal digits ('`0`'–'`9`', and either '`A`'–'`F`' or '`a`'–'`f`'). A maximum of two digits are allowed after the '`\x`'. Any further hexadecimal digits are treated as simple letters or numbers. (c.e.) (The '`\x`' escape sequence is not allowed in POSIX awk.)

> **CAUTION:** In ISO C, the escape sequence continues until the first nonhexadecimal digit is seen. For many years, `gawk` would continue incorporating hexadecimal digits into the value until a nonhexadecimal digit or the end of the string was encountered. However, using more than two hexadecimal digits produced undefined results. As of version 4.2, only two digits are processed.

`\u`*hh*`...` The hexadecimal value *hh*, where *hh* stands for a sequence of one or more hexadecimal digits ('`0`'–'`9`', and either '`A`'–'`F`' or '`a`'–'`f`'). A maximum of eight digits are allowed after the '`\u`'. Any further hexadecimal digits are treated as simple letters or numbers. (c.e.) (The '`\u`' escape sequence is not allowed in POSIX awk.)

This escape sequence is intended for designating a character in the current locale's character set.[1] `gawk` first converts the given digits into an integer and then translates the given "wide character" value into the current locale's multibyte encoding. If the wide character value does not represent a valid character, or if the character is valid but cannot be encoded into the current locale's multibyte encoding, the value becomes `"?"`. `gawk` issues a warning message when this happens.

`\/` A literal slash (should be used for regexp constants only). This sequence is used when you want to write a regexp constant that contains a slash (such as `/.*:\/home\/[[:alnum:]]+:.*/`; the '`[[:alnum:]]`' notation is discussed in Section 3.4 [Using Bracket Expressions], page 60). Because the regexp is delimited by slashes, you need to escape any slash that is part of the pattern, in order to tell `awk` to keep processing the rest of the regexp.

`\"` A literal double quote (should be used for string constants only). This sequence is used when you want to write a string constant that contains a double quote (such as `"He said \"hi!\" to her."`). Because the string is delimited by double quotes, you need to escape any double quote that is part of the string, in order to tell `awk` to keep processing the rest of the string.

In `gawk`, a number of additional two-character sequences that begin with a backslash have special meaning in regexps. See Section 3.7 [`gawk`-Specific Regexp Operators], page 64.

In a regexp, a backslash before any character that is not in the previous list and not listed in Section 3.7 [`gawk`-Specific Regexp Operators], page 64, means that the next character should be taken literally, even if it would normally be a regexp operator. For example, `/a\+b/` matches the three characters '`a+b`'.

For complete portability, do not use a backslash before any character not shown in the previous list or that is not a regular expression operator. (The 2024 POSIX standard explicitly lists the operators that can be escaped, leaving it undefined as to what happens for any other escaped character. But the bottom line is as described previously.)

[1] Typically, this is a Unicode-based locale, but it doesn't have to be.

Backslash Before Regular Characters

If you place a backslash in a string constant before something that is not one of the characters previously listed, POSIX `awk` purposely leaves what happens as undefined. There are two choices:

Strip the backslash out
: This is what BWK `awk` and `gawk` both do. For example, `"a\qc"` is the same as `"aqc"`. (Because this is such an easy bug both to introduce and to miss, `gawk` warns you about it.) Consider '`FS = "[ \t]+\|[ \t]+"`' to use vertical bars surrounded by whitespace as the field separator. There should be two backslashes in the string: '`FS = "[ \t]+\\|[ \t]+"`'.

Leave the backslash alone
: Some other `awk` implementations do this. In such implementations, typing `"a\qc"` is the same as typing `"a\\qc"`.

To summarize:

- The escape sequences in the preceding list are always processed first, for both string constants and regexp constants. This happens very early, as soon as `awk` reads your program.
- `gawk` processes both regexp constants and dynamic regexps (see Section 3.6 [Using Dynamic Regexps], page 63), for the special operators listed in Section 3.7 [gawk-Specific Regexp Operators], page 64.
- A backslash before any other character means to treat that character literally.

Escape Sequences for Metacharacters

Suppose you use an octal or hexadecimal (`\x` or `\u`) escape to represent a regexp metacharacter. (See Section 3.3 [Regular Expression Operators], page 54.) Does `awk` treat the character as a literal character or as a regexp operator?

Historically, such characters were taken literally. However, the POSIX standard indicates that they should be treated as real metacharacters, which is what `gawk` does. In compatibility mode (see Section 2.2 [Command-Line Options], page 33), `gawk` treats the characters represented by octal and hexadecimal escape sequences literally when used in regexp constants. Thus, `/a\52b/` is equivalent to `/a\*b/`.

3.3 Regular Expression Operators

You can combine regular expressions with special characters, called *regular expression operators* or *metacharacters*, to increase the power and versatility of regular expressions.

3.3.1 Regexp Operators in `awk`

The escape sequences described earlier in Section 3.2 [Escape Sequences], page 52, are valid inside a regexp. They are introduced by a '\' and are recognized and converted into corresponding real characters as the very first step in processing regexps.

Here is a list of metacharacters. All characters that are not escape sequences and that are not listed here stand for themselves:

`\` This suppresses the special meaning of a character when matching. For example, '`\$`' matches the character '`$`'.

`^` This matches the beginning of a string. '`^@chapter`' matches '`@chapter`' at the beginning of a string, for example, and can be used to identify chapter beginnings in Texinfo source files. The '`^`' is known as an *anchor*, because it anchors the pattern to match only at the beginning of the string.

It is important to realize that '`^`' does not match the beginning of a line (the point right after a '`\n`' newline character) embedded in a string. The condition is not true in the following example:

```
if ("line1\nLINE 2" ~ /^L/) ...
```

`$` This is similar to '`^`', but it matches only at the end of a string. For example, '`p$`' matches a record that ends with a '`p`'. The '`$`' is an anchor and does not match the end of a line (the point right before a '`\n`' newline character) embedded in a string. The condition in the following example is not true:

```
if ("line1\nLINE 2" ~ /1$/) ...
```

`.` (period) This matches any single character, *including* the newline character. For example, '`.P`' matches any single character followed by a '`P`' in a string. Using concatenation, we can make a regular expression such as '`U.A`', which matches any three-character sequence that begins with '`U`' and ends with '`A`'.

In strict POSIX mode (see Section 2.2 [Command-Line Options], page 33), '`.`' does not match the NUL character, which is a character with all bits equal to zero. Otherwise, NUL is just another character. Other versions of `awk` may not be able to match the NUL character.

`[...]` This is called a *bracket expression*.[2] It matches any *one* of the characters that are enclosed in the square brackets. For example, '`[MVX]`' matches any one of the characters '`M`', '`V`', or '`X`' in a string. A full discussion of what can be inside the square brackets of a bracket expression is given in Section 3.4 [Using Bracket Expressions], page 60.

`[^...]` This is a *complemented bracket expression*. The first character after the '`[`' *must* be a '`^`'. It matches any characters *except* those in the square brackets. For example, '`[^awk]`' matches any character that is not an '`a`', '`w`', or '`k`'.

`|` This is the *alternation operator* and it is used to specify alternatives. The '`|`' has the lowest precedence of all the regular expression operators. For example, '`^P|[aeiouy]`' matches any string that matches either '`^P`' or '`[aeiouy]`'. This means it matches any string that starts with '`P`' or contains (anywhere within it) a lowercase English vowel.

The alternation applies to the largest possible regexps on either side.

[2] In other literature, you may see a bracket expression referred to as either a *character set*, a *character class*, or a *character list*.

`(...)` Parentheses are used for grouping in regular expressions, as in arithmetic. They can be used to concatenate regular expressions containing the alternation operator, '`|`'. For example, '`@(samp|code)\{[^}]+\}`' matches both '`@code{foo}`' and '`@samp{bar}`'. (These are Texinfo formatting control sequences. The '`+`' is explained further on in this list.)

The left or opening parenthesis is always a metacharacter; to match one literally, precede it with a backslash. However, the right or closing parenthesis is only special when paired with a left parenthesis; an unpaired right parenthesis is (silently) treated as a regular character.

`*` This symbol means that the preceding regular expression should be repeated as many times as necessary to find a match. For example, '`ph*`' applies the '`*`' symbol to the preceding '`h`' and looks for matches of one '`p`' followed by any number of '`h`'s. This also matches just '`p`' if no '`h`'s are present.

There are two subtle points to understand about how '`*`' works. First, the '`*`' applies only to the single preceding regular expression component (e.g., in '`ph*`', it applies just to the '`h`'). To cause '`*`' to apply to a larger subexpression, use parentheses: '`(ph)*`' matches '`ph`', '`phph`', '`phphph`', and so on.

Second, '`*`' finds as many repetitions as possible. If the text to be matched is '`phhhhhhhhhhhhhooey`', '`ph*`' matches all of the '`h`'s.

`*?` Shortest match or *non-greedy* version of the '`*`' operator. This operator and the other non-greedy operators are discussed separately, shortly, in Section 3.3.3 [Shortest Match, or "Non-greedy" Regexp Operators], page 58.

`+` This symbol is similar to '`*`', except that the preceding expression must be matched at least once. This means that '`wh+y`' would match '`why`' and '`whhy`', but not '`wy`', whereas '`wh*y`' would match all three.

`+?` Shortest match or non-greedy version of the '`+`' operator.

`?` This symbol is similar to '`*`', except that the preceding expression can be matched either once or not at all. For example, '`fe?d`' matches '`fed`' and '`fd`', but nothing else.

`??` Shortest match or non-greedy version of the '`?`' operator.

`{`*n*`}`
`{`*n*`,}`
`{`*n*`,`*m*`}` One or two numbers inside braces denote an *interval expression*. If there is one number in the braces, the preceding regexp is repeated *n* times. If there are two numbers separated by a comma, the preceding regexp is repeated *n* to *m* times. If there is one number followed by a comma, then the preceding regexp is repeated at least *n* times:

`wh{3}y`	Matches '`whhhy`', but not '`why`' or '`whhhhy`'.
`wh{3,5}y`	Matches '`whhhy`', '`whhhhy`', or '`whhhhhy`' only.
`wh{2,}y`	Matches '`whhy`', '`whhhy`', and so on.

`{`*n*`}?`
`{`*n*`,}?`
`{`*n*`,`*m*`}?` Shortest match or non-greedy versions of the '`{}`' operators.

In regular expressions, the '`*`', '`+`', and '`?`' operators, as well as the braces '`{`' and '`}`', have the highest precedence, followed by concatenation, and finally by '`|`'. As in arithmetic, parentheses can change how operators are grouped.

According to the POSIX specification, when '`*`', '`+`', '`?`', or '`{`' are not preceded by a character, the behavior is "undefined." In practice, for `gawk`, the '`*`', '`+`', '`?`' and '`{`' operators stand for themselves when there is nothing in the regexp that precedes them. For example, `/+/` matches a literal plus sign. However, many other versions of `awk` treat such a usage as a syntax error.

What About The Empty Regexp?

We describe here an advanced regexp usage. Feel free to skip it upon first reading.

You can supply an empty regexp constant ('`//`') in all places where a regexp is expected. Is this useful? What does it match?

It is useful. It matches the (invisible) empty string at the start and end of a string of characters, as well as the empty string between characters. This is best illustrated with the `gsub()` function, which makes global substitutions in a string (see Section 9.1.4 [String-Manipulation Functions], page 200). Normal usage of `gsub()` is like so:

```
$ awk '
> BEGIN {
>     x = "ABC_CBA"
>     gsub(/B/, "bb", x)
>     print x
> }'
 ⊣ AbbC_CbbA
```

We can use `gsub()` to see where the empty strings are that match the empty regexp:

```
$ awk '
> BEGIN {
>     x = "ABC"
>     gsub(//, "x", x)
>     print x
> }'
 ⊣ xAxBxCx
```

3.3.2 Some Notes On Interval Expressions

Interval expressions were not traditionally available in `awk`. They were added as part of the POSIX standard to make `awk` and `egrep` consistent with each other.

Initially, because old programs may use '`{`' and '`}`' in regexp constants, `gawk` did *not* match interval expressions in regexps.

However, beginning with version 4.0, `gawk` does match interval expressions by default. This is because compatibility with POSIX has become more important to most `gawk` users than compatibility with old programs.

For programs that use '{' and '}' in regexp constants, it is good practice to always escape them with a backslash. Then the regexp constants are valid and work the way you want them to, using any version of awk.[3]

When '{' and '}' appear in regexp constants in a way that cannot be interpreted as an interval expression (such as /q{a}/), then they stand for themselves.

As mentioned, interval expressions were not traditionally available in awk. In March of 2019, BWK awk (finally) acquired them. Starting with version 5.2, gawk's --traditional option no longer disables interval expressions in regular expressions.

POSIX says that interval expressions containing repetition counts greater than 255 produce unspecified results.

In the manual for GNU grep, Paul Eggert notes the following:

> Interval expressions may be implemented internally via repetition. For example, '^(a|bc){2,4}$' might be implemented as '^(a|bc)(a|bc)((a|bc)(a|bc)?)?$'. A large repetition count may exhaust memory or greatly slow matching. Even small counts can cause problems if cascaded; for example, 'grep -E ".*{10,}{10,}{10,}{10,}{10,}"' is likely to overflow a stack. Fortunately, regular expressions like these are typically artificial, and cascaded repetitions do not conform to POSIX so cannot be used in portable programs anyway.

This same caveat applies to gawk.

3.3.3 Shortest Match, or "Non-greedy" Regexp Operators

Traditionally, regexps have always matched the leftmost, longest sequence of characters. For example, given the text 'abxxxcd', the regexp 'x+' could match one, two, or all three 'x' characters. By defining a regexp to match the longest possible sequence, we know that 'x+' will match all three 'x's. Such behavior may be termed *greedy*, since a regexp will match as many characters as possible.

The Perl language introduced "non-greedy," or shortest-match operators. In the above example, 'x+' would only match a single 'x'.

The 2024 POSIX standard introduced shortest-match operators into POSIX EREs. Syntactically, you create a shortest-match operator by appending a '?' to one of the traditional regexp operators: '*', '+', '?', or '{}'.

The shortest-match operators don't always match what you might think would be the smallest sequence of characters, since the general, leftmost-longest rule still applies to the overall regexp.

To illustrate the differences, we use a program named shortest-match.awk. This program takes several strings, and replaces the text matching a given pattern with a single 'X'. The program uses a number of gawk-specific features which haven't yet been described. We therefore delay presenting the code until Section 11.3.12 [Demonstrating Shortest and Longest Match Operators], page 337.

For each string, the program prints the following:

- The original string, in quotes.

[3] Use two backslashes if you're using a string constant with a regexp operator or function.

- The pattern used with a shortest match operator and the result, indented.
- Further indented is a list of the start and lengths of the submatches. Submatch zero is the whole string, submatch one is the first parenthesized expression, and so on.
- The pattern used with a regular match operator and the result, indented.
- The same start plus length information for submatches of the long pattern.

Here is the output, with commentary:

```
"aaaxxxzzz"
    shortpat: /x+?/, result: "aaaXxxzzz"
        0: (s: 4, l: 1) -> "x"
    longpat: /x+/, result: "aaaXzzz"
        0: (s: 4, l: 3) -> "xxx"
```

For the shortest match, only one '`x`' is replaced. For the longest match, every '`x`' is replaced. This is pretty straightforward.

```
"aaaxxxyzzz"
    shortpat: /x+?y/, result: "aaaXzzz"
        0: (s: 4, l: 4) -> "xxxy"
    longpat: /x+y/, result: "aaaXzzz"
        0: (s: 4, l: 4) -> "xxxy"
```

In this case, the result is the same, since the longest possible string of characters is matched.

```
"aaaxxxxxxxxxxxxxxxxzzz"
    shortpat: /(x+?)(x+)(x+?)(x+)/, result: "aaaXzzz"
        0: (s: 4, l: 16) -> "xxxxxxxxxxxxxxxx"
        1: (s: 4, l: 1) -> "x"
        2: (s: 5, l: 13) -> "xxxxxxxxxxxxx"
        3: (s: 18, l: 1) -> "x"
        4: (s: 19, l: 1) -> "x"
    longpat: /(x+)(x+)(x+)(x+)/, result: "aaaXzzz"
        0: (s: 4, l: 16) -> "xxxxxxxxxxxxxxxx"
        1: (s: 4, l: 13) -> "xxxxxxxxxxxxx"
        2: (s: 17, l: 1) -> "x"
        3: (s: 18, l: 1) -> "x"
        4: (s: 19, l: 1) -> "x"
```

This case is more interesting. The same total amount of text is matched for both patterns. However, the text matched by the subexpressions differs between the two cases. In the longest-match case, the longest possible subexpressions match first.

```
"aaaxyxxyxxyxzzz"
    shortpat: /((x+)(y+?)(x+))+/, result: "aaaXyxxyxzzz"
        0: (s: 4, l: 4) -> "xyxx"
        1: (s: 4, l: 4) -> "xyxx"
        2: (s: 4, l: 1) -> "x"
        3: (s: 5, l: 1) -> "y"
        4: (s: 6, l: 2) -> "xx"
    longpat: /((x+)(y+)(x+))+/, result: "aaaXzzz"
        0: (s: 4, l: 9) -> "xyxxyxxyx"
```

```
        1: (s: 10, l: 3) -> "xyx"
        2: (s: 10, l: 1) -> "x"
        3: (s: 11, l: 1) -> "y"
        4: (s: 12, l: 1) -> "x"
```

This case needs careful examination. There is a '+' on the outside, meaning that the total inner expression may match multiple times. For the longest-match expression, that indeed happens. The subexpressions two through four have the start and length values for the last occasion where the inner expression matched. The shortest-match expression only matched the inner expression once.

```
"aaaxyxxyxxyxzzz"
    shortpat: /((x+)(y+?)(x+)){2}/, result: "aaaXyxzzz"
        0: (s: 4, l: 7) -> "xyxxyxx"
        1: (s: 7, l: 4) -> "xyxx"
        2: (s: 7, l: 1) -> "x"
        3: (s: 8, l: 1) -> "y"
        4: (s: 9, l: 2) -> "xx"
    longpat: /((x+)(y+)(x+)){2}/, result: "aaaXyxzzz"
        0: (s: 4, l: 7) -> "xyxxyxx"
        1: (s: 7, l: 4) -> "xyxx"
        2: (s: 7, l: 1) -> "x"
        3: (s: 8, l: 1) -> "y"
        4: (s: 9, l: 2) -> "xx"
```

Here, the results are identical; both the nature of the string to be matched and the POSIX longest-leftmost rule, cause this to happen.

The MinRX regular expression matching engine, which is `gawk`'s default matcher (see Section 3.9 [Selecting the Regexp Matching Engine], page 67), supports the shortest-match operators. The older GNU matchers do not. Also, when invoked with the `--traditional` option, shortest-match operators are not supported, since traditional `awk` does not have these operators.

3.4 Using Bracket Expressions

As mentioned earlier, a bracket expression matches any character among those listed between the opening and closing square brackets.

Within a bracket expression, a *range expression* consists of two characters separated by a hyphen. It matches any single character that sorts between the two characters, based upon the system's native character set. For example, '`[0-9]`' is equivalent to '`[0123456789]`'. (See Section A.8 [Regexp Ranges and Locales: A Long Sad Story], page 497, for an explanation of how the POSIX standard and `gawk` have changed over time. This is mainly of historical interest.)

With the increasing popularity of the Unicode character standard, there is an additional wrinkle to consider. Octal and hexadecimal escape sequences inside bracket expressions are taken to represent only single-byte characters (characters whose values fit within the range 0–255). To match a range of characters where the endpoints of the range are larger than 255, enter the multibyte encodings of the characters directly, or use the `\u` escape sequence.

To include one of the characters '\', ']', '-', or '^' in a bracket expression, put a '\' in front of it. For example:

```
[d\]]
```

matches either 'd' or ']'. Additionally, if you place ']' right after the opening '[' ('[]d]'), the closing bracket is treated as one of the characters to be matched. Inside bracket expressions, it's not necessary to escape the other standard regular expression operators, such as '*' and '?', and for full portability you should not.

> **NOTE:** Note that the additional regular expression operators that begin with a backslash, such as '\<', or '\w', have no meaning when used inside a bracket expression. There, the backslash is taken to mean escape the following character, so '[\w]' is the same as '[w]', and '[\<]' is the same as '[<]'.

The treatment of '\' in bracket expressions is compatible with other `awk` implementations and is also mandated by POSIX.[4] The regular expressions in `awk` are a superset of the POSIX specification for Extended Regular Expressions (EREs). POSIX EREs are based on the regular expressions accepted by the traditional `egrep` utility.

Character classes are a feature introduced in the POSIX standard. A character class is a special notation for describing lists of characters that have a specific attribute, but the actual characters can vary from country to country and/or from character set to character set. For example, the notion of what is an alphabetic character differs between the United States and France.

A character class is only valid in a regexp *inside* the brackets of a bracket expression. Character classes consist of '[:', a keyword denoting the class, and ':]'. Table 3.1 lists the character classes defined by the POSIX standard.

Class	Meaning
[:alnum:]	Alphanumeric characters
[:alpha:]	Alphabetic characters
[:blank:]	Space and TAB characters
[:cntrl:]	Control characters
[:digit:]	Numeric characters
[:graph:]	Characters that are both printable and visible (a space is printable but not visible, whereas an 'a' is both)
[:lower:]	Lowercase alphabetic characters
[:print:]	Printable characters (characters that are not control characters)
[:punct:]	Punctuation characters (characters that are not letters, digits, control characters, or space characters)
[:space:]	Space characters (these are: space, TAB, newline, carriage return, formfeed and vertical tab)
[:upper:]	Uppercase alphabetic characters
[:xdigit:]	Characters that are hexadecimal digits

Table 3.1: POSIX character classes

[4] See the POSIX standard for `awk`. The standard doesn't relate to the case of '\]', but it does explicitly relate to '\' before a regular expression metacharacter.

For example, before the POSIX standard, you had to write `/[A-Za-z0-9]/` to match alphanumeric characters. If your character set had other alphabetic characters in it, this would not match them. With the POSIX character classes, you can write `/[[:alnum:]]/` to match the alphabetic and numeric characters in your character set.

Some utilities that match regular expressions provide a nonstandard '`[:ascii:]`' character class; `awk` does not. However, you can simulate such a construct using '`[\x00-\x7F]`'. This matches all values numerically between zero and 127, which is the defined range of the ASCII character set. Use a complemented character list ('`[^\x00-\x7F]`') to match any single-byte characters that are not in the ASCII range.

> **NOTE:** Some older versions of Unix `awk` treat `[:blank:]` like `[:space:]`, incorrectly matching more characters than they should. Caveat Emptor.

Two additional special sequences can appear in bracket expressions. These apply to non-ASCII character sets, which can have single symbols (called *collating elements*) that are represented with more than one character. They can also have several characters that are equivalent for *collating*, or sorting, purposes. (For example, in French, a plain "e" and a grave-accented "è" are equivalent.) These sequences are:

Collating symbols
: Multicharacter collating elements enclosed between '`[.`' and '`.]`'. For example, if '`ch`' is a collating element, then '`[[.ch.]]`' is a regexp that matches this collating element, whereas '`[ch]`' is a regexp that matches either '`c`' or '`h`'.

Equivalence classes
: Locale-specific names for a list of characters that are equal. The name is enclosed between '`[=`' and '`=]`'. For example, the name '`e`' might be used to represent all of "e," "ê," "è," and "é." In this case, '`[[=e=]]`' is a regexp that matches any of '`e`', '`ê`', '`é`', or '`è`'.

These features are very valuable in non-English-speaking locales.

> **CAUTION:** The library functions that `gawk` uses for regular expression matching currently recognize only POSIX character classes; they do not recognize collating symbols or equivalence classes.

Inside a bracket expression, an opening bracket ('`[`') that does not start a character class, collating element or equivalence class is taken literally. This is also true of '`.`' and '`*`'.

3.5 How Much Text Matches?

Consider the following:

```
echo aaaabcd | awk '{ sub(/a+/, "<A>"); print }'
```

This example uses the `sub()` function to make a change to the input record. (`sub()` replaces the first instance of any text matched by the first argument with the string provided as the second argument; see Section 9.1.4 [String-Manipulation Functions], page 200.) Here, the regexp `/a+/` indicates "one or more '`a`' characters," and the replacement text is '`<A>`'.

The input contains four '`a`' characters. `awk` (and POSIX) regular expressions always match the leftmost, *longest* sequence of input characters that can match. Thus, all four '`a`' characters are replaced with '`<A>`' in this example:

```
$ echo aaaabcd | awk '{ sub(/a+/, "<A>"); print }'
```

```
⊣ <A>bcd
```

For simple match/no-match tests, this is not so important. But when doing text matching and substitutions with the `match()`, `sub()`, `gsub()`, and `gensub()` functions, it is very important. Understanding this principle is also important for regexp-based record and field splitting (see Section 4.1 [How Input Is Split into Records], page 69, and also see Section 4.5 [Specifying How Fields Are Separated], page 77).

3.6 Using Dynamic Regexps

The righthand side of a '`~`' or '`!~`' operator need not be a regexp constant (i.e., a string of characters between slashes). It may be any expression. The expression is evaluated and converted to a string if necessary; the contents of the string are then used as the regexp. A regexp computed in this way is called a *dynamic regexp* or a *computed regexp*:

```
BEGIN { digits_regexp = "[[:digit:]]+" }
$0 ~ digits_regexp    { print }
```

This sets `digits_regexp` to a regexp that describes one or more digits, and tests whether the input record matches this regexp.

> **NOTE:** When using the '`~`' and '`!~`' operators, be aware that there is a difference between a regexp constant enclosed in slashes and a string constant enclosed in double quotes. If you are going to use a string constant, you have to understand that the string is, in essence, scanned *twice*: the first time when `awk` reads your program, and the second time when it goes to match the string on the lefthand side of the operator with the pattern on the right. This is true of any string-valued expression (such as `digits_regexp`, shown in the previous example), not just string constants.

What difference does it make if the string is scanned twice? The answer has to do with escape sequences, and particularly with backslashes. To get a backslash into a regular expression inside a string, you have to type two backslashes.

For example, `/\*/` is a regexp constant for a literal '`*`'. Only one backslash is needed. To do the same thing with a string, you have to type `"\\*"`. The first backslash escapes the second one so that the string actually contains the two characters '`\`' and '`*`'.

Given that you can use both regexp and string constants to describe regular expressions, which should you use? The answer is "regexp constants," for several reasons:

- String constants are more complicated to write and more difficult to read. Using regexp constants makes your programs less error-prone. Not understanding the difference between the two kinds of constants is a common source of errors.
- It is more efficient to use regexp constants. `awk` can note that you have supplied a regexp and store it internally in a form that makes pattern matching more efficient. When using a string constant, `awk` must first convert the string into this internal form and then perform the pattern matching.
- Using regexp constants is better form; it shows clearly that you intend a regexp match.

Using \n in Bracket Expressions of Dynamic Regexps

Some older versions of `awk` do not allow the newline character to be used inside a bracket expression for a dynamic regexp:

```
$ awk '$0 ~ "[ \t\n]"'
error  awk: newline in character class [
error  ]...
error   source line number 1
error   context is
error         $0 ~ "[ >>>  \t\n]" <<<
```

But a newline in a regexp constant works with no problem:

```
$ awk '$0 ~ /[ \t\n]/'
here is a sample line
⊣ here is a sample line
Ctrl-d
```

`gawk` does not have this problem, and it isn't likely to occur often in practice, but it's worth noting for future reference.

3.7 gawk-Specific Regexp Operators

GNU software that deals with regular expressions provides a number of additional regexp operators. These operators are described in this section and are specific to `gawk`; they are not available in other `awk` implementations. Most of the additional operators deal with word matching. For our purposes, a *word* is a sequence of one or more letters, digits, or underscores ('_'):

`\s` Matches any space character as defined by the current locale. Think of it as shorthand for '`[[:space:]]`'.

`\S` Matches any character that is not a space, as defined by the current locale. Think of it as shorthand for '`[^[:space:]]`'.

`\w` Matches any word-constituent character—that is, it matches any letter, digit, or underscore. Think of it as shorthand for '`[[:alnum:]_]`'.

`\W` Matches any character that is not word-constituent. Think of it as shorthand for '`[^[:alnum:]_]`'.

`\<` Matches the empty string at the beginning of a word. For example, `/\<away/` matches '`away`' but not '`stowaway`'.

`\>` Matches the empty string at the end of a word. For example, `/stow\>/` matches '`stow`' but not '`stowaway`'.

`\y` Matches the empty string at either the beginning or the end of a word (i.e., the word boundary). For example, '`\yballs?\y`' matches either '`ball`' or '`balls`', as a separate word.

`\B` Matches the empty string that occurs between two word-constituent characters. For example, `/\Brat\B/` matches '`crate`', but it does not match '`dirty rat`'.

'\B' is essentially the opposite of '\y'. Another way to think of this is that '\B' matches the empty string provided it's not at the edge of a word.

There are two other operators that work on buffers. In Emacs, a *buffer* is, naturally, an Emacs buffer. Other GNU programs, including `gawk`, consider the entire string to match as the buffer. The operators are:

`\`` Matches the empty string at the beginning of a buffer (string)

`\'` Matches the empty string at the end of a buffer (string)

Because '^' and '$' always work in terms of the beginning and end of strings, these operators don't add any new capabilities for `awk`. They are provided for compatibility with other GNU software.

In other GNU software, the word-boundary operator is '\b'. However, that conflicts with the `awk` language's definition of '\b' as backspace, so `gawk` uses a different letter. An alternative method would have been to require two backslashes in the GNU operators, but this was deemed too confusing. The current method of using '\y' for the GNU '\b' appears to be the lesser of two evils.

Backreferences Are Not Supported

In POSIX Basic Regular Expressions (BREs), you can specify what are called *backreferences* in regular expressions. For instance, in `grep`, a regexp like '`\(..\)\1`' lets you match two instances of the same subexpression in a row, such as '`abab`' or '`2323`'.

This construct is not supported in POSIX Extended Regular Expressions (EREs) such as are used in `awk` and `gawk`. Besides being less efficient for matching, the numeric escape ('`\1`' in the example) would conflict with the ability to have octal escape sequences in regular expressions (see Section 3.2 [Escape Sequences], page 52).

This is true even though the underlying regexp matching engine(s) used by `gawk` or other `awk` implementations might support such a feature.

We are told that BusyBox `awk` (see Section B.5 [Other Freely Available `awk` Implementations], page 523) is an exception, and that it allows backreferences, but only in dynamic regexps; for example '`"aa" ~ "(.)\1"`', whereas it treats the '\1' in '`"aa" ~ /(.)\1/`' as an octal escape sequence.

The various command-line options (see Section 2.2 [Command-Line Options], page 33) control how `gawk` interprets characters in regexps:

No options
: In the default case, `gawk` provides all the facilities of POSIX regexps and the previously described GNU regexp operators.

`--posix`
: Match only POSIX regexps; the GNU operators are not special (e.g., '\w' matches a literal 'w'). Interval expressions are allowed.

`--traditional`
: Match traditional Unix `awk` regexps. The GNU operators are not special. Because BWK `awk` supports them, the POSIX character classes ('`[[:alnum:]]`',

etc.) are available. So too, interval expressions are allowed. Characters described by octal and hexadecimal escape sequences are treated literally, even if they represent regexp metacharacters.

`--re-interval`
: This option remains for backwards compatibility but no longer has any real effect.

3.8 Case Sensitivity in Matching

Case is normally significant in regular expressions, both when matching ordinary characters (i.e., not metacharacters) and inside bracket expressions. Thus, a '`w`' in a regular expression matches only a lowercase '`w`' and not an uppercase '`W`'.

The simplest way to do a case-independent match is to use a bracket expression—for example, '`[Ww]`'. However, this can be cumbersome if you need to use it often, and it can make the regular expressions harder to read. There are two alternatives that you might prefer.

One way to perform a case-insensitive match at a particular point in the program is to convert the data to a single case, using the `tolower()` or `toupper()` built-in string functions (which we haven't discussed yet; see Section 9.1.4 [String-Manipulation Functions], page 200). For example:

```
tolower($1) ~ /foo/  { ... }
```

converts the first field to lowercase before matching against it. This works in any POSIX-compliant `awk`.

Another method, specific to `gawk`, is to set the variable `IGNORECASE` to a nonzero value (see Section 7.5 [Predefined Variables], page 167). When `IGNORECASE` is not zero, *all* regexp and string operations ignore case.

Changing the value of `IGNORECASE` dynamically controls the case sensitivity of the program as it runs. Case is significant by default because `IGNORECASE` (like most variables) is initialized to zero:

```
x = "aB"
if (x ~ /ab/) ...   # this test will fail

IGNORECASE = 1
if (x ~ /ab/) ...   # now it will succeed
```

In general, you cannot use `IGNORECASE` to make certain rules case insensitive and other rules case sensitive, as there is no straightforward way to set `IGNORECASE` just for the pattern of a particular rule.[5] To do this, use either bracket expressions or `tolower()`. However, one thing you can do with `IGNORECASE` only is dynamically turn case sensitivity on or off for all the rules at once.

`IGNORECASE` can be set on the command line or in a `BEGIN` rule (see Section 2.3 [Other Command-Line Arguments], page 40; also see Section 7.1.4.1 [Startup and Cleanup Actions],

[5] Experienced C and C++ programmers will note that it is possible, using something like '`IGNORECASE = 1 && /foObAr/ { ... }`' and '`IGNORECASE = 0 || /foobar/ { ... }`'. However, this is somewhat obscure and we don't recommend it.

page 154). Setting `IGNORECASE` from the command line is a way to make a program case insensitive without having to edit it.

In multibyte locales, the equivalences between upper- and lowercase characters are tested based on the wide-character values of the locale's character set. Prior to version 5.0, single-byte characters were tested based on the ISO-8859-1 (ISO Latin-1) character set. However, as of version 5.0, single-byte characters are also tested based on the values of the locale's character set.[6]

The value of `IGNORECASE` has no effect if `gawk` is in compatibility mode (see Section 2.2 [Command-Line Options], page 33). Case is always significant in compatibility mode.

3.9 Selecting the Regexp Matching Engine

Release 5.4.0 of `gawk` introduced a new regular expression matching engine, named MinRX.

MinRX is fully compliant with the POSIX standard for Extended Regular Expressions (EREs), including the additional features needed by `awk` and `gawk`. It is also a little stricter that the original matchers are in terms of accepting valid regular expression syntax when specifying a regexp. (These restrictions apply to corner cases that should not come up in day-to-day use.)

Previously, `gawk` used GNU `regex` and `dfa` from GNULIB. These matchers are fast and generally robust, albeit not fully POSIX compliant. MinRX replaces both of them.

Because regular expression matching is such a fundamental part of what `awk` programs do, introducing a new regular expression engine has some risk associated with it. To alleviate the risk, for the term of one major release, `gawk` continues to provide access to the original regexp matchers should that be needed.

If the environment variable `GAWK_GNU_MATCHERS` exists, then `gawk` switches to using GNU `regex` and `dfa`, as previously. Otherwise, the MinRX matcher is the default and that is what it uses.

Should you find a need to switch from MinRX to the original matchers, *please* submit a bug report describing what did not work (see Section B.4 [Reporting Problems and Bugs], page 518). Doing so is very important, as it will help the maintainers and the MinRX author fix any issues that are found.

After one major release, the old matchers, and the use of the `GAWK_GNU_MATCHERS` environment variable, will be removed from `gawk`.

3.10 Summary

- Regular expressions describe sets of strings to be matched. In `awk`, regular expression constants are written enclosed between slashes: `/.../`.
- Regexp constants may be used standalone in patterns and in conditional expressions, or as part of matching expressions using the '`~`' and '`!~`' operators.
- Escape sequences let you represent nonprintable characters and also let you represent regexp metacharacters as literal characters to be matched.
- Regexp operators provide grouping, alternation, and repetition.

[6] If you don't understand this, don't worry about it; it just means that `gawk` does the right thing.

- Bracket expressions give you a shorthand for specifying sets of characters that can match at a particular point in a regexp. Within bracket expressions, POSIX character classes let you specify certain groups of characters in a locale-independent fashion.
- Regular expressions match the leftmost longest text in the string being matched. This matters for cases where you need to know the extent of the match, such as for text substitution and when the record separator is a regexp.
- Matching expressions may use dynamic regexps (i.e., string values treated as regular expressions).
- `gawk`'s `IGNORECASE` variable lets you control the case sensitivity of regexp matching. In other `awk` versions, use `tolower()` or `toupper()`.

4 Reading Input Files

In the typical `awk` program, `awk` reads all input either from the standard input (by default, this is the keyboard, but often it is a pipe from another command) or from files whose names you specify on the `awk` command line. If you specify input files, `awk` reads them in order, processing all the data from one before going on to the next. The name of the current input file can be found in the predefined variable `FILENAME` (see Section 7.5 [Predefined Variables], page 167).

The input is read in units called *records*, and is processed by the rules of your program one record at a time. By default, each record is one line. Each record is automatically split into chunks called *fields*. This makes it more convenient for programs to work on the parts of a record.

On rare occasions, you may need to use the `getline` function. The `getline` function is valuable both because it can do explicit input from any number of files, and because the files used with it do not have to be named on the `awk` command line (see Section 4.10 [Explicit Input with `getline`], page 92).

4.1 How Input Is Split into Records

`awk` divides the input for your program into records and fields. It keeps track of the number of records that have been read so far from the current input file. This value is stored in a predefined variable called `FNR`, which is reset to zero every time a new file is started. Another predefined variable, `NR`, records the total number of input records read so far from all data files. It starts at zero, but is never automatically reset to zero.

Normally, records are separated by newline characters. You can control how records are separated by assigning values to the built-in variable `RS`. If `RS` is any single character, that character separates records. Otherwise (in `gawk`), `RS` is treated as a regular expression. This mechanism is explained in greater detail shortly.

> **NOTE:** When `gawk` is invoked with the `--csv` option, nothing in this section applies. See Section 4.5.4 [Working With Comma Separated Value Files], page 80, for the details.

4.1.1 Record Splitting with Standard `awk`

Records are separated by a character called the *record separator*. By default, the record separator is the newline character. This is why records are, by default, single lines. To use a different character for the record separator, simply assign that character to the predefined variable `RS`.

Like any other variable, the value of `RS` can be changed in the `awk` program with the assignment operator, '`=`' (see Section 6.2.3 [Assignment Expressions], page 135). The new record-separator character should be enclosed in quotation marks, which indicate a string constant. Often, the right time to do this is at the beginning of execution, before any input is processed, so that the very first record is read with the proper separator. To do this, use the special `BEGIN` pattern (see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154). For example:

```
awk 'BEGIN { RS = "u" }
     { print $0 }' mail-list
```

changes the value of `RS` to ‘`u`’, before reading any input. The new value is a string whose first character is the letter “u”; as a result, records are separated by the letter “u”. Then the input file is read, and the second rule in the `awk` program (the action with no pattern) prints each record. Because each `print` statement adds a newline at the end of its output, this `awk` program copies the input with each ‘`u`’ changed to a newline. Here are the results of running the program on `mail-list`:

```
$ awk 'BEGIN { RS = "u" }
>      { print $0 }' mail-list
⊣ Amelia       555-5553     amelia.zodiac
⊣ sq
⊣ e@gmail.com    F
⊣ Anthony      555-3412     anthony.assert
⊣ ro@hotmail.com   A
⊣ Becky        555-7685     becky.algebrar
⊣ m@gmail.com      A
⊣ Bill         555-1675     bill.drowning@hotmail.com       A
⊣ Broderick    555-0542     broderick.aliq
⊣ otiens@yahoo.com R
⊣ Camilla      555-2912     camilla.inf
⊣ sar
⊣ m@skynet.be     R
⊣ Fabi
⊣ s       555-1234     fabi
⊣ s.
⊣ ndevicesim
⊣ s@
⊣ cb.ed
⊣     F
⊣ J
⊣ lie        555-6699     j
⊣ lie.perscr
⊣ tabor@skeeve.com   F
⊣ Martin       555-6480     martin.codicib
⊣ s@hotmail.com    A
⊣ Sam
⊣ el       555-3430     sam
⊣ el.lanceolis@sh
⊣ .ed
⊣         A
⊣ Jean-Pa
⊣ l    555-2127     jeanpa
⊣ l.campanor
⊣ m@ny
⊣ .ed
⊣      R
⊣
```

Note that the entry for the name 'Bill' is not split. In the original data file (see Section 1.2 [Data files for the Examples], page 24), the line looks like this:

```
Bill          555-1675      bill.drowning@hotmail.com       A
```

It contains no 'u', so there is no reason to split the record, unlike the others, which each have one or more occurrences of the 'u'. In fact, this record is treated as part of the previous record; the newline separating them in the output is the original newline in the data file, not the one added by `awk` when it printed the record!

Another way to change the record separator is on the command line, using the variable-assignment feature (see Section 2.3 [Other Command-Line Arguments], page 40):

```
awk '{ print $0 }' RS="u" mail-list
```

This sets `RS` to 'u' before processing `mail-list`.

Using an alphabetic character such as 'u' for the record separator is highly likely to produce strange results. Using an unusual character such as '/' is more likely to produce correct behavior in the majority of cases, but there are no guarantees. The moral is: Know Your Data.

`gawk` allows `RS` to be a full regular expression (discussed shortly; see Section 4.1.2 [Record Splitting with gawk], page 71). Even so, using a regular expression metacharacter, such as '.' as the single character in the value of `RS` has no special effect: it is treated literally. This is required for backwards compatibility with both Unix `awk` and with POSIX.

Reaching the end of an input file terminates the current input record, even if the last character in the file is not the character in `RS`.

The empty string `""` (a string without any characters) has a special meaning as the value of `RS`. It means that records are separated by one or more blank lines and nothing else. See Section 4.9 [Multiple-Line Records], page 90, for more details.

If you change the value of `RS` in the middle of an `awk` run, the new value is used to delimit subsequent records, but the record currently being processed, as well as records already processed, are not affected.

After the end of the record has been determined, `gawk` sets the variable `RT` to the text in the input that matched `RS`.

4.1.2 Record Splitting with `gawk`

When using `gawk`, the value of `RS` is not limited to a one-character string. If it contains more than one character, it is treated as a regular expression (see Chapter 3 [Regular Expressions], page 51). (c.e.) In general, each record ends at the next string that matches the regular expression; the next record starts at the end of the matching string. This general rule is actually at work in the usual case, where `RS` contains just a newline: a record ends at the beginning of the next matching string (the next newline in the input), and the following record starts just after the end of this string (at the first character of the following line). The newline, because it matches `RS`, is not part of either record.

When `RS` is a single character, `RT` contains the same single character. However, when `RS` is a regular expression, `RT` contains the actual input text that matched the regular expression.

If the input file ends without any text matching `RS`, `gawk` sets `RT` to the null string.

The following example illustrates both of these features. It sets RS equal to a regular expression that matches either a newline or a series of one or more uppercase letters with optional leading and/or trailing whitespace:

```
$ echo record 1 AAAA record 2 BBBB record 3 |
> gawk 'BEGIN { RS = "\n|( *[[:upper:]]+ *)" }
>             { print "Record =", $0,"and RT = [" RT "]" }'
⊣ Record = record 1 and RT = [ AAAA ]
⊣ Record = record 2 and RT = [ BBBB ]
⊣ Record = record 3 and RT = [
⊣ ]
```

The square brackets delineate the contents of RT, letting you see the leading and trailing whitespace. The final value of RT is a newline. See Section 11.3.8 [A Simple Stream Editor], page 327, for a more useful example of RS as a regexp and RT.

If you set RS to a regular expression that allows optional trailing text, such as 'RS = "abc(XYZ)?"', it is possible, due to implementation constraints, that gawk may match the leading part of the regular expression, but not the trailing part, particularly if the input text that could match the trailing part is fairly long. gawk attempts to avoid this problem, but currently, there's no guarantee that this will never happen.

Caveats When Using Regular Expressions for RS

Remember that in awk, the '^' and '$' anchor metacharacters match the beginning and end of a *string*, and not the beginning and end of a *line*. As a result, something like 'RS = "^[[:upper:]]"' can only match at the beginning of a file. This is because gawk views the input file as one long string that happens to contain newline characters. It is thus best to avoid anchor metacharacters in the value of RS.

Record splitting with regular expressions works differently than regexp matching with the sub(), gsub(), and gensub() (see Section 9.1.4 [String-Manipulation Functions], page 200). Those functions allow a regexp to match the empty string; record splitting does not. Thus, for example 'RS = "()"' does *not* split records between characters.

The use of RS as a regular expression and the RT variable are gawk extensions; they are not available in compatibility mode (see Section 2.2 [Command-Line Options], page 33). In compatibility mode, only the first character of the value of RS determines the end of the record.

mawk has allowed RS to be a regexp for decades. As of October, 2019, BWK awk also supports it. Neither version supplies RT, however.

`RS = "\0"` Is Not Portable

There are times when you might want to treat an entire data file as a single record. The only way to make this happen is to give `RS` a value that you know doesn't occur in the input file. This is hard to do in a general way, such that a program always works for arbitrary input files.

You might think that for text files, the NUL character, which consists of a character with all bits equal to zero, is a good value to use for `RS` in this case:

```
BEGIN { RS = "\0" }  # whole file becomes one record?
```

`gawk` in fact accepts this, and uses the NUL character for the record separator. This works for certain special files, such as `/proc/environ` on GNU/Linux systems, where the NUL character is in fact the record separator. However, this usage is *not* portable to most other `awk` implementations.

Almost all other `awk` implementations[1] store strings internally as C-style strings. C strings use the NUL character as the string terminator. In effect, this means that '`RS = "\0"`' is the same as '`RS = ""`'.

It happens that recent versions of `mawk` can use the NUL character as a record separator. However, this is a special case: `mawk` does not allow embedded NUL characters in strings. (This may change in a future version of `mawk`.)

See Section 10.2.8 [Reading a Whole File at Once], page 257, for an interesting way to read whole files. If you are using `gawk`, see Section 17.7.10 [Reading an Entire File], page 476, for another option.

4.2 Examining Fields

When `awk` reads an input record, the record is automatically *parsed* or separated by the `awk` utility into chunks called *fields*. By default, fields are separated by *whitespace*, like words in a line. Whitespace in `awk` means any string of one or more spaces, TABs, or newlines; other characters that are considered whitespace by other languages (such as formfeed, vertical tab, etc.) are *not* considered whitespace by `awk`.

The purpose of fields is to make it more convenient for you to refer to these pieces of the record. You don't have to use them—you can operate on the whole record if you want—but fields are what make simple `awk` programs so powerful.

You use a dollar sign ('`$`') to refer to a field in an `awk` program, followed by the number of the field you want. Thus, `$1` refers to the first field, `$2` to the second, and so on. (Unlike in the Unix shells, the field numbers are not limited to single digits. `$127` is the 127th field in the record.) For example, suppose the following is a line of input:

```
This seems like a pretty nice example.
```

Here the first field, or `$1`, is '`This`', the second field, or `$2`, is '`seems`', and so on. Note that the last field, `$7`, is '`example.`'. Because there is no space between the '`e`' and the '`.`', the period is considered part of the seventh field.

[1] At least that we know about.

NF is a predefined variable whose value is the number of fields in the current record. awk automatically updates the value of NF each time it reads a record. No matter how many fields there are, the last field in a record can be represented by $NF. So, $NF is the same as $7, which is 'example.'. If you try to reference a field beyond the last one (such as $8 when the record has only seven fields), you get the empty string. If used in a numeric operation, you get zero.[2]

The use of $0, which looks like a reference to the "zeroth" field, is a special case: it represents the whole input record. Use it when you are not interested in specific fields. Here are some more examples:

```
$ awk '$1 ~ /li/ { print $0 }' mail-list
⊣ Amelia       555-5553     amelia.zodiacusque@gmail.com    F
⊣ Julie        555-6699     julie.perscrutabor@skeeve.com   F
```

This example prints each record in the file mail-list whose first field contains the string 'li'.

By contrast, the following example looks for 'li' in *the entire record* and prints the first and last fields for each matching input record:

```
$ awk '/li/ { print $1, $NF }' mail-list
⊣ Amelia F
⊣ Broderick R
⊣ Julie F
⊣ Samuel A
```

4.3 Nonconstant Field Numbers

A field number need not be a constant. Any expression in the awk language can be used after a '$' to refer to a field. The value of the expression specifies the field number. If the value is a string, rather than a number, it is converted to a number. Consider this example:

```
awk '{ print $NR }'
```

Recall that NR is the number of records read so far: one in the first record, two in the second, and so on. So this example prints the first field of the first record, the second field of the second record, and so on. For the twentieth record, field number 20 is printed; most likely, the record has fewer than 20 fields, so this prints a blank line. Here is another example of using expressions as field numbers:

```
awk '{ print $(2*2) }' mail-list
```

awk evaluates the expression '(2*2)' and uses its value as the number of the field to print. The '*' represents multiplication, so the expression '2*2' evaluates to four. The parentheses are used so that the multiplication is done before the '$' operation; they are necessary whenever there is a binary operator[3] in the field-number expression. This example, then, prints the type of relationship (the fourth field) for every line of the file mail-list. (All of the awk operators are listed, in order of decreasing precedence, in Section 6.5 [Operator Precedence (How Operators Nest)], page 148.)

[2] In either case, with the --lint option, gawk warns that you are referencing an uninitialized field.

[3] A *binary operator*, such as '*' for multiplication, is one that takes two operands. The distinction is required because awk also has unary (one-operand) and ternary (three-operand) operators.

If the field number you compute is zero, you get the entire record. Thus, '`$(2-2)`' has the same value as `$0`. Similarly, string expressions that evaluate to zero also yield the entire record. For example, '`$"answer"`', '`$"0foo"`', or even '`$("foo" "bar")`'.

Negative field numbers are not allowed; trying to reference one usually terminates the program. (The POSIX standard does not define what happens when you reference a negative field number. `gawk` notices this and terminates your program. Other `awk` implementations may behave differently.)

As mentioned in Section 4.2 [Examining Fields], page 73, `awk` stores the current record's number of fields in the built-in variable `NF` (also see Section 7.5 [Predefined Variables], page 167). Thus, the expression `$NF` is not a special feature—it is the direct consequence of evaluating `NF` and using its value as a field number.

4.4 Changing the Contents of a Field

The contents of a field, as seen by `awk`, can be changed within an `awk` program; this changes what `awk` perceives as the current input record. (The actual input is untouched; `awk` *never* modifies the input file.) Consider the following example and its output:

```
$ awk '{ nboxes = $3 ; $3 = $3 - 10
>        print nboxes, $3 }' inventory-shipped
⊣ 25 15
⊣ 32 22
⊣ 24 14
...
```

The program first saves the original value of field three in the variable `nboxes`. The '`-`' sign represents subtraction, so this program reassigns field three, `$3`, as the original value of field three minus ten: '`$3 - 10`'. (See Section 6.2.1 [Arithmetic Operators], page 132.) Then it prints the original and new values for field three. (Someone in the warehouse made a consistent mistake while inventorying the red boxes.)

For this to work, the text in `$3` must make sense as a number; the string of characters must be converted to a number for the computer to do arithmetic on it. The number resulting from the subtraction is converted back to a string of characters that then becomes field three. See Section 6.1.4 [Conversion of Strings and Numbers], page 130.

When the value of a field is changed (as perceived by `awk`), the text of the input record is recalculated to contain the new field where the old one was. In other words, `$0` changes to reflect the altered field. Thus, this program prints a copy of the input file, with 10 subtracted from the second field of each line:

```
$ awk '{ $2 = $2 - 10; print $0 }' inventory-shipped
⊣ Jan 3 25 15 115
⊣ Feb 5 32 24 226
⊣ Mar 5 24 34 228
...
```

It is also possible to assign contents to fields that are out of range. For example:

```
$ awk '{ $6 = ($5 + $4 + $3 + $2)
>        print $6 }' inventory-shipped
⊣ 168
```

```
⊣ 297
⊣ 301
...
```

We've just created `$6`, whose value is the sum of fields `$2`, `$3`, `$4`, and `$5`. The '`+`' sign represents addition. For the file `inventory-shipped`, `$6` represents the total number of parcels shipped for a particular month.

Creating a new field changes `awk`'s internal copy of the current input record, which is the value of `$0`. Thus, if you do '`print $0`' after adding a field, the record printed includes the new field, with the appropriate number of field separators between it and the previously existing fields.

This recomputation affects and is affected by `NF` (the number of fields; see Section 4.2 [Examining Fields], page 73). For example, the value of `NF` is set to the number of the highest field you create. The exact format of `$0` is also affected by a feature that has not been discussed yet: the *output field separator*, `OFS`, used to separate the fields (see Section 5.3 [Output Separators], page 105).

Note, however, that merely *referencing* an out-of-range field does *not* change the value of either `$0` or `NF`. Referencing an out-of-range field only produces an empty string. For example:

```
if ($(NF+1) != "")
    print "can't happen"
else
    print "everything is normal"
```

should print '`everything is normal`', because `NF+1` is certain to be out of range. (See Section 7.4.1 [The `if-else` Statement], page 158, for more information about `awk`'s `if-else` statements. See Section 6.3.2 [Variable Typing and Comparison Expressions], page 139, for more information about the '`!=`' operator.)

It is important to note that making an assignment to an existing field changes the value of `$0` but does not change the value of `NF`, even when you assign the empty string to a field. For example:

```
$ echo a b c d | awk '{ OFS = ":"; $2 = ""
>                       print $0; print NF }'
⊣ a::c:d
⊣ 4
```

The field is still there; it just has an empty value, delimited by the two colons between '`a`' and '`c`'. This example shows what happens if you create a new field:

```
$ echo a b c d | awk '{ OFS = ":"; $2 = ""; $6 = "new"
>                       print $0; print NF }'
⊣ a::c:d::new
⊣ 6
```

The intervening field, `$5`, is created with an empty value (indicated by the second pair of adjacent colons), and `NF` is updated with the value six.

Decrementing `NF` throws away the values of the fields after the new value of `NF` and recomputes `$0`. Here is an example:

```
$ echo a b c d e f | awk '{ print "NF =", NF;
```

```
>                                   NF = 3; print $0 }'
⊣ NF = 6
⊣ a b c
```

CAUTION: Some versions of `awk` don't rebuild `$0` when `NF` is decremented. Until August, 2018, this included BWK `awk`; fortunately his version now handles this correctly.

Finally, there are times when it is convenient to force `awk` to rebuild the entire record, using the current values of the fields and `OFS`. To do this, use the seemingly innocuous assignment:

```
$1 = $1   # force record to be reconstituted
print $0  # or whatever else with $0
```

This forces `awk` to rebuild the record. It does help to add a comment, as we've shown here.

There is a flip side to the relationship between `$0` and the fields. Any assignment to `$0` causes the record to be reparsed into fields using the *current* value of `FS`. This also applies to any built-in function that updates `$0`, such as `sub()` and `gsub()` (see Section 9.1.4 [String-Manipulation Functions], page 200).

Understanding `$0`

It is important to remember that `$0` is the *full* record, exactly as it was read from the input. This includes any leading or trailing whitespace, and the exact whitespace (or other characters) that separates the fields.

It is a common error to try to change the field separators in a record simply by setting `FS` and `OFS`, and then expecting a plain '`print`' or '`print $0`' to print the modified record.

But this does not work, because nothing was done to change the record itself. Instead, you must force the record to be rebuilt, typically with a statement such as '`$1 = $1`', as described earlier.

4.5 Specifying How Fields Are Separated

The *field separator*, which is either a single character or a regular expression, controls the way `awk` splits an input record into fields. `awk` scans the input record for character sequences that match the separator; the fields themselves are the text between the matches.

In the examples that follow, we use the bullet symbol (•) to represent spaces in the output. If the field separator is '`oo`', then the following line:

```
moo goo gai pan
```

is split into three fields: '`m`', '`•g`', and '`•gai•pan`'. Note the leading spaces in the values of the second and third fields.

The field separator is represented by the predefined variable `FS`. Shell programmers take note: `awk` does *not* use the name `IFS` that is used by the POSIX-compliant shells (such as the Unix Bourne shell, `sh`, or Bash).

The value of `FS` can be changed in the `awk` program with the assignment operator, '`=`' (see Section 6.2.3 [Assignment Expressions], page 135). Often, the right time to do this is at the beginning of execution before any input has been processed, so that the very first record is read with the proper separator. To do this, use the special `BEGIN` pattern (see

Section 7.1.4 [The BEGIN and END Special Patterns], page 154). For example, here we set the value of FS to the string ":":

```
awk 'BEGIN { FS = ":" } ; { print $2 }'
```

Given the input line:

```
John Q. Smith: 29 Oak St.: Walamazoo: MI 42139
```

this awk program extracts and prints the string '•29•Oak•St.'.

Sometimes the input data contains separator characters that don't separate fields the way you thought they would. For instance, the person's name in the example we just used might have a title or suffix attached, such as:

```
John Q. Smith: LXIX: 29 Oak St.: Walamazoo: MI 42139
```

The same program would extract '•LXIX' instead of '•29•Oak•St.'. If you were expecting the program to print the address, you would be surprised. The moral is to choose your data layout and separator characters carefully to prevent such problems. (If the data is not in a form that is easy to process, perhaps you can massage it first with a separate awk program.)

4.5.1 Whitespace Normally Separates Fields

Fields are normally separated by whitespace sequences (spaces, TABs, and newlines), not by single spaces. Two spaces in a row do not delimit an empty field. The default value of the field separator FS is a string containing a single space, " ". If awk interpreted this value in the usual way, each space character would separate fields, so two spaces in a row would make an empty field between them. The reason this does not happen is that a single space as the value of FS is a special case—it is taken to specify the default manner of delimiting fields.

If FS is any other single character, such as ",", then each occurrence of that character separates two fields. Two consecutive occurrences delimit an empty field. If the character occurs at the beginning or the end of the line, that too delimits an empty field. The space character is the only single character that does not follow these rules.

4.5.2 Using Regular Expressions to Separate Fields

The previous subsection discussed the use of single characters or simple strings as the value of FS. More generally, the value of FS may be a string containing any regular expression. In this case, each match in the record for the regular expression separates fields. For example, the assignment:

```
FS = ", \t"
```

makes every area of an input line that consists of a comma followed by a space and a TAB into a field separator.

For a less trivial example of a regular expression, try using single spaces to separate fields the way single commas are used. FS can be set to "[ ]" (left bracket, space, right bracket). This regular expression matches a single space and nothing else (see Chapter 3 [Regular Expressions], page 51).

There is an important difference between the two cases of 'FS = " "' (a single space) and 'FS = "[\t\n]+"' (a regular expression matching one or more spaces, TABs, or newlines). For both values of FS, fields are separated by *runs* (multiple adjacent occurrences) of spaces, TABs, and/or newlines. However, when the value of FS is " ", awk first strips leading and

trailing whitespace from the record and then decides where the fields are. For example, the following pipeline prints 'b':

```
$ echo ' a b c d ' | awk '{ print $2 }'
⊣ b
```

However, this pipeline prints 'a' (note the extra spaces around each letter):

```
$ echo ' a  b  c  d ' | awk 'BEGIN { FS = "[ \t\n]+" }
>                                  { print $2 }'
⊣ a
```

In this case, the first field is null, or empty.

The stripping of leading and trailing whitespace also comes into play whenever `$0` is recomputed. For instance, study this pipeline:

```
$ echo '   a b c d' | awk '{ print; $2 = $2; print }'
⊣    a b c d
⊣ a b c d
```

The first `print` statement prints the record as it was read, with leading whitespace intact. The assignment to `$2` rebuilds `$0` by concatenating `$1` through `$NF` together, separated by the value of `OFS` (which is a space by default). Because the leading whitespace was ignored when finding `$1`, it is not part of the new `$0`. Finally, the last `print` statement prints the new `$0`.

There is an additional subtlety to be aware of when using regular expressions for field splitting. It is not well specified in the POSIX standard, or anywhere else, what '`^`' means when splitting fields. Does the '`^`' match only at the beginning of the entire record? Or is each field separator a new string? It turns out that different `awk` versions answer this question differently, and you should not rely on any specific behavior in your programs.

As a point of information, BWK `awk` allows '`^`' to match only at the beginning of the record. `gawk` also works this way. For example:

```
$ echo 'xxAA  xxBxx  C' |
> gawk -F '(^x+)|( +)' '{ for (i = 1; i <= NF; i++)
>                           printf "-->%s<--\n", $i }'
⊣ --><--
⊣ -->AA<--
⊣ -->xxBxx<--
⊣ -->C<--
```

Finally, field splitting with regular expressions works differently than regexp matching with the `sub()`, `gsub()`, and `gensub()` (see Section 9.1.4 [String-Manipulation Functions], page 200). Those functions allow a regexp to match the empty string; field splitting does not. Thus, for example '`FS = "()"`' does *not* split fields between characters.

4.5.3 Making Each Character a Separate Field

There are times when you may want to examine each character of a record separately. This can be done in `gawk` by simply assigning the null string (`""`) to `FS`. (c.e.) In this case, each individual character in the record becomes a separate field. For example:

```
$ echo a b | gawk 'BEGIN { FS = "" }
>                 {
```

```
>                       for (i = 1; i <= NF; i = i + 1)
>                           print "Field", i, "is", $i
>                   }'
 ⊣ Field 1 is a
 ⊣ Field 2 is
 ⊣ Field 3 is b
```

Traditionally, the behavior of `FS` equal to `""` was not defined. In this case, most versions of Unix `awk` simply treat the entire record as only having one field. In compatibility mode (see Section 2.2 [Command-Line Options], page 33), if `FS` is the null string, then `gawk` also behaves this way.

4.5.4 Working With Comma Separated Value Files

Many commonly-used tools use a comma to separate fields, instead of whitespace. This is particularly true of popular spreadsheet programs. There is no universally accepted standard for the format of these files, although RFC 4180 lists the common practices.

For decades, anyone wishing to work with CSV files and `awk` had to "roll their own" solution. (For an example, see Section 4.7 [Defining Fields by Content], page 87). In 2023, Brian Kernighan decided to add CSV support to his version of `awk`. In order to keep up, `gawk` too provides the same support as his version. To use CSV data, invoke `gawk` with either of the `-k` or `--csv` options.

Fields in CSV files are separated by commas. In order to allow a comma to appear inside a field (i.e., as data), the field may be quoted by beginning and ending it with double quotes. In order to allow a double quote inside a field, the field *must* be quoted, and two double quotes represent an actual double quote. The double quote that starts a quoted field must be the first character after the comma. Table 4.1 shows some examples.

Input	**Field Contents**
`abc def`	`abc def`
`"quoted data"`	`quoted data`
`"quoted, data"`	`quoted, data`
`"She said ""Stop!""."`	`She said "Stop!".`

Table 4.1: Examples of CSV data

Additionally, and here's where it gets messy, newlines are also allowed inside double-quoted fields! In order to deal with such things, when processing CSV files, `gawk` scans the input data looking for newlines that are not enclosed in double quotes. Thus, use of the `--csv` option totally overrides normal record processing with `RS` (see Section 4.1 [How Input Is Split into Records], page 69), as well as field splitting with any of `FS`, `FIELDWIDTHS`, or `FPAT`.

Carriage-Return–Line-Feed Line Endings In CSV Files

`\r\n` *is the invention of the devil.*
—*Brian Kernighan*

Many CSV files are imported from systems where the line terminator for text files is a carriage-return–line-feed pair (CR-LF, '`\r`' followed by '`\n`'). For ease of use, when processing CSV files, `gawk` converts CR-LF pairs into a single newline. That is, the '`\r`' is removed.

This occurs only when a CR is paired with an LF; a standalone CR is left alone. This behavior is consistent with Windows systems which automatically convert CR-LF in files into a plain LF in memory, and also with the commonly available `unix2dos` utility program.

The behavior of the `split()` function (not formally discussed yet, see Section 9.1.4 [String-Manipulation Functions], page 200) differs slightly when processing CSV files. When called with two arguments ('`split(`*`string`*`, `*`array`*`)`'), `split()` does CSV-based splitting. Otherwise, it behaves normally.

If `--csv` has been used, `PROCINFO["CSV"]` will exist. Otherwise, it will not. See Section 7.5.2 [Built-in Variables That Convey Information], page 169.

Finally, if `--csv` has been used, assigning a value to any of `FS`, `FIELDWIDTHS`, `FPAT`, or `RS` generates a warning message.

To be clear, `gawk` takes RFC 4180 as its specification for CSV input data. There are no mechanisms for accepting nonstandard CSV data, such as files that use a semicolon instead of a comma as the separator.

4.5.5 Setting `FS` from the Command Line

`FS` can be set on the command line. Use the `-F` option to do so. For example:

```
awk -F, 'program' input-files
```

sets `FS` to the '`,`' character. Notice that the option uses an uppercase '`F`' instead of a lowercase '`f`'. The latter option (`-f`) specifies a file containing an `awk` program.

The value used for the argument to `-F` is processed in exactly the same way as assignments to the predefined variable `FS`. Any special characters in the field separator must be escaped appropriately. For example, to use a '`\`' as the field separator on the command line, you would have to type:

```
# same as FS = "\\"
awk -F\\\\ '...' files ...
```

Because '`\`' is used for quoting in the shell, `awk` sees '`-F\\`'. Then `awk` processes the '`\\`' for escape characters (see Section 3.2 [Escape Sequences], page 52), finally yielding a single '`\`' to use for the field separator.

As a special case, in compatibility mode (see Section 2.2 [Command-Line Options], page 33), if the argument to `-F` is '`t`', then `FS` is set to the TAB character. If you type '`-F\t`' at the shell, without any quotes, the '`\`' gets deleted, so `awk` figures that you really want your fields to be separated with TABs and not '`t`'s. Use '`-v FS="t"`' or '`-F"[t]"`'

on the command line if you really do want to separate your fields with 't's. Use '`-F '\t'`' when not in compatibility mode to specify that TABs separate fields.

As an example, let's use an `awk` program file called `edu.awk` that contains the pattern `/edu/` and the action '`print $1`':

```
/edu/   { print $1 }
```

Let's also set `FS` to be the '`-`' character and run the program on the file `mail-list`. The following command prints a list of the names of the people that work at or attend a university, and the first three digits of their phone numbers:

```
$ awk -F- -f edu.awk mail-list
⊣ Fabius       555
⊣ Samuel       555
⊣ Jean
```

Note the third line of output. The third line in the original file looked like this:

```
Jean-Paul    555-2127     jeanpaul.campanorum@nyu.edu     R
```

The '`-`' as part of the person's name was used as the field separator, instead of the '`-`' in the phone number that was originally intended. This demonstrates why you have to be careful in choosing your field and record separators.

Perhaps the most common use of a single character as the field separator occurs when processing the Unix system password file. On many Unix systems, each user has a separate entry in the system password file, with one line per user. The information in these lines is separated by colons. The first field is the user's login name and the second is the user's encrypted or shadow password. (A shadow password is indicated by the presence of a single '`x`' in the second field.) A password file entry might look like this:

```
arnold:x:2076:10:Arnold Robbins:/home/arnold:/bin/bash
```

The following program searches the system password file and prints the entries for users whose full name is not indicated:

```
awk -F: '$5 == ""' /etc/passwd
```

4.5.6 Making the Full Line Be a Single Field

Occasionally, it's useful to treat the whole input line as a single field. This can be done easily and portably simply by setting `FS` to `"\n"` (a newline):[4]

```
awk -F'\n' 'program' files ...
```

When you do this, `$1` is the same as `$0`.

[4] Thanks to Andrew Schorr for this tip.

Changing `FS` Does Not Affect the Fields

According to the POSIX standard, `awk` is supposed to behave as if each record is split into fields at the time it is read. In particular, this means that if you change the value of `FS` after a record is read, the values of the fields (i.e., how they were split) should reflect the old value of `FS`, not the new one.

However, many older implementations of `awk` do not work this way. Instead, they defer splitting the fields until a field is actually referenced. The fields are split using the *current* value of `FS`! This behavior can be difficult to diagnose. The following example illustrates the difference between the two methods:

```
sed 1q /etc/passwd | awk '{ FS = ":" ; print $1 }'
```

which usually prints:

```
root
```

on an incorrect implementation of `awk`, while `gawk` prints the full first line of the file, something like:

```
root:x:0:0:Root:/:
```

(The `sed`[5] command prints just the first line of `/etc/passwd`.)

4.5.7 Field-Splitting Summary

It is important to remember that when you assign a string constant as the value of `FS`, it undergoes normal `awk` string processing. For example, with Unix `awk` and `gawk`, the assignment '`FS = "\.."`' assigns the character string `".."` to `FS` (the backslash is stripped). This creates a regexp meaning "fields are separated by occurrences of any two characters." If instead you want fields to be separated by a literal period followed by any single character, use '`FS = "\\.."`'.

The following list summarizes how fields are split, based on the value of `FS` ('`==`' means "is equal to"):

`gawk was invoked with --csv`
: Field splitting follows the rules given in Section 4.5.4 [Working With Comma Separated Value Files], page 80. The value of `FS` is ignored.

`FS == " "`
: Fields are separated by runs of whitespace. Leading and trailing whitespace are ignored. This is the default.

`FS ==` *`any other single character`*
: Fields are separated by each occurrence of the character. Multiple successive occurrences delimit empty fields, as do leading and trailing occurrences. The character can even be a regexp metacharacter; it does not need to be escaped.

`FS ==` *`regexp`*
: Fields are separated by occurrences of characters that match *regexp*. Leading and trailing matches of *regexp* delimit empty fields.

[5] The `sed` utility is a "stream editor." Its behavior is also defined by the POSIX standard.

`FS == ""` Each individual character in the record becomes a separate field. (This is a common extension; it is not specified by the POSIX standard.)

`FS` and `IGNORECASE`

The `IGNORECASE` variable (see Section 7.5.1 [Built-in Variables That Control `awk`], page 167) affects field splitting *only* when the value of `FS` is a regexp. It has no effect when `FS` is a single character, even if that character is a letter. Thus, in the following code:

```
FS = "c"
IGNORECASE = 1
$0 = "aCa"
print $1
```

The output is '`aCa`'. If you really want to split fields on an alphabetic character while ignoring case, use a regexp that will do it for you (e.g., '`FS = "[c]"`'). In this case, `IGNORECASE` will take effect.

4.6 Reading Fixed-Width Data

This section discusses an advanced feature of `gawk`. If you are a novice `awk` user, you might want to skip it on the first reading.

`gawk` provides a facility for dealing with fixed-width fields with no distinctive field separator. We discuss this feature in the following subsections.

4.6.1 Processing Fixed-Width Data

An example of fixed-width data would be the input for old Fortran programs where numbers are run together, or the output of programs that did not anticipate the use of their output as input for other programs.

An example of the latter is a table where all the columns are lined up by the use of a variable number of spaces and *empty fields are just spaces*. Clearly, `awk`'s normal field splitting based on `FS` does not work well in this case. Although a portable `awk` program can use a series of `substr()` calls on `$0` (see Section 9.1.4 [String-Manipulation Functions], page 200), this is awkward and inefficient for a large number of fields.

The splitting of an input record into fixed-width fields is specified by assigning a string containing space-separated numbers to the built-in variable `FIELDWIDTHS`. Each number specifies the width of the field, *including* columns between fields. If you want to ignore the columns between fields, you can specify the width as a separate field that is subsequently ignored. It is a fatal error to supply a field width that has a negative value.

The following data is the output of the Unix `w` utility. It is useful to illustrate the use of `FIELDWIDTHS`:

```
 10:06pm  up 21 days, 14:04,  23 users
User     tty       login  idle   JCPU   PCPU  what
hzuo     ttyV0     8:58pm            9      5  vi p24.tex
hzang    ttyV3     6:37pm    50                -csh
eklye    ttyV5     9:53pm            7      1  em thes.tex
dportein ttyV6     8:17pm  1:47                -csh
gierd    ttyD3    10:00pm     1                elm
dave     ttyD4     9:47pm            4      4  w
brent    ttyp0    26Jun91  4:46  26:46   4:41  bash
dave     ttyq4    26Jun9115days     46     46  wnewmail
```

The following program takes this input, converts the idle time to number of seconds, and prints out the first two fields and the calculated idle time:

```
BEGIN  { FIELDWIDTHS = "9 6 10 6 7 7 35" }
NR > 2 {
    idle = $4
    sub(/^ +/, "", idle)   # strip leading spaces
    if (idle == "")
        idle = 0
    if (idle ~ /:/) {      # hh:mm
        split(idle, t, ":")
        idle = t[1] * 60 + t[2]
    }
    if (idle ~ /days/)
        idle *= 24 * 60 * 60

    print $1, $2, idle
}
```

NOTE: The preceding program uses a number of `awk` features that haven't been introduced yet.

Running the program on the data produces the following results:

```
hzuo      ttyV0  0
hzang     ttyV3  50
eklye     ttyV5  0
dportein  ttyV6  107
gierd     ttyD3  1
dave      ttyD4  0
brent     ttyp0  286
dave      ttyq4  1296000
```

Another (possibly more practical) example of fixed-width input data is the input from a deck of balloting cards. In some parts of the United States, voters mark their choices by punching holes in computer cards. These cards are then processed to count the votes for any particular candidate or on any particular issue. Because a voter may choose not to vote on some issue, any column on the card may be empty. An `awk` program for processing such data could use the `FIELDWIDTHS` feature to simplify reading the data. (Of course, getting `gawk` to run on a system with card readers is another story!)

4.6.2 Skipping Intervening Fields

Starting in version 4.2, each field width may optionally be preceded by a colon-separated value specifying the number of characters to skip before the field starts. Thus, the preceding program could be rewritten to specify `FIELDWIDTHS` like so:

```
BEGIN  { FIELDWIDTHS = "8 1:5 4:7 6 1:6 1:6 2:33" }
```

This strips away some of the white space separating the fields. With such a change, the program produces the following results:

```
hzang    ttyV3 50
eklye    ttyV5 0
dportein ttyV6 107
gierd    ttyD3 1
dave     ttyD4 0
brent    ttyp0 286
dave     ttyq4 1296000
```

4.6.3 Capturing Optional Trailing Data

There are times when fixed-width data may be followed by additional data that has no fixed length. Such data may or may not be present, but if it is, it should be possible to get at it from an `awk` program.

Starting with version 4.2, in order to provide a way to say "anything else in the record after the defined fields," `gawk` allows you to add a final '`*`' character to the value of `FIELDWIDTHS`. There can only be one such character, and it must be the final non-whitespace character in `FIELDWIDTHS`. For example:

```
$ cat fw.awk                              Show the program
⊣ BEGIN { FIELDWIDTHS = "2 2 *" }
⊣ { print NF, $1, $2, $3 }
$ cat fw.in                               Show sample input
⊣ 1234abcdefghi
$ gawk -f fw.awk fw.in                    Run the program
⊣ 3 12 34 abcdefghi
```

4.6.4 Field Values With Fixed-Width Data

So far, so good. But what happens if there isn't as much data as there should be based on the contents of `FIELDWIDTHS`? Or, what happens if there is more data than expected?

For many years, what happens in these cases was not well defined. Starting with version 4.2, the rules are as follows:

Enough data for some fields
: For example, if `FIELDWIDTHS` is set to `"2 3 4"` and the input record is '`aabbb`'. In this case, `NF` is set to two.

Not enough data for a field
: For example, if `FIELDWIDTHS` is set to `"2 3 4"` and the input record is '`aab`'. In this case, `NF` is set to two and `$2` has the value `"b"`. The idea is that even though there aren't as many characters as were expected, there are some, so the data should be made available to the program.

Too much data
: For example, if `FIELDWIDTHS` is set to `"2 3 4"` and the input record is 'aabbbccccddd'. In this case, `NF` is set to three and the extra characters ('ddd') are ignored. If you want `gawk` to capture the extra characters, supply a final '`*`' in the value of `FIELDWIDTHS`.

Too much data, but with '`*`' supplied
: For example, if `FIELDWIDTHS` is set to `"2 3 4 *"` and the input record is 'aabbbccccddd'. In this case, `NF` is set to four, and `$4` has the value `"ddd"`.

4.7 Defining Fields by Content

This section discusses an advanced feature of `gawk`. If you are a novice `awk` user, you might want to skip it on the first reading.

Normally, when using `FS`, `gawk` defines the fields as the parts of the record that occur in between each field separator. In other words, `FS` defines what a field *is not*, instead of what a field *is*. However, there are times when we really want to define the fields by what they are, and not by what they are not.

The `FPAT` variable offers a solution for cases like this. The value of `FPAT` should be a string that provides a regular expression. This regular expression describes the contents of each field.

We can explore the strengths, and some limitations, of `FPAT` using the case of comma-separated values (CSV) data. This case is somewhat obsolete as `gawk` now has built-in CSV parsing (see Section 4.5.4 [Working With Comma Separated Value Files], page 80). Nonetheless, it remains useful as an example of what `FPAT`-based field parsing can do. It is also useful for versions of `gawk` prior to version 5.3.

Many spreadsheet programs, for example, can export their data into text files, where each record is terminated with a newline, and fields are separated by commas. If commas only separated the data, there wouldn't be an issue with using '`FS = ","`' to split the data into fields. The problem comes when one of the fields contains an *embedded* comma. In such cases, most programs embed the field in double quotes.[6] So, we might have data like this:

```
Robbins,Arnold,,"1234 A Pretty Street, NE",MyTown,MyState,12345-6789,USA
```

In the case of CSV data as presented here, each field is either "anything that is not a comma," or "a double quote, anything that is not a double quote, and a closing double quote." We also need to bear in mind that some fields may be empty. If written as a regular expression constant (see Chapter 3 [Regular Expressions], page 51), we would have `/([^,]*)|("[^"]+")/`. Writing this as a string requires us to escape the double quotes, leading to:

```
FPAT = "([^,]*)|(\"[^\"]+\")"
```

Putting this to use, here is a simple program to parse the data:

```
BEGIN {
    FPAT = "([^,]*)|(\"[^\"]+\")"
}
```

[6] The CSV format lacked a formal standard definition for many years. RFC 4180 standardizes the most common practices.

```
{
    print "NF =", NF
    for (i = 1; i <= NF; i++) {
        printf("$%d = <%s>\n", i, $i)
    }
}
```

When run, we get the following:

```
$ gawk -f simple-csv.awk addresses.csv
⊣ NF = 8
⊣ $1 = <Robbins>
⊣ $2 = <Arnold>
⊣ $3 = <>
⊣ $4 = <"1234 A Pretty Street, NE">
⊣ $5 = <MyTown>
⊣ $6 = <MyState>
⊣ $7 = <12345-6789>
⊣ $8 = <USA>
```

Note the empty data field in the value of `$3` and the embedded comma in the value of `$4`, in which the data remains wrapped in its enclosing double quotes.

The use of enclosing double quotes has a consequence for fields that contain double quotes as part of the data itself. For those fields, a double quote appearing inside a field must be escaped by preceding it with another double quote, as shown in the third and fourth lines of the following example:

```
1,2,3
p,"q,r",s
p,"q""r",s
p,"q,""r",s
p,"",s
p,,s
```

Manuel Collado suggests that the simplest `FPAT` expression that recognizes this kind of CSV field is `/([^,]*)|("([^"]|"")+")/`.

The following program uses this improved `FPAT` expression to split the example CSV fields above, extracts the underlying data from any double-quoted fields, and finally prints the data as tab-separated values. The latter is accomplished by setting `OFS` to a TAB character.

```
BEGIN {
    FPAT = "([^,]*)|(\"([^\"]|\"\")+\")"
    OFS = "\t"    # Print tab-separated values
}
```

```
{
    for (i = 1; i <= NF; i++) {
        # Extract data from double-quoted fields
        if (substr($i, 1, 1) == "\"") {
            gsub(/^"|"$/, "", $i)    # Remove enclosing quotes
            gsub(/""/, "\"", $i)     # Convert "" to "
        }
    }
    $1 = $1    # force rebuild of the record
    print
}
```

When run, it produces:

```
$ gawk -f quoted-csv.awk sample.csv
⊣ 1       2       3
⊣ p       q,r     s
⊣ p       q"r     s
⊣ p       q,"r    s
⊣ p               s
⊣ p               s
```

Some programs export CSV data that contain *embedded newlines* between the double quotes, and here we run into a limitation of `FPAT`: it provides no way to deal with this. Hence, using `FPAT` to do your own CSV parsing is an elegant approach for the majority of cases, but not all.

For a more general solution to working with CSV data, see Section 4.5.4 [Working With Comma Separated Value Files], page 80. If your version of `gawk` is prior to version 5.3, we recommend that you use Manuel Collado's `CSVMODE` library for `gawk`.

As with `FS`, the `IGNORECASE` variable (see Section 7.5.1 [Built-in Variables That Control awk], page 167) affects field splitting with `FPAT`.

Assigning a value to `FPAT` overrides field splitting with `FS` and with `FIELDWIDTHS`.

Finally, the `patsplit()` function makes the same functionality available for splitting regular strings (see Section 9.1.4 [String-Manipulation Functions], page 200).

4.7.1 `FS` Versus `FPAT`: A Subtle Difference

As we discussed earlier, `FS` describes the data between fields ("what fields are not") and `FPAT` describes the fields themselves ("what fields are"). This leads to a subtle difference in how fields are found when using regexps as the value for `FS` or `FPAT`.

In order to distinguish one field from another, there must be a non-empty separator between each field. This makes intuitive sense—otherwise one could not distinguish fields from separators.

Thus, regular expression matching as done when splitting fields with `FS` is not allowed to match the null string; it must always match at least one character, in order to be able to proceed through the entire record.

On the other hand, regular expression matching with `FPAT` can match the null string, and the non-matching intervening characters function as the separators.

This same difference is reflected in how matching is done with the `split()` and `patsplit()` functions (see Section 9.1.4 [String-Manipulation Functions], page 200).

4.8 Checking How `gawk` Is Splitting Records

As we've seen, `gawk` provides three independent methods to split input records into fields. The mechanism used is based on which of the three variables—`FS`, `FIELDWIDTHS`, or `FPAT`—was last assigned to. In addition, an API input parser may choose to override the record parsing mechanism; please refer to Section 17.4.6.4 [Customized Input Parsers], page 429, for further information about this feature.

To restore normal field splitting after using `FIELDWIDTHS` and/or `FPAT`, simply assign a value to `FS`. You can use '`FS = FS`' to do this, without having to know the current value of `FS`.

In order to tell which kind of field splitting is in effect, use `PROCINFO["FS"]` (see Section 7.5.2 [Built-in Variables That Convey Information], page 169). The value is `"FS"` if regular field splitting is being used, `"FIELDWIDTHS"` if fixed-width field splitting is being used, or `"FPAT"` if content-based field splitting is being used:

```
if ("CSV" in PROCINFO)
    CSV-based field splitting ...
else if (PROCINFO["FS"] == "FS")
    regular field splitting ...
else if (PROCINFO["FS"] == "FIELDWIDTHS")
    fixed-width field splitting ...
else if (PROCINFO["FS"] == "FPAT")
    content-based field splitting ...
else
    API input parser field splitting ...  (advanced feature)
```

This information is useful when writing a function that needs to temporarily change `FS`, `FIELDWIDTHS`, or `FPAT`, read some records, and then restore the original settings (see Section 10.5 [Reading the User Database], page 273, for an example of such a function).

4.9 Multiple-Line Records

In some databases, a single line cannot conveniently hold all the information in one entry. In such cases, you can use multiline records. The first step in doing this is to choose your data format.

One technique is to use an unusual character or string to separate records. For example, you could use the formfeed character (written '`\f`' in `awk`, as in C) to separate them, making each record a page of the file. To do this, just set the variable `RS` to `"\f"` (a string containing the formfeed character). Any other character could equally well be used, as long as it won't be part of the data in a record.

Another technique is to have blank lines separate records. By a special dispensation, an empty string as the value of `RS` indicates that records are separated by one or more blank lines. When `RS` is set to the empty string, each record always ends at the first blank line encountered. The next record doesn't start until the first nonblank line that follows. No matter how many blank lines appear in a row, they all act as one record separator. (Blank lines must be completely empty; lines that contain only whitespace do not count.)

You can achieve the same effect as 'RS = ""' by assigning the string "\n\n+" to RS. This regexp matches the newline at the end of the record and one or more blank lines after the record. In addition, a regular expression always matches the longest possible sequence when there is a choice (see Section 3.5 [How Much Text Matches?], page 62). So, the next record doesn't start until the first nonblank line that follows—no matter how many blank lines appear in a row, they are considered one record separator.

However, there is an important difference between 'RS = ""' and 'RS = "\n\n+"'. In the first case, leading newlines in the input data file are ignored, and if a file ends without extra blank lines after the last record, the final newline is removed from the record. In the second case, this special processing is not done.

Now that the input is separated into records, the second step is to separate the fields in the records. One way to do this is to divide each of the lines into fields in the normal manner. This happens by default as the result of a special feature. When RS is set to the empty string *and* FS is set to a single character, the newline character *always* acts as a field separator. This is in addition to whatever field separations result from FS.

> **NOTE:** When FS is the null string ("") or a regexp, this special feature of RS does not apply. It does apply to the default field separator of a single space: 'FS = " "'.
>
> Note that language in the POSIX specification implies that this special feature should apply when FS is a regexp. However, Unix awk has never behaved that way, nor has gawk. This is essentially a bug in POSIX.

The original motivation for this special exception was probably to provide useful behavior in the default case (i.e., FS is equal to " "). This feature can be a problem if you really don't want the newline character to separate fields, because there is no way to prevent it. However, you can work around this by using the split() function to break up the record manually (see Section 9.1.4 [String-Manipulation Functions], page 200). If you have a single-character field separator, you can work around the special feature in a different way, by making FS into a regexp for that single character. For example, if the field separator is a percent character, instead of 'FS = "%"', use 'FS = "[%]"'.

Another way to separate fields is to put each field on a separate line: to do this, just set the variable FS to the string "\n". (This single-character separator matches a single newline.) A practical example of a data file organized this way might be a mailing list, where blank lines separate the entries. Consider a mailing list in a file named addresses, which looks like this:

```
Jane Doe
123 Main Street
Anywhere, SE 12345-6789

John Smith
456 Tree-lined Avenue
Smallville, MW 98765-4321
...
```

A simple program to process this file is as follows:

```
# addrs.awk --- simple mailing list program
```

```
# Records are separated by blank lines.
# Each line is one field.
BEGIN { RS = "" ; FS = "\n" }

{
      print "Name is:", $1
      print "Address is:", $2
      print "City and State are:", $3
      print ""
}
```

Running the program produces the following output:

```
$ awk -f addrs.awk addresses
⊣ Name is: Jane Doe
⊣ Address is: 123 Main Street
⊣ City and State are: Anywhere, SE 12345-6789
⊣
⊣ Name is: John Smith
⊣ Address is: 456 Tree-lined Avenue
⊣ City and State are: Smallville, MW 98765-4321
⊣
...
```

See Section 11.3.4 [Printing Mailing Labels], page 319, for a more realistic program dealing with address lists. The following list summarizes how records are split, based on the value of `RS`:

`RS == "\n"`
: Records are separated by the newline character (‘`\n`’). In effect, every line in the data file is a separate record, including blank lines. This is the default.

`RS ==` *`any single character`*
: Records are separated by each occurrence of the character. Multiple successive occurrences delimit empty records.

`RS == ""`
: Records are separated by runs of blank lines. When `FS` is a single character, then the newline character always serves as a field separator, in addition to whatever value `FS` may have. Leading and trailing newlines in a file are ignored.

`RS ==` *`regexp`*
: Records are separated by occurrences of characters that match *regexp*. Leading and trailing matches of *regexp* delimit empty records. (This is a `gawk` extension; it is not specified by the POSIX standard.)

If not in compatibility mode (see Section 2.2 [Command-Line Options], page 33), `gawk` sets `RT` to the input text that matched the value specified by `RS`. But if the input file ended without any text that matches `RS`, then `gawk` sets `RT` to the null string.

4.10 Explicit Input with `getline`

So far we have been getting our input data from `awk`’s main input stream—either the standard input (usually your keyboard, sometimes the output from another program) or

the files specified on the command line. The `awk` language has a special built-in function called `getline` that can be used to read input under your explicit control.

The `getline` function is used in several different ways and should *not* be used by beginners. The examples that follow the explanation of the `getline` function include material that has not been covered yet. Therefore, come back and study the `getline` function *after* you have reviewed the rest of Parts I and II and have a good knowledge of how `awk` works.

The `getline` function returns 1 if it finds a record and 0 if it encounters the end of the file. If there is some error in getting a record, such as a file that cannot be opened, then `getline` returns −1. In this case, `gawk` sets the variable `ERRNO` to a string describing the error that occurred.

If `ERRNO` indicates that the I/O operation may be retried, and `PROCINFO["`*`input`*`", "RETRY"]` is set, then `getline` returns −2 instead of −1, and further calls to `getline` may be attempted. See Section 4.12 [Retrying Reads After Certain Input Errors], page 101, for further information about this feature.

In the following examples, *command* stands for a string value that represents a shell command.

> **NOTE:** When `--sandbox` is specified (see Section 2.2 [Command-Line Options], page 33), reading lines from files, pipes, and coprocesses is disabled.

4.10.1 Using `getline` with No Arguments

The `getline` function can be used without arguments to read input from the current input file. All it does in this case is read the next input record and split it up into fields. This is useful if you've finished processing the current record, but want to do some special processing on the next record *right now*. For example:

```
# Remove text between /* and */, inclusive
{
    while ((start = index($0, "/*")) != 0) {
        out = substr($0, 1, start - 1)  # leading part of the string
        rest = substr($0, start + 2)    # ... */ ...
        while ((end = index(rest, "*/")) == 0) {  # is */ in trailing part?
            # get more text
            if (getline <= 0) {
                print("unexpected EOF or error:", ERRNO) > "/dev/stderr"
                exit
            }
            # build up the line using string concatenation
            rest = rest $0
        }
        rest = substr(rest, end + 2)  # remove comment
        # build up the output line using string concatenation
        $0 = out rest
    }
    print $0
}
```

This `awk` program deletes C-style comments (‘`/* ... */`’) from the input. It uses a number of features we haven't covered yet, including string concatenation (see Section 6.2.2 [String Concatenation], page 134) and the `index()` and `substr()` built-in functions (see Section 9.1.4 [String-Manipulation Functions], page 200). By replacing the ‘`print $0`’ with other statements, you could perform more complicated processing on the decommented input, such as searching for matches of a regular expression.

Here is some sample input:

```
mon/*comment*/key
rab/*commen
t*/bit
horse /*comment*/more text
part 1 /*comment*/part 2 /*comment*/part 3
no comment
```

When run, the output is:

```
$ awk -f strip_comments.awk example_text
⊣ monkey
⊣ rabbit
⊣ horse more text
⊣ part 1 part 2 part 3
⊣ no comment
```

This form of the `getline` function sets `NF`, `NR`, `FNR`, `RT`, and the value of `$0`.

> **NOTE:** The new value of `$0` is used to test the patterns of any subsequent rules. The original value of `$0` that triggered the rule that executed `getline` is lost. By contrast, the `next` statement reads a new record but immediately begins processing it normally, starting with the first rule in the program. See Section 7.4.8 [The `next` Statement], page 164.

4.10.2 Using `getline` into a Variable

You can use ‘`getline` *var*’ to read the next record from `awk`'s input into the variable *var*. No other processing is done. For example, suppose the next line is a comment or a special string, and you want to read it without triggering any rules. This form of `getline` allows you to read that line and store it in a variable so that the main read-a-line-and-check-each-rule loop of `awk` never sees it. The following example swaps every two lines of input:

```
{
     if ((getline tmp) > 0) {
          print tmp
          print $0
     } else
          print $0
}
```

It takes the following list:

```
wan
tew
free
phore
```

and produces these results:

```
tew
wan
phore
free
```

The `getline` function used in this way sets only the variables `NR`, `FNR`, and `RT` (and, of course, *var*). The record is not split into fields, so the values of the fields (including `$0`) and the value of `NF` do not change.

4.10.3 Using `getline` from a File

Use '`getline < file`' to read the next record from *file*. Here, *file* is a string-valued expression that specifies the file name. '`< file`' is called a *redirection* because it directs input to come from a different place. For example, the following program reads its input record from the file `secondary.input` when it encounters a first field with a value equal to 10 in the current input file:

```
{
    if ($1 == 10) {
         getline < "secondary.input"
         print
    } else
         print
}
```

Because the main input stream is not used, the values of `NR` and `FNR` are not changed. However, the record it reads is split into fields in the normal manner, so the values of `$0` and the other fields are changed, resulting in a new value of `NF`. `RT` is also set.

According to POSIX, '`getline < expression`' is ambiguous if *expression* contains unparenthesized operators other than '`$`'; for example, '`getline < dir "/" file`' is ambiguous because the concatenation operator (not discussed yet; see Section 6.2.2 [String Concatenation], page 134) is not parenthesized. You should write it as '`getline < (dir "/" file)`' if you want your program to be portable to all `awk` implementations.

4.10.4 Using `getline` into a Variable from a File

Use '`getline var < file`' to read input from the file *file*, and put it in the variable *var*. As earlier, *file* is a string-valued expression that specifies the file from which to read.

In this version of `getline`, none of the predefined variables are changed and the record is not split into fields. The only variable changed is *var*.[7] For example, the following program copies all the input files to the output, except for records that say '`@include filename`'. Such a record is replaced by the contents of the file *filename*:

```
{
     if (NF == 2 && $1 == "@include") {
          while ((getline line < $2) > 0)
               print line
          close($2)
```

[7] This is not quite true. `RT` could be changed if `RS` is a regular expression.

```
        } else
                print
}
```

Note here how the name of the extra input file is not built into the program; it is taken directly from the data, specifically from the second field on the `@include` line.

The `close()` function is called to ensure that if two identical `@include` lines appear in the input, the entire specified file is included twice. See Section 5.9 [Closing Input and Output Redirections], page 117.

One deficiency of this program is that it does not process nested `@include` directives (i.e., `@include` directives in included files) the way a true macro preprocessor would. See Section 11.3.9 [An Easy Way to Use Library Functions], page 328, for a program that does handle nested `@include` directives.

4.10.5 Using `getline` from a Pipe

> *Omniscience has much to recommend it. Failing that, attention to details would be useful.*
>
> —*Brian Kernighan*

The output of a command can also be piped into `getline`, using '*command* `| getline`'. In this case, the string *command* is run as a shell command and its output is piped into `awk` to be used as input. This form of `getline` reads one record at a time from the pipe. For example, the following program copies its input to its output, except for lines that begin with '`@execute`', which are replaced by the output produced by running the rest of the line as a shell command:

```
{
        if ($1 == "@execute") {
                tmp = substr($0, 10)        # Remove "@execute"
                while ((tmp | getline) > 0)
                        print
                close(tmp)
        } else
                print
}
```

The `close()` function is called to ensure that if two identical '`@execute`' lines appear in the input, the command is run for each one. Given the input:

```
foo
bar
baz
@execute who
bletch
```

the program might produce:

```
foo
bar
baz
arnold     ttyv0   Jul 13 14:22
miriam     ttyp0   Jul 13 14:23     (murphy:0)
```

```
bill       ttyp1   Jul 13 14:23     (murphy:0)
bletch
```

Notice that this program ran the command `who` and printed the result. (If you try this program yourself, you will of course get different results, depending upon who is logged in on your system.)

This variation of `getline` splits the record into fields, sets the value of `NF`, and recomputes the value of `$0`. The values of `NR` and `FNR` are not changed. `RT` is set.

According to POSIX, '*expression* `|` `getline`' is ambiguous if *expression* contains unparenthesized operators other than '`$`'—for example, '`"echo " "date" | getline`' is ambiguous because the concatenation operator is not parenthesized. You should write it as '`("echo " "date") | getline`' if you want your program to be portable to all `awk` implementations.

> **NOTE:** Unfortunately, `gawk` has not been consistent in its treatment of a construct like '`"echo " "date" | getline`'. Most versions, including the current version, treat it as '`("echo " "date") | getline`'. (This is also how BWK `awk` behaves.) Some versions instead treat it as '`"echo " ("date" | getline)`'. (This is how `mawk` behaves.) In short, *always* use explicit parentheses, and then you won't have to worry.

4.10.6 Using `getline` into a Variable from a Pipe

When you use '*command* `|` `getline` *var*', the output of *command* is sent through a pipe to `getline` and into the variable *var*. For example, the following program reads the current date and time into the variable `current_time`, using the `date` utility, and then prints it:

```
BEGIN {
     "date" | getline current_time
     close("date")
     print "Report printed on " current_time
}
```

In this version of `getline`, none of the predefined variables are changed and the record is not split into fields. However, `RT` is set.

4.10.7 Using `getline` from a Coprocess

Reading input into `getline` from a pipe is a one-way operation. The command that is started with '*command* `|` `getline`' only sends data *to* your `awk` program.

On occasion, you might want to send data to another program for processing and then read the results back. `gawk` allows you to start a *coprocess*, with which two-way communications are possible. This is done with the '`|&`' operator. Typically, you write data to the coprocess first and then read the results back, as shown in the following:

```
print "some query" |& "db_server"
"db_server" |& getline
```

which sends a query to `db_server` and then reads the results.

The values of `NR` and `FNR` are not changed, because the main input stream is not used. However, the record is split into fields in the normal manner, thus changing the values of `$0`, of the other fields, and of `NF` and `RT`.

Coprocesses are an advanced feature. They are discussed here only because this is the section on `getline`. See Section 12.4 [Two-Way Communications with Another Process], page 351, where coprocesses are discussed in more detail.

4.10.8 Using `getline` into a Variable from a Coprocess

When you use '*command* `|&` `getline` *var*', the output from the coprocess *command* is sent through a two-way pipe to `getline` and into the variable *var*.

In this version of `getline`, none of the predefined variables are changed and the record is not split into fields. The only variable changed is *var*. However, `RT` is set.

4.10.9 Points to Remember About `getline`

Here are some miscellaneous points about `getline` that you should bear in mind:

- When `getline` changes the value of `$0` and `NF`, `awk` does *not* automatically jump to the start of the program and start testing the new record against every pattern. However, the new record is tested against any subsequent rules.
- Some very old `awk` implementations limit the number of pipelines that an `awk` program may have open to just one. In `gawk`, there is no such limit. You can open as many pipelines (and coprocesses) as the underlying operating system permits.
- An interesting side effect occurs if you use `getline` without a redirection inside a `BEGIN` rule. Because an unredirected `getline` reads from the command-line data files, the first `getline` function causes `awk` to set the value of `FILENAME`. Normally, `FILENAME` does not have a value inside `BEGIN` rules, because you have not yet started to process the command-line data files. (See Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154; also see Section 7.5.2 [Built-in Variables That Convey Information], page 169.)

- Using `FILENAME` with `getline` ('`getline < FILENAME`') is likely to be a source of confusion. `awk` opens a separate input stream from the current input file. However, by not using a variable, `$0` and `NF` are still updated. If you're doing this, it's probably by accident, and you should reconsider what it is you're trying to accomplish.
- Section 4.10.10 [Summary of `getline` Variants], page 99, presents a table summarizing the `getline` variants and which variables they can affect. It is worth noting that those variants that do not use redirection can cause `FILENAME` to be updated if they cause `awk` to start reading a new input file.
- `getline` is not a statement (unlike `print`), it's an expression. It has a result value, and can be used as part as a larger expression, in control statements, and so on. Here are examples of the "read until EOF/error" idiom:

```
while ("sort FILE" | getline line > 0)
    print line
while (getline line < "file.txt" > 0)
    print line
```

  If you need to test the error code for being less than zero, you need to enclose `getline` in parentheses, to avoid it being interpreted as input redirection:

```
if ((getline VAR) < 0)
    print "Read error";
```

It is, in fact, best to parenthesize calls to `getline` in all control expressions, as some versions of `awk` require this. Thus, the previous examples are best written this way:

```
while (("sort FILE" | getline line) > 0)
    print line
while ((getline line < "file.txt") > 0)
    print line
```

- If the variable being assigned is an expression with side effects, different versions of `awk` behave differently upon encountering end-of-file. Some versions don't evaluate the expression; many versions (including `gawk`) do. Here is an example, courtesy of Duncan Moore:

```
BEGIN {
    system("echo 1 > f")
    while ((getline a[++c] < "f") > 0) { }
    print c
}
```

Here, the side effect is the '`++c`'. Is `c` incremented if end-of-file is encountered before the element in `a` is assigned?

Despite the lack of parentheses when calling `getline`, `gawk` evaluates the expression '`a[++c]`' before attempting to read from `f`. However, some versions of `awk` only evaluate the expression once they know that there is a string value to be assigned.

4.10.10 Summary of `getline` Variants

Table 4.2 summarizes the eight variants of `getline`, listing which predefined variables are set by each one, and whether the variant is standard or a `gawk` extension. Note: for each variant, `gawk` sets the `RT` predefined variable.

Variant	**Effect**	`awk` / `gawk`
`getline`	Sets `$0`, `NF`, `FNR`, `NR`, and `RT`	`awk`
`getline` *var*	Sets *var*, `FNR`, `NR`, and `RT`	`awk`
`getline <` *file*	Sets `$0`, `NF`, and `RT`	`awk`
`getline` *var* `<` *file*	Sets *var* and `RT`	`awk`
command `| getline`	Sets `$0`, `NF`, and `RT`	`awk`
command `| getline` *var*	Sets *var* and `RT`	`awk`
command `|& getline`	Sets `$0`, `NF`, and `RT`	`gawk`
command `|& getline` *var*	Sets *var* and `RT`	`gawk`

Table 4.2: `getline` variants and what they set

4.11 Reading Input with a Timeout

This section describes a feature that is specific to `gawk`.

You may specify a timeout in milliseconds for reading input from the keyboard, a pipe, or two-way communication, including TCP/IP sockets. This can be done on a per-input, per-command, or per-connection basis, by setting a special element in the `PROCINFO` array (see Section 7.5.2 [Built-in Variables That Convey Information], page 169):

```
PROCINFO["input_name", "READ_TIMEOUT"] = timeout in milliseconds
```

When set, this causes `gawk` to time out and return failure if no data is available to read within the specified timeout period. For example, a TCP client can decide to give up on receiving any response from the server after a certain amount of time:

```
Service = "/inet/tcp/0/localhost/daytime"
PROCINFO[Service, "READ_TIMEOUT"] = 100
if ((Service |& getline) > 0)
    print $0
else if (ERRNO != "")
    print ERRNO
```

Here is how to read interactively from the user[8] without waiting for more than five seconds:

```
PROCINFO["/dev/stdin", "READ_TIMEOUT"] = 5000
while ((getline < "/dev/stdin") > 0)
    print $0
```

`gawk` terminates the read operation if input does not arrive after waiting for the timeout period, returns failure, and sets `ERRNO` to an appropriate string value. A negative or zero value for the timeout is the same as specifying no timeout at all.

A timeout can also be set for reading from the keyboard in the implicit loop that reads input records and matches them against patterns, like so:

```
$ gawk 'BEGIN { PROCINFO["-", "READ_TIMEOUT"] = 5000 }
> { print "You entered: " $0 }'
gawk
⊣ You entered: gawk
```

In this case, failure to respond within five seconds results in the following error message:

```
error  gawk: cmd. line:2: (FILENAME=- FNR=1) fatal: error reading input file `-': Conn
```

The timeout can be set or changed at any time, and will take effect on the next attempt to read from the input device. In the following example, we start with a timeout value of one second, and progressively reduce it by one-tenth of a second until we wait indefinitely for the input to arrive:

```
PROCINFO[Service, "READ_TIMEOUT"] = 1000
while ((Service |& getline) > 0) {
    print $0
    PROCINFO[Service, "READ_TIMEOUT"] -= 100
}
```

NOTE: You should not assume that the read operation will block exactly after the tenth record has been printed. It is possible that `gawk` will read and buffer more than one record's worth of data the first time. Because of this, changing the value of timeout like in the preceding example is not very useful.

If the `PROCINFO` element is not present and the `GAWK_READ_TIMEOUT` environment variable exists, `gawk` uses its value to initialize the timeout value. The exclusive use of the environment variable to specify timeout has the disadvantage of not being able to control it on a per-command or per-connection basis.

[8] This assumes that standard input is the keyboard.

gawk considers a timeout event to be an error even though the attempt to read from the underlying device may succeed in a later attempt. This is a limitation, and it also means that you cannot use this to multiplex input from two or more sources. See Section 4.12 [Retrying Reads After Certain Input Errors], page 101, for a way to enable later I/O attempts to succeed.

Assigning a timeout value prevents read operations from being blocked indefinitely. But bear in mind that there are other ways gawk can stall waiting for an input device to be ready. A network client can sometimes take a long time to establish a connection before it can start reading any data, or the attempt to open a FIFO special file for reading can be blocked indefinitely until some other process opens it for writing.

4.12 Retrying Reads After Certain Input Errors

This section describes a feature that is specific to gawk.

When gawk encounters an error while reading input, by default getline returns −1, and subsequent attempts to read from that file result in an end-of-file indication. However, you may optionally instruct gawk to allow I/O to be retried when certain errors are encountered by setting a special element in the PROCINFO array (see Section 7.5.2 [Built-in Variables That Convey Information], page 169):

```
PROCINFO["input_name", "RETRY"] = 1
```

When this element exists, gawk checks the value of the system (C language) errno variable when an I/O error occurs. If errno indicates a subsequent I/O attempt may succeed, getline instead returns −2 and further calls to getline may succeed. This applies to the errno values EAGAIN, EWOULDBLOCK, EINTR, or ETIMEDOUT.

This feature is useful in conjunction with PROCINFO["input_name", "READ_TIMEOUT"] or situations where a file descriptor has been configured to behave in a non-blocking fashion.

4.13 Directories on the Command Line

According to the POSIX standard, files named on the awk command line must be text files; it is a fatal error if they are not. Most versions of awk treat a directory on the command line as a fatal error.

By default, gawk produces a warning for a directory on the command line, but otherwise ignores it. This makes it easier to use shell wildcards with your awk program:

```
$ gawk -f whizprog.awk *          Directories could kill this program
```

If either of the --posix or --traditional options is given, then gawk reverts to treating a directory on the command line as a fatal error.

See Section 17.7.6 [Reading Directories], page 474, for a way to treat directories as usable data from an awk program.

4.14 Summary

- Input is split into records based on the value of RS. The possibilities are as follows:

Value of RS	Records are split on ...	awk / gawk
Any single character	That character	awk

The empty string ("")	Runs of two or more newlines	`awk`
A regexp	Text that matches the regexp	`gawk`

- `FNR` indicates how many records have been read from the current input file; `NR` indicates how many records have been read in total.
- `gawk` sets `RT` to the text matched by `RS`.
- After splitting the input into records, `awk` further splits the records into individual fields, named `$1`, `$2`, and so on. `$0` is the whole record, and `NF` indicates how many fields there are. The default way to split fields is between whitespace characters.
- Fields may be referenced using a variable, as in `$NF`. Fields may also be assigned values, which causes the value of `$0` to be recomputed when it is later referenced. Assigning to a field with a number greater than `NF` creates the field and rebuilds the record, using `OFS` to separate the fields. Incrementing `NF` does the same thing. Decrementing `NF` throws away fields and rebuilds the record.
- Field splitting is more complicated than record splitting:

Field separator value	**Fields are split ...**	`awk` / `gawk`
`FS == " "`	On runs of whitespace	`awk`
`FS ==` *`any single character`*	On that character	`awk`
`FS ==` *`regexp`*	On text matching the regexp	`awk`
`FS == ""`	Such that each individual character is a separate field	`gawk`
`FIELDWIDTHS ==` *`list of columns`*	Based on character position	`gawk`
`FPAT ==` *`regexp`*	On the text surrounding text matching the regexp	`gawk`

- Using '`FS = "\n"`' causes the entire record to be a single field (assuming that newlines separate records).
- `FS` may be set from the command line using the `-F` option. This can also be done using command-line variable assignment.
- Use `PROCINFO["FS"]` to see how fields are being split.
- Use `getline` in its various forms to read additional records from the default input stream, from a file, or from a pipe or coprocess.
- Use `PROCINFO[`*`file`*`, "READ_TIMEOUT"]` to cause reads to time out for *file*.
- Directories on the command line are fatal for standard `awk`; `gawk` ignores them if not in POSIX mode.

4.15 Exercises

1. Using the `FIELDWIDTHS` variable (see Section 4.6 [Reading Fixed-Width Data], page 84), write a program to read election data, where each record represents one voter's votes. Come up with a way to define which columns are associated with each ballot item, and print the total votes, including abstentions, for each item.

5 Printing Output

One of the most common programming actions is to *print*, or output, some or all of the input. Use the `print` statement for simple output, and the `printf` statement for fancier formatting. The `print` statement is not limited when computing *which* values to print. However, with two exceptions, you cannot specify *how* to print them—how many columns, whether to use exponential notation or not, and so on. (For the exceptions, see Section 5.3 [Output Separators], page 105, and Section 5.4 [Controlling Numeric Output with `print`], page 106.) For printing with specifications, you need the `printf` statement (see Section 5.5 [Using `printf` Statements for Fancier Printing], page 106).

Besides basic and formatted printing, this chapter also covers I/O redirections to files and pipes, introduces the special file names that `gawk` processes internally, and discusses the `close()` built-in function.

5.1 The `print` Statement

Use the `print` statement to produce output with simple, standardized formatting. You specify only the strings or numbers to print, in a list separated by commas. They are output, separated by single spaces, followed by a newline. The statement looks like this:

```
print item1, item2, ...
```

The entire list of items may be optionally enclosed in parentheses. The parentheses are necessary if any of the item expressions uses the '`>`' relational operator; otherwise it could be confused with an output redirection (see Section 5.6 [Redirecting Output of `print` and `printf`], page 112).

The items to print can be constant strings or numbers, fields of the current record (such as `$1`), variables, or any `awk` expression. Numeric values are converted to strings and then printed.

The simple statement '`print`' with no items is equivalent to '`print $0`': it prints the entire current record. To print a blank line, use '`print ""`'. To print a fixed piece of text, use a string constant, such as `"Don't Panic"`, as one item. If you forget to use the double quote characters, your text is taken as an `awk` expression, and you will probably get an error. Keep in mind that a space is printed between any two items.

Note that the `print` statement is a statement and not an expression—you can't use it in the pattern part of a pattern–action statement, for example.

5.2 `print` Statement Examples

Each `print` statement makes at least one line of output. However, it isn't limited to only one line. If an item value is a string containing a newline, the newline is output along with the rest of the string. A single `print` statement can make any number of lines this way.

The following is an example of printing a string that contains embedded newlines:

```
$ awk 'BEGIN { print "line one\nline two\nline three" }'
⊣ line one
⊣ line two
⊣ line three
```

The next example, which is run on the `inventory-shipped` file, prints the first two fields of each input record, with a space between them:

```
$ awk '{ print $1, $2 }' inventory-shipped
⊣ Jan 13
⊣ Feb 15
⊣ Mar 15
...
```

A common mistake in using the `print` statement is to omit the comma between two items. This often has the effect of making the items run together in the output, with no space. The reason for this is that juxtaposing two string expressions in `awk` means to concatenate them. Here is the same program, without the comma:

```
$ awk '{ print $1 $2 }' inventory-shipped
⊣ Jan13
⊣ Feb15
⊣ Mar15
...
```

To someone unfamiliar with the `inventory-shipped` file, neither example's output makes much sense. A heading line at the beginning would make it clearer. Let's add some headings to our table of months (`$1`) and green crates shipped (`$2`). We do this using a `BEGIN` rule (see Section 7.1.4 [The BEGIN and END Special Patterns], page 154) so that the headings are only printed once:

```
awk 'BEGIN {  print "Month Crates"
              print "----- ------" }
           {  print $1, $2 }' inventory-shipped
```

When run, the program prints the following:

```
Month Crates
----- ------
Jan 13
Feb 15
Mar 15
...
```

The only problem, however, is that the headings and the table data don't line up! We can fix this by printing some spaces between the two fields:

```
awk 'BEGIN { print "Month Crates"
             print "----- ------" }
           { print $1, "     ", $2 }' inventory-shipped
```

Lining up columns this way can get pretty complicated when there are many columns to fix. Counting spaces for two or three columns is simple, but any more than this can take up a lot of time. This is why the `printf` statement was created (see Section 5.5 [Using printf Statements for Fancier Printing], page 106); one of its specialties is lining up columns of data.

> **NOTE:** You can continue either a `print` or `printf` statement simply by putting a newline after any comma (see Section 1.6 [awk Statements Versus Lines], page 28).

5.3 Output Separators

As mentioned previously, a `print` statement contains a list of items separated by commas. In the output, the items are normally separated by single spaces. However, this doesn't need to be the case; a single space is simply the default. Any string of characters may be used as the *output field separator* by setting the predefined variable `OFS`. The initial value of this variable is the string `" "` (i.e., a single space).

The output from an entire `print` statement is called an *output record*. Each `print` statement outputs one output record, and then outputs a string called the *output record separator* (or `ORS`). The initial value of `ORS` is the string `"\n"` (i.e., a newline character). Thus, each `print` statement normally makes a separate line.

In order to change how output fields and records are separated, assign new values to the variables `OFS` and `ORS`. The usual place to do this is in the `BEGIN` rule (see Section 7.1.4 [The BEGIN and END Special Patterns], page 154), so that it happens before any input is processed. It can also be done with assignments on the command line, before the names of the input files, or using the `-v` command-line option (see Section 2.2 [Command-Line Options], page 33). The following example prints the first and second fields of each input record, separated by a semicolon, with a blank line added after each newline:

```
$ awk 'BEGIN { OFS = ";"; ORS = "\n\n" }
>            { print $1, $2 }' mail-list
⊣ Amelia;555-5553
⊣
⊣ Anthony;555-3412
⊣
⊣ Becky;555-7685
⊣
⊣ Bill;555-1675
⊣
⊣ Broderick;555-0542
⊣
⊣ Camilla;555-2912
⊣
⊣ Fabius;555-1234
⊣
⊣ Julie;555-6699
⊣
⊣ Martin;555-6480
⊣
⊣ Samuel;555-3430
⊣
⊣ Jean-Paul;555-2127
⊣
```

If the value of `ORS` does not contain a newline, the program's output runs together on a single line.

5.4 Controlling Numeric Output with `print`

When printing numeric values with the `print` statement, `awk` internally converts each number to a string of characters and prints that string. `awk` uses the `sprintf()` function to do this conversion (see Section 9.1.4 [String-Manipulation Functions], page 200). For now, it suffices to say that the `sprintf()` function accepts a *format specification* that tells it how to format numbers (or strings), and that there are a number of different ways in which numbers can be formatted. The different format specifications are discussed more fully in Section 5.5.2 [Format-Control Letters], page 107.

The predefined variable `OFMT` contains the format specification that `print` uses with `sprintf()` when it wants to convert a number to a string for printing. The default value of `OFMT` is `"%.6g"`. The way `print` prints numbers can be changed by supplying a different format specification for the value of `OFMT`, as shown in the following example:

```
$ awk 'BEGIN {
>   OFMT = "%.0f"  # print numbers as integers (rounds)
>   print 17.23, 17.54 }'
⊣ 17 18
```

More detail on how `awk` converts numeric values into strings is provided in Section 6.1.4.1 [How `awk` Converts Between Strings and Numbers], page 130. In particular, for `print`, `awk` uses the value of `OFMT` instead of that of `CONVFMT`, but otherwise behaves exactly the same as described in that section.

According to the POSIX standard, `awk`'s behavior is undefined if `OFMT` contains anything but a floating-point conversion specification.

5.5 Using `printf` Statements for Fancier Printing

For more precise control over the output format than what is provided by `print`, use `printf`. With `printf` you can specify the width to use for each item, as well as various formatting choices for numbers (such as what output base to use, whether to print an exponent, whether to print a sign, and how many digits to print after the decimal point).

5.5.1 Introduction to the `printf` Statement

A simple `printf` statement looks like this:

```
printf format, item1, item2, ...
```

As for `print`, the entire list of arguments may optionally be enclosed in parentheses. Here too, the parentheses are necessary if any of the item expressions uses the '`>`' relational operator; otherwise, it can be confused with an output redirection (see Section 5.6 [Redirecting Output of `print` and `printf`], page 112).

The difference between `printf` and `print` is the *format* argument. This is an expression whose value is taken as a string; it specifies how to output each of the other arguments. It is called the *format string*.

The format string is very similar to that in the ISO C library function `printf()`. Most of *format* is text to output verbatim. Scattered among this text are *format specifiers*—one per item. Each format specifier says to output the next item in the argument list at that place in the format.

The `printf` statement does not automatically append a newline to its output. It outputs only what the format string specifies. So if a newline is needed, you must include one in the format string. The output separator variables `OFS` and `ORS` have no effect on `printf` statements. For example:

```
$ awk 'BEGIN {
>     ORS = "\nOUCH!\n"; OFS = "+"
>     msg = "Don\47t Panic!"
>     printf "%s\n", msg
> }'
 ⊣ Don't Panic!
```

Here, neither the '`+`' nor the '`OUCH!`' appears in the output message.

5.5.2 Format-Control Letters

A format specifier starts with the character '`%`' and ends with a *format-control letter*—it tells the `printf` statement how to output one item. The format-control letter specifies what *kind* of value to print. The rest of the format specifier is made up of optional *modifiers* that control *how* to print the value, such as the field width. Here is a list of the format-control letters:

`%a`, `%A` A floating point number of the form [`-`]`0x`*`h.hhhh`*`p+-`*`dd`* (C99 hexadecimal floating point format). For `%A`, uppercase letters are used instead of lowercase ones.

> **NOTE:** The current POSIX standard requires support for `%a` and `%A` in `awk`. As far as we know, besides `gawk`, the only other version of `awk` that actually implements it is BWK `awk`. It's use is thus highly nonportable!
>
> Furthermore, these formats are not available on any system where the underlying C library `printf()` function does not support them. As of this writing, among current systems, only older OpenVMS versions are known to not support them.

`%c` Print a number as a character; thus, '`printf "%c", 65`' outputs the letter '`A`'. The output for a string value is the first character of the string.

> **NOTE:** The POSIX standard says the first character of a string is printed. In locales with multibyte characters, `gawk` attempts to convert the leading bytes of the string into a valid wide character and then to print the multibyte encoding of that character. Similarly, when printing a numeric value, `gawk` allows the value to be within the numeric range of values that can be held in a wide character. If the conversion to multibyte encoding fails, `gawk` uses the low eight bits of the value as the character to print.
>
> Other `awk` versions generally restrict themselves to printing the first byte of a string or to numeric values within the range of a single byte (0–255).

`%d`, `%i` Print a decimal integer. The two control letters are equivalent. (The '`%i`' specification is for compatibility with ISO C.)

`%e`, `%E` Print a number in scientific (exponential) notation. For example:

```
printf "%4.3e\n", 1950
```

prints '`1.950e+03`', with a total of four significant figures, three of which follow the decimal point. (The '`4.3`' represents two modifiers, discussed in the next subsection.) '`%E`' uses '`E`' instead of '`e`' in the output.

`%f` Print a number in floating-point notation. For example:

```
printf "%4.3f", 1950
```

prints '`1950.000`', with a minimum of four significant figures, three of which follow the decimal point. (The '`4.3`' represents two modifiers, discussed in the next subsection.)

On systems supporting IEEE 754 floating-point format, values representing negative infinity are formatted as '`-inf`' or '`-infinity`', and positive infinity as '`inf`' or '`infinity`'. The special "not a number" value formats as '`-nan`' or '`nan`' (see Section 16.4.1.4 [Floating Point Values They Didn't Talk About In School], page 405).

`%F` Like '`%f`', but the infinity and "not a number" values are spelled using uppercase letters.

The '`%F`' format is a POSIX extension to ISO C; not all systems support it. On those that don't, `gawk` uses '`%f`' instead.

`%g`, `%G` Print a number in either scientific notation or in floating-point notation, whichever uses fewer characters; if the result is printed in scientific notation, '`%G`' uses '`E`' instead of '`e`'.

`%o` Print an unsigned octal integer (see Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124).

`%s` Print a string.

`%u` Print an unsigned decimal integer. (This format is of marginal use, because all numbers in `awk` are floating point; it is provided primarily for compatibility with C.)

`%x`, `%X` Print an unsigned hexadecimal integer; '`%X`' uses the letters '`A`' through '`F`' instead of '`a`' through '`f`' (see Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124).

`%%` Print a single '`%`'. This does not consume an argument and it ignores any modifiers.

NOTE: When using the integer format-control letters for values that are outside the range of the widest C integer type, `gawk` switches to the '`%g`' format specifier. If `--lint` is provided on the command line (see Section 2.2 [Command-Line Options], page 33), `gawk` warns about this. Other versions of `awk` may print invalid values or do something else entirely.

NOTE: The IEEE 754 standard for floating-point arithmetic allows for special values that represent "infinity" (positive and negative) and values that are "not a number" (NaN).

Input and output of these values occurs as text strings. This is somewhat problematic for the `awk` language, which predates the IEEE standard. Further details are provided in Section 16.7 [Standards Versus Existing Practice], page 411; please see there.

5.5.3 Modifiers for `printf` Formats

A format specification can also include *modifiers* that can control how much of the item's value is printed, as well as how much space it gets. The modifiers come between the '`%`' and the format-control letter. We use the bullet symbol "•" in the following examples to represent spaces in the output. Here are the possible modifiers, in the order in which they may appear:

`M``$` An integer constant followed by a '`$`' is a *positional specifier*. Normally, format specifications are applied to arguments in the order given in the format string. With a positional specifier, the format specification is applied to a specific argument, instead of what would be the next argument in the list. Positional specifiers begin counting with one. Thus:

```
printf "%s %s\n", "don't", "panic"
printf "%2$s %1$s\n", "panic", "don't"
```

prints the famous friendly message twice.

At first glance, this feature doesn't seem to be of much use. It is in fact a `gawk` extension, intended for use in translating messages at runtime. See Section 13.4.2 [Rearranging `printf` Arguments], page 370, which describes how and why to use positional specifiers. For now, we ignore them.

`-` (Minus) The minus sign, used before the width modifier (see later on in this list), says to left-justify the argument within its specified width. Normally, the argument is printed right-justified in the specified width. Thus:

```
printf "%-4s", "foo"
```

prints '`foo•`'.

space For numeric conversions, prefix positive values with a space and negative values with a minus sign.

`+` The plus sign, used before the width modifier (see later on in this list), says to always supply a sign for numeric conversions, even if the data to format is positive. The '`+`' overrides the space modifier.

`#` Use an "alternative form" for certain control letters. For '`%o`', supply a leading zero. For '`%x`' and '`%X`', supply a leading '`0x`' or '`0X`' for a nonzero result. For '`%e`', '`%E`', '`%f`', and '`%F`', the result always contains a decimal point. For '`%g`' and '`%G`', trailing zeros are not removed from the result.

`0` A leading '`0`' (zero) acts as a flag indicating that output should be padded with zeros instead of spaces. This applies only to the numeric output formats. This flag only has an effect when the field width is wider than the value to print.

`'` A single quote or apostrophe character is a POSIX extension to ISO C. It indicates that the integer part of a floating-point value, or the entire part of an

integer decimal value, should have a thousands-separator character in it. This only works in locales that support such characters. For example:

```
$ cat thousands.awk          Show source program
⊣ BEGIN { printf "%'d\n", 1234567 }
$ LC_ALL=C gawk -f thousands.awk
⊣ 1234567                    Results in "C" locale
$ LC_ALL=en_US.UTF-8 gawk -f thousands.awk
⊣ 1,234,567                  Results in US English UTF locale
```

For more information about locales and internationalization issues, see Section 6.6 [Where You Are Makes a Difference], page 149.

> **NOTE:** The '' flag is a nice feature, but its use complicates things: it becomes difficult to use it in command-line programs. For information on appropriate quoting tricks, see Section 1.1.6 [Shell Quoting Issues], page 21.

width This is a number specifying the desired minimum width of a field. Inserting any number between the '%' sign and the format-control character forces the field to expand to this width. The default way to do this is to pad with spaces on the left. For example:

```
printf "%4s", "foo"
```

prints '␣foo'.

The value of *width* is a minimum width, not a maximum. If the item value requires more than *width* characters, it can be as wide as necessary. Thus, the following:

```
printf "%4s", "foobar"
```

prints 'foobar'.

Preceding the *width* with a minus sign causes the output to be padded with spaces on the right, instead of on the left.

.prec A period followed by an integer constant specifies the precision to use when printing. The meaning of the precision varies by control letter:

`%d`, `%i`, `%o`, `%u`, `%x`, `%X`
: Minimum number of digits to print.

`%e`, `%E`, `%f`, `%F`
: Number of digits to the right of the decimal point.

`%g`, `%G`
: Maximum number of significant digits.

`%s`
: Maximum number of characters from the string that should print.

Thus, the following:

```
printf "%.4s", "foobar"
```

prints 'foob'.

The C library `printf`'s dynamic *width* and *prec* capability (e.g., `"%*.*s"`) is supported. Instead of supplying explicit *width* and/or *prec* values in the format string, they are passed in the argument list. For example:

```
w = 5
```

```
p = 3
s = "abcdefg"
printf "%*.*s\n", w, p, s
```

is exactly equivalent to:

```
s = "abcdefg"
printf "%5.3s\n", s
```

Both programs output '••abc'. Earlier versions of `awk` did not support this capability. If you must use such a version, you may simulate this feature by using concatenation to build up the format string, like so:

```
w = 5
p = 3
s = "abcdefg"
printf "%" w "." p "s\n", s
```

This is not particularly easy to read, but it does work.

C programmers may be used to supplying additional modifiers ('`h`', '`j`', '`l`', '`L`', '`t`', and '`z`') in `printf` format strings. These are not valid in `awk`. Most `awk` implementations silently ignore them. If `--lint` is provided on the command line (see Section 2.2 [Command-Line Options], page 33), `gawk` warns about their use. If `--posix` is supplied, their use is a fatal error.

5.5.4 Examples Using `printf`

The following simple example shows how to use `printf` to make an aligned table:

```
awk '{ printf "%-10s %s\n", $1, $2 }' mail-list
```

This command prints the names of the people (`$1`) in the file `mail-list` as a string of 10 characters that are left-justified. It also prints the phone numbers (`$2`) next on the line. This produces an aligned two-column table of names and phone numbers, as shown here:

```
$ awk '{ printf "%-10s %s\n", $1, $2 }' mail-list
⊣ Amelia     555-5553
⊣ Anthony    555-3412
⊣ Becky      555-7685
⊣ Bill       555-1675
⊣ Broderick  555-0542
⊣ Camilla    555-2912
⊣ Fabius     555-1234
⊣ Julie      555-6699
⊣ Martin     555-6480
⊣ Samuel     555-3430
⊣ Jean-Paul  555-2127
```

In this case, the phone numbers had to be printed as strings because the numbers are separated by dashes. Printing the phone numbers as numbers would have produced just the first three digits: '`555`'. This would have been pretty confusing.

It wasn't necessary to specify a width for the phone numbers because they are last on their lines. They don't need to have spaces after them.

The table could be made to look even nicer by adding headings to the tops of the columns. This is done using a `BEGIN` rule (see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154) so that the headers are only printed once, at the beginning of the `awk` program:

```
awk 'BEGIN { print "Name      Number"
             print "----      ------" }
           { printf "%-10s %s\n", $1, $2 }' mail-list
```

The preceding example mixes `print` and `printf` statements in the same program. Using just `printf` statements can produce the same results:

```
awk 'BEGIN { printf "%-10s %s\n", "Name", "Number"
             printf "%-10s %s\n", "----", "------" }
           { printf "%-10s %s\n", $1, $2 }' mail-list
```

Printing each column heading with the same format specification used for the column elements ensures that the headings are aligned just like the columns.

The fact that the same format specification is used three times can be emphasized by storing it in a variable, like this:

```
awk 'BEGIN { format = "%-10s %s\n"
             printf format, "Name", "Number"
             printf format, "----", "------" }
           { printf format, $1, $2 }' mail-list
```

5.6 Redirecting Output of `print` and `printf`

So far, the output from `print` and `printf` has gone to the standard output, usually the screen. Both `print` and `printf` can also send their output to other places. This is called *redirection*.

> **NOTE:** When `--sandbox` is specified (see Section 2.2 [Command-Line Options], page 33), redirecting output to files, pipes, and coprocesses is disabled.

A redirection appears after the `print` or `printf` statement. Redirections in `awk` are written just like redirections in shell commands, except that they are written inside the `awk` program.

There are four forms of output redirection: output to a file, output appended to a file, output through a pipe to another command, and output to a coprocess. We show them all for the `print` statement, but they work identically for `printf`:

`print` *items* `>` *output-file*

> This redirection prints the items into the output file named *output-file*. The file name *output-file* can be any expression. Its value is changed to a string and then used as a file name (see Chapter 6 [Expressions], page 123).
>
> When this type of redirection is used, the *output-file* is erased before the first output is written to it. Subsequent writes to the same *output-file* do not erase *output-file*, but append to it. (This is different from how you use redirections in shell scripts.) If *output-file* does not exist, it is created. For example, here is how an `awk` program can write a list of peoples' names to one file named `name-list`, and a list of phone numbers to another file named `phone-list`:
>
> ```
> $ awk '{ print $2 > "phone-list"
> ```

```
>        print $1 > "name-list" }' mail-list
$ cat phone-list
⊣ 555-5553
⊣ 555-3412
...
$ cat name-list
⊣ Amelia
⊣ Anthony
...
```

Each output file contains one name or number per line.

`print` *items* `>>` *output-file*
: This redirection prints the items into the preexisting output file named *output-file*. The difference between this and the single-'`>`' redirection is that the old contents (if any) of *output-file* are not erased. Instead, the `awk` output is appended to the file. If *output-file* does not exist, then it is created.

`print` *items* `|` *command*
: It is possible to send output to another program through a pipe instead of into a file. This redirection opens a pipe to *command*, and writes the values of *items* through this pipe to another process created to execute *command*.

  The redirection argument *command* is actually an `awk` expression. Its value is converted to a string whose contents give the shell command to be run. For example, the following produces two files, one unsorted list of peoples' names, and one list sorted in reverse alphabetical order:

```
awk '{ print $1 > "names.unsorted"
       command = "sort -r > names.sorted"
       print $1 | command }' mail-list
```

  The unsorted list is written with an ordinary redirection, while the sorted list is written by piping through the `sort` utility.

  The next example uses redirection to mail a message to the mailing list `bug-system`. This might be useful when trouble is encountered in an `awk` script run periodically for system maintenance:

```
report = "mail bug-system"
print("Awk script failed:", $0) | report
print("at record number", FNR, "of", FILENAME) | report
close(report)
```

  The `close()` function is called here because it's a good idea to close the pipe as soon as all the intended output has been sent to it. See Section 5.9 [Closing Input and Output Redirections], page 117, for more information.

  This example also illustrates the use of a variable to represent a *file* or *command*—it is not necessary to always use a string constant. Using a variable is generally a good idea, because (if you mean to refer to that same file or command) `awk` requires that the string value be written identically every time.

`print` *items* `|&` *command*
: This redirection prints the items to the input of *command*. The difference between this and the single-'`|`' redirection is that the output from *command* can be read with `getline`. Thus, *command* is a *coprocess*, which works together with but is subsidiary to the `awk` program.

  This feature is a `gawk` extension, and is not available in POSIX `awk`. See Section 4.10.7 [Using `getline` from a Coprocess], page 97, for a brief discussion. See Section 12.4 [Two-Way Communications with Another Process], page 351, for a more complete discussion.

Redirecting output using '`>`', '`>>`', '`|`', or '`|&`' asks the system to open a file, pipe, or coprocess only if the particular *file* or *command* you specify has not already been written to by your program or if it has been closed since it was last written to. In other words, files, pipes, and coprocesses remain open until explicitly closed. All further `print` and `printf` statements continue to write to the same open file, pipe, or coprocess.

In the shell, when you are building up a file a line at a time, you first use '`>`' to create the file, and then you use '`>>`' for subsequent additions to it, like so:

```
echo Name: Arnold Robbins > data
echo Street Address: 1234 A Pretty Street, NE >> data
echo City and State: MyTown, MyState 12345-6789 >> data
```

In `awk`, the '`>`' and '`>>`' operators are subtly different. The operator you use the *first time* you write to a file determines how `awk` will open (or create) the file. If you use '`>`', the file is truncated, and then all subsequent output appends data to the file, even if additional `print` or `printf` statements continue to use '`>`'. If you use '`>>`' the first time, then existing data is not truncated, and all subsequent `print` or `printf` statements append data to the file.

You should be consistent and always use the same operator for all output to the same file. (You can mix '`>`' and '`>>`', and nothing bad will happen, but mixing the operators is considered to be bad style in `awk`. If invoked with the `--lint` option, `gawk` issues a warning when it encounters both operators being used for the same open file.)

As mentioned earlier (see Section 4.10.9 [Points to Remember About `getline`], page 98), many older `awk` implementations limit the number of pipelines that an `awk` program may have open to just one! In `gawk`, there is no such limit. `gawk` allows a program to open as many pipelines as the underlying operating system permits.

Piping into `sh`

A particularly powerful way to use redirection is to build command lines and pipe them into the shell, `sh`. For example, suppose you have a list of files brought over from a system where all the file names are stored in uppercase, and you wish to rename them to have names in all lowercase. The following program is both simple and efficient:

```
{ printf("mv %s %s\n", $0, tolower($0)) | "sh" }

END { close("sh") }
```

The `tolower()` function returns its argument string with all uppercase characters converted to lowercase (see Section 9.1.4 [String-Manipulation Functions], page 200). The program builds up a list of command lines, using the `mv` utility to rename the files. It then sends the list to the shell for execution.

See Section 10.2.9 [Quoting Strings to Pass to the Shell], page 258, for a function that can help in generating command lines to be fed to the shell.

5.7 Special Files for Standard Preopened Data Streams

Running programs conventionally have three input and output streams already available to them for reading and writing. These are known as the *standard input*, *standard output*, and *standard error output*. These open streams (and any other open files or pipes) are often referred to by the technical term *file descriptors*.

These streams are, by default, connected to your keyboard and screen, but they are often redirected with the shell, via the '`<`', '`<<`', '`>`', '`>>`', '`>&`', and '`|`' operators. Standard error is typically used for writing error messages; the reason there are two separate streams, standard output and standard error, is so that they can be redirected separately.

In traditional implementations of `awk`, the only way to write an error message to standard error in an `awk` program is as follows:

```
print "Serious error detected!" | "cat 1>&2"
```

This works by opening a pipeline to a shell command that can access the standard error stream that it inherits from the `awk` process. This is far from elegant, and it also requires a separate process. So people writing `awk` programs often don't do this. Instead, they send the error messages to the screen, like this:

```
print "Serious error detected!" > "/dev/tty"
```

(`/dev/tty` is a special file supplied by the operating system that is connected to your keyboard and screen. It represents the "terminal,"[1] which on modern systems is a keyboard and screen, not a serial console.) This generally has the same effect, but not always: although the standard error stream is usually the screen, it can be redirected; when that happens, writing to the screen is not correct. In fact, if `awk` is run from a background job, it may not have a terminal at all. Then opening `/dev/tty` fails.

`gawk`, BWK `awk`, and `mawk` provide special file names for accessing the three standard streams. If the file name matches one of these special names when `gawk` (or one of the

[1] The "tty" in `/dev/tty` stands for "Teletype," a serial terminal.

others) redirects input or output, then it directly uses the descriptor that the file name stands for. These special file names work for all operating systems that `gawk` has been ported to, not just those that are POSIX-compliant:

`/dev/stdin`
: The standard input (file descriptor 0).

`/dev/stdout`
: The standard output (file descriptor 1).

`/dev/stderr`
: The standard error output (file descriptor 2).

With these facilities, the proper way to write an error message then becomes:

```
print "Serious error detected!" > "/dev/stderr"
```

Note the use of double quotes around the file name. Like with any other redirection, the value must be a string. It is a common error to omit the double quotes, which leads to confusing results.

`gawk` does not treat these file names as special when in POSIX-compatibility mode. However, because BWK `awk` supports them, `gawk` does support them even when invoked with the `--traditional` option (see Section 2.2 [Command-Line Options], page 33).

5.8 Special File names in `gawk`

Besides access to standard input, standard output, and standard error, `gawk` provides access to any open file descriptor. Additionally, there are special file names reserved for TCP/IP networking.

5.8.1 Accessing Other Open Files with `gawk`

Besides the `/dev/stdin`, `/dev/stdout`, and `/dev/stderr` special file names mentioned earlier, `gawk` provides syntax for accessing any other inherited open file:

`/dev/fd/`*`N`*
: The file associated with file descriptor *N*. Such a file must be opened by the program initiating the `awk` execution (typically the shell). Unless special pains are taken in the shell from which `gawk` is invoked, only descriptors 0, 1, and 2 are available.

The file names `/dev/stdin`, `/dev/stdout`, and `/dev/stderr` are essentially aliases for `/dev/fd/0`, `/dev/fd/1`, and `/dev/fd/2`, respectively. However, those names are more self-explanatory.

Note that using `close()` on a file name of the form `"/dev/fd/`*`N`*`"`, for file descriptor numbers above two, does actually close the given file descriptor.

5.8.2 Special Files for Network Communications

`gawk` programs can open a two-way TCP/IP connection, acting as either a client or a server. This is done using a special file name of the form:

```
/net-type/protocol/local-port/remote-host/remote-port
```

The *net-type* is one of '`inet`', '`inet4`', or '`inet6`'. The *protocol* is one of '`tcp`' or '`udp`', and the other fields represent the other essential pieces of information for making a networking connection. These file names are used with the '`|&`' operator for communicating with a coprocess (see Section 12.4 [Two-Way Communications with Another Process], page 351). This is an advanced feature, mentioned here only for completeness. Full discussion is delayed until Section 12.5 [Using `gawk` for Network Programming], page 354.

5.8.3 Special File name Caveats

Here are some things to bear in mind when using the special file names that `gawk` provides:

- Recognition of the file names for the three standard preopened files is disabled only in POSIX mode.
- Recognition of the other special file names is disabled if `gawk` is in compatibility mode (either `--traditional` or `--posix`; see Section 2.2 [Command-Line Options], page 33).
- `gawk` *always* interprets these special file names. For example, using '`/dev/fd/4`' for output actually writes on file descriptor 4, and not on a new file descriptor that is `dup()`ed from file descriptor 4. Most of the time this does not matter; however, it is important to *not* close any of the files related to file descriptors 0, 1, and 2. Doing so results in unpredictable behavior.

5.9 Closing Input and Output Redirections

If the same file name or the same shell command is used with `getline` more than once during the execution of an `awk` program (see Section 4.10 [Explicit Input with `getline`], page 92), the file is opened (or the command is executed) the first time only. At that time, the first record of input is read from that file or command. The next time the same file or command is used with `getline`, another record is read from it, and so on.

Similarly, when a file or pipe is opened for output, `awk` remembers the file name or command associated with it, and subsequent writes to the same file or command are appended to the previous writes. The file or pipe stays open until `awk` exits.

This implies that special steps are necessary in order to read the same file again from the beginning, or to rerun a shell command (rather than reading more output from the same command). The `close()` function makes these things possible:

```
close(filename)
```

or:

```
close(command)
```

The argument *filename* or *command* can be any expression. Its value must *exactly* match the string that was used to open the file or start the command (spaces and other "irrelevant" characters included). For example, if you open a pipe with this:

```
"sort -r names" | getline foo
```

then you must close it with this:

```
close("sort -r names")
```

Once this function call is executed, the next `getline` from that file or command, or the next `print` or `printf` to that file or command, reopens the file or reruns the command. Because the expression that you use to close a file or pipeline must exactly match the

expression used to open the file or run the command, it is good practice to use a variable to store the file name or command. The previous example becomes the following:

```
sortcom = "sort -r names"
sortcom | getline foo
...
close(sortcom)
```

This helps avoid hard-to-find typographical errors in your `awk` programs. Here are some of the reasons for closing an output file:

- To write a file and read it back later on in the same `awk` program. Close the file after writing it, then begin reading it with `getline`.
- To write numerous files, successively, in the same `awk` program. If the files aren't closed, eventually `awk` may exceed a system limit on the number of open files in one process. It is best to close each one when the program has finished writing it.
- To make a command finish. When output is redirected through a pipe, the command reading the pipe normally continues to try to read input as long as the pipe is open. Often this means the command cannot really do its work until the pipe is closed. For example, if output is redirected to the `mail` program, the message is not actually sent until the pipe is closed.
- To run the same program a second time, with the same arguments. This is not the same thing as giving more input to the first run!

  For example, suppose a program pipes output to the `mail` program. If it outputs several lines redirected to this pipe without closing it, they make a single message of several lines. By contrast, if the program closes the pipe after each line of output, then each line makes a separate message.

If you use more files than the system allows you to have open, `gawk` attempts to multiplex the available open files among your data files. `gawk`'s ability to do this depends upon the facilities of your operating system, so it may not always work. It is therefore both good practice and good portability advice to always use `close()` on your files when you are done with them. In fact, if you are using a lot of pipes, it is essential that you close commands when done. For example, consider something like this:

```
{
    ...
    command = ("grep " $1 " /some/file | my_prog -q " $3)
    while ((command | getline) > 0) {
        process output of command
    }
    # need close(command) here
}
```

This example creates a new pipeline based on data in *each* record. Without the call to `close()` indicated in the comment, `awk` creates child processes to run the commands, until it eventually runs out of file descriptors for more pipelines.

Even though each command has finished (as indicated by the end-of-file return status from `getline`), the child process is not terminated;[2] more importantly, the file descriptor for the pipe is not closed and released until `close()` is called or `awk` exits.

`close()` silently does nothing if given an argument that does not represent a file, pipe, or coprocess that was opened with a redirection. In such a case, it returns a negative value, indicating an error. In addition, `gawk` sets `ERRNO` to a string indicating the error.

Note also that '`close(FILENAME)`' has no "magic" effects on the implicit loop that reads through the files named on the command line. It is, more likely, a close of a file that was never opened with a redirection, so `awk` silently does nothing, except return a negative value.

When using the '`|&`' operator to communicate with a coprocess, it is occasionally useful to be able to close one end of the two-way pipe without closing the other. This is done by supplying a second argument to `close()`. As in any other call to `close()`, the first argument is the name of the command or special file used to start the coprocess. The second argument should be a string, with either of the values `"to"` or `"from"`. Case does not matter. As this is an advanced feature, discussion is delayed until Section 12.4 [Two-Way Communications with Another Process], page 351, which describes it in more detail and gives an example.

5.9.1 Using `close()`'s Return Value

In many older versions of Unix `awk`, the `close()` function is actually a statement. It is a syntax error to try and use the return value from `close()`:

```
command = "..."
command | getline info
retval = close(command)  # syntax error in many Unix awks
```

`gawk` treats `close()` as a function. The return value is -1 if the argument names something that was never opened with a redirection, or if there is a system problem closing the file or process. In these cases, `gawk` sets the predefined variable `ERRNO` to a string describing the problem.

In `gawk`, starting with version 4.2, when closing a pipe or coprocess (input or output), the return value is the exit status of the command, as described in Table 5.1.[3] Otherwise, it is the return value from the system's `close()` or `fclose()` C functions when closing input or output files, respectively. This value is zero if the close succeeds, or -1 if it fails. Recent versions of BWK `awk` also return the same values from `close()`.

Situation	**Return value from `close()`**
Normal exit of command	Command's exit status
Death by signal of command	256 + number of murderous signal
Death by signal of command with core dump	512 + number of murderous signal
Some kind of error	-1

Table 5.1: Return values from `close()` of a pipe

[2] The technical terminology is rather morbid. The finished child is called a "zombie," and cleaning up after it is referred to as "reaping."

[3] Prior to version 4.2, the return value from closing a pipe or co-process was the full 16-bit exit value as defined by the `wait()` system call.

The POSIX standard is very vague; it says that `close()` returns zero on success and a nonzero value otherwise. In general, different implementations vary in what they report when closing pipes; thus, the return value cannot be used portably. In POSIX mode (see Section 2.2 [Command-Line Options], page 33), `gawk` just returns zero when closing a pipe.

5.10 Speeding Up Pipe Output

This section describes a `gawk`-specific feature.

Normally, when you send data down a pipeline to a command with `print` or `printf`, `gawk` *flushes* the output down the pipe. That is, output is not buffered, but written directly. This assures, that pipeline output intermixed with `gawk`'s output comes out in the expected order:

```
print "something"                        # goes to standard output
print "something else" | "some-command" # also to standard output
print "more stuff"                       # and this too
```

There can be a price to pay for this; flushing data down the pipeline uses more CPU time, and in certain environments this can become expensive.

You can tell `gawk` not to flush buffered data in one of two ways:

- Set `PROCINFO["BUFFERPIPE"]` to any value. When this is done, `gawk` will buffer data for all pipelines.
- Set `PROCINFO["`*`command`*`", "BUFFERPIPE"]` to any value. In this case, only *command*'s data will be fully buffered.

You *must* create one or the other of these elements in `PROCINFO` before the first `print` or `printf` to the pipeline. Doing so after output has already been sent is too late.

Be aware that using this feature may change the output behavior of your programs, so exercise caution.

5.11 Enabling Nonfatal Output

This section describes a `gawk`-specific feature.

In standard `awk`, output with `print` or `printf` to a nonexistent file, or some other I/O error (such as filling up the disk) is a fatal error.

```
$ gawk 'BEGIN { print "hi" > "/no/such/file" }'
error  gawk: cmd. line:1: fatal: can't redirect to `/no/such/file' (No
error  such file or directory)
```

`gawk` makes it possible to detect that an error has occurred, allowing you to possibly recover from the error, or at least print an error message of your choosing before exiting. You can do this in one of two ways:

- For all output files, by assigning any value to `PROCINFO["NONFATAL"]`.
- On a per-file basis, by assigning any value to `PROCINFO[`*`filename`*`, "NONFATAL"]`. Here, *filename* is the name of the file to which you wish output to be nonfatal.

Once you have enabled nonfatal output, you must check `ERRNO` after every relevant `print` or `printf` statement to see if something went wrong. It is also a good idea to initialize `ERRNO` to zero before attempting the output. For example:

```
$ gawk '
```

```
> BEGIN {
>     PROCINFO["NONFATAL"] = 1
>     ERRNO = 0
>     print "hi" > "/no/such/file"
>     if (ERRNO) {
>         print("Output failed:", ERRNO) > "/dev/stderr"
>         exit 1
>     }
> }'
error  Output failed: No such file or directory
```

Here, `gawk` did not produce a fatal error; instead it let the `awk` program code detect the problem and handle it.

This mechanism works also for standard output and standard error. For standard output, you may use `PROCINFO["-", "NONFATAL"]` or `PROCINFO["/dev/stdout", "NONFATAL"]`. For standard error, use `PROCINFO["/dev/stderr", "NONFATAL"]`.

When attempting to open a TCP/IP socket (see Section 12.5 [Using gawk for Network Programming], page 354), `gawk` tries multiple times. The `GAWK_SOCK_RETRIES` environment variable (see Section 2.5.3 [Other Environment Variables], page 44) allows you to override `gawk`'s builtin default number of attempts. However, once nonfatal I/O is enabled for a given socket, `gawk` only retries once, relying on `awk`-level code to notice that there was a problem.

5.12 Summary

- The `print` statement prints comma-separated expressions. Each expression is separated by the value of `OFS` and terminated by the value of `ORS`. `OFMT` provides the conversion format for numeric values for the `print` statement.
- The `printf` statement provides finer-grained control over output, with format-control letters for different data types and various flags that modify the behavior of the format-control letters.
- Output from both `print` and `printf` may be redirected to files, pipes, and coprocesses.
- `gawk` provides special file names for access to standard input, output, and error, and for network communications.
- Use `close()` to close open file, pipe, and coprocess redirections. For coprocesses, it is possible to close only one direction of the communications.
- Normally errors with `print` or `printf` are fatal. `gawk` lets you make output errors be nonfatal either for all files or on a per-file basis. You must then check for errors after every relevant output statement.

5.13 Exercises

1. Rewrite the program:

```
awk 'BEGIN { print "Month Crates"
             print "-----  ------" }
           { print $1, "     ", $2 }' inventory-shipped
```

   from Section 5.3 [Output Separators], page 105, by using a new value of `OFS`.

2. Use the `printf` statement to line up the headings and table data for the `inventory-shipped` example that was covered in Section 5.1 [The `print` Statement], page 103.
3. What happens if you forget the double quotes when redirecting output, as follows:

```
BEGIN { print "Serious error detected!" > /dev/stderr }
```

6 Expressions

Expressions are the basic building blocks of `awk` patterns and actions. An expression evaluates to a value that you can print, test, or pass to a function. Additionally, an expression can assign a new value to a variable or a field by using an assignment operator.

An expression can serve as a pattern or action statement on its own. Most other kinds of statements contain one or more expressions that specify the data on which to operate. As in other languages, expressions in `awk` can include variables, array references, constants, and function calls, as well as combinations of these with various operators.

6.1 Constants, Variables, and Conversions

Expressions are built up from values and the operations performed upon them. This section describes the elementary objects that provide the values used in expressions.

6.1.1 Constant Expressions

The simplest type of expression is the *constant*, which always has the same value. There are three types of constants: numeric, string, and regular expression.

Each is used in the appropriate context when you need a data value that isn't going to change. Numeric constants can have different forms, but are internally stored in an identical manner.

6.1.1.1 Numeric and String Constants

A *numeric constant* stands for a number. This number can be an integer, a decimal fraction, or a number in scientific (exponential) notation.[1] Here are some examples of numeric constants that all have the same value:

```
105
1.05e+2
1050e-1
```

A *string constant* consists of a sequence of characters enclosed in double quotation marks. For example:

```
"parrot"
```

represents the string whose contents are '`parrot`'. Strings in `gawk` can be of any length, and they can contain any of the possible eight-bit ASCII characters, including ASCII NUL (character code zero). Other `awk` implementations may have difficulty with some character codes.

Some languages allow you to continue long strings across multiple lines by ending the line with a backslash. For example in C:

```
#include <stdio.h>

int main()
{
```

[1] The internal representation of all numbers, including integers, uses double-precision floating-point numbers. On most modern systems, these are in IEEE 754 standard format. See Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399, for much more information.

```
    printf("hello, \
world\n");
    return 0;
}
```

In such a case, the C compiler removes both the backslash and the newline, producing a string as if it had been typed '`"hello, world\n"`'. This is useful when a single string needs to contain a large amount of text.

The POSIX standard says explicitly that newlines are not allowed inside string constants. And indeed, all `awk` implementations report an error if you try to do so. For example:

```
$ gawk 'BEGIN { print "hello,
> world" }'
 ⊣ gawk: cmd. line:1: BEGIN { print "hello,
 ⊣ gawk: cmd. line:1:               ^ unterminated string
 ⊣ gawk: cmd. line:1: BEGIN { print "hello,
 ⊣ gawk: cmd. line:1:               ^ syntax error
```

Although POSIX doesn't define what happens if you use an escaped newline, as in the previous C example, all known versions of `awk` allow you to do so. Unfortunately, what each one does with such a string varies. `gawk`, `mawk`, and the OpenSolaris POSIX `awk` (see Section B.5 [Other Freely Available `awk` Implementations], page 523) elide the backslash and newline, as in C:

```
$ gawk 'BEGIN { print "hello, \
> world" }'
 ⊣ hello, world
```

In POSIX mode (see Section 2.2 [Command-Line Options], page 33), `gawk` does not allow escaped newlines. Otherwise, it behaves as just described.

BWK `awk`[2] and BusyBox `awk` remove the backslash but leave the newline intact, as part of the string:

```
$ nawk 'BEGIN { print "hello, \
> world" }'
 ⊣ hello,
 ⊣ world
```

6.1.1.2 Octal and Hexadecimal Numbers

In `awk`, all numbers are in decimal (i.e., base 10). Many other programming languages allow you to specify numbers in other bases, often octal (base 8) and hexadecimal (base 16). In octal, the numbers go 0, 1, 2, 3, 4, 5, 6, 7, 10, 11, 12, and so on. Just as '`11`' in decimal is 1 times 10 plus 1, so '`11`' in octal is 1 times 8 plus 1. This equals 9 in decimal. In hexadecimal, there are 16 digits. Because the everyday decimal number system only has ten digits ('`0`'–'`9`'), the letters '`a`' through '`f`' represent the rest. (Case in the letters is usually irrelevant; hexadecimal '`a`' and '`A`' have the same value.) Thus, '`11`' in hexadecimal is 1 times 16 plus 1, which equals 17 in decimal.

Just by looking at plain '`11`', you can't tell what base it's in. So, in C, C++, and other languages derived from C, there is a special notation to signify the base. Octal numbers start with a leading '`0`', and hexadecimal numbers start with a leading '`0x`' or '`0X`':

[2] In all examples throughout this book, `nawk` is BWK `awk`.

`11` Decimal value 11

`011` Octal 11, decimal value 9

`0x11` Hexadecimal 11, decimal value 17

This example shows the difference:

```
$ gawk 'BEGIN { printf "%d, %d, %d\n", 011, 11, 0x11 }'
⊣ 9, 11, 17
```

Being able to use octal and hexadecimal constants in your programs is most useful when working with data that cannot be represented conveniently as characters or as regular numbers, such as binary data of various sorts.

`gawk` allows the use of octal and hexadecimal constants in your program text. However, such numbers in the input data are not treated differently; doing so by default would break old programs. (If you really need to do this, use the `--non-decimal-data` command-line option; see Section 12.1 [Allowing Nondecimal Input Data], page 343.) If you have octal or hexadecimal data, you can use the `strtonum()` function (see Section 9.1.4 [String-Manipulation Functions], page 200) to convert the data into a number. Most of the time, you will want to use octal or hexadecimal constants when working with the built-in bit-manipulation functions; see Section 9.1.7 [Bit-Manipulation Functions], page 220, for more information.

Unlike in some early C implementations, '`8`' and '`9`' are not valid in octal constants. For example, `gawk` treats '`018`' as decimal 18:

```
$ gawk 'BEGIN { print "021 is", 021 ; print 018 }'
⊣ 021 is 17
⊣ 18
```

Hexadecimal integer constants have been part of the C language since the beginning. The C99 standard added support for hexadecimal floating-point values. This is a floating point number of the form [`-`]`0x`*h*[`.`*hhhh*]`p+-`*dd*. The '`p`' introduces the exponent, and is *required*. The radix point and following digits are optional. As with integer hexadecimal constants, both '`0x`' and '`0X`' may be used, and case in the letters '`a`' through '`f`' does not matter.

Beginning with version 5.4.0, `gawk` supports hexadecimal floating point values, as constants in `awk` program source code, with the `strtonum()` built-in function, and with the `--non-decimal-data` command-line option. Here is an example:

```
$ gawk 'BEGIN { print 0xdeadbeefp-1 }'
⊣ 1.86796e+09
```

For this to work correctly, the version of `strtod()` in the system's underlying C library must understand such constants. On modern systems this isn't a problem.

Octal and hexadecimal source code constants are a `gawk` extension. If `gawk` is in compatibility mode (see Section 2.2 [Command-Line Options], page 33), they are not available.

A Constant's Base Does Not Affect Its Value

Once a numeric constant has been converted internally into a number, `gawk` no longer remembers what the original form of the constant was; the internal value is always used. This has particular consequences for conversion of numbers to strings:

```
$ gawk 'BEGIN { printf "0x11 is <%s>\n", 0x11 }'
⊣ 0x11 is <17>
```

6.1.1.3 Regular Expression Constants

A *regexp constant* is a regular expression description enclosed in slashes, such as `/^beginning and end$/`. Most regexps used in `awk` programs are constant, but the '`~`' and '`!~`' matching operators can also match computed or dynamic regexps (which are typically just ordinary strings or variables that contain a regexp, but could be more complex expressions).

6.1.2 Using Regular Expression Constants

Regular expression constants consist of text describing a regular expression enclosed in slashes (such as `/the +answer/`). This section describes how such constants work in POSIX `awk` and `gawk`, and then goes on to describe *strongly typed regexp constants*, which are a `gawk` extension.

6.1.2.1 Standard Regular Expression Constants

When used on the righthand side of the '`~`' or '`!~`' operators, a regexp constant merely stands for the regexp that is to be matched. However, regexp constants (such as `/foo/`) may be used like simple expressions. When a regexp constant appears by itself, it has the same meaning as if it appeared in a pattern (i.e., '`($0 ~ /foo/)`'). See Section 7.1.2 [Expressions as Patterns], page 151. This means that the following two code segments:

```
if ($0 ~ /barfly/ || $0 ~ /camelot/)
    print "found"
```

and:

```
if (/barfly/ || /camelot/)
    print "found"
```

are exactly equivalent. One rather bizarre consequence of this rule is that the following Boolean expression is valid, but does not do what its author probably intended:

```
# Note that /foo/ is on the left of the ~
if (/foo/ ~ $1) print "found foo"
```

This code is "obviously" testing `$1` for a match against the regexp `/foo/`. But in fact, the expression '`/foo/ ~ $1`' really means '`($0 ~ /foo/) ~ $1`'. In other words, first match the input record against the regexp `/foo/`. The result is either zero or one, depending upon the success or failure of the match. That result is then matched against the first field in the record. Because it is unlikely that you would ever really want to make this kind of test, `gawk` issues a warning when it sees this construct in a program. Another consequence of this rule is that the assignment statement:

```
matches = /foo/
```

assigns either zero or one to the variable `matches`, depending upon the contents of the current input record.

Constant regular expressions are also used as the first argument for the `gensub()`, `sub()`, and `gsub()` functions, as the second argument of the `match()` function, and as the third argument of the `split()` and `patsplit()` functions (see Section 9.1.4 [String-Manipulation Functions], page 200). Modern implementations of `awk`, including `gawk`, allow the third argument of `split()` to be a regexp constant, but some older implementations do not.

Because some built-in functions accept regexp constants as arguments, confusion can arise when attempting to use regexp constants as arguments to user-defined functions (see Section 9.2 [User-Defined Functions], page 225). For example:

```
function mysub(pat, repl, str, global)
{
    if (global)
        gsub(pat, repl, str)
    else
        sub(pat, repl, str)
    return str
}

{
    ...
    text = "hi! hi yourself!"
    mysub(/hi/, "howdy", text, 1)
    ...
}
```

In this example, the programmer wants to pass a regexp constant to the user-defined function `mysub()`, which in turn passes it on to either `sub()` or `gsub()`. However, what really happens is that the `pat` parameter is assigned a value of either one or zero, depending upon whether or not `$0` matches `/hi/`. `gawk` issues a warning when it sees a regexp constant used as a parameter to a user-defined function, because passing a truth value in this way is probably not what was intended.

6.1.2.2 Strongly Typed Regexp Constants

This section describes a `gawk`-specific feature.

As we saw in the previous section, regexp constants (`/.../`) hold a strange position in the `awk` language. In most contexts, they act like an expression: '`$0 ~ /.../`'. In other contexts, they denote only a regexp to be matched. In no case are they really a "first class citizen" of the language. That is, you cannot define a scalar variable whose type is "regexp" in the same sense that you can define a variable to be a number or a string:

```
num = 42        Numeric variable
str = "hi"      String variable
re = /foo/      Wrong! re is the result of $0 ~ /foo/
```

For a number of more advanced use cases, it would be nice to have regexp constants that are *strongly typed*; in other words, that denote a regexp useful for matching, and not an expression.

`gawk` provides this feature. A strongly typed regexp constant looks almost like a regular regexp constant, except that it is preceded by an '`@`' sign:

```
re = @/foo/       Regexp variable
```

Strongly typed regexp constants *cannot* be used everywhere that a regular regexp constant can, because this would make the language even more confusing. Instead, you may use them only in certain contexts:

- On the righthand side of the '`~`' and '`!~`' operators: '`some_var ~ @/foo/`' (see Section 3.1 [How to Use Regular Expressions], page 51).
- In the `case` part of a `switch` statement (see Section 7.4.5 [The `switch` Statement], page 161).
- As an argument to one of the built-in functions that accept regexp constants: `gensub()`, `gsub()`, `match()`, `patsplit()`, `split()`, and `sub()` (see Section 9.1.4 [String-Manipulation Functions], page 200).
- As a parameter in a call to a user-defined function (see Section 9.2 [User-Defined Functions], page 225).
- As the return value of a user-defined function.
- On the righthand side of an assignment to a variable: '`some_var = @/foo/`'. In this case, the type of `some_var` is regexp. Additionally, `some_var` can be used with '`~`' and '`!~`', passed to one of the built-in functions listed above, or passed as a parameter to a user-defined function.

You may use the `-v` option (see Section 2.2 [Command-Line Options], page 33) to assign a strongly-typed regexp constant to a variable on the command line, like so:

```
gawk -v pattern='@/something(interesting)+/' ...
```

You may also make such assignments as regular command-line arguments (see Section 2.3 [Other Command-Line Arguments], page 40).

You may use the `typeof()` built-in function (see Section 9.1.8 [Getting Type Information], page 223) to determine if a variable or function parameter is a regexp variable.

The true power of this feature comes from the ability to create variables that have regexp type. Such variables can be passed on to user-defined functions, without the confusing aspects of computed regular expressions created from strings or string constants. They may also be passed through indirect function calls (see Section 9.5 [Indirect Function Calls], page 238) and on to the built-in functions that accept regexp constants.

When used in numeric conversions, strongly typed regexp variables convert to zero. When used in string conversions, they convert to the string value of the original regexp text.

There is an additional, interesting corner case. When used as the third argument to `sub()` or `gsub()`, they retain their type. Thus, if you have something like this:

```
re = @/don't panic/
sub(/don't/, "do", re)
print typeof(re), re
```

then `re` retains its type, but now attempts to match the string '`do panic`'. This provides a (very indirect) way to create regexp-typed variables at runtime.

6.1.3 Variables

Variables are ways of storing values at one point in your program for use later in another part of your program. They can be manipulated entirely within the program text, and they can also be assigned values on the `awk` command line.

6.1.3.1 Using Variables in a Program

Variables let you give names to values and refer to them later. Variables have already been used in many of the examples. The name of a variable must be a sequence of letters, digits, or underscores, and it may not begin with a digit. Here, a *letter* is any one of the 52 upper- and lowercase English letters. Other characters that may be defined as letters in non-English locales are not valid in variable names. Case is significant in variable names; `a` and `A` are distinct variables.

A variable name is a valid expression by itself; it represents the variable's current value. Variables are given new values with *assignment operators*, *increment operators*, and *decrement operators* (see Section 6.2.3 [Assignment Expressions], page 135). In addition, the `sub()` and `gsub()` functions can change a variable's value, and the `match()`, `split()`, and `patsplit()` functions can change the contents of their array parameters (see Section 9.1.4 [String-Manipulation Functions], page 200).

A few variables have special built-in meanings, such as `FS` (the field separator) and `NF` (the number of fields in the current input record). See Section 7.5 [Predefined Variables], page 167, for a list of the predefined variables. These predefined variables can be used and assigned just like all other variables, but their values are also used or changed automatically by `awk`. All predefined variables' names are entirely uppercase.

Variables in `awk` can be assigned either numeric or string values. The kind of value a variable holds can change over the life of a program. By default, variables are initialized to the empty string, which is zero if converted to a number. There is no need to explicitly initialize a variable in `awk`, which is what you would do in C and in most other traditional languages.

6.1.3.2 Assigning Variables on the Command Line

Any `awk` variable can be set by including a *variable assignment* among the arguments on the command line when `awk` is invoked (see Section 2.3 [Other Command-Line Arguments], page 40). Such an assignment has the following form:

```
variable=text
```

With it, a variable is set either at the beginning of the `awk` run or in between input files. When the assignment is preceded with the `-v` option, as in the following:

```
-v variable=text
```

the variable is set at the very beginning, even before the `BEGIN` rules execute. The `-v` option and its assignment must precede all the file name arguments, as well as the program text. (See Section 2.2 [Command-Line Options], page 33, for more information about the `-v` option.) Otherwise, the variable assignment is performed at a time determined by its position among the input file arguments—after the processing of the preceding input file argument. For example:

```
awk '{ print $n }' n=4 inventory-shipped n=2 mail-list
```

prints the value of field number `n` for all input records. Before the first file is read, the command line sets the variable `n` equal to four. This causes the fourth field to be printed in lines from `inventory-shipped`. After the first file has finished, but before the second file is started, `n` is set to two, so that the second field is printed in lines from `mail-list`:

```
$ awk '{ print $n }' n=4 inventory-shipped n=2 mail-list
⊣ 15
⊣ 24
...
⊣ 555-5553
⊣ 555-3412
...
```

Command-line arguments are made available for explicit examination by the `awk` program in the `ARGV` array (see Section 7.5.3 [Using `ARGC` and `ARGV`], page 177). `awk` processes the values of command-line assignments for escape sequences (see Section 3.2 [Escape Sequences], page 52).

Normally, variables assigned on the command line (with or without the `-v` option) are treated as strings. When such variables are used as numbers, `awk`'s normal automatic conversion of strings to numbers takes place, and everything "just works."

However, `gawk` supports variables whose types are "regexp". You can assign variables of this type using the following syntax:

```
gawk -v 're1=@/foo|bar/' '...' /path/to/file1 're2=@/baz|quux/' /path/to/file2
```

Strongly typed regexps are an advanced feature (see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127). We mention them here only for completeness.

6.1.4 Conversion of Strings and Numbers

Number-to-string and string-to-number conversion are generally straightforward. There can be subtleties to be aware of; this section discusses this important facet of `awk`.

6.1.4.1 How `awk` Converts Between Strings and Numbers

Strings are converted to numbers and numbers are converted to strings, if the context of the `awk` program demands it. For example, if the value of either `foo` or `bar` in the expression '`foo + bar`' happens to be a string, it is converted to a number before the addition is performed. If numeric values appear in string concatenation, they are converted to strings. Consider the following:

```
two = 2; three = 3
print (two three) + 4
```

This prints the (numeric) value 27. The numeric values of the variables `two` and `three` are converted to strings and concatenated together. The resulting string is converted back to the number 23, to which 4 is then added.

If, for some reason, you need to force a number to be converted to a string, concatenate that number with the empty string, `""`. To force a string to be converted to a number, add zero to that string. A string is converted to a number by interpreting any numeric prefix of the string as numerals: `"2.5"` converts to 2.5, `"1e3"` converts to 1,000, and `"25fix"` has a numeric value of 25. Strings that can't be interpreted as valid numbers convert to zero.

The exact manner in which numbers are converted into strings is controlled by the `awk` predefined variable `CONVFMT` (see Section 7.5 [Predefined Variables], page 167). Numbers are converted using the `sprintf()` function with `CONVFMT` as the format specifier (see Section 9.1.4 [String-Manipulation Functions], page 200).

`CONVFMT`'s default value is `"%.6g"`, which creates a value with at most six significant digits. For some applications, you might want to change it to specify more precision. On most modern machines, 17 digits is usually enough to capture a floating-point number's value exactly.[3]

Strange results can occur if you set `CONVFMT` to a string that doesn't tell `sprintf()` how to format floating-point numbers in a useful way. For example, if you forget the '`%`' in the format, `awk` converts all numbers to the same constant string.

As a special case, if a number is an integer, then the result of converting it to a string is *always* an integer, no matter what the value of `CONVFMT` may be. Given the following code fragment:

```
CONVFMT = "%2.2f"
a = 12
b = a ""
```

`b` has the value `"12"`, not `"12.00"`.

Pre-POSIX `awk` Used `OFMT` for String Conversion

Prior to the POSIX standard, `awk` used the value of `OFMT` for converting numbers to strings. `OFMT` specifies the output format to use when printing numbers with `print`. `CONVFMT` was introduced in order to separate the semantics of conversion from the semantics of printing. Both `CONVFMT` and `OFMT` have the same default value: `"%.6g"`. In the vast majority of cases, old `awk` programs do not change their behavior. See Section 5.1 [The `print` Statement], page 103, for more information on the `print` statement.

6.1.4.2 Locales Can Influence Conversion

Where you are can matter when it comes to converting between numbers and strings. The local character set and language—the *locale*—can affect numeric formats. In particular, for `awk` programs, it affects the decimal point character and the thousands-separator character. The `"C"` locale, and most English-language locales, use the period character ('`.`') as the decimal point and don't have a thousands separator. However, many (if not most) European and non-English locales use the comma ('`,`') as the decimal point character. European locales often use either a space or a period as the thousands separator, if they have one.

The POSIX standard says that `awk` always uses the period as the decimal point when reading the `awk` program source code, and for command-line variable assignments (see Section 2.3 [Other Command-Line Arguments], page 40). However, when interpreting input data, for `print` and `printf` output, and for number-to-string conversion, the local decimal point character is used. In all cases, numbers in source code and in input data cannot have a thousands separator. Here are some examples indicating the difference in behavior, on a GNU/Linux system:

```
$ export POSIXLY_CORRECT=1                    Force POSIX behavior
```

[3] Pathological cases can require up to 752 digits (!), but we doubt that you need to worry about this.

```
$ gawk 'BEGIN { printf "%g\n", 3.1415927 }'
⊣ 3.14159
$ LC_ALL=en_DK.utf-8 gawk 'BEGIN { printf "%g\n", 3.1415927 }'
⊣ 3,14159
$ echo 4,321 | gawk '{ print $1 + 1 }'
⊣ 5
$ echo 4,321 | LC_ALL=en_DK.utf-8 gawk '{ print $1 + 1 }'
⊣ 5,321
```

The `en_DK.utf-8` locale is for English in Denmark, where the comma acts as the decimal point separator. In the normal `"C"` locale, `gawk` treats '`4,321`' as 4, while in the Danish locale, it's treated as the full number including the fractional part, 4.321.

Some earlier versions of `gawk` fully complied with this aspect of the standard. However, many users in non-English locales complained about this behavior, because their data used a period as the decimal point, so the default behavior was restored to use a period as the decimal point character. You can use the `--use-lc-numeric` option (see Section 2.2 [Command-Line Options], page 33) to force `gawk` to use the locale's decimal point character. (`gawk` also uses the locale's decimal point character when in POSIX mode, either via `--posix` or the `POSIXLY_CORRECT` environment variable, as shown previously.)

Table 6.1 describes the cases in which the locale's decimal point character is used and when a period is used. Some of these features have not been described yet.

Feature	**Default**	`--posix` **or** `--use-lc-numeric`
`%'g`	Use locale	Use locale
`%g`	Use period	Use locale
Input	Use period	Use locale
`strtonum()`	Use period	Use locale

Table 6.1: Locale decimal point versus a period

Finally, modern-day formal standards and the IEEE standard floating-point representation can have an unusual but important effect on the way `gawk` converts some special string values to numbers. The details are presented in Section 16.7 [Standards Versus Existing Practice], page 411.

6.2 Operators: Doing Something with Values

This section introduces the *operators* that make use of the values provided by constants and variables.

6.2.1 Arithmetic Operators

The `awk` language uses the common arithmetic operators when evaluating expressions. All of these arithmetic operators follow normal precedence rules and work as you would expect them to.

The following example uses a file named `grades`, which contains a list of student names as well as three test scores per student (it's a small class):

```
Pat   100 97 58
Sandy  84 72 93
```

```
Chris  72 92 89
```

This program takes the file `grades` and prints the average of the scores:

```
$ awk '{ sum = $2 + $3 + $4 ; avg = sum / 3
>        print $1, avg }' grades
⊣ Pat 85
⊣ Sandy 83
⊣ Chris 84.3333
```

The following list provides the arithmetic operators in `awk`, in order from the highest precedence to the lowest:

`x ^ y`
`x ** y` Exponentiation; *x* raised to the *y* power. '`2 ^ 3`' has the value eight; the character sequence '`**`' is equivalent to '`^`'. (c.e.)

`- x` Negation.

`+ x` Unary plus; the expression is converted to a number.

`x * y` Multiplication.

`x / y` Division; because all numbers in `awk` are floating-point numbers, the result is *not* rounded to an integer—'`3 / 4`' has the value 0.75. (It is a common mistake, especially for C programmers, to forget that *all* numbers in `awk` are floating point, and that division of integer-looking constants produces a real number, not an integer.)

`x % y` Remainder; further discussion is provided in the text, just after this list.

`x + y` Addition.

`x - y` Subtraction.

Unary plus and minus have the same precedence, the multiplication operators all have the same precedence, and addition and subtraction have the same precedence.

When computing the remainder of '`x % y`', the quotient is rounded toward zero to an integer and multiplied by *y*. This result is subtracted from *x*; this operation is sometimes known as "trunc-mod." The following relation always holds:

```
b * int(a / b) + (a % b) == a
```

One possibly undesirable effect of this definition of remainder is that '`x % y`' is negative if *x* is negative. Thus:

```
-17 % 8 = -1
```

This definition is compliant with the POSIX standard, which says that the `%` operator produces results equivalent to using the standard C `fmod()` function, and that function in turn works as just described.

In other `awk` implementations, the signedness of the remainder may be machine-dependent.

> **NOTE:** The POSIX standard only specifies the use of '`^`' for exponentiation. For maximum portability, do not use the '`**`' operator.

6.2.2 String Concatenation

It seemed like a good idea at the time.
—Brian Kernighan

There is only one string operation: concatenation. It does not have a specific operator to represent it. Instead, concatenation is performed by writing expressions next to one another, with no operator. For example:

```
$ awk '{ print "Field number one: " $1 }' mail-list
⊣ Field number one: Amelia
⊣ Field number one: Anthony
...
```

Without the space in the string constant after the ':', the line runs together. For example:

```
$ awk '{ print "Field number one:" $1 }' mail-list
⊣ Field number one:Amelia
⊣ Field number one:Anthony
...
```

Because string concatenation does not have an explicit operator, it is often necessary to ensure that it happens at the right time by using parentheses to enclose the items to concatenate. For example, you might expect that the following code fragment concatenates `file` and `name`:

```
file = "file"
name = "name"
print "something meaningful" > file name
```

This produces a syntax error with some versions of Unix `awk`.[4] It is necessary to use the following:

```
print "something meaningful" > (file name)
```

Parentheses should be used around concatenation in all but the most common contexts, such as on the righthand side of '`=`'. Be careful about the kinds of expressions used in string concatenation. In particular, the order of evaluation of expressions used for concatenation is undefined in the `awk` language. Consider this example:

```
BEGIN {
    a = "don't"
    print (a " " (a = "panic"))
}
```

It is not defined whether the second assignment to `a` happens before or after the value of `a` is retrieved for producing the concatenated value. The result could be either '`don't panic`', or '`panic panic`'.

The precedence of concatenation, when mixed with other operators, is often counter-intuitive. Consider this example:

```
$ awk 'BEGIN { print -12 " " -24 }'
⊣ -12-24
```

[4] It happens that BWK `awk`, `gawk`, and `mawk` all "get it right," but you should not rely on this.

This "obviously" is concatenating −12, a space, and −24. But where did the space disappear to? The answer lies in the combination of operator precedences and `awk`'s automatic conversion rules. To get the desired result, write the program this way:

```
$ awk 'BEGIN { print -12 " " (-24) }'
⊣ -12 -24
```

This forces `awk` to treat the '`-`' on the '`-24`' as unary. Otherwise, it's parsed as follows:

$$\begin{aligned} & -12\ (\text{" "} - 24) \\ \Rightarrow\ & -12\ (0 - 24) \\ \Rightarrow\ & -12\ (-24) \\ \Rightarrow\ & -12-24 \end{aligned}$$

As mentioned earlier, when mixing concatenation with other operators, *parenthesize*. Otherwise, you're never quite sure what you'll get.

6.2.3 Assignment Expressions

An *assignment* is an expression that stores a (usually different) value into a variable. For example, let's assign the value one to the variable `z`:

```
z = 1
```

After this expression is executed, the variable `z` has the value one. Whatever old value `z` had before the assignment is forgotten.

Assignments can also store string values. For example, the following stores the value `"this food is good"` in the variable `message`:

```
thing = "food"
predicate = "good"
message = "this " thing " is " predicate
```

This also illustrates string concatenation. The '`=`' sign is called an *assignment operator*. It is the simplest assignment operator because the value of the righthand operand is stored unchanged. Most operators (addition, concatenation, and so on) have no effect except to compute a value. If the value isn't used, there's no reason to use the operator. An assignment operator is different; it does produce a value, but even if you ignore it, the assignment still makes itself felt through the alteration of the variable. We call this a *side effect*.

The lefthand operand of an assignment need not be a variable (see Section 6.1.3 [Variables], page 129); it can also be a field (see Section 4.4 [Changing the Contents of a Field], page 75) or an array element (see Chapter 8 [Arrays in `awk`], page 181). These are all called *lvalues*, which means they can appear on the lefthand side of an assignment operator. The righthand operand may be any expression; it produces the new value that the assignment stores in the specified variable, field, or array element. (Such values are called *rvalues*.)

It is important to note that variables do *not* have permanent types. A variable's type is simply the type of whatever value was last assigned to it. In the following program fragment, the variable `foo` has a numeric value at first, and a string value later on:

```
foo = 1
print foo
foo = "bar"
print foo
```

When the second assignment gives `foo` a string value, the fact that it previously had a numeric value is forgotten.

String values that do not begin with a digit have a numeric value of zero. After executing the following code, the value of `foo` is five:

```
foo = "a string"
foo = foo + 5
```

> **NOTE:** Using a variable as a number and then later as a string can be confusing and is poor programming style. The previous two examples illustrate how `awk` works, *not* how you should write your programs!

An assignment is an expression, so it has a value—the same value that is assigned. Thus, '`z = 1`' is an expression with the value one. One consequence of this is that you can write multiple assignments together, such as:

```
x = y = z = 5
```

This example stores the value five in all three variables (`x`, `y`, and `z`). It does so because the value of '`z = 5`', which is five, is stored into `y` and then the value of '`y = z = 5`', which is five, is stored into `x`.

Assignments may be used anywhere an expression is called for. For example, it is valid to write '`x != (y = 1)`' to set `y` to one, and then test whether `x` equals one. But this style tends to make programs hard to read; such nesting of assignments should be avoided, except perhaps in a one-shot program.

Aside from '`=`', there are several other assignment operators that do arithmetic with the old value of the variable. For example, the operator '`+=`' computes a new value by adding the righthand value to the old value of the variable. Thus, the following assignment adds five to the value of `foo`:

```
foo += 5
```

This is equivalent to the following:

```
foo = foo + 5
```

Use whichever makes the meaning of your program clearer.

There are situations where using '`+=`' (or any assignment operator) is *not* the same as simply repeating the lefthand operand in the righthand expression. For example:

```
# Thanks to Pat Rankin for this example
BEGIN  {
    foo[rand()] += 5
    for (x in foo)
       print x, foo[x]

    bar[rand()] = bar[rand()] + 5
    for (x in bar)
       print x, bar[x]
}
```

The indices of `bar` are practically guaranteed to be different, because `rand()` returns different values each time it is called. (Arrays and the `rand()` function haven't been covered yet. See Chapter 8 [Arrays in `awk`], page 181, and see Section 9.1.3 [Numeric Functions],

page 198, for more information.) This example illustrates an important fact about assignment operators: the lefthand expression is only evaluated *once*.

It is up to the implementation as to which expression is evaluated first, the lefthand or the righthand. Consider this example:

```
i = 1
a[i += 2] = i + 1
```

The value of `a[3]` could be either two or four.

Table 6.2 lists the arithmetic assignment operators. In each case, the righthand operand is an expression whose value is converted to a number.

Operator	**Effect**
lvalue `+=` *increment*	Add *increment* to the value of *lvalue*.
lvalue `-=` *decrement*	Subtract *decrement* from the value of *lvalue*.
lvalue `*=` *coefficient*	Multiply the value of *lvalue* by *coefficient*.
lvalue `/=` *divisor*	Divide the value of *lvalue* by *divisor*.
lvalue `%=` *modulus*	Set *lvalue* to its remainder by *modulus*.
lvalue `^=` *power*	Raise *lvalue* to the power *power*.
lvalue `**=` *power*	Raise *lvalue* to the power *power*. (c.e.)

Table 6.2: Arithmetic assignment operators

NOTE: Only the '`^=`' operator is specified by POSIX. For maximum portability, do not use the '`**=`' operator.

Syntactic Ambiguities Between '/=' and Regular Expressions

There is a syntactic ambiguity between the `/=` assignment operator and regexp constants whose first character is an '`=`'. This is most notable in some commercial `awk` versions. For example:

```
$ awk /==/ /dev/null
error  awk: syntax error at source line 1
error   context is
error           >>> /= <<<
error  awk: bailing out at source line 1
```

A workaround is:

```
awk '/[=]=/' /dev/null
```

`gawk` does not have this problem; BWK `awk` and `mawk` also do not.

6.2.4 Increment and Decrement Operators

Increment and *decrement operators* increase or decrease the value of a variable by one. An assignment operator can do the same thing, so the increment operators add no power to the `awk` language; however, they are convenient abbreviations for very common operations.

The operator used for adding one is written '`++`'. It can be used to increment a variable either before or after taking its value. To *pre-increment* a variable `v`, write '`++v`'. This adds one to the value of `v`—that new value is also the value of the expression. (The assignment expression '`v += 1`' is completely equivalent.) Writing the '`++`' after the variable specifies

post-increment. This increments the variable value just the same; the difference is that the value of the increment expression itself is the variable's *old* value. Thus, if `foo` has the value four, then the expression '`foo++`' has the value four, but it changes the value of `foo` to five. In other words, the operator returns the old value of the variable, but with the side effect of incrementing it.

The post-increment '`foo++`' is nearly the same as writing '`(foo += 1) - 1`'. It is not perfectly equivalent because all numbers in `awk` are floating point—in floating point, '`foo + 1 - 1`' does not necessarily equal `foo`. But the difference is minute as long as you stick to numbers that are fairly small (less than 10^{12}).

Fields and array elements are incremented just like variables. (Use '`$(i++)`' when you want to do a field reference and a variable increment at the same time. The parentheses are necessary because of the precedence of the field reference operator '`$`'.)

The decrement operator '`--`' works just like '`++`', except that it subtracts one instead of adding it. As with '`++`', it can be used before the lvalue to pre-decrement or after it to post-decrement. Following is a summary of increment and decrement expressions:

`++`*`lvalue`* Increment *lvalue*, returning the new value as the value of the expression.

`lvalue``++` Increment *lvalue*, returning the *old* value of *lvalue* as the value of the expression.

`--`*`lvalue`* Decrement *lvalue*, returning the new value as the value of the expression. (This expression is like '`++`*`lvalue`*', but instead of adding, it subtracts.)

`lvalue``--` Decrement *lvalue*, returning the *old* value of *lvalue* as the value of the expression. (This expression is like '*`lvalue`*`++`', but instead of adding, it subtracts.)

Operator Evaluation Order

Doctor, it hurts when I do this!
Then don't do that!
—*Groucho Marx*

What happens for something like the following?

```
b = 6
print b += b++
```

Or something even stranger?

```
b = 6
b += ++b + b++
print b
```

In other words, when do the various side effects prescribed by the postfix operators ('`b++`') take effect? When side effects happen is *implementation-defined*. In other words, it is up to the particular version of `awk`. The result for the first example may be 12 or 13, and for the second, it may be 22 or 23.

In short, doing things like this is not recommended and definitely not anything that you can rely upon for portability. You should avoid such things in your own programs.

6.3 Truth Values and Conditions

In certain contexts, expression values also serve as "truth values"; i.e., they determine what should happen next as the program runs. This section describes how `awk` defines "true" and "false" and how values are compared.

6.3.1 True and False in `awk`

Many programming languages have a special representation for the concepts of "true" and "false." Such languages usually use the special constants `true` and `false`, or perhaps their uppercase equivalents. However, `awk` is different. It borrows a very simple concept of true and false from C. In `awk`, any nonzero numeric value *or* any nonempty string value is true. Any other value (zero or the null string, `""`) is false. The following program prints '`A strange truth value`' three times:

```
BEGIN {
   if (3.1415927)
       print "A strange truth value"
   if ("Four Score And Seven Years Ago")
       print "A strange truth value"
   if (j = 57)
       print "A strange truth value"
}
```

There is a surprising consequence of the "nonzero or non-null" rule: the string constant `"0"` is actually true, because it is non-null.

6.3.2 Variable Typing and Comparison Expressions

The Guide is definitive. Reality is frequently inaccurate.
—Douglas Adams, The Hitchhiker's Guide to the Galaxy

Unlike in other programming languages, in `awk` variables do not have a fixed type. Instead, they can be either a number or a string, depending upon the value that is assigned to them. We look now at how variables are typed, and how `awk` compares variables.

6.3.2.1 String Type versus Numeric Type

Scalar objects in `awk` (variables, array elements, and fields) are *dynamically* typed. This means their type can change as the program runs, from *untyped* before any use,[5] to string or number, and then from string to number or number to string, as the program progresses. (`gawk` also provides regexp-typed scalars, but let's ignore that for now; see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127.)

You can't do much with untyped variables, other than tell that they are untyped. The following program tests `a` against `""` and `0`; the test succeeds when `a` has never been assigned a value. It also uses the built-in `typeof()` function (not presented yet; see Section 9.1.8 [Getting Type Information], page 223) to show `a`'s type:

```
$ gawk 'BEGIN { print (a == "" && a == 0 ?
> "a is untyped" : "a has a type!") ; print typeof(a) }'
⊣ a is untyped
```

[5] `gawk` calls this *unassigned*, as the following example shows.

```
⊣ unassigned
```

A scalar has numeric type when assigned a numeric value, such as from a numeric constant, or from another scalar with numeric type:

```
$ gawk 'BEGIN { a = 42 ; print typeof(a)
> b = a ; print typeof(b) }'
number
number
```

Similarly, a scalar has string type when assigned a string value, such as from a string constant, or from another scalar with string type:

```
$ gawk 'BEGIN { a = "forty two" ; print typeof(a)
> b = a ; print typeof(b) }'
string
string
```

So far, this is all simple and straightforward. What happens, though, when `awk` has to process data from a user? Let's start with field data. What should the following command produce as output?

```
echo hello | awk '{ printf("%s %s < 42\n", $1,
                           ($1 < 42 ? "is" : "is not")) }'
```

Since '`hello`' is alphabetic data, `awk` can only do a string comparison. Internally, it converts `42` into `"42"` and compares the two string values `"hello"` and `"42"`. Here's the result:

```
$ echo hello | awk '{ printf("%s %s < 42\n", $1,
>                            ($1 < 42 ? "is" : "is not")) }'
⊣ hello is not < 42
```

However, what happens when data from a user *looks like* a number? On the one hand, in reality, the input data consists of characters, not binary numeric values. But, on the other hand, the data looks numeric, and `awk` really ought to treat it as such. And indeed, it does:

```
$ echo 37 | awk '{ printf("%s %s < 42\n", $1,
>                          ($1 < 42 ? "is" : "is not")) }'
⊣ 37 is < 42
```

Here are the rules for when `awk` treats data as a number, and for when it treats data as a string.

The POSIX standard uses the term *numeric string* for input data that looks numeric. The '`37`' in the previous example is a numeric string. So what is the type of a numeric string? Answer: numeric.

The type of a variable is important because the types of two variables determine how they are compared. Variable typing follows these definitions and rules:

- A numeric constant or the result of a numeric operation has the *numeric* attribute.
- A string constant or the result of a string operation has the *string* attribute.
- Fields, `getline` input, `FILENAME`, `ARGV` elements, `ENVIRON` elements, and the elements of an array created by `match()`, `split()`, and `patsplit()` that are numeric strings have the *strnum* attribute.[6] Otherwise, they have the *string* attribute. Uninitialized variables also have the *strnum* attribute.

[6] Thus, a POSIX numeric string and `gawk`'s strnum are the same thing.

- Attributes propagate across assignments but are not changed by any use.

The last rule is particularly important. In the following program, `a` has numeric type, even though it is later used in a string operation:

```
BEGIN {
     a = 12.345
     b = a " is a cute number"
     print b
}
```

When two operands are compared, either string comparison or numeric comparison may be used. This depends upon the attributes of the operands, according to the following symmetric matrix:

	STRING	NUMERIC	STRNUM
STRING	string	string	string
NUMERIC	string	numeric	numeric
STRNUM	string	numeric	numeric

The basic idea is that user input that looks numeric—and *only* user input—should be treated as numeric, even though it is actually made of characters and is therefore also a string. Thus, for example, the string constant `" +3.14"`, when it appears in program source code, is a string—even though it looks numeric—and is *never* treated as a number for comparison purposes.

In short, when one operand is a "pure" string, such as a string constant, then a string comparison is performed. Otherwise, a numeric comparison is performed. (The primary difference between a number and a strnum is that for strnums `gawk` preserves the original string value that the scalar had when it came in.)

This point bears additional emphasis: Input that looks numeric *is* numeric. All other input is treated as strings.

Thus, the six-character input string '` +3.14`' receives the strnum attribute. In contrast, the eight characters `" +3.14"` appearing in program text comprise a string constant. The following examples print '`1`' when the comparison between the two different constants is true, and '`0`' otherwise:

```
$ echo ' +3.14' | awk '{ print($0 == " +3.14") }'     True
⊣ 1
$ echo ' +3.14' | awk '{ print($0 == "+3.14") }'      False
⊣ 0
$ echo ' +3.14' | awk '{ print($0 == "3.14") }'       False
⊣ 0
$ echo ' +3.14' | awk '{ print($0 == 3.14) }'         True
⊣ 1
$ echo ' +3.14' | awk '{ print($1 == " +3.14") }'     False
⊣ 0
$ echo ' +3.14' | awk '{ print($1 == "+3.14") }'      True
⊣ 1
$ echo ' +3.14' | awk '{ print($1 == "3.14") }'       False
```

```
⊣ 0
$ echo ' +3.14' | awk '{ print($1 == 3.14) }'          True
⊣ 1
```

You can see the type of an input field (or other user input) using `typeof()`:

```
$ echo hello 37 | gawk '{ print typeof($1), typeof($2) }'
⊣ string strnum
```

6.3.2.2 Comparison Operators

Comparison expressions compare strings or numbers for relationships such as equality. They are written using *relational operators*, which are a superset of those in C. Table 6.3 describes them.

Expression	Result
x `<` *y*	True if *x* is less than *y*
x `<=` *y*	True if *x* is less than or equal to *y*
x `>` *y*	True if *x* is greater than *y*
x `>=` *y*	True if *x* is greater than or equal to *y*
x `==` *y*	True if *x* is equal to *y*
x `!=` *y*	True if *x* is not equal to *y*
x `~` *y*	True if the string *x* matches the regexp denoted by *y*
x `!~` *y*	True if the string *x* does not match the regexp denoted by *y*
subscript `in` *array*	True if the array *array* has an element with the subscript *subscript*

Table 6.3: Relational operators

Comparison expressions have the value one if true and zero if false. When comparing operands of mixed types, numeric operands are converted to strings using the value of `CONVFMT` (see Section 6.1.4 [Conversion of Strings and Numbers], page 130).

Strings are compared by comparing the first character of each, then the second character of each, and so on. Thus, `"10"` is less than `"9"`. If there are two strings where one is a prefix of the other, the shorter string is less than the longer one. Thus, `"abc"` is less than `"abcd"`.

It is very easy to accidentally mistype the '`==`' operator and leave off one of the '`=`' characters. The result is still valid `awk` code, but the program does not do what is intended:

```
if (a = b)    # oops! should be a == b
   ...
else
   ...
```

Unless `b` happens to be zero or the null string, the `if` part of the test always succeeds. Because the operators are so similar, this kind of error is very difficult to spot when scanning the source code.

The following list of expressions illustrates the kinds of comparisons `awk` performs, as well as what the result of each comparison is:

`1.5 <= 2.0`
: Numeric comparison (true)

`"abc" >= "xyz"`
: String comparison (false)

`1.5 != " +2"`
: String comparison (true)

`"1e2" < "3"`
: String comparison (true)

```
a = 2; b = "2"
a == b
```
: String comparison (true)

```
a = 2; b = " +2"
a == b
```
: String comparison (false)

In this example:

```
$ echo 1e2 3 | awk '{ print ($1 < $2) ? "true" : "false" }'
⊣ false
```

the result is '`false`' because both `$1` and `$2` are user input. They are numeric strings—therefore both have the strnum attribute, dictating a numeric comparison. The purpose of the comparison rules and the use of numeric strings is to attempt to produce the behavior that is "least surprising," while still "doing the right thing."

String comparisons and regular expression comparisons are very different. For example:

```
x == "foo"
```

has the value one, or is true if the variable `x` is precisely '`foo`'. By contrast:

```
x ~ /foo/
```

has the value one if `x` contains '`foo`', such as `"Oh, what a fool am I!"`.

The righthand operand of the '`~`' and '`!~`' operators may be either a regexp constant (`/...`) or an ordinary expression. In the latter case, the value of the expression as a string is used as a dynamic regexp (see Section 3.1 [How to Use Regular Expressions], page 51; also see Section 3.6 [Using Dynamic Regexps], page 63).

A constant regular expression in slashes by itself is also an expression. */regexp/* is an abbreviation for the following comparison expression:

```
$0 ~ /regexp/
```

One special place where `/foo/` is *not* an abbreviation for '`$0 ~ /foo/`' is when it is the righthand operand of '`~`' or '`!~`'. See Section 6.1.2 [Using Regular Expression Constants], page 126, where this is discussed in more detail.

6.3.2.3 String Comparison Based on Locale Collating Order

The POSIX standard used to say that all string comparisons are performed based on the locale's *collating order*. This is the order in which characters sort, as defined by the locale (for more discussion, see Section 6.6 [Where You Are Makes a Difference], page 149). This order is usually very different from the results obtained when doing straight byte-by-byte comparison.[7]

[7] Technically, string comparison is supposed to behave the same way as if the strings were compared with the C `strcoll()` function.

Because this behavior differs considerably from existing practice, `gawk` only implemented it when in POSIX mode (see Section 2.2 [Command-Line Options], page 33). Here is an example to illustrate the difference, in an `en_US.UTF-8` locale:

```
$ gawk 'BEGIN { printf("ABC < abc = %s\n",
>                      ("ABC" < "abc" ? "TRUE" : "FALSE")) }'
⊣ ABC < abc = TRUE
$ gawk --posix 'BEGIN { printf("ABC < abc = %s\n",
>                              ("ABC" < "abc" ? "TRUE" : "FALSE")) }'
⊣ ABC < abc = FALSE
```

Fortunately, as of August 2016, comparison based on locale collating order is no longer required for the `==` and `!=` operators.[8] However, comparison based on locales is still required for `<`, `<=`, `>`, and `>=`. POSIX thus recommends as follows:

> Since the `==` operator checks whether strings are identical, not whether they collate equally, applications needing to check whether strings collate equally can use:
>
> ```
> a <= b && a >= b
> ```

As of version 4.2, `gawk` continues to use locale collating order for `<`, `<=`, `>`, and `>=` only in POSIX mode.

6.3.3 Boolean Expressions

A *Boolean expression* is a combination of comparison expressions or matching expressions, using the Boolean operators "or" ('`||`'), "and" ('`&&`'), and "not" ('`!`'), along with parentheses to control nesting. The truth value of the Boolean expression is computed by combining the truth values of the component expressions. Boolean expressions are also referred to as *logical expressions*. The terms are equivalent.

Boolean expressions can be used wherever comparison and matching expressions can be used. They can be used in `if`, `while`, `do`, and `for` statements (see Section 7.4 [Control Statements in Actions], page 158). They have numeric values (one if true, zero if false) that come into play if the result of the Boolean expression is stored in a variable or used in arithmetic.

In addition, every Boolean expression is also a valid pattern, so you can use one as a pattern to control the execution of rules. The Boolean operators are:

boolean1 `&&` *boolean2*
: True if both *boolean1* and *boolean2* are true. For example, the following statement prints the current input record if it contains both '`edu`' and '`li`':

  ```
  if ($0 ~ /edu/ && $0 ~ /li/) print
  ```

  The subexpression *boolean2* is evaluated only if *boolean1* is true. This can make a difference when *boolean2* contains expressions that have side effects. In the case of '`$0 ~ /foo/ && ($2 == bar++)`', the variable `bar` is not incremented if there is no substring '`foo`' in the record.

boolean1 `||` *boolean2*
: True if at least one of *boolean1* or *boolean2* is true. For example, the following statement prints all records in the input that contain *either* '`edu`' or '`li`':

[8] See the Austin Group website.

```
if ($0 ~ /edu/ || $0 ~ /li/) print
```

The subexpression *boolean2* is evaluated only if *boolean1* is false. This can make a difference when *boolean2* contains expressions that have side effects. (Thus, this test never really distinguishes records that contain both 'edu' and 'li'—as soon as 'edu' is matched, the full test succeeds.)

`! boolean` True if *boolean* is false. For example, the following program prints 'no home!' in the unusual event that the HOME environment variable is not defined:

```
BEGIN { if (! ("HOME" in ENVIRON))
            print "no home!" }
```

(The `in` operator is described in Section 8.1.2 [Referring to an Array Element], page 183.)

The '`&&`' and '`||`' operators are called *short-circuit* operators because of the way they work. Evaluation of the full expression is "short-circuited" if the result can be determined partway through its evaluation.

Statements that end with '`&&`' or '`||`' can be continued simply by putting a newline after them. But you cannot put a newline in front of either of these operators without using backslash continuation (see Section 1.6 [`awk` Statements Versus Lines], page 28).

The actual value of an expression using the '`!`' operator is either one or zero, depending upon the truth value of the expression it is applied to. The '`!`' operator is often useful for changing the sense of a flag variable from false to true and back again. For example, the following program is one way to print lines in between special bracketing lines:

```
$1 == "START"   { interested = ! interested; next }
interested      { print }
$1 == "END"     { interested = ! interested; next }
```

The variable `interested`, as with all `awk` variables, starts out initialized to zero, which is also false. When a line is seen whose first field is 'START', the value of `interested` is toggled to true, using '`!`'. The next rule prints lines as long as `interested` is true. When a line is seen whose first field is 'END', `interested` is toggled back to false.[9]

Most commonly, the '`!`' operator is used in the conditions of `if` and `while` statements, where it often makes more sense to phrase the logic in the negative:

```
if (! some condition || some other condition) {
    ... do whatever processing ...
}
```

NOTE: The `next` statement is discussed in Section 7.4.8 [The `next` Statement], page 164. `next` tells `awk` to skip the rest of the rules, get the next record, and start processing the rules over again at the top. The reason it's there is to avoid printing the bracketing 'START' and 'END' lines.

6.3.4 Conditional Expressions

A *conditional expression* is a special kind of expression that has three operands. It allows you to use one expression's value to select one of two other expressions. The conditional expression in `awk` is the same as in the C language, as shown here:

```
selector ? if-true-exp : if-false-exp
```

[9] This program has a bug; it prints lines starting with 'END'. How would you fix it?

There are three subexpressions. The first, *selector*, is always computed first. If it is "true" (not zero or not null), then *if-true-exp* is computed next, and its value becomes the value of the whole expression. Otherwise, *if-false-exp* is computed next, and its value becomes the value of the whole expression. For example, the following expression produces the absolute value of `x`:

```
x >= 0 ? x : -x
```

Each time the conditional expression is computed, only one of *if-true-exp* and *if-false-exp* is used; the other is ignored. This is important when the expressions have side effects. For example, this conditional expression examines element `i` of either array `a` or array `b`, and increments `i`:

```
x == y ? a[i++] : b[i++]
```

This is guaranteed to increment `i` exactly once, because each time only one of the two increment expressions is executed and the other is not. See Chapter 8 [Arrays in awk], page 181, for more information about arrays.

As a minor `gawk` extension, a statement that uses '`?:`' can be continued simply by putting a newline after either character. However, putting a newline in front of either character does not work without using backslash continuation (see Section 1.6 [awk Statements Versus Lines], page 28). If `--posix` is specified (see Section 2.2 [Command-Line Options], page 33), this extension is disabled.

6.4 Function Calls

A *function* is a name for a particular calculation. This enables you to ask for it by name at any point in the program. For example, the function `sqrt()` computes the square root of a number.

A fixed set of functions are *built in*, which means they are available in every `awk` program. The `sqrt()` function is one of these. See Section 9.1 [Built-in Functions], page 197, for a list of built-in functions and their descriptions. In addition, you can define functions for use in your program. See Section 9.2 [User-Defined Functions], page 225, for instructions on how to do this. Finally, `gawk` lets you write functions in C or C++ that may be called from your program (see Chapter 17 [Writing Extensions for gawk], page 415).

The way to use a function is with a *function call* expression, which consists of the function name followed immediately by a list of *arguments* in parentheses. The arguments are expressions that provide the raw materials for the function's calculations. When there is more than one argument, they are separated by commas. If there are no arguments, just write '`()`' after the function name. The following examples show function calls with and without arguments:

```
sqrt(x^2 + y^2)          one argument
atan2(y, x)              two arguments
rand()                   no arguments
```

CAUTION: Do not put any space between the function name and the opening parenthesis! A user-defined function name looks just like the name of a variable—a space would make the expression look like concatenation of a variable with an expression inside parentheses. With built-in functions, space before

the parenthesis is harmless, but it is best not to get into the habit of using space to avoid mistakes with user-defined functions.

Each function expects a particular number of arguments. For example, the `sqrt()` function must be called with a single argument, the number of which to take the square root:

```
sqrt(argument)
```

Some of the built-in functions have one or more optional arguments. If those arguments are not supplied, the functions use a reasonable default value. See Section 9.1 [Built-in Functions], page 197, for full details. If arguments are omitted in calls to user-defined functions, then those arguments are treated as local variables. Such local variables act like the empty string if referenced where a string value is required, and like zero if referenced where a numeric value is required (see Section 9.2 [User-Defined Functions], page 225).

As an advanced feature, `gawk` provides indirect function calls, which is a way to choose the function to call at runtime, instead of when you write the source code to your program. We defer discussion of this feature until later; see Section 9.5 [Indirect Function Calls], page 238.

Like every other expression, the function call has a value, often called the *return value*, which is computed by the function based on the arguments you give it. In this example, the return value of '`sqrt(argument)`' is the square root of *argument*. The following program reads numbers, one number per line, and prints the square root of each one:

```
$ awk '{ print "The square root of", $1, "is", sqrt($1) }'
1
⊣ The square root of 1 is 1
3
⊣ The square root of 3 is 1.73205
5
⊣ The square root of 5 is 2.23607
Ctrl-d
```

A function can also have side effects, such as assigning values to certain variables or doing I/O. This program shows how the `match()` function (see Section 9.1.4 [String-Manipulation Functions], page 200) changes the variables `RSTART` and `RLENGTH`:

```
{
    if (match($1, $2))
        print RSTART, RLENGTH
    else
        print "no match"
}
```

Here is a sample run:

```
$ awk -f matchit.awk
aaccdd  c+
⊣ 3 2
foo     bar
⊣ no match
abcdefg e
⊣ 5 1
```

6.5 Operator Precedence (How Operators Nest)

Operator precedence determines how operators are grouped when different operators appear close by in one expression. For example, '`*`' has higher precedence than '`+`'; thus, '`a + b * c`' means to multiply `b` and `c`, and then add `a` to the product (i.e., '`a + (b * c)`').

The normal precedence of the operators can be overruled by using parentheses. Think of the precedence rules as saying where the parentheses are assumed to be. In fact, it is wise to always use parentheses whenever there is an unusual combination of operators, because other people who read the program may not remember what the precedence is in this case. Even experienced programmers occasionally forget the exact rules, which leads to mistakes. Explicit parentheses help prevent any such mistakes.

When operators of equal precedence are used together, the leftmost operator groups first, except for the assignment, conditional, and exponentiation operators, which group in the opposite order. Thus, '`a - b + c`' groups as '`(a - b) + c`' and '`a = b = c`' groups as '`a = (b = c)`'.

Normally the precedence of prefix unary operators does not matter, because there is only one way to interpret them: innermost first. Thus, '`$++i`' means '`$(++i)`' and '`++$x`' means '`++($x)`'. However, when another operator follows the operand, then the precedence of the unary operators can matter. '`$x^2`' means '`($x)^2`', but '`-x^2`' means '`-(x^2)`', because '`-`' has lower precedence than '`^`', whereas '`$`' has higher precedence. Also, operators cannot be combined in a way that violates the precedence rules; for example, '`$$0++--`' is not a valid expression because the first '`$`' has higher precedence than the '`++`'; to avoid the problem the expression can be rewritten as '`$($0++)--`'.

This list presents `awk`'s operators, in order of highest to lowest precedence:

`(...)` Grouping.

`$` Field reference.

`++ --` Increment, decrement.

`^ **` Exponentiation. These operators group right to left.

`+ - !` Unary plus, minus, logical "not."

`* / %` Multiplication, division, remainder.

`+ -` Addition, subtraction.

String concatenation
: There is no special symbol for concatenation. The operands are simply written side by side (see Section 6.2.2 [String Concatenation], page 134).

`< <= == != > >= >> | |&`
: Relational and redirection. The relational operators and the redirections have the same precedence level. Characters such as '`>`' serve both as relationals and as redirections; the context distinguishes between the two meanings.

  Note that the I/O redirection operators in `print` and `printf` statements belong to the statement level, not to expressions. The redirection does not produce an expression that could be the operand of another operator. As a result, it does not make sense to use a redirection operator near another operator of lower

precedence without parentheses. Such combinations (e.g., '`print foo > a ? b : c`') result in syntax errors. The correct way to write this statement is '`print foo > (a ? b : c)`'.

`~ !~` Matching, nonmatching.

`in` Array membership.

`&&` Logical "and."

`||` Logical "or."

`?:` Conditional. This operator groups right to left.

`= += -= *= /= %= ^= **=`
Assignment. These operators group right to left.

> **NOTE:** The '`|&`', '`**`', and '`**=`' operators are not specified by POSIX. For maximum portability, do not use them.

6.6 Where You Are Makes a Difference

Modern systems support the notion of *locales*: a way to tell the system about the local character set and language. The ISO C standard defines a default `"C"` locale, which is an environment that is typical of what many C programmers are used to.

Once upon a time, the locale setting used to affect regexp matching, but this is no longer true (see Section A.8 [Regexp Ranges and Locales: A Long Sad Story], page 497).

Locales can affect record splitting. For the normal case of '`RS = "\n"`', the locale is largely irrelevant. For other single-character record separators, setting '`LC_ALL=C`' in the environment will give you much better performance when reading records. Otherwise, `gawk` has to make several function calls, *per input character*, to find the record terminator.

Locales can affect how dates and times are formatted (see Section 9.1.6 [Time Functions], page 215). For example, a common way to abbreviate the date September 4, 2015, in the United States is "9/4/15." In many countries in Europe, however, it is abbreviated "4.9.15." Thus, the '`%x`' specification in a `"US"` locale might produce '`9/4/15`', while in a `"EUROPE"` locale, it might produce '`4.9.15`'.

According to POSIX, string comparison is also affected by locales (similar to regular expressions). The details are presented in Section 6.3.2.3 [String Comparison Based on Locale Collating Order], page 143.

Finally, the locale affects the value of the decimal point character used when `gawk` parses input data. This is discussed in detail in Section 6.1.4 [Conversion of Strings and Numbers], page 130.

6.7 Summary

- Expressions are the basic elements of computation in programs. They are built from constants, variables, function calls, and combinations of the various kinds of values with operators.
- `awk` supplies three kinds of constants: numeric, string, and regexp. `gawk` lets you specify numeric constants in octal and hexadecimal (bases 8 and 16) as well as decimal

(base 10). In certain contexts, a standalone regexp constant such as `/foo/` has the same meaning as '`$0 ~ /foo/`'.

- Variables hold values between uses in computations. A number of built-in variables provide information to your `awk` program, and a number of others let you control how `awk` behaves.
- Numbers are automatically converted to strings, and strings to numbers, as needed by `awk`. Numeric values are converted as if they were formatted with `sprintf()` using the format in `CONVFMT`. Locales can influence the conversions.
- `awk` provides the usual arithmetic operators (addition, subtraction, multiplication, division, modulus), and unary plus and minus. It also provides comparison operators, Boolean operators, an array membership testing operator, and regexp matching operators. String concatenation is accomplished by placing two expressions next to each other; there is no explicit operator. The three-operand '`?:`' operator provides an "if-else" test within expressions.
- Assignment operators provide convenient shorthands for common arithmetic operations.
- In `awk`, a value is considered to be true if it is nonzero *or* non-null. Otherwise, the value is false.
- A variable's type is set upon each assignment and may change over its lifetime. The type determines how it behaves in comparisons (string or numeric).
- Function calls return a value that may be used as part of a larger expression. Expressions used to pass parameter values are fully evaluated before the function is called. `awk` provides built-in and user-defined functions; this is described in Chapter 9 [Functions], page 197.
- Operator precedence specifies the order in which operations are performed, unless explicitly overridden by parentheses. `awk`'s operator precedence is compatible with that of C.
- Locales can affect the format of data as output by an `awk` program, and occasionally the format for data read as input.

7 Patterns, Actions, and Variables

As you have already seen, each `awk` statement consists of a pattern with an associated action. This chapter describes how you build patterns and actions, what kinds of things you can do within actions, and `awk`'s predefined variables.

The pattern–action rules and the statements available for use within actions form the core of `awk` programming. In a sense, everything covered up to here has been the foundation that programs are built on top of. Now it's time to start building something useful.

7.1 Pattern Elements

Patterns in `awk` control the execution of rules—a rule is executed when its pattern matches the current input record. The following is a summary of the types of `awk` patterns:

`/regular expression/`
: A regular expression. It matches when the text of the input record fits the regular expression. (See Chapter 3 [Regular Expressions], page 51.)

`expression`
: A single expression. It matches when its value is nonzero (if a number) or non-null (if a string). (See Section 7.1.2 [Expressions as Patterns], page 151.)

`begpat, endpat`
: A pair of patterns separated by a comma, specifying a *range* of records. The range includes both the initial record that matches *begpat* and the final record that matches *endpat*. (See Section 7.1.3 [Specifying Record Ranges with Patterns], page 153.)

`BEGIN`
`END`
: Special patterns for you to supply startup or cleanup actions for your `awk` program. (See Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154.)

`BEGINFILE`
`ENDFILE`
: Special patterns for you to supply startup or cleanup actions to be done on a per-file basis. (See Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155.)

`empty`
: The empty pattern matches every input record. (See Section 7.1.6 [The Empty Pattern], page 156.)

7.1.1 Regular Expressions as Patterns

Regular expressions are one of the first kinds of patterns presented in this book. This kind of pattern is simply a regexp constant in the pattern part of a rule. Its meaning is '`$0 ~ /pattern/`'. The pattern matches when the input record matches the regexp. For example:

```
/foo|bar|baz/  { buzzwords++ }
END            { print buzzwords, "buzzwords seen" }
```

7.1.2 Expressions as Patterns

Any `awk` expression is valid as an `awk` pattern. The pattern matches if the expression's value is nonzero (if a number) or non-null (if a string). The expression is reevaluated each

time the rule is tested against a new input record. If the expression uses fields such as `$1`, the value depends directly on the new input record's text; otherwise, it depends on only what has happened so far in the execution of the `awk` program.

Comparison expressions, using the comparison operators described in Section 6.3.2 [Variable Typing and Comparison Expressions], page 139, are a very common kind of pattern. Regexp matching and nonmatching are also very common expressions. The left operand of the '`~`' and '`!~`' operators is a string. The right operand is either a constant regular expression enclosed in slashes (*`/regexp/`*), or any expression whose string value is used as a dynamic regular expression (see Section 3.6 [Using Dynamic Regexps], page 63). The following example prints the second field of each input record whose first field is precisely '`li`':

```
$ awk '$1 == "li" { print $2 }' mail-list
```

(There is no output, because there is no person with the exact name '`li`'.) Contrast this with the following regular expression match, which accepts any record with a first field that contains '`li`':

```
$ awk '$1 ~ /li/ { print $2 }' mail-list
⊣ 555-5553
⊣ 555-6699
```

A regexp constant as a pattern is also a special case of an expression pattern. The expression `/li/` has the value one if '`li`' appears in the current input record. Thus, as a pattern, `/li/` matches any record containing '`li`'.

Boolean expressions are also commonly used as patterns. Whether the pattern matches an input record depends on whether its subexpressions match. For example, the following command prints all the records in `mail-list` that contain both '`edu`' and '`li`':

```
$ awk '/edu/ && /li/' mail-list
⊣ Samuel       555-3430     samuel.lanceolis@shu.edu        A
```

The following command prints all records in `mail-list` that contain *either* '`edu`' or '`li`' (or both, of course):

```
$ awk '/edu/ || /li/' mail-list
⊣ Amelia       555-5553     amelia.zodiacusque@gmail.com    F
⊣ Broderick    555-0542     broderick.aliquotiens@yahoo.com R
⊣ Fabius       555-1234     fabius.undevicesimus@ucb.edu    F
⊣ Julie        555-6699     julie.perscrutabor@skeeve.com   F
⊣ Samuel       555-3430     samuel.lanceolis@shu.edu        A
⊣ Jean-Paul    555-2127     jeanpaul.campanorum@nyu.edu     R
```

The following command prints all records in `mail-list` that do *not* contain the string '`li`':

```
$ awk '! /li/' mail-list
⊣ Anthony      555-3412     anthony.asserturo@hotmail.com   A
⊣ Becky        555-7685     becky.algebrarum@gmail.com      A
⊣ Bill         555-1675     bill.drowning@hotmail.com       A
⊣ Camilla      555-2912     camilla.infusarum@skynet.be     R
⊣ Fabius       555-1234     fabius.undevicesimus@ucb.edu    F
⊣ Martin       555-6480     martin.codicibus@hotmail.com    A
⊣ Jean-Paul    555-2127     jeanpaul.campanorum@nyu.edu     R
```

The subexpressions of a Boolean operator in a pattern can be constant regular expressions, comparisons, or any other `awk` expressions. Range patterns are not expressions, so they cannot appear inside Boolean patterns. Likewise, the special patterns `BEGIN`, `END`, `BEGINFILE`, and `ENDFILE`, which never match any input record, are not expressions and cannot appear inside Boolean patterns.

The precedence of the different operators that can appear in patterns is described in Section 6.5 [Operator Precedence (How Operators Nest)], page 148.

7.1.3 Specifying Record Ranges with Patterns

A *range pattern* is made of two patterns separated by a comma, in the form '*`begpat, endpat`*'. It is used to match ranges of consecutive input records. The first pattern, *begpat*, controls where the range begins, while *endpat* controls where the pattern ends. For example, the following:

```
awk '$1 == "on", $1 == "off"' myfile
```

prints every record in `myfile` between '`on`'/'`off`' pairs, inclusive.

A range pattern starts out by matching *begpat* against every input record. When a record matches *begpat*, the range pattern is *turned on*, and the range pattern matches this record as well. As long as the range pattern stays turned on, it automatically matches every input record read. The range pattern also matches *endpat* against every input record; when this succeeds, the range pattern is *turned off* again for the following record. Then the range pattern goes back to checking *begpat* against each record.

The record that turns on the range pattern and the one that turns it off both match the range pattern. If you don't want to operate on these records, you can write `if` statements in the rule's action to distinguish them from the records you are interested in.

It is possible for a pattern to be turned on and off by the same record. If the record satisfies both conditions, then the action is executed for just that record. For example, suppose there is text between two identical markers (e.g., the '`%`' symbol), each on its own line, that should be ignored. A first attempt would be to combine a range pattern that describes the delimited text with the `next` statement (not discussed yet, see Section 7.4.8 [The `next` Statement], page 164). This causes `awk` to skip any further processing of the current record and start over again with the next input record. Such a program looks like this:

```
/^%$/,/^%$/    { next }
               { print }
```

This program fails because the range pattern is both turned on and turned off by the first line, which just has a '`%`' on it. To accomplish this task, write the program in the following manner, using a flag:

```
/^%$/     { skip = ! skip; next }
skip == 1 { next } # skip lines with `skip' set
```

In a range pattern, the comma ('`,`') has the lowest precedence of all the operators (i.e., it is evaluated last). Thus, the following program attempts to combine a range pattern with another, simpler test:

```
echo Yes | awk '/1/,/2/ || /Yes/'
```

The intent of this program is '`(/1/,/2/) || /Yes/`'. However, `awk` interprets this as '`/1/, (/2/ || /Yes/)`'. This cannot be changed or worked around; range patterns do not combine with other patterns:

```
$ echo Yes | gawk '(/1/,/2/) || /Yes/'
error  gawk: cmd. line:1: (/1/,/2/) || /Yes/
error  gawk: cmd. line:1:            ^ syntax error
```

As a minor point of interest, although it is poor style, POSIX allows you to put a newline after the comma in a range pattern.

7.1.4 The `BEGIN` and `END` Special Patterns

All the patterns described so far are for matching input records. The `BEGIN` and `END` special patterns are different. They supply startup and cleanup actions for `awk` programs. `BEGIN` and `END` rules must have actions; there is no default action for these rules because there is no current record when they run. `BEGIN` and `END` rules are often referred to as "`BEGIN` and `END` blocks" by longtime `awk` programmers.

7.1.4.1 Startup and Cleanup Actions

A `BEGIN` rule is executed once only, before the first input record is read. Likewise, an `END` rule is executed once only, after all the input is read. For example:

```
$ awk '
> BEGIN { print "Analysis of \"li\"" }
> /li/  { ++n }
> END   { print "\"li\" appears in", n, "records." }' mail-list
⊣ Analysis of "li"
⊣ "li" appears in 4 records.
```

This program finds the number of records in the input file `mail-list` that contain the string '`li`'. The `BEGIN` rule prints a title for the report. There is no need to use the `BEGIN` rule to initialize the counter `n` to zero, as `awk` does this automatically (see Section 6.1.3 [Variables], page 129). The second rule increments the variable `n` every time a record containing the pattern '`li`' is read. The `END` rule prints the value of `n` at the end of the run.

The special patterns `BEGIN` and `END` cannot be used in ranges or with Boolean operators (indeed, they cannot be used with any operators). An `awk` program may have multiple `BEGIN` and/or `END` rules. They are executed in the order in which they appear: all the `BEGIN` rules at startup and all the `END` rules at termination.

`BEGIN` and `END` rules may be intermixed with other rules. This feature was added in the 1987 version of `awk` and is included in the POSIX standard. The original (1978) version of `awk` required the `BEGIN` rule to be placed at the beginning of the program, the `END` rule to be placed at the end, and only allowed one of each. This is no longer required, but it is a good idea to follow this template in terms of program organization and readability.

Multiple `BEGIN` and `END` rules are useful for writing library functions, because each library file can have its own `BEGIN` and/or `END` rule to do its own initialization and/or cleanup. The order in which library functions are named on the command line controls the order in which their `BEGIN` and `END` rules are executed. Therefore, you have to be careful when writing such rules in library files so that the order in which they are executed doesn't matter. See Section 2.2 [Command-Line Options], page 33, for more information on using library

functions. See Chapter 10 [A Library of awk Functions], page 247, for a number of useful library functions.

If an awk program has only BEGIN rules and no other rules, then the program exits after the BEGIN rules are run.[1] However, if an END rule exists, then the input is read, even if there are no other rules in the program. This is necessary in case the END rule checks the FNR and NR variables, or the fields.

7.1.4.2 Input/Output from BEGIN and END Rules

There are several (sometimes subtle) points to be aware of when doing I/O from a BEGIN or END rule. The first has to do with the value of $0 in a BEGIN rule. Because BEGIN rules are executed before any input is read, there simply is no input record, and therefore no fields, when executing BEGIN rules. References to $0 and the fields yield a null string or zero, depending upon the context. One way to give $0 a real value is to execute a getline function without a variable (see Section 4.10 [Explicit Input with getline], page 92). Another way is simply to assign a value to $0.

The second point is similar to the first, but from the other direction. Traditionally, due largely to implementation issues, $0 and NF were *undefined* inside an END rule. The POSIX standard specifies that NF is available in an END rule. It contains the number of fields from the last input record. Most probably due to an oversight, the standard does not say that $0 is also preserved, although logically one would think that it should be. In fact, all of BWK awk, mawk, and gawk preserve the value of $0 for use in END rules. Be aware, however, that some other implementations and many older versions of Unix awk do not.

The third point follows from the first two. The meaning of 'print' inside a BEGIN or END rule is the same as always: 'print $0'. If $0 is the null string, then this prints an empty record. Many longtime awk programmers use an unadorned 'print' in BEGIN and END rules to mean 'print ""', relying on $0 being null. Although one might generally get away with this in BEGIN rules, it is a very bad idea in END rules, at least in gawk. It is also poor style, because if an empty line is needed in the output, the program should print one explicitly.

Finally, the next and nextfile statements are not allowed in a BEGIN rule, because the implicit read-a-record-and-match-against-the-rules loop has not started yet. Similarly, those statements are not valid in an END rule, because all the input has been read. (See Section 7.4.8 [The next Statement], page 164, and see Section 7.4.9 [The nextfile Statement], page 165.)

7.1.5 The BEGINFILE and ENDFILE Special Patterns

This section describes a gawk-specific feature.

Two special kinds of rule, BEGINFILE and ENDFILE, give you "hooks" into gawk's command-line file processing loop. As with the BEGIN and END rules (see the previous section), BEGINFILE rules in a program execute in the order they are read by gawk. Similarly, all ENDFILE rules also execute in the order they are read.

The bodies of the BEGINFILE rules execute just before gawk reads the first record from a file. FILENAME is set to the name of the current file, and FNR is set to zero.

Prior to version 5.1.1 of gawk, as an accident of the implementation, $0 and the fields retained any previous values they had in BEGINFILE rules. Starting with version 5.1.1, $0

[1] The original version of awk kept reading and ignoring input until the end of the file was seen.

and the fields are cleared, since no record has been read yet from the file that is about to be processed.

The `BEGINFILE` rule provides you the opportunity to accomplish two tasks that would otherwise be difficult or impossible to perform:

- You can test if the file is readable. Normally, it is a fatal error if a file named on the command line cannot be opened for reading. However, you can bypass the fatal error and move on to the next file on the command line.

  You do this by checking if the `ERRNO` variable is not the empty string; if so, then `gawk` was not able to open the file. In this case, your program can execute the `nextfile` statement (see Section 7.4.9 [The `nextfile` Statement], page 165). This causes `gawk` to skip the file entirely. Otherwise, `gawk` exits with the usual fatal error.
- If you have written extensions that modify the record handling (by inserting an "input parser"; see Section 17.4.6.4 [Customized Input Parsers], page 429), you can invoke them at this point, before `gawk` has started processing the file. (This is a *very* advanced feature, currently used only by the `gawkextlib` project.)

The `ENDFILE` rule is called when `gawk` has finished processing the last record in an input file. For the last input file, it will be called before any `END` rules. The `ENDFILE` rule is executed even for empty input files.

Normally, when an error occurs when reading input in the normal input-processing loop, the error is fatal. However, if a `BEGINFILE` rule is present, the error becomes non-fatal, and instead `ERRNO` is set. This makes it possible to catch and process I/O errors at the level of the `awk` program.

The `next` statement (see Section 7.4.8 [The `next` Statement], page 164) is not allowed inside either a `BEGINFILE` or an `ENDFILE` rule. The `nextfile` statement is allowed only inside a `BEGINFILE` rule, not inside an `ENDFILE` rule.

The `getline` function (see Section 4.10 [Explicit Input with `getline`], page 92) is restricted inside both `BEGINFILE` and `ENDFILE`: only redirected forms of `getline` are allowed.

`BEGINFILE` and `ENDFILE` are `gawk` extensions. In most other `awk` implementations, or if `gawk` is in compatibility mode (see Section 2.2 [Command-Line Options], page 33), they are not special.

7.1.6 The Empty Pattern

An empty (i.e., nonexistent) pattern is considered to match *every* input record. For example, the program:

```
awk '{ print $1 }' mail-list
```

prints the first field of every record.

7.2 Using Shell Variables in Programs

`awk` programs are often used as components in larger programs written in shell. For example, it is very common to use a shell variable to hold a pattern that the `awk` program searches for. There are two ways to get the value of the shell variable into the body of the `awk` program.

A common method is to use shell quoting to substitute the variable's value into the program inside the script. For example, consider the following program:

```
printf "Enter search pattern: "
read pattern
awk "/$pattern/ "'{ nmatches++ }
     END { print nmatches, "found" }' /path/to/data
```

The `awk` program consists of two pieces of quoted text that are concatenated together to form the program. The first part is double-quoted, which allows substitution of the `pattern` shell variable inside the quotes. The second part is single-quoted.

Variable substitution via quoting works, but can potentially be messy. It requires a good understanding of the shell's quoting rules (see Section 1.1.6 [Shell Quoting Issues], page 21), and it's often difficult to correctly match up the different quotes when reading the program.

A better method is to use `awk`'s variable assignment feature (see Section 6.1.3.2 [Assigning Variables on the Command Line], page 129) to assign the shell variable's value to an `awk` variable. Then use dynamic regexps to match the pattern (see Section 3.6 [Using Dynamic Regexps], page 63). The following shows how to redo the previous example using this technique:

```
printf "Enter search pattern: "
read pattern
awk -v pat="$pattern" '$0 ~ pat { nmatches++ }
       END { print nmatches, "found" }' /path/to/data
```

Now, the `awk` program is just one single-quoted string. The assignment '`-v pat="$pattern"`' still requires double quotes, in case there is whitespace in the value of `$pattern`. The `awk` variable `pat` could be named `pattern` too, but that would be more confusing. Using a variable also provides more flexibility, as the variable can be used anywhere inside the program—for printing, as an array subscript, or for any other use—without requiring the quoting tricks at every point in the program.

7.3 Actions

An `awk` program or script consists of a series of rules and function definitions interspersed. (Functions are described later. See Section 9.2 [User-Defined Functions], page 225.) A rule contains a pattern and an action, either of which (but not both) may be omitted. The purpose of the *action* is to tell `awk` what to do once a match for the pattern is found. Thus, in outline, an `awk` program generally looks like this:

```
[pattern] { action }
 pattern [{ action }]
...
function name(args) { ... }
...
```

An action consists of one or more `awk` *statements*, enclosed in braces ('`{...}`'). Each statement specifies one thing to do. The statements are separated by newlines or semicolons. The braces around an action must be used even if the action contains only one statement, or if it contains no statements at all. However, if you omit the action entirely, omit the braces as well. An omitted action is equivalent to '`{ print $0 }`':

```
/foo/  { }      match foo, do nothing — empty action
```

`/foo/` *match* `foo`*, print the record — omitted action*

The following types of statements are supported in `awk`:

Expressions
: Call functions or assign values to variables (see Chapter 6 [Expressions], page 123). Executing this kind of statement simply computes the value of the expression. This is useful when the expression has side effects (see Section 6.2.3 [Assignment Expressions], page 135).

Control statements
: Specify the control flow of `awk` programs. The `awk` language gives you C-like constructs (`if`, `for`, `while`, and `do`) as well as a few special ones (see Section 7.4 [Control Statements in Actions], page 158).

Compound statements
: Enclose one or more statements in braces. A compound statement is used in order to put several statements together in the body of an `if`, `while`, `do`, or `for` statement.

Input statements
: Use the `getline` function (see Section 4.10 [Explicit Input with `getline`], page 92). Also supplied in `awk` are the `next` statement (see Section 7.4.8 [The `next` Statement], page 164) and the `nextfile` statement (see Section 7.4.9 [The `nextfile` Statement], page 165).

Output statements
: Such as `print` and `printf`. See Chapter 5 [Printing Output], page 103.

Deletion statements
: For deleting array elements. See Section 8.4 [The `delete` Statement], page 190.

7.4 Control Statements in Actions

Control statements, such as `if`, `while`, and so on, control the flow of execution in `awk` programs. Most of `awk`'s control statements are patterned after similar statements in C.

All the control statements start with special keywords, such as `if` and `while`, to distinguish them from simple expressions. Many control statements contain other statements. For example, the `if` statement contains another statement that may or may not be executed. The contained statement is called the *body*. To include more than one statement in the body, group them into a single *compound statement* with braces, separating them with newlines or semicolons.

7.4.1 The `if-else` Statement

The `if-else` statement is `awk`'s decision-making statement. It looks like this:

`if (`*condition*`)` *then-body* [`else` *else-body*]

The *condition* is an expression that controls what the rest of the statement does. If the *condition* is true, *then-body* is executed; otherwise, *else-body* is executed. The `else` part of the statement is optional. The condition is considered false if its value is zero or the null string; otherwise, the condition is true. Refer to the following:

```
if (x % 2 == 0)
    print "x is even"
else
    print "x is odd"
```

In this example, if the expression '`x % 2 == 0`' is true (i.e., if the value of `x` is evenly divisible by two), then the first `print` statement is executed; otherwise, the second `print` statement is executed. If the `else` keyword appears on the same line as *then-body* and *then-body* is not a compound statement (i.e., not surrounded by braces), then a semicolon must separate *then-body* from the `else`. To illustrate this, the previous example can be rewritten as:

```
if (x % 2 == 0) print "x is even"; else
        print "x is odd"
```

If the '`;`' is left out, `awk` can't interpret the statement and it produces a syntax error. Don't actually write programs this way, because a human reader might fail to see the `else` if it is not the first thing on its line.

7.4.2 The `while` Statement

In programming, a *loop* is a part of a program that can be executed two or more times in succession. The `while` statement is the simplest looping statement in `awk`. It repeatedly executes a statement as long as a condition is true. For example:

```
while (condition)
  body
```

body is a statement called the *body* of the loop, and *condition* is an expression that controls how long the loop keeps running. The first thing the `while` statement does is test the *condition*. If the *condition* is true, it executes the statement *body*. After *body* has been executed, *condition* is tested again, and if it is still true, *body* executes again. This process repeats until the *condition* is no longer true. If the *condition* is initially false, the body of the loop never executes and `awk` continues with the statement following the loop. This example prints the first three fields of each record, one per line:

```
awk '
{
    i = 1
    while (i <= 3) {
        print $i
        i++
    }
}' inventory-shipped
```

The body of this loop is a compound statement enclosed in braces, containing two statements. The loop works in the following manner: first, the value of `i` is set to one. Then, the `while` statement tests whether `i` is less than or equal to three. This is true when `i` equals one, so the `i`th field is printed. Then the '`i++`' increments the value of `i` and the loop repeats. The loop terminates when `i` reaches four.

A newline is not required between the condition and the body; however, using one makes the program clearer unless the body is a compound statement or else is very simple. The

newline after the open brace that begins the compound statement is not required either, but the program is harder to read without it.

7.4.3 The `do-while` Statement

The `do` loop is a variation of the `while` looping statement. The `do` loop executes the *body* once and then repeats the *body* as long as the *condition* is true. It looks like this:

```
do
  body
while (condition)
```

Even if the *condition* is false at the start, the *body* executes at least once (and only once, unless executing *body* makes *condition* true). Contrast this with the corresponding `while` statement:

```
while (condition)
    body
```

This statement does not execute the *body* even once if the *condition* is false to begin with. The following is an example of a `do` statement:

```
{
    i = 1
    do {
        print $0
        i++
    } while (i <= 10)
}
```

This program prints each input record 10 times. However, it isn't a very realistic example, because in this case an ordinary `while` would do just as well. This situation reflects actual experience; only occasionally is there a real use for a `do` statement.

7.4.4 The `for` Statement

The `for` statement makes it more convenient to count iterations of a loop. The general form of the `for` statement looks like this:

```
for (initialization; condition; increment)
  body
```

The *initialization*, *condition*, and *increment* parts are arbitrary `awk` expressions, and *body* stands for any `awk` statement.

The `for` statement starts by executing *initialization*. Then, as long as the *condition* is true, it repeatedly executes *body* and then *increment*. Typically, *initialization* sets a variable to either zero or one, *increment* adds one to it, and *condition* compares it against the desired number of iterations. For example:

```
awk '
{
    for (i = 1; i <= 3; i++)
        print $i
}' inventory-shipped
```

This prints the first three fields of each input record, with one input field per output line.

C and C++ programmers might expect to be able to use the comma operator to set more than one variable in the *initialization* part of the `for` loop, or to increment multiple variables in the *increment* part of the loop, like so:

```
for (i = 0, j = length(a); i < j; i++, j--) ...    C/C++, not awk!
```

You cannot do this; the comma operator is not supported in `awk`. There are workarounds, but they are nonobvious and can lead to code that is difficult to read and understand. It is best, therefore, to simply write additional initializations as separate statements preceding the `for` loop and to place additional increment statements at the end of the loop's body.

Most often, *increment* is an increment expression, as in the earlier example. But this is not required; it can be any expression whatsoever. For example, the following statement prints all the powers of two between 1 and 100:

```
for (i = 1; i <= 100; i *= 2)
    print i
```

If there is nothing to be done, any of the three expressions in the parentheses following the `for` keyword may be omitted. Thus, '`for (; x > 0;)`' is equivalent to '`while (x > 0)`'. If the *condition* is omitted, it is treated as true, effectively yielding an *infinite loop* (i.e., a loop that never terminates).

In most cases, a `for` loop is an abbreviation for a `while` loop, as shown here:

```
initialization
while (condition) {
  body
  increment
}
```

The only exception is when the `continue` statement (see Section 7.4.7 [The `continue` Statement], page 164) is used inside the loop. Changing a `for` statement to a `while` statement in this way can change the effect of the `continue` statement inside the loop.

The `awk` language has a `for` statement in addition to a `while` statement because a `for` loop is often both less work to type and more natural to think of. Counting the number of iterations is very common in loops. It can be easier to think of this counting as part of looping rather than as something to do inside the loop.

There is an alternative version of the `for` loop, for iterating over all the indices of an array:

```
for (i in array)
    do something with array[i]
```

See Section 8.1.5 [Scanning All Elements of an Array], page 185, for more information on this version of the `for` loop.

7.4.5 The `switch` Statement

This section describes a `gawk`-specific feature. If `gawk` is in compatibility mode (see Section 2.2 [Command-Line Options], page 33), it is not available.

The `switch` statement allows the evaluation of an expression and the execution of statements based on a `case` match. Case statements are checked for a match in the order they are defined. If no suitable `case` is found, the `default` section is executed, if supplied.

Each `case` contains a single constant, be it numeric, string, or regexp. The `switch` expression is evaluated, and then each `case`'s constant is compared against the result in turn. The type of constant determines the comparison: numeric or string do the usual comparisons. A regexp constant (either regular, `/foo/`, or strongly typed, `@/foo/`) does a regular expression match against the string value of the original expression. The general form of the `switch` statement looks like this:

```
switch (expression) {
case value or regular expression:
    case-body
default:
    default-body
}
```

Control flow in the `switch` statement works as it does in C. Once a match to a given case is made, the case statement bodies execute until a `break`, `continue`, `next`, `nextfile`, or `exit` is encountered, or the end of the `switch` statement itself. For example:

```
while ((c = getopt(ARGC, ARGV, "aksx")) != -1) {
    switch (c) {
    case "a":
        # report size of all files
        all_files = TRUE;
        break
    case "k":
        BLOCK_SIZE = 1024       # 1K block size
        break
    case "s":
        # do sums only
        sum_only = TRUE
        break
    case "x":
        # don't cross filesystems
        fts_flags = or(fts_flags, FTS_XDEV)
        break
    case "?":
    default:
        usage()
        break
    }
}
```

Note that if none of the statements specified here halt execution of a matched `case` statement, execution falls through to the next `case` until execution halts. In this example, the `case` for `"?"` falls through to the `default` case, which is to call a function named `usage()`. (The `getopt()` function being called here is described in Section 10.4 [Processing Command-Line Options], page 266.)

7.4.6 The `break` Statement

The `break` statement serves two purposes. One purpose is to break out of the `switch` statement. This was discussed in Section 7.4.5 [The `switch` Statement], page 161.

The other purpose is that it jumps out of the innermost `for`, `while`, or `do` loop that encloses it. The following example finds the smallest divisor of any integer, and also identifies prime numbers:

```
# find smallest divisor of num
{
    num = $1
    for (divisor = 2; divisor * divisor <= num; divisor++) {
        if (num % divisor == 0)
            break
    }
    if (num % divisor == 0)
        printf "Smallest divisor of %d is %d\n", num, divisor
    else
        printf "%d is prime\n", num
}
```

When the remainder is zero in the first `if` statement, `awk` immediately *breaks out* of the containing `for` loop. This means that `awk` proceeds immediately to the statement following the loop and continues processing. (This is very different from the `exit` statement, which stops the entire `awk` program. See Section 7.4.10 [The `exit` Statement], page 166.)

The following program illustrates how the *condition* of a `for` or `while` statement could be replaced with a `break` inside an `if`:

```
# find smallest divisor of num
{
    num = $1
    for (divisor = 2; ; divisor++) {
        if (num % divisor == 0) {
            printf "Smallest divisor of %d is %d\n", num, divisor
            break
        }
        if (divisor * divisor > num) {
            printf "%d is prime\n", num
            break
        }
    }
}
```

Note that `break` breaks out of only the innermost enclosing statement. Thus a `break` inside a `switch` statement inside a loop only breaks out of the `switch`.

The `break` statement has no meaning when used outside the body of a loop or `switch`. However, although it was never documented, historical implementations of `awk` treated the `break` statement outside of a loop as if it were a `next` statement (see Section 7.4.8 [The `next` Statement], page 164). Recent versions of BWK `awk` no longer allow this usage, nor does `gawk`.

7.4.7 The `continue` Statement

Similar to `break`, the `continue` statement is used only inside `for`, `while`, and `do` loops. It skips over the rest of the loop body, causing the next cycle around the loop to begin immediately. Contrast this with `break`, which jumps out of the loop altogether.

The `continue` statement in a `for` loop directs `awk` to skip the rest of the body of the loop and resume execution with the increment-expression of the `for` statement. The following program illustrates this fact:

```
BEGIN {
     for (x = 0; x <= 20; x++) {
         if (x == 5)
             continue
         printf "%d ", x
     }
     print ""
}
```

This program prints all the numbers from 0 to 20—except for 5, for which the `printf` is skipped. Because the increment '`x++`' is not skipped, `x` does not remain stuck at 5. Contrast the `for` loop from the previous example with the following `while` loop:

```
BEGIN {
     x = 0
     while (x <= 20) {
         if (x == 5)
             continue
         printf "%d ", x
         x++
     }
     print ""
}
```

This program loops forever once `x` reaches 5, because the increment ('`x++`') is never reached.

The `continue` statement has no special meaning with respect to the `switch` statement, nor does it have any meaning when used outside the body of a loop. Historical versions of `awk` treated a `continue` statement outside a loop the same way they treated a `break` statement outside a loop: as if it were a `next` statement (see Section 7.4.8 [The `next` Statement], page 164). Recent versions of BWK `awk` no longer work this way, nor does `gawk`.

7.4.8 The `next` Statement

The `next` statement forces `awk` to immediately stop processing the current record and go on to the next record. This means that no further rules are executed for the current record, and the rest of the current rule's action isn't executed.

Contrast this with the effect of the `getline` function (see Section 4.10 [Explicit Input with `getline`], page 92). That also causes `awk` to read the next record immediately, but it does not alter the flow of control in any way (i.e., the rest of the current action executes with a new input record).

At the highest level, `awk` program execution is a loop that reads an input record and then tests each rule's pattern against it. If you think of this loop as a `for` statement whose body contains the rules, then the `next` statement is analogous to a `continue` statement. It skips to the end of the body of this implicit loop and executes the increment (which reads another record).

For example, suppose an `awk` program works only on records with four fields, and it shouldn't fail when given bad input. To avoid complicating the rest of the program, write a "weed out" rule near the beginning, in the following manner:

```
NF != 4 {
    printf("%s:%d: skipped: NF != 4\n", FILENAME, FNR) > "/dev/stderr"
    next
}
```

Because of the `next` statement, the program's subsequent rules won't see the bad record. The error message is redirected to the standard error output stream, as error messages should be. For more detail, see Section 5.8 [Special File names in gawk], page 116.

If the `next` statement causes the end of the input to be reached, then the code in any `END` rules is executed. See Section 7.1.4 [The BEGIN and END Special Patterns], page 154.

The `next` statement is not allowed inside `BEGINFILE` and `ENDFILE` rules. See Section 7.1.5 [The BEGINFILE and ENDFILE Special Patterns], page 155.

According to the POSIX standard, the behavior is undefined if the `next` statement is used in a `BEGIN` or `END` rule. `gawk` treats it as a syntax error. Although POSIX does not disallow it, most other `awk` implementations don't allow the `next` statement inside function bodies (see Section 9.2 [User-Defined Functions], page 225). Just as with any other `next` statement, a `next` statement inside a function body reads the next record and starts processing it with the first rule in the program.

7.4.9 The `nextfile` Statement

The `nextfile` statement is similar to the `next` statement. However, instead of abandoning processing of the current record, the `nextfile` statement instructs `awk` to stop processing the current data file.

Upon execution of the `nextfile` statement, `FILENAME` is updated to the name of the next data file listed on the command line, `FNR` is reset to one, and processing starts over with the first rule in the program. If the `nextfile` statement causes the end of the input to be reached, then the code in any `END` rules is executed. An exception to this is when `nextfile` is invoked during execution of any statement in an `END` rule; in this case, it causes the program to stop immediately. See Section 7.1.4 [The BEGIN and END Special Patterns], page 154.

The `nextfile` statement is useful when there are many data files to process but it isn't necessary to process every record in every file. Without `nextfile`, in order to move on to the next data file, a program would have to continue scanning the unwanted records. The `nextfile` statement accomplishes this much more efficiently.

In `gawk`, execution of `nextfile` causes additional things to happen: any `ENDFILE` rules are executed if `gawk` is not currently in an `END` rule, `ARGIND` is incremented, and any `BEGINFILE` rules are executed. (`ARGIND` hasn't been introduced yet. See Section 7.5 [Predefined Variables], page 167.)

There is an additional, special, use case with `gawk`. `nextfile` is useful inside a `BEGINFILE` rule to skip over a file that would otherwise cause `gawk` to exit with a fatal error. In this special case, `ENDFILE` rules are not executed. See Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155.

Although it might seem that '`close(FILENAME)`' would accomplish the same as `nextfile`, this isn't true. `close()` is reserved for closing files, pipes, and coprocesses that are opened with redirections. It is not related to the main processing that `awk` does with the files listed in `ARGV`.

> **NOTE:** For many years, `nextfile` was a common extension. In September 2012, it was accepted for inclusion into the POSIX standard. See the Austin Group website.

The current version of BWK `awk` and `mawk` also support `nextfile`. However, they don't allow the `nextfile` statement inside function bodies (see Section 9.2 [User-Defined Functions], page 225). `gawk` does; a `nextfile` inside a function body reads the first record from the next file and starts processing it with the first rule in the program, just as any other `nextfile` statement.

7.4.10 The `exit` Statement

The `exit` statement causes `awk` to immediately stop executing the current rule and to stop processing input; any remaining input is ignored. The `exit` statement is written as follows:

`exit` [*return code*]

When an `exit` statement is executed from a `BEGIN` rule, the program stops processing everything immediately. No input records are read. However, if an `END` rule is present, as part of executing the `exit` statement, the `END` rule is executed (see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154). If `exit` is used in the body of an `END` rule, it causes the program to stop immediately.

An `exit` statement that is not part of a `BEGIN` or `END` rule stops the execution of any further automatic rules for the current record, skips reading any remaining input records, and executes the `END` rule if there is one. `gawk` also skips any `ENDFILE` rules; they do not execute.

In such a case, if you don't want the `END` rule to do its job, set a variable to a nonzero value before the `exit` statement and check that variable in the `END` rule. See Section 10.2.2 [Assertions], page 250, for an example that does this.

If an argument is supplied to `exit`, its value is used as the exit status code for the `awk` process. If no argument is supplied, `exit` causes `awk` to return a "success" status. In the case where an argument is supplied to a first `exit` statement, and then `exit` is called a second time from an `END` rule with no argument, `awk` uses the previously supplied exit value.

See Section 2.6 [`gawk`'s Exit Status], page 46, for more information.

For example, suppose an error condition occurs that is difficult or impossible to handle. Conventionally, programs report this by exiting with a nonzero status. An `awk` program can do this using an `exit` statement with a nonzero argument, as shown in the following example:

```
BEGIN {
    if (("date" | getline date_now) <= 0) {
        print "Can't get system date" > "/dev/stderr"
        exit 1
    }
    print "current date is", date_now
    close("date")
}
```

NOTE: For full portability, exit values should be between zero and 126, inclusive. Negative values, and values of 127 or greater, may not produce consistent results across different operating systems.

7.5 Predefined Variables

Most `awk` variables are available to use for your own purposes; they never change unless your program assigns values to them, and they never affect anything unless your program examines them. However, a few variables in `awk` have special built-in meanings. `awk` examines some of these automatically, so that they enable you to tell `awk` how to do certain things. Others are set automatically by `awk`, so that they carry information from the internal workings of `awk` to your program.

This section documents all of `gawk`'s predefined variables, most of which are also documented in the chapters describing their areas of activity.

7.5.1 Built-in Variables That Control `awk`

The following is an alphabetical list of variables that you can change to control how `awk` does certain things.

The variables that are specific to `gawk` are marked with a pound sign ('`#`'). These variables are `gawk` extensions. In other `awk` implementations or if `gawk` is in compatibility mode (see Section 2.2 [Command-Line Options], page 33), they are not special. (Any exceptions are noted in the description of each variable.)

`BINMODE` `#` On non-POSIX systems, this variable specifies use of binary mode for all I/O. Numeric values of one, two, or three specify that input files, output files, or all files, respectively, should use binary I/O. A numeric value less than zero is treated as zero, and a numeric value greater than three is treated as three. Alternatively, string values of `"r"` or `"w"` specify that input files and output files, respectively, should use binary I/O. A string value of `"rw"` or `"wr"` indicates that all files should use binary I/O. Any other string value is treated the same as `"rw"`, but causes `gawk` to generate a warning message. `BINMODE` is described in more detail in Section B.3.1.3 [Using `gawk` on PC Operating Systems], page 511. `mawk` (see Section B.5 [Other Freely Available `awk` Implementations], page 523) also supports this variable, but only using numeric values.

`CONVFMT` A string that controls the conversion of numbers to strings (see Section 6.1.4 [Conversion of Strings and Numbers], page 130). It works by being passed, in effect, as the first argument to the `sprintf()` function (see Section 9.1.4 [String-Manipulation Functions], page 200). Its default value is `"%.6g"`. `CONVFMT` was introduced by the POSIX standard.

`FIELDWIDTHS` #
: A space-separated list of columns that tells `gawk` how to split input with fixed columnar boundaries. Starting in version 4.2, each field width may optionally be preceded by a colon-separated value specifying the number of characters to skip before the field starts. Assigning a value to `FIELDWIDTHS` overrides the use of `FS` and `FPAT` for field splitting. See Section 4.6 [Reading Fixed-Width Data], page 84, for more information.

`FPAT` #
: A regular expression (as a string) that tells `gawk` to create the fields based on text that matches the regular expression. Assigning a value to `FPAT` overrides the use of `FS` and `FIELDWIDTHS` for field splitting. See Section 4.7 [Defining Fields by Content], page 87, for more information.

`FS`
: The input field separator (see Section 4.5 [Specifying How Fields Are Separated], page 77). The value is a single-character string or a multicharacter regular expression that matches the separations between fields in an input record. If the value is the null string (`""`), then each character in the record becomes a separate field. (This behavior is a `gawk` extension. POSIX `awk` does not specify the behavior when `FS` is the null string. Nonetheless, some other versions of `awk` also treat `""` specially.)

  The default value is `" "`, a string consisting of a single space. As a special exception, this value means that any sequence of spaces, TABs, and/or newlines is a single separator. It also causes spaces, TABs, and newlines at the beginning and end of a record to be ignored.

  You can set the value of `FS` on the command line using the `-F` option:

  ```
  awk -F, 'program' input-files
  ```

  If `gawk` is using `FIELDWIDTHS` or `FPAT` for field splitting, assigning a value to `FS` causes `gawk` to return to the normal, `FS`-based field splitting. An easy way to do this is to simply say '`FS = FS`', perhaps with an explanatory comment.

`IGNORECASE` #
: If `IGNORECASE` is nonzero or non-null, then all string comparisons and all regular expression matching are case-independent. This applies to regexp matching with '`~`' and '`!~`', the `gensub()`, `gsub()`, `index()`, `match()`, `patsplit()`, `split()`, and `sub()` functions, record termination with `RS`, and field splitting with `FS` and `FPAT`. However, the value of `IGNORECASE` does *not* affect array subscripting and it does not affect field splitting when using a single-character field separator. See Section 3.8 [Case Sensitivity in Matching], page 66.

`LINT` #
: When this variable is true (nonzero or non-null), `gawk` behaves as if the `--lint` command-line option is in effect (see Section 2.2 [Command-Line Options], page 33). With a value of `"fatal"`, lint warnings become fatal errors. With a value of `"invalid"`, only warnings about things that are actually invalid are issued. (This is not fully implemented yet.) Any other true value prints nonfatal warnings. Assigning a false value to `LINT` turns off the lint warnings.

  This variable is a `gawk` extension. It is not special in other `awk` implementations. Unlike with the other special variables, changing `LINT` does affect the production of lint warnings, even if `gawk` is in compatibility mode. Much as the `--lint`

and `--traditional` options independently control different aspects of `gawk`'s behavior, the control of lint warnings during program execution is independent of the flavor of `awk` being executed.

`OFMT` A string that controls conversion of numbers to strings (see Section 6.1.4 [Conversion of Strings and Numbers], page 130) for printing with the `print` statement. It works by being passed as the first argument to the `sprintf()` function (see Section 9.1.4 [String-Manipulation Functions], page 200). Its default value is `"%.6g"`. Earlier versions of `awk` used `OFMT` to specify the format for converting numbers to strings in general expressions; this is now done by `CONVFMT`.

`OFS` The output field separator (see Section 5.3 [Output Separators], page 105). It is output between the fields printed by a `print` statement. Its default value is `" "`, a string consisting of a single space.

`ORS` The output record separator. It is output at the end of every `print` statement. Its default value is `"\n"`, the newline character. (See Section 5.3 [Output Separators], page 105.)

`PREC` # The working precision of arbitrary-precision floating-point numbers, 53 bits by default (see Section 16.4.4 [Setting the Precision], page 407).

`ROUNDMODE` #
The rounding mode to use for arbitrary-precision arithmetic on numbers, by default `"N"` (`roundTiesToEven` in the IEEE 754 standard; see Section 16.4.5 [Setting the Rounding Mode], page 408).

`RS` The input record separator. Its default value is a string containing a single newline character, which means that an input record consists of a single line of text. It can also be the null string, in which case records are separated by runs of blank lines. If it is a regexp, records are separated by matches of the regexp in the input text. (See Section 4.1 [How Input Is Split into Records], page 69.)

The ability for `RS` to be a regular expression is a `gawk` extension. In most other `awk` implementations, or if `gawk` is in compatibility mode (see Section 2.2 [Command-Line Options], page 33), just the first character of `RS`'s value is used.

`SUBSEP` The subscript separator. It has the default value of `"\034"` and is used to separate the parts of the indices of a multidimensional array. Thus, the expression '`foo["A", "B"]`' really accesses `foo["A\034B"]` (see Section 8.5 [Multidimensional Arrays], page 192).

`TEXTDOMAIN` #
Used for internationalization of programs at the `awk` level. It sets the default text domain for specially marked string constants in the source text, as well as for the `dcgettext()`, `dcngettext()`, and `bindtextdomain()` functions (see Chapter 13 [Internationalization with gawk], page 365). The default value of `TEXTDOMAIN` is `"messages"`.

7.5.2 Built-in Variables That Convey Information

The following is an alphabetical list of variables that `awk` sets automatically on certain occasions in order to provide information to your program.

The variables that are specific to `gawk` are marked with a pound sign (‘`#`’). These variables are `gawk` extensions. In other `awk` implementations or if `gawk` is in compatibility mode (see Section 2.2 [Command-Line Options], page 33), they are not special:

`ARGC`, `ARGV`
: The command-line arguments available to `awk` programs are stored in an array called `ARGV`. `ARGC` is the number of command-line arguments present. See Section 2.3 [Other Command-Line Arguments], page 40. Unlike most `awk` arrays, `ARGV` is indexed from 0 to `ARGC` − 1. In the following example:

```
$ awk 'BEGIN {
>         for (i = 0; i < ARGC; i++)
>             print ARGV[i]
>      }' inventory-shipped mail-list
⊣ awk
⊣ inventory-shipped
⊣ mail-list
```

  `ARGV[0]` contains ‘`awk`’, `ARGV[1]` contains ‘`inventory-shipped`’, and `ARGV[2]` contains ‘`mail-list`’. The value of `ARGC` is three, one more than the index of the last element in `ARGV`, because the elements are numbered from zero.

  The names `ARGC` and `ARGV`, as well as the convention of indexing the array from 0 to `ARGC` − 1, are derived from the C language’s method of accessing command-line arguments.

  The value of `ARGV[0]` can vary from system to system. Also, you should note that the program text is *not* included in `ARGV`, nor are any of `awk`’s command-line options. See Section 7.5.3 [Using `ARGC` and `ARGV`], page 177, for information about how `awk` uses these variables.

`ARGIND` `#`
: The index in `ARGV` of the current file being processed. Every time `gawk` opens a new data file for processing, it sets `ARGIND` to the index in `ARGV` of the file name. When `gawk` is processing the input files, ‘`FILENAME == ARGV[ARGIND]`’ is always true.

  This variable is useful in file processing; it allows you to tell how far along you are in the list of data files as well as to distinguish between successive instances of the same file name on the command line.

  While you can change the value of `ARGIND` within your `awk` program, `gawk` automatically sets it to a new value when it opens the next file.

`ENVIRON`
: An associative array containing the values of the environment. The array indices are the environment variable names; the elements are the values of the particular environment variables. For example, `ENVIRON["HOME"]` might be `/home/arnold`.

  For POSIX `awk`, changing this array does not affect the environment passed on to any programs that `awk` may spawn via redirection or the `system()` function.

  However, beginning with version 4.2, if not in POSIX compatibility mode, `gawk` does update its own environment when `ENVIRON` is changed, thus changing the environment seen by programs that it creates. You should therefore be

especially careful if you modify `ENVIRON["PATH"]`, which is the search path for finding executable programs.

This can also affect the running `gawk` program, since some of the built-in functions may pay attention to certain environment variables. The most notable instance of this is `mktime()` (see Section 9.1.6 [Time Functions], page 215), which pays attention the value of the `TZ` environment variable on many systems.

Some operating systems may not have environment variables. On such systems, the `ENVIRON` array is empty (except for `ENVIRON["AWKPATH"]` and `ENVIRON["AWKLIBPATH"]`; see Section 2.5.1 [The `AWKPATH` Environment Variable], page 42, and see Section 2.5.2 [The `AWKLIBPATH` Environment Variable], page 43).

`ERRNO` # If a system error occurs during a redirection for `getline`, during a read for `getline`, or during a `close()` operation, then `ERRNO` contains a string describing the error.

In addition, `gawk` clears `ERRNO` before opening each command-line input file. This enables checking if the file is readable inside a `BEGINFILE` pattern (see Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155).

Otherwise, `ERRNO` works similarly to the C variable `errno`. Except for the case just mentioned, `gawk` *never* clears it (sets it to zero or `""`). Thus, you should only expect its value to be meaningful when an I/O operation returns a failure value, such as `getline` returning −1. You are, of course, free to clear it yourself before doing an I/O operation.

If the value of `ERRNO` corresponds to a system error in the C `errno` variable, then `PROCINFO["errno"]` will be set to the value of `errno`. For non-system errors, `PROCINFO["errno"]` will be zero.

`FILENAME` The name of the current input file. When no data files are listed on the command line, `awk` reads from the standard input and `FILENAME` is set to `"-"`. `FILENAME` changes each time a new file is read (see Chapter 4 [Reading Input Files], page 69). Inside a `BEGIN` rule, the value of `FILENAME` is `""`, because there are no input files being processed yet.[2] Note, though, that using `getline` (see Section 4.10 [Explicit Input with `getline`], page 92) inside a `BEGIN` rule can give `FILENAME` a value.

`FNR` The current record number in the current file. `awk` increments `FNR` each time it reads a new record (see Section 4.1 [How Input Is Split into Records], page 69). `awk` resets `FNR` to zero each time it starts a new input file.

`NF` The number of fields in the current input record. `NF` is set each time a new record is read, when a new field is created, or when `$0` changes (see Section 4.2 [Examining Fields], page 73).

Unlike most of the variables described in this subsection, assigning a value to `NF` has the potential to affect `awk`'s internal workings. In particular, assignments

[2] Some early implementations of Unix `awk` initialized `FILENAME` to `"-"`, even if there were data files to be processed. This behavior was incorrect and should not be relied upon in your programs.

to NF can be used to create fields in or remove fields from the current record. See Section 4.4 [Changing the Contents of a Field], page 75.

FUNCTAB # An array whose indices and corresponding values are the names of all the built-in, user-defined, and extension functions in the program.

> **NOTE:** Attempting to use the `delete` statement with the FUNCTAB array causes a fatal error. Any attempt to assign to an element of FUNCTAB also causes a fatal error.

NR The number of input records `awk` has processed since the beginning of the program's execution (see Section 4.1 [How Input Is Split into Records], page 69). `awk` increments NR each time it reads a new record.

PROCINFO #

The elements of this array provide access to information about the running `awk` program. The following elements (listed alphabetically) are guaranteed to be available:

PROCINFO["argv"]

The PROCINFO["argv"] array contains all of the command-line arguments (after glob expansion and redirection processing on platforms where that must be done manually by the program) with subscripts ranging from 0 through `argc` − 1. For example, PROCINFO["argv"][0] will contain the name by which `gawk` was invoked. Here is an example of how this feature may be used:

```
gawk '
BEGIN {
        for (i = 0; i < length(PROCINFO["argv"]); i++)
                print i, PROCINFO["argv"][i]
}'
```

Please note that this differs from the standard ARGV array which does not include command-line arguments that have already been processed by `gawk` (see Section 7.5.3 [Using ARGC and ARGV], page 177).

PROCINFO["egid"]

The value of the `getegid()` system call.

PROCINFO["errno"]

The value of the C `errno` variable when ERRNO is set to the associated error message.

PROCINFO["euid"]

The value of the `geteuid()` system call.

PROCINFO["FS"]

This is "FS" if field splitting with FS is in effect, "FIELDWIDTHS" if field splitting with FIELDWIDTHS is in effect, "FPAT" if field matching with FPAT is in effect, or "API" if field splitting is controlled by an API input parser.

`PROCINFO["gid"]`
: The value of the `getgid()` system call.

`PROCINFO["identifiers"]`
: A subarray, indexed by the names of all identifiers used in the text of the `awk` program. An *identifier* is simply the name of a variable (be it scalar or array), built-in function, user-defined function, or extension function. For each identifier, the value of the element is one of the following:

  `"array"` The identifier is an array.

  `"builtin"`
  : The identifier is a built-in function.

  `"extension"`
  : The identifier is an extension function loaded via `@load` or `-l`.

  `"scalar"` The identifier is a scalar.

  `"untyped"`
  : The identifier is untyped (could be used as a scalar or an array; `gawk` doesn't know yet).

  `"user"` The identifier is a user-defined function.

  The values indicate what `gawk` knows about the identifiers after it has finished parsing the program; they are *not* updated while the program runs.

`PROCINFO["platform"]`
: This element gives a string indicating the platform for which `gawk` was compiled. The value will be one of the following:

  `"mingw"` Microsoft Windows, using MinGW.

  `"os390"` OS/390 (also known as z/OS).

  `"posix"` GNU/Linux, Cygwin, macOS, and legacy Unix systems.

  `"vms"` OpenVMS.

`PROCINFO["pgrpid"]`
: The process group ID of the current process.

`PROCINFO["pid"]`
: The process ID of the current process.

`PROCINFO["pma"]`
: The version of the PMA memory allocator compiled into `gawk`. This element will not be present if the PMA allocator is not available for use. See Section 12.7 [Preserving Data Between Runs], page 360.

`PROCINFO["ppid"]`
: The parent process ID of the current process.

`PROCINFO["strftime"]`
: The default time format string for `strftime()`. Assigning a new value to this element changes the default. See Section 9.1.6 [Time Functions], page 215.

`PROCINFO["uid"]`
: The value of the `getuid()` system call.

`PROCINFO["version"]`
: The version of `gawk`.

The following additional elements in the array are available to provide information about the MPFR and GMP libraries if your version of `gawk` supports arbitrary-precision arithmetic (see Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with `gawk`], page 399):

`PROCINFO["gmp_version"]`
: The version of the GNU MP library.

`PROCINFO["mpfr_version"]`
: The version of the GNU MPFR library.

`PROCINFO["prec_max"]`
: The maximum precision supported by MPFR.

`PROCINFO["prec_min"]`
: The minimum precision required by MPFR.

The following additional elements in the array are available to provide information about the version of the extension API, if your version of `gawk` supports dynamic loading of extension functions (see Chapter 17 [Writing Extensions for `gawk`], page 415):

`PROCINFO["api_major"]`
: The major version of the extension API.

`PROCINFO["api_minor"]`
: The minor version of the extension API.

On some systems, there may be elements in the array, `"group1"` through `"group`*N*`"` for some *N*. *N* is the number of supplementary groups that the process has. Use the `in` operator to test for these elements (see Section 8.1.2 [Referring to an Array Element], page 183).

The following elements allow you to change `gawk`'s behavior:

`PROCINFO["BUFFERPIPE"]`
: If this element exists, all output to pipelines becomes buffered. See Section 5.10 [Speeding Up Pipe Output], page 120.

`PROCINFO["`*command*`", "BUFFERPIPE"]`
: Make output to *command* buffered. See Section 5.10 [Speeding Up Pipe Output], page 120.

`PROCINFO["NONFATAL"]`
: If this element exists, then I/O errors for all redirections become nonfatal. See Section 5.11 [Enabling Nonfatal Output], page 120.

`PROCINFO["name", "NONFATAL"]`
: Make I/O errors for *name* be nonfatal. See Section 5.11 [Enabling Nonfatal Output], page 120.

`PROCINFO["command", "pty"]`
: For two-way communication to *command*, use a pseudo-tty instead of setting up a two-way pipe. See Section 12.4 [Two-Way Communications with Another Process], page 351, for more information.

`PROCINFO["input_name", "READ_TIMEOUT"]`
: Set a timeout for reading from input redirection *input_name*. See Section 4.11 [Reading Input with a Timeout], page 99, for more information.

`PROCINFO["input_name", "RETRY"]`
: If an I/O error that may be retried occurs when reading data from *input_name*, and this array entry exists, then `getline` returns −2 instead of following the default behavior of returning −1 and configuring *input_name* to return no further data. An I/O error that may be retried is one where `errno` has the value `EAGAIN`, `EWOULDBLOCK`, `EINTR`, or `ETIMEDOUT`. This may be useful in conjunction with `PROCINFO["input_name", "READ_TIMEOUT"]` or situations where a file descriptor has been configured to behave in a non-blocking fashion. See Section 4.12 [Retrying Reads After Certain Input Errors], page 101, for more information.

`PROCINFO["sorted_in"]`
: If this element exists in `PROCINFO`, its value controls the order in which array indices will be processed by '`for (indx in array)`' loops. This is an advanced feature, so we defer the full description until later; see Section 8.1.6 [Using Predefined Array Scanning Orders with gawk], page 186.

`RLENGTH`
: The length of the substring matched by the `match()` function (see Section 9.1.4 [String-Manipulation Functions], page 200). `RLENGTH` is set by invoking the `match()` function. Its value is the length of the matched string, or −1 if no match is found.

`RSTART`
: The start index in characters of the substring that is matched by the `match()` function (see Section 9.1.4 [String-Manipulation Functions], page 200). `RSTART` is set by invoking the `match()` function. Its value is the position of the string where the matched substring starts, or zero if no match was found.

`RT` #
: The input text that matched the text denoted by `RS`, the record separator. It is set every time a record is read.

`SYMTAB` #
: An array whose indices are the names of all defined global variables and arrays in the program. `SYMTAB` makes `gawk`'s symbol table visible to the `awk` programmer. It is built as `gawk` parses the program and is complete before the program starts to run.

  The array may be used for indirect access to read or write the value of a variable:

```
foo = 5
```

```
SYMTAB["foo"] = 4
print foo    # prints 4
```

The `isarray()` function (see Section 9.1.8 [Getting Type Information], page 223) may be used to test if an element in `SYMTAB` is an array. Also, you may not use the `delete` statement with the `SYMTAB` array.

Prior to version 5.0 of `gawk`, you could use an index for `SYMTAB` that was not a predefined identifier:

```
SYMTAB["xxx"] = 5
print SYMTAB["xxx"]
```

This no longer works, instead producing a fatal error, as it led to rampant confusion.

The `SYMTAB` array is more interesting than it looks. Andrew Schorr points out that it effectively gives `awk` data pointers. Consider his example:

```
# Indirect multiply of any variable by amount, return result

function multiply(variable, amount)
{
    return SYMTAB[variable] *= amount
}
```

You would use it like this:

```
BEGIN {
    answer = 10.5
    multiply("answer", 4)
    print "The answer is", answer
}
```

When run, this produces:

```
$ gawk -f answer.awk
⊣ The answer is 42
```

NOTE: In order to avoid severe time-travel paradoxes,[3] neither `FUNCTAB` nor `SYMTAB` is available as an element within the `SYMTAB` array.

[3] Not to mention difficult implementation issues.

Changing NR and FNR

awk increments NR and FNR each time it reads a record, instead of setting them to the absolute value of the number of records read. This means that a program can change these variables and their new values are incremented for each record. The following example shows this:

```
$ echo '1
> 2
> 3
> 4' | awk 'NR == 2 { NR = 17 }
> { print NR }'
 ⊣ 1
 ⊣ 17
 ⊣ 18
 ⊣ 19
```

Before FNR was added to the awk language (see Section A.1 [Major Changes Between V7 and SVR3.1], page 483), many awk programs used this feature to track the number of records in a file by resetting NR to zero when FILENAME changed.

7.5.3 Using ARGC and ARGV

Section 7.5.2 [Built-in Variables That Convey Information], page 169, presented the following program describing the information contained in ARGC and ARGV:

```
$ awk 'BEGIN {
>         for (i = 0; i < ARGC; i++)
>             print ARGV[i]
>       }' inventory-shipped mail-list
 ⊣ awk
 ⊣ inventory-shipped
 ⊣ mail-list
```

In this example, ARGV[0] contains 'awk', ARGV[1] contains 'inventory-shipped', and ARGV[2] contains 'mail-list'. Notice that the awk program is not entered in ARGV. The other command-line options, with their arguments, are also not entered. This includes variable assignments done with the -v option (see Section 2.2 [Command-Line Options], page 33). Normal variable assignments on the command line *are* treated as arguments and do show up in the ARGV array. Given the following program in a file named showargs.awk:

```
BEGIN {
    printf "A=%d, B=%d\n", A, B
    for (i = 0; i < ARGC; i++)
        printf "\tARGV[%d] = %s\n", i, ARGV[i]
}
END   { printf "A=%d, B=%d\n", A, B }
```

Running it produces the following:

```
$ awk -v A=1 -f showargs.awk B=2 /dev/null
 ⊣ A=1, B=0
```

```
⊣         ARGV[0] = awk
⊣         ARGV[1] = B=2
⊣         ARGV[2] = /dev/null
⊣ A=1, B=2
```

A program can alter `ARGC` and the elements of `ARGV`. Each time `awk` reaches the end of an input file, it uses the next element of `ARGV` as the name of the next input file. By storing a different string there, a program can change which files are read. Use `"-"` to represent the standard input. Storing additional elements and incrementing `ARGC` causes additional files to be read.

If the value of `ARGC` is decreased, that eliminates input files from the end of the list. By recording the old value of `ARGC` elsewhere, a program can treat the eliminated arguments as something other than file names.

To eliminate a file from the middle of the list, store the null string (`""`) into `ARGV` in place of the file's name. As a special feature, `awk` ignores file names that have been replaced with the null string. Another option is to use the `delete` statement to remove elements from `ARGV` (see Section 8.4 [The `delete` Statement], page 190).

All of these actions are typically done in the `BEGIN` rule, before actual processing of the input begins. See Section 11.2.4 [Splitting a Large File into Pieces], page 300, and see Section 11.2.5 [Duplicating Output into Multiple Files], page 304, for examples of each way of removing elements from `ARGV`.

To actually get options into an `awk` program, end the `awk` options with `--` and then supply the `awk` program's options, in the following manner:

```
awk -f myprog.awk -- -v -q file1 file2 ...
```

The following fragment processes `ARGV` in order to examine, and then remove, the previously mentioned command-line options:

```
BEGIN {
    for (i = 1; i < ARGC; i++) {
        if (ARGV[i] == "-v")
            verbose = 1
        else if (ARGV[i] == "-q")
            debug = 1
        else if (ARGV[i] ~ /^-./) {
            e = sprintf("%s: unrecognized option -- %c",
                    ARGV[0], substr(ARGV[i], 2, 1))
            print e > "/dev/stderr"
        } else
            break
        delete ARGV[i]
    }
}
```

Ending the `awk` options with `--` isn't necessary in `gawk`. Unless `--posix` has been specified, `gawk` silently puts any unrecognized options into `ARGV` for the `awk` program to deal with. As soon as it sees an unknown option, `gawk` stops looking for other options that it might otherwise recognize. The previous command line with `gawk` would be:

```
gawk -f myprog.awk -q -v file1 file2 ...
```

Because `-q` is not a valid `gawk` option, it and the following `-v` are passed on to the `awk` program. (See Section 10.4 [Processing Command-Line Options], page 266, for an `awk` library function that parses command-line options.)

When designing your program, you should choose options that don't conflict with `gawk`'s, because it will process any options that it accepts before passing the rest of the command line on to your program. Using '`#!`' with the `-E` option may help (see Section 1.1.4 [Executable `awk` Programs], page 19, and see Section 2.2 [Command-Line Options], page 33).

7.6 Summary

- Pattern–action pairs make up the basic elements of an `awk` program. Patterns are either normal expressions, range expressions, or regexp constants; one of the special keywords `BEGIN`, `END`, `BEGINFILE`, or `ENDFILE`; or empty. The action executes if the current record matches the pattern. Empty (missing) patterns match all records.
- I/O from `BEGIN` and `END` rules has certain constraints. This is also true, only more so, for `BEGINFILE` and `ENDFILE` rules. The latter two give you "hooks" into `gawk`'s file processing, allowing you to recover from a file that otherwise would cause a fatal error (such as a file that cannot be opened).
- Shell variables can be used in `awk` programs by careful use of shell quoting. It is easier to pass a shell variable into `awk` by using the `-v` option and an `awk` variable.
- Actions consist of statements enclosed in curly braces. Statements are built up from expressions, control statements, compound statements, input and output statements, and deletion statements.
- The control statements in `awk` are `if-else`, `while`, `for`, and `do-while`. `gawk` adds the `switch` statement. There are two flavors of `for` statement: one for performing general looping, and the other for iterating through an array.
- `break` and `continue` let you exit early or start the next iteration of a loop (or get out of a `switch`).
- `next` and `nextfile` let you read the next record and start over at the top of your program or skip to the next input file and start over, respectively.
- The `exit` statement terminates your program. When executed from an action (or function body), it transfers control to the `END` statements. From an `END` statement body, it exits immediately. You may pass an optional numeric value to be used as `awk`'s exit status.
- Some predefined variables provide control over `awk`, mainly for I/O. Other variables convey information from `awk` to your program.
- `ARGC` and `ARGV` make the command-line arguments available to your program. Manipulating them from a `BEGIN` rule lets you control how `awk` will process the provided data files.

8 Arrays in awk

An *array* is a table of values called *elements*. The elements of an array are distinguished by their *indices*. Indices may be either numbers or strings.

This chapter describes how arrays work in `awk`, how to use array elements, how to scan through every element in an array, and how to remove array elements. It also describes how `awk` simulates multidimensional arrays, as well as some of the less obvious points about array usage. The chapter moves on to discuss `gawk`'s facility for sorting arrays, and ends with a brief description of `gawk`'s ability to support true arrays of arrays.

8.1 The Basics of Arrays

This section presents the basics: working with elements in arrays one at a time, and traversing all of the elements in an array.

8.1.1 Introduction to Arrays

> *Doing linear scans over an associative array is like trying to club someone to death with a loaded Uzi.*
>
> —*Larry Wall*

The `awk` language provides one-dimensional arrays for storing groups of related strings or numbers. Every `awk` array must have a name. Array names have the same syntax as variable names; any valid variable name would also be a valid array name. But one name cannot be used in both ways (as an array and as a variable) in the same `awk` program.

Arrays in `awk` superficially resemble arrays in other programming languages, but there are fundamental differences. In `awk`, it isn't necessary to specify the size of an array before starting to use it. Additionally, any number or string, not just consecutive integers, may be used as an array index.

In most other languages, arrays must be *declared* before use, including a specification of how many elements or components they contain. In such languages, the declaration causes a contiguous block of memory to be allocated for that many elements. Usually, an index in the array must be a nonnegative integer. For example, the index zero specifies the first element in the array, which is actually stored at the beginning of the block of memory. Index one specifies the second element, which is stored in memory right after the first element, and so on. It is impossible to add more elements to the array, because it has room only for as many elements as given in the declaration. (Some languages allow arbitrary starting and ending indices—e.g., '`15 .. 27`'—but the size of the array is still fixed when the array is declared.)

A contiguous array of four elements might look like Figure 8.1, conceptually, if the element values are eight, `"foo"`, `""`, and 30.

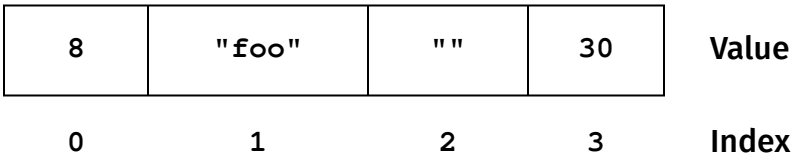

Figure 8.1: A contiguous array

Only the values are stored; the indices are implicit from the order of the values. Here, eight is the value at index zero, because eight appears in the position with zero elements before it.

Arrays in `awk` are different—they are *associative*. This means that each array is a collection of pairs—an index and its corresponding array element value:

Index	Value
3	30
1	"foo"
0	8
2	""

The pairs are shown in jumbled order because their order is irrelevant.[1]

One advantage of associative arrays is that new pairs can be added at any time. For example, suppose a tenth element is added to the array whose value is `"number ten"`. The result is:

Index	Value
10	"number ten"
3	30
1	"foo"
0	8
2	""

Now the array is *sparse*, which just means some indices are missing. It has elements 0–3 and 10, but doesn't have elements 4, 5, 6, 7, 8, or 9.

Another consequence of associative arrays is that the indices don't have to be nonnegative integers. Any number, or even a string, can be an index. For example, the following is an array that translates words from English to French:

Index	Value
"dog"	"chien"
"cat"	"chat"
"one"	"un"
1	"un"

Here we decided to translate the number one in both spelled-out and numeric form—thus illustrating that a single array can have both numbers and strings as indices. (In fact, array subscripts are always strings. There are some subtleties to how numbers work when used as

[1] The ordering will vary among `awk` implementations, which typically use hash tables to store array elements and values.

array subscripts; this is discussed in more detail in Section 8.2 [Using Numbers to Subscript Arrays], page 189.) Here, the number `1` isn't double-quoted, because `awk` automatically converts it to a string.

The value of `IGNORECASE` has no effect upon array subscripting. The identical string value used to store an array element must be used to retrieve it. When `awk` creates an array (e.g., with the `split()` built-in function), that array's indices are consecutive integers starting at one. (See Section 9.1.4 [String-Manipulation Functions], page 200.)

`awk`'s arrays are efficient—the time to access an element is independent of the number of elements in the array.

8.1.2 Referring to an Array Element

The principal way to use an array is to refer to one of its elements. An *array reference* is an expression as follows:

```
array[index-expression]
```

Here, *array* is the name of an array. The expression *index-expression* is the index of the desired element of the array.

The value of the array reference is the current value of that array element. For example, `foo[4.3]` is an expression referencing the element of array `foo` at index '`4.3`'.

A reference to an array element that has no recorded value yields a value of `""`, the null string. This includes elements that have not been assigned any value as well as elements that have been deleted (see Section 8.4 [The `delete` Statement], page 190).

> **NOTE:** A reference to an element that does not exist *automatically* creates that array element, with the null string as its value. (In some cases, this is unfortunate, because it might waste memory inside `awk`.)
>
> Novice `awk` programmers often make the mistake of checking if an element exists by checking if the value is empty:
>
> ```
> # Check if "foo" exists in a:          Incorrect!
> if (a["foo"] != "") ...
> ```
>
> This is incorrect for two reasons. First, it *creates* `a["foo"]` if it didn't exist before! Second, it is valid (if a bit unusual) to set an array element equal to the empty string.

To determine whether an element exists in an array at a certain index, use the following expression:

```
indx in array
```

This expression tests whether the particular index *indx* exists, without the side effect of creating that element if it is not present. The expression has the value one (true) if `array[indx]` exists and zero (false) if it does not exist. (We use *indx* here, because '`index`' is the name of a built-in function.) For example, this statement tests whether the array `frequencies` contains the index '`2`':

```
if (2 in frequencies)
    print "Subscript 2 is present."
```

Note that this is *not* a test of whether the array `frequencies` contains an element whose *value* is two. There is no way to do that except to scan all the elements. Also, this *does not* create `frequencies[2]`, while the following (incorrect) alternative does:

```
if (frequencies[2] != "")
    print "Subscript 2 is present."
```

8.1.3 Assigning Array Elements

Array elements can be assigned values just like `awk` variables:

array`[`*index-expression*`] = `*value*

array is the name of an array. The expression *index-expression* is the index of the element of the array that is assigned a value. The expression *value* is the value to assign to that element of the array.

8.1.4 Basic Array Example

The following program takes a list of lines, each beginning with a line number, and prints them out in order of line number. The line numbers are not in order when they are first read—instead, they are scrambled. This program sorts the lines by making an array using the line numbers as subscripts. The program then prints out the lines in sorted order of their numbers. It is a very simple program and gets confused upon encountering repeated numbers, gaps, or lines that don't begin with a number:

```
{
    if ($1 > max)
        max = $1
    arr[$1] = $0
}

END {
    for (x = 1; x <= max; x++)
        print arr[x]
}
```

The first rule keeps track of the largest line number seen so far; it also stores each line into the array `arr`, at an index that is the line's number. The second rule runs after all the input has been read, to print out all the lines. When this program is run with the following input:

```
5  I am the Five man
2  Who are you?  The new number two!
4  . . . And four on the floor
1  Who is number one?
3  I three you.
```

Its output is:

```
1  Who is number one?
2  Who are you?  The new number two!
3  I three you.
4  . . . And four on the floor
5  I am the Five man
```

If a line number is repeated, the last line with a given number overrides the others. Gaps in the line numbers can be handled with an easy improvement to the program's `END` rule, as follows:

```
END {
    for (x = 1; x <= max; x++)
        if (x in arr)
            print arr[x]
}
```

As mentioned, the program is simplistic. It can be easily confused; for example, by using negative or nonalphabetic line numbers. The point here is merely to demonstrate basic array usage.

8.1.5 Scanning All Elements of an Array

In programs that use arrays, it is often necessary to use a loop that executes once for each element of an array. In other languages, where arrays are contiguous and indices are limited to nonnegative integers, this is easy: all the valid indices can be found by counting from the lowest index up to the highest. This technique won't do the job in `awk`, because any number or string can be an array index. So `awk` has a special kind of `for` statement for scanning an array:

```
for (var in array)
    body
```

This loop executes *body* once for each index in *array* that the program has previously used, with the variable *var* set to that index.

The following program uses this form of the `for` statement. The first rule scans the input records and notes which words appear (at least once) in the input, by storing a one into the array `used` with the word as the index. The second rule scans the elements of `used` to find all the distinct words that appear in the input. It prints each word that is more than 10 characters long and also prints the number of such words. See Section 9.1.4 [String-Manipulation Functions], page 200, for more information on the built-in function `length()`.

```
# Record a 1 for each word that is used at least once
{
    for (i = 1; i <= NF; i++)
        used[$i] = 1
}

# Find number of distinct words more than 10 characters long
END {
    for (x in used) {
        if (length(x) > 10) {
            ++num_long_words
            print x
        }
    }
    print num_long_words, "words longer than 10 characters"
}
```

See Section 11.3.5 [Generating Word-Usage Counts], page 321, for a more detailed example of this type.

The order in which elements of the array are accessed by this statement is determined by the internal arrangement of the array elements within `awk` and in standard `awk` cannot be controlled or changed. This can lead to problems if new elements are added to *array* by statements in the loop body; it is not predictable whether the `for` loop will reach them. Similarly, changing *var* inside the loop may produce strange results. It is best to avoid such things.

As a point of information, `gawk` sets up the list of elements to be iterated over before the loop starts, and does not change it. But not all `awk` versions do so. Consider this program, named `loopcheck.awk`:

```
BEGIN {
    a["here"] = "here"
    a["is"] = "is"
    a["a"] = "a"
    a["loop"] = "loop"
    for (i in a) {
        j++
        a[j] = j
        print i
    }
}
```

Here is what happens when run with `gawk` (and `mawk`):

```
$ gawk -f loopcheck.awk
⊣ here
⊣ loop
⊣ a
⊣ is
```

Contrast this to BWK `awk`:

```
$ nawk -f loopcheck.awk
⊣ loop
⊣ here
⊣ is
⊣ a
⊣ 1
```

8.1.6 Using Predefined Array Scanning Orders with `gawk`

This subsection describes a feature that is specific to `gawk`.

By default, when a `for` loop traverses an array, the order is undefined, meaning that the `awk` implementation determines the order in which the array is traversed. This order is usually based on the internal implementation of arrays and will vary from one version of `awk` to the next.

Often, though, you may wish to do something simple, such as "traverse the array by comparing the indices in ascending order," or "traverse the array by comparing the values in descending order." `gawk` provides two mechanisms that give you this control:

- Set `PROCINFO["sorted_in"]` to one of a set of predefined values. We describe this now.

- Set PROCINFO["sorted_in"] to the name of a user-defined function to use for comparison of array elements. This advanced feature is described later in Section 12.3 [Controlling Array Traversal and Array Sorting], page 344.

The following special values for PROCINFO["sorted_in"] are available:

"@unsorted"
: Array elements are processed in arbitrary order, which is the default awk behavior.

"@ind_str_asc"
: Order by indices in ascending order compared as strings; this is the most basic sort. (Internally, array indices are always strings, so with 'a[2*5] = 1' the index is "10" rather than numeric 10.)

"@ind_num_asc"
: Order by indices in ascending order but force them to be treated as numbers in the process. Any index with a non-numeric value will end up positioned as if it were zero.

"@val_type_asc"
: Order by element values in ascending order (rather than by indices). Ordering is by the type assigned to the element (see Section 6.3.2 [Variable Typing and Comparison Expressions], page 139). All numeric values come before all string values, which in turn come before all subarrays. (Subarrays have not been described yet; see Section 8.6 [Arrays of Arrays], page 193.)

  If you choose to use this feature in traversing FUNCTAB (see Section 7.5.2 [Built-in Variables That Convey Information], page 169), then the order is built-in functions first (see Section 9.1 [Built-in Functions], page 197), then user-defined functions (see Section 9.2 [User-Defined Functions], page 225) next, and finally functions loaded from an extension (see Chapter 17 [Writing Extensions for gawk], page 415).

"@val_str_asc"
: Order by element values in ascending order (rather than by indices). Scalar values are compared as strings. If the string values are identical, the index string values are compared instead. When comparing non-scalar values, "@val_type_asc" sort ordering is used, so subarrays, if present, come out last.

"@val_num_asc"
: Order by element values in ascending order (rather than by indices). Scalar values are compared as numbers. Non-scalar values are compared using "@val_type_asc" sort ordering, so subarrays, if present, come out last. When numeric values are equal, the string values are used to provide an ordering: this guarantees consistent results across different versions of the C qsort() function,[2] which gawk uses internally to perform the sorting. If the string values are also identical, the index string values are compared instead.

[2] When two elements compare as equal, the C qsort() function does not guarantee that they will maintain their original relative order after sorting. Using the string value to provide a unique ordering when the numeric values are equal ensures that gawk behaves consistently across different environments.

`"@ind_str_desc"`
: Like `"@ind_str_asc"`, but the string indices are ordered from high to low.

`"@ind_num_desc"`
: Like `"@ind_num_asc"`, but the numeric indices are ordered from high to low.

`"@val_type_desc"`
: Like `"@val_type_asc"`, but the element values, based on type, are ordered from high to low. Subarrays, if present, come out first.

`"@val_str_desc"`
: Like `"@val_str_asc"`, but the element values, treated as strings, are ordered from high to low. If the string values are identical, the index string values are compared instead. When comparing non-scalar values, `"@val_type_desc"` sort ordering is used, so subarrays, if present, come out first.

`"@val_num_desc"`
: Like `"@val_num_asc"`, but the element values, treated as numbers, are ordered from high to low. If the numeric values are equal, the string values are compared instead. If they are also identical, the index string values are compared instead. Non-scalar values are compared using `"@val_type_desc"` sort ordering, so subarrays, if present, come out first.

The array traversal order is determined before the `for` loop starts to run. Changing `PROCINFO["sorted_in"]` in the loop body does not affect the loop. For example:

```
$ gawk '
> BEGIN {
>    a[4] = 4
>    a[3] = 3
>    for (i in a)
>        print i, a[i]
> }'
 ⊣ 4 4
 ⊣ 3 3
$ gawk '
> BEGIN {
>    PROCINFO["sorted_in"] = "@ind_str_asc"
>    a[4] = 4
>    a[3] = 3
>    for (i in a)
>        print i, a[i]
> }'
 ⊣ 3 3
 ⊣ 4 4
```

When sorting an array by element values, if a value happens to be a subarray then it is considered to be greater than any string or numeric value, regardless of what the subarray itself contains, and all subarrays are treated as being equal to each other. Their order relative to each other is determined by their index strings.

Here are some additional things to bear in mind about sorted array traversal:

- The value of PROCINFO["sorted_in"] is global. That is, it affects all array traversal for loops. If you need to change it within your own code, you should see if it's defined and save and restore the value:

```
...
if ("sorted_in" in PROCINFO)
    save_sorted = PROCINFO["sorted_in"]

PROCINFO["sorted_in"] = "@val_str_desc" # or whatever
...
if (save_sorted)
    PROCINFO["sorted_in"] = save_sorted
```

- As already mentioned, the default array traversal order is represented by "@unsorted". You can also get the default behavior by assigning the null string to PROCINFO["sorted_in"] or by just deleting the "sorted_in" element from the PROCINFO array with the delete statement. (The delete statement hasn't been described yet; see Section 8.4 [The delete Statement], page 190.)

In addition, gawk provides built-in functions for sorting arrays; see Section 12.3.2 [Sorting Array Values and Indices with gawk], page 349.

8.2 Using Numbers to Subscript Arrays

An important aspect to remember about arrays is that *array subscripts are always strings*. When a numeric value is used as a subscript, it is converted to a string value before being used for subscripting (see Section 6.1.4 [Conversion of Strings and Numbers], page 130). This means that the value of the predefined variable CONVFMT can affect how your program accesses elements of an array. For example:

```
xyz = 12.153
data[xyz] = 1
CONVFMT = "%2.2f"
if (xyz in data)
    printf "%s is in data\n", xyz
else
    printf "%s is not in data\n", xyz
```

This prints '12.15 is not in data'. The first statement gives xyz a numeric value. Assigning to data[xyz] subscripts data with the string value "12.153" (using the default conversion value of CONVFMT, "%.6g"). Thus, the array element data["12.153"] is assigned the value one. The program then changes the value of CONVFMT. The test '(xyz in data)' generates a new string value from xyz—this time "12.15"—because the value of CONVFMT only allows two significant digits. This test fails, because "12.15" is different from "12.153".

According to the rules for conversions (see Section 6.1.4 [Conversion of Strings and Numbers], page 130), integer values always convert to strings as integers, no matter what the value of CONVFMT may happen to be. So the usual case of the following works:

```
for (i = 1; i <= maxsub; i++)
    do something with array[i]
```

The "integer values always convert to strings as integers" rule has an additional consequence for array indexing. Octal and hexadecimal constants (see Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124) are converted internally into numbers, and their original form is forgotten. This means, for example, that `array[17]`, `array[021]`, and `array[0x11]` all refer to the same element!

As with many things in `awk`, the majority of the time things work as you would expect them to. But it is useful to have a precise knowledge of the actual rules, as they can sometimes have a subtle effect on your programs.

8.3 Using Uninitialized Variables as Subscripts

Suppose it's necessary to write a program to print the input data in reverse order. A reasonable attempt to do so (with some test data) might look like this:

```
$ echo 'line 1
> line 2
> line 3' | awk '{ l[lines] = $0; ++lines }
> END {
>     for (i = lines - 1; i >= 0; i--)
>        print l[i]
> }'
 ⊣ line 3
 ⊣ line 2
```

Unfortunately, the very first line of input data did not appear in the output!

Upon first glance, we would think that this program should have worked. The variable `lines` is uninitialized, and uninitialized variables have the numeric value zero. So, `awk` should have printed the value of `l[0]`.

The issue here is that subscripts for `awk` arrays are *always* strings. Uninitialized variables, when used as strings, have the value `""`, not zero. Thus, '`line 1`' ends up stored in `l[""]`. The following version of the program works correctly:

```
{ l[lines++] = $0 }
END {
    for (i = lines - 1; i >= 0; i--)
       print l[i]
}
```

Here, the '`++`' forces `lines` to be numeric, thus making the "old value" numeric zero. This is then converted to `"0"` as the array subscript.

Even though it is somewhat unusual, the null string (`""`) is a valid array subscript. `gawk` warns about the use of the null string as a subscript if `--lint` is provided on the command line (see Section 2.2 [Command-Line Options], page 33).

8.4 The `delete` Statement

To remove an individual element of an array, use the `delete` statement:

```
delete array[index-expression]
```

Once an array element has been deleted, any value the element once had is no longer available. It is as if the element had never been referred to or been given a value. The following is an example of deleting elements in an array:

```
for (i in frequencies)
    delete frequencies[i]
```

This example removes all the elements from the array `frequencies`. Once an element is deleted, a subsequent `for` statement to scan the array does not report that element and using the `in` operator to check for the presence of that element returns zero (i.e., false):

```
delete foo[4]
if (4 in foo)
    print "This will never be printed"
```

It is important to note that deleting an element is *not* the same as assigning it a null value (the empty string, `""`). For example:

```
foo[4] = ""
if (4 in foo)
  print "This is printed, even though foo[4] is empty"
```

It is not an error to delete an element that does not exist. However, if `--lint` is provided on the command line (see Section 2.2 [Command-Line Options], page 33), `gawk` issues a warning message when an element that is not in the array is deleted.

All the elements of an array may be deleted with a single statement by leaving off the subscript in the `delete` statement, as follows:

```
delete array
```

Using this version of the `delete` statement is about three times more efficient than the equivalent loop that deletes each element one at a time.

This form of the `delete` statement is also supported by BWK `awk` and `mawk`, as well as by a number of other implementations.

> **NOTE:** For many years, using `delete` without a subscript was a common extension. In September 2012, it was accepted for inclusion into the POSIX standard. See the Austin Group website.

The following statement provides a portable but nonobvious way to clear out an array:[3]

```
split("", array)
```

The `split()` function (see Section 9.1.4 [String-Manipulation Functions], page 200) clears out the target array first. This call asks it to split apart the null string. Because there is no data to split out, the function simply clears the array and then returns.

> **CAUTION:** Deleting all the elements from an array does not change its type; you cannot clear an array and then use the array's name as a scalar (i.e., a regular variable). For example, the following does not work:
>
> ```
> a[1] = 3
> delete a
> a = 3
> ```

[3] Thanks to Michael Brennan for pointing this out.

8.5 Multidimensional Arrays

A *multidimensional array* is an array in which an element is identified by a sequence of indices instead of a single index. For example, a two-dimensional array requires two indices. The usual way (in many languages, including `awk`) to refer to an element of a two-dimensional array named `grid` is with `grid[x,y]`.

Multidimensional arrays are supported in `awk` through concatenation of indices into one string. `awk` converts the indices into strings (see Section 6.1.4 [Conversion of Strings and Numbers], page 130) and concatenates them together, with a separator between them. This creates a single string that describes the values of the separate indices. The combined string is used as a single index into an ordinary, one-dimensional array. The separator used is the value of the built-in variable `SUBSEP`.

For example, suppose we evaluate the expression '`foo[5,12] = "value"`' when the value of `SUBSEP` is `"@"`. The numbers 5 and 12 are converted to strings and concatenated with an '`@`' between them, yielding `"5@12"`; thus, the array element `foo["5@12"]` is set to `"value"`.

Once the element's value is stored, `awk` has no record of whether it was stored with a single index or a sequence of indices. The two expressions '`foo[5,12]`' and '`foo[5 SUBSEP 12]`' are always equivalent.

The default value of `SUBSEP` is the string `"\034"`, which contains a nonprinting character that is unlikely to appear in an `awk` program or in most input data. The usefulness of choosing an unlikely character comes from the fact that index values that contain a string matching `SUBSEP` can lead to combined strings that are ambiguous. Suppose that `SUBSEP` is `"@"`; then '`foo["a@b", "c"]`' and '`foo["a", "b@c"]`' are indistinguishable because both are actually stored as '`foo["a@b@c"]`'.

To test whether a particular index sequence exists in a multidimensional array, use the same operator (`in`) that is used for single-dimensional arrays. Write the whole sequence of indices in parentheses, separated by commas, as the left operand:

```
if ((subscript1, subscript2, ...) in array)
    ...
```

Here is an example that treats its input as a two-dimensional array of fields; it rotates this array 90 degrees clockwise and prints the result. It assumes that all lines have the same number of elements:

```
{
     if (max_nf < NF)
          max_nf = NF
     max_nr = NR
     for (x = 1; x <= NF; x++)
          vector[x, NR] = $x
}

END {
     for (x = 1; x <= max_nf; x++) {
          for (y = max_nr; y >= 1; --y)
               printf("%s ", vector[x, y])
          printf("\n")
     }
```

```
}
```

When given the input:

```
1 2 3 4 5 6
2 3 4 5 6 1
3 4 5 6 1 2
4 5 6 1 2 3
```

the program produces the following output:

```
4 3 2 1
5 4 3 2
6 5 4 3
1 6 5 4
2 1 6 5
3 2 1 6
```

8.5.1 Scanning Multidimensional Arrays

There is no special `for` statement for scanning a "multidimensional" array. There cannot be one, because, in truth, `awk` does not have multidimensional arrays or elements—there is only a multidimensional *way of accessing* an array.

However, if your program has an array that is always accessed as multidimensional, you can get the effect of scanning it by combining the scanning `for` statement (see Section 8.1.5 [Scanning All Elements of an Array], page 185) with the built-in `split()` function (see Section 9.1.4 [String-Manipulation Functions], page 200). It works in the following manner:

```
for (combined in array) {
    split(combined, separate, SUBSEP)
    ...
}
```

This sets the variable `combined` to each concatenated combined index in the array, and splits it into the individual indices by breaking it apart where the value of `SUBSEP` appears. The individual indices then become the elements of the array `separate`.

Thus, if a value is previously stored in `array[1, "foo"]`, then an element with index `"1\034foo"` exists in `array`. (Recall that the default value of `SUBSEP` is the character with code 034.) Sooner or later, the `for` statement finds that index and does an iteration with the variable `combined` set to `"1\034foo"`. Then the `split()` function is called as follows:

```
split("1\034foo", separate, "\034")
```

The result is to set `separate[1]` to `"1"` and `separate[2]` to `"foo"`. Presto! The original sequence of separate indices is recovered.

8.6 Arrays of Arrays

`gawk` goes beyond standard `awk`'s multidimensional array access and provides true arrays of arrays. Elements of a subarray are referred to by their own indices enclosed in square brackets, just like the elements of the main array. For example, the following creates a two-element subarray at index `1` of the main array `a`:

```
a[1][1] = 1
a[1][2] = 2
```

This simulates a true two-dimensional array. Each subarray element can contain another subarray as a value, which in turn can hold other arrays as well. In this way, you can create arrays of three or more dimensions. The indices can be any `awk` expressions, including scalars separated by commas (i.e., a regular `awk` simulated multidimensional subscript). So the following is valid in `gawk`:

```
a[1][3][1, "name"] = "barney"
```

Each subarray and the main array can be of different length. In fact, the elements of an array or its subarray do not all have to have the same type. This means that the main array and any of its subarrays can be nonrectangular, or jagged in structure. You can assign a scalar value to the index `4` of the main array `a`, even though `a[1]` is itself an array and not a scalar:

```
a[4] = "An element in a jagged array"
```

The terms *dimension*, *row*, and *column* are meaningless when applied to such an array, but we will use "dimension" henceforth to imply the maximum number of indices needed to refer to an existing element. The type of any element that has already been assigned cannot be changed by assigning a value of a different type. You have to first delete the current element, which effectively makes `gawk` forget about the element at that index:

```
delete a[4]
a[4][5][6][7] = "An element in a four-dimensional array"
```

This removes the scalar value from index `4` and then inserts a three-level nested subarray containing a scalar. You can also delete an entire subarray or subarray of subarrays:

```
delete a[4][5]
a[4][5] = "An element in subarray a[4]"
```

But recall that you can not delete the main array `a` and then use it as a scalar.

The built-in functions that take array arguments can also be used with subarrays. For example, the following code fragment uses `length()` (see Section 9.1.4 [String-Manipulation Functions], page 200) to determine the number of elements in the main array `a` and its subarrays:

```
print length(a), length(a[1]), length(a[1][3])
```

This results in the following output for our main array `a`:

```
2, 3, 1
```

The '*`subscript` `in` `array`*' expression (see Section 8.1.2 [Referring to an Array Element], page 183) works similarly for both regular `awk`-style arrays and arrays of arrays. For example, the tests '`1 in a`', '`3 in a[1]`', and '`(1, "name") in a[1][3]`' all evaluate to one (true) for our array `a`.

The '`for (item in array)`' statement (see Section 8.1.5 [Scanning All Elements of an Array], page 185) can be nested to scan all the elements of an array of arrays if it is rectangular in structure. In order to print the contents (scalar values) of a two-dimensional array of arrays (i.e., in which each first-level element is itself an array, not necessarily of the same length), you could use the following code:

```
for (i in array)
    for (j in array[i])
        print array[i][j]
```

The `isarray()` function (see Section 9.1.8 [Getting Type Information], page 223) lets you test if an array element is itself an array:

```
for (i in array) {
    if (isarray(array[i])) {
        for (j in array[i]) {
            print array[i][j]
        }
    }
    else
        print array[i]
}
```

If the structure of a jagged array of arrays is known in advance, you can often devise workarounds using control statements. For example, the following code prints the elements of our main array `a`:

```
for (i in a) {
    for (j in a[i]) {
        if (j == 3) {
            for (k in a[i][j])
                print a[i][j][k]
        } else
            print a[i][j]
    }
}
```

See Section 10.7 [Traversing Arrays of Arrays], page 281, for a user-defined function that "walks" an arbitrarily dimensioned array of arrays.

8.7 Summary

- Standard `awk` provides one-dimensional associative arrays (arrays indexed by string values). All arrays are associative; numeric indices are converted automatically to strings.
- Array elements are referenced as *`array[indx]`*. Referencing an element creates it if it did not exist previously.
- The proper way to see if an array has an element with a given index is to use the `in` operator: '*`indx` `in` `array`*'.
- Use '`for (`*`indx`* `in` *`array`*`) ...`' to scan through all the individual elements of an array. In the body of the loop, *indx* takes on the value of each element's index in turn.
- The order in which a '`for (`*`indx`* `in` *`array`*`)`' loop traverses an array is undefined in POSIX `awk` and varies among implementations. `gawk` lets you control the order by assigning special predefined values to `PROCINFO["sorted_in"]`.
- Use '`delete` *`array[indx]`*' to delete an individual element. To delete all of the elements in an array, use '`delete` *`array`*'. This latter feature has been a common extension for many years and is now standard, but may not be supported by all commercial versions of `awk`.

- Standard `awk` simulates multidimensional arrays by separating subscript values with commas. The values are concatenated into a single string, separated by the value of `SUBSEP`. The fact that such a subscript was created in this way is not retained; thus, changing `SUBSEP` may have unexpected consequences. You can use '`(`*`sub1`*`, `*`sub2`*`, ...) in `*`array`*'' to see if such a multidimensional subscript exists in *array*.
- `gawk` provides true arrays of arrays. You use a separate set of square brackets for each dimension in such an array: `data[row][col]`, for example. Array elements may thus be either scalar values (number or string) or other arrays.
- Use the `isarray()` built-in function to determine if an array element is itself a subarray.

9 Functions

This chapter describes awk's built-in functions, which fall into three categories: numeric, string, and I/O. gawk provides additional groups of functions to work with values that represent time, do bit manipulation, sort arrays, provide type information, and internationalize and localize programs.

Besides the built-in functions, awk has provisions for writing new functions that the rest of a program can use. The second half of this chapter describes these *user-defined* functions. Finally, we explore indirect function calls, a gawk-specific extension that lets you determine at runtime what function is to be called.

9.1 Built-in Functions

Built-in functions are always available for your awk program to call. This section defines all the built-in functions in awk; some of these are mentioned in other sections but are summarized here for your convenience.

9.1.1 Calling Built-in Functions

To call one of awk's built-in functions, write the name of the function followed by arguments in parentheses. For example, '`atan2(y + z, 1)`' is a call to the function `atan2()` and has two arguments.

Whitespace is ignored between the built-in function name and the opening parenthesis, but nonetheless it is good practice to avoid using whitespace there. User-defined functions do not permit whitespace in this way, and it is easier to avoid mistakes by following a simple convention that always works—no whitespace after a function name.

Each built-in function accepts a certain number of arguments. In some cases, arguments can be omitted. The defaults for omitted arguments vary from function to function and are described under the individual functions. In some awk implementations, extra arguments given to built-in functions are ignored. However, in gawk, it is a fatal error to give extra arguments to a built-in function.

When a function is called, expressions that create the function's actual parameters are evaluated completely before the call is performed. For example, in the following code fragment:

```
i = 4
j = sqrt(i++)
```

the variable i is incremented to the value five before `sqrt()` is called with a value of four for its actual parameter. The order of evaluation of the expressions used for the function's parameters is undefined. Thus, avoid writing programs that assume that parameters are evaluated from left to right or from right to left. For example:

```
i = 5
j = atan2(++i, i *= 2)
```

If the order of evaluation is left to right, then i first becomes six, and then 12, and `atan2()` is called with the two arguments six and 12. But if the order of evaluation is right to left, i first becomes 10, then 11, and `atan2()` is called with the two arguments 11 and 10.

9.1.2 Generating Boolean Values

This function is specific to `gawk`. It is not available in compatibility mode (see Section 2.2 [Command-Line Options], page 33):

`mkbool(`*expression*`)`
: Return a Boolean-typed value based on the regular Boolean value of *expression*. Boolean "true" values have numeric value one. Boolean "false" values have numeric zero. This is discussed in more detail in Section 12.2 [Boolean Typed Values], page 344.

9.1.3 Numeric Functions

The following list describes all of the built-in functions that work with numbers. Optional parameters are enclosed in square brackets ([ ]):

`atan2(`*y*`, `*x*`)`
: Return the arctangent of *y* `/` *x* in radians. You can use '`pi = atan2(0, -1)`' to retrieve the value of π.

`cos(`*x*`)`
: Return the cosine of *x*, with *x* in radians.

`exp(`*x*`)`
: Return the exponential of *x* (`e ^ `*x*) or report an error if *x* is out of range. The range of values *x* can have depends on your machine's floating-point representation.

`int(`*x*`)`
: Return the nearest integer to *x*, located between *x* and zero and truncated toward zero. For example, `int(3)` is 3, `int(3.9)` is 3, `int(-3.9)` is -3, and `int(-3)` is -3 as well.

`log(`*x*`)`
: Return the natural logarithm of *x*, if *x* is positive; otherwise, return NaN ("not a number") on IEEE 754 systems. Additionally, `gawk` prints a warning message when `x` is negative.

`rand()`
: Return a random number. The values of `rand()` are uniformly distributed between zero and one. The value could be zero but is never one.[1]

  Often random integers are needed instead. Following is a user-defined function that can be used to obtain a random nonnegative integer less than *n*:

```
function randint(n)
{
    return int(n * rand())
}
```

  The multiplication produces a random number greater than or equal to zero and less than `n`. Using `int()`, this result is made into an integer between zero and `n` $-$ 1, inclusive.

[1] The C version of `rand()` on many Unix systems is known to produce fairly poor sequences of random numbers. However, nothing requires that an `awk` implementation use the C `rand()` to implement the `awk` version of `rand()`. In fact, for many years, `gawk` used the BSD `random()` function, which is considerably better than `rand()`, to produce random numbers. From version 4.1.4, courtesy of Nelson H.F. Beebe, `gawk` uses the Bays-Durham shuffle buffer algorithm which considerably extends the period of the random number generator, and eliminates short-range and long-range correlations that might exist in the original generator.

The following example uses a similar function to produce random integers between one and *n*. This program prints a new random number for each input record:

```
# Function to roll a simulated die.
function roll(n) { return 1 + int(rand() * n) }

# Roll 3 six-sided dice and
# print total number of points.
{
    printf("%d points\n", roll(6) + roll(6) + roll(6))
}
```

CAUTION: In most `awk` implementations, including `gawk`, `rand()` starts generating numbers from the same starting number, or *seed*, each time you run `awk`.[2] Thus, a program generates the same results each time you run it. The numbers are random within one `awk` run but predictable from run to run. This is convenient for debugging, but if you want a program to do different things each time it is used, you must change the seed to a value that is different in each run. To do this, use `srand()`.

`sin(`*x*`)` Return the sine of *x*, with *x* in radians.

`sqrt(`*x*`)` Return the positive square root of *x*. `gawk` prints a warning message if *x* is negative. Thus, `sqrt(4)` is 2.

`srand(`[*x*]`)`

Set the starting point, or seed, for generating random numbers to the value *x*.

Each seed value leads to a particular sequence of random numbers.[3] Thus, if the seed is set to the same value a second time, the same sequence of random numbers is produced again.

CAUTION: Different `awk` implementations use different random-number generators internally. Don't expect the same `awk` program to produce the same series of random numbers when executed by different versions of `awk`.

If the argument *x* is omitted, as in '`srand()`', then the current date and time of day are used for a seed. This is the way to get random numbers that are truly unpredictable.

The return value of `srand()` is the previous seed. This makes it easy to keep track of the seeds in case you need to consistently reproduce sequences of random numbers.

POSIX does not specify the initial seed; it differs among `awk` implementations.

---

[2] `mawk` uses a different seed each time.

[3] Computer-generated random numbers really are not truly random. They are technically known as *pseudorandom*. This means that although the numbers in a sequence appear to be random, you can in fact generate the same sequence of random numbers over and over again.

9.1.4 String-Manipulation Functions

The functions in this section look at or change the text of one or more strings.

`gawk` understands locales (see Section 6.6 [Where You Are Makes a Difference], page 149) and does all string processing in terms of *characters*, not *bytes*. This distinction is particularly important to understand for locales where one character may be represented by multiple bytes. Thus, for example, `length()` returns the number of characters in a string, and not the number of bytes used to represent those characters. Similarly, `index()` works with character indices, and not byte indices.

> **CAUTION:** A number of functions deal with indices into strings. For these functions, the first character of a string is at position (index) one. This is different from C and the languages descended from it, where the first character is at position zero. You need to remember this when doing index calculations, particularly if you are used to C.

In the following list, optional parameters are enclosed in square brackets ([ ]). Several functions perform string substitution; the full discussion is provided in the description of the `sub()` function, which comes toward the end, because the list is presented alphabetically.

Those functions that are specific to `gawk` are marked with a pound sign (‘`#`’). They are not available in compatibility mode (see Section 2.2 [Command-Line Options], page 33):

`asort(`*source* [`,` *dest* [`,` *how*]]`)` `#`
`asorti(`*source* [`,` *dest* [`,` *how*]]`)` `#`

These two functions are similar in behavior, so they are described together.

> **NOTE:** The following description ignores the third argument, *how*, as it requires understanding features that we have not discussed yet. Thus, the discussion here is a deliberate simplification. (We do provide all the details later on; see Section 12.3.2 [Sorting Array Values and Indices with `gawk`], page 349, for the full story.)

Both functions return the number of elements in the array *source*. For `asort()`, `gawk` sorts the values of *source* and replaces the indices of the sorted values of *source* with sequential integers starting with one. If the optional array *dest* is specified, then *source* is duplicated into *dest*. *dest* is then sorted, leaving the indices of *source* unchanged.

When comparing strings, `IGNORECASE` affects the sorting (see Section 12.3.2 [Sorting Array Values and Indices with `gawk`], page 349). If the *source* array contains subarrays as values (see Section 8.6 [Arrays of Arrays], page 193), they will come last, after all scalar values. Subarrays are *not* recursively sorted.

For example, if the contents of `a` are as follows:

```
a["last"] = "de"
a["first"] = "sac"
a["middle"] = "cul"
```

A call to `asort()`:

```
asort(a)
```

results in the following contents of `a`:

```
a[1] = "cul"
a[2] = "de"
a[3] = "sac"
```

The `asorti()` function works similarly to `asort()`; however, the *indices* are sorted, instead of the values. Thus, in the previous example, starting with the same initial set of indices and values in `a`, calling '`asorti(a)`' would yield:

```
a[1] = "first"
a[2] = "last"
a[3] = "middle"
```

NOTE: You may not use either `SYMTAB` or `FUNCTAB` as the second argument to these functions. Attempting to do so produces a fatal error. You may use them as the first argument, but only if providing a second array to use for the actual sorting.

You are allowed to use the same array for both the *source* and *dest* arguments, but doing so only makes sense if you're also supplying the third argument.

`gensub(`*regexp*`,` *replacement*`,` *how* [`,` *target*]`) #`

Search the target string *target* for matches of the regular expression *regexp*. If *how* is a string beginning with '`g`' or '`G`' (short for "global"), then replace all matches of *regexp* with *replacement*. Otherwise, treat *how* as a number indicating which match of *regexp* to replace. Treat numeric values less than one as if they were one. If no *target* is supplied, use `$0`. Return the modified string as the result of the function. The original target string is *not* changed.

The returned value is *always* a string, even if the original *target* was a number or a regexp value.

`gensub()` is a general substitution function. Its purpose is to provide more features than the standard `sub()` and `gsub()` functions.

`gensub()` provides an additional feature that is not available in `sub()` or `gsub()`: the ability to specify components of a regexp in the replacement text. This is done by using parentheses in the regexp to mark the components and then specifying '`\`*N*' in the replacement text, where *N* is a digit from 1 to 9. For example:

```
$ gawk '
> BEGIN {
>       a = "abc def"
>       b = gensub(/(.+) (.+)/, "\\2 \\1", "g", a)
>       print b
> }'
 ⊣ def abc
```

As with `sub()`, you must type two backslashes in order to get one into the string. In the replacement text, the sequence '`\0`' represents the entire matched text, as does the character '`&`'.

The following example shows how you can use the third argument to control which match of the regexp should be changed:

```
$ echo a b c a b c |
```

```
> gawk '{ print gensub(/a/, "AA", 2) }'
⊣ a b c AA b c
```

In this case, `$0` is the default target string. `gensub()` returns the new string as its result, which is passed directly to `print` for printing.

If the *how* argument is a string that does not begin with '`g`' or '`G`', or if it is a number that is less than or equal to zero, only one substitution is performed. If *how* is zero, `gawk` issues a warning message.

If *regexp* does not match *target*, `gensub()`'s return value is the original unchanged value of *target*. Note that, as mentioned above, the returned value is a string, even if *target* was not.

In the replacement string, a backslash before a non-digit character is simply elided. For example, '`\q`' becomes '`q`' in the result. If the final character in the replacement string is a backslash, it is left alone.

`gsub(`*regexp*`, `*replacement*` [, `*target*`])`

Search *target* for *all* of the longest, leftmost, *nonoverlapping* matching substrings it can find and replace them with *replacement*. The '`g`' in `gsub()` stands for "global," which means replace everywhere. For example:

```
{ gsub(/Britain/, "United Kingdom"); print }
```

replaces all occurrences of the string '`Britain`' with '`United Kingdom`' for all input records.

The `gsub()` function returns the number of substitutions made. If the variable to search and alter (*target*) is omitted, then the entire input record (`$0`) is used. As in `sub()`, the characters '`&`' and '`\`' are special, and the third argument must be assignable.

`index(`*in*`, `*find*`)`

Search the string *in* for the first occurrence of the string *find*, and return the position in characters where that occurrence begins in the string *in*. Consider the following example:

```
$ awk 'BEGIN { print index("peanut", "an") }'
⊣ 3
```

If *find* is not found, `index()` returns zero.

With BWK `awk` and `gawk`, it is a fatal error to use a regexp constant for *find*. Other implementations allow it, simply treating the regexp constant as an expression meaning '`$0 ~ /regexp/`'.

`length([`*string*`])`

Return the number of characters in *string*. If *string* is a number, the length of the digit string representing that number is returned. For example, `length("abcde")` is five. By contrast, `length(15 * 35)` works out to three. In this example, $15 \cdot 35 = 525$, and 525 is then converted to the string `"525"`, which has three characters.

If no argument is supplied, `length()` returns the length of `$0`.

> **NOTE:** In older versions of `awk`, the `length()` function could be called without any parentheses. Doing so is considered poor prac-

tice, although the 2008 POSIX standard explicitly allows it, to support historical practice. For programs to be maximally portable, always supply the parentheses.

For historical compatibility with Unix `awk`, if `length()` is called with a variable that has not been used, `gawk` forces the variable to be a scalar. Other implementations of `awk` leave the variable without a type. Consider:

```
$ gawk 'BEGIN { print length(x) ; x[1] = 1 }'
⊣ 0
error  gawk: fatal: attempt to use scalar `x' as array

$ nawk 'BEGIN { print length(x) ; x[1] = 1 }'
⊣ 0
```

If `--lint` has been specified on the command line, `gawk` issues a warning about this.

With `gawk` and several other `awk` implementations, when given an array argument, the `length()` function returns the number of elements in the array. This is less useful than it might seem at first, as the array is not guaranteed to be indexed from one to the number of elements in it.

Applying `length()` to an array was standardized by POSIX in 2024. Thus this usage should become more portable over time.

`match(`*`string`*`,` *`regexp`* [`,` *`array`*`])`

Search *string* for the longest, leftmost substring matched by the regular expression *regexp* and return the character position (index) at which that substring begins (one, if it starts at the beginning of *string*). If no match is found, return zero.

The *regexp* argument may be either a regexp constant (`/.../`) or a string constant (`"..."`). In the latter case, the string is treated as a regexp to be matched. See Section 3.6 [Using Dynamic Regexps], page 63, for a discussion of the difference between the two forms, and the implications for writing your program correctly.

The order of the first two arguments is the opposite of most other string functions that work with regular expressions, such as `sub()` and `gsub()`. It might help to remember that for `match()`, the order is the same as for the '`~`' operator: '*`string ~ regexp`*'.

The `match()` function sets the predefined variable `RSTART` to the index. It also sets the predefined variable `RLENGTH` to the length in characters of the matched substring. If no match is found, `RSTART` is set to zero, and `RLENGTH` to −1.

For example:

```
{
    if ($1 == "FIND")
        regex = $2
    else {
        where = match($0, regex)
        if (where != 0)
```

```
                print "Match of", regex, "found at", where, "in", $0
        }
}
```

This program looks for lines that match the regular expression stored in the variable `regex`. This regular expression can be changed. If the first word on a line is '`FIND`', `regex` is changed to be the second word on that line. Therefore, if given:

```
FIND ru+n
My program runs
but not very quickly
FIND Melvin
JF+KM
This line is property of Reality Engineering Co.
Melvin was here.
```

`awk` prints:

```
Match of ru+n found at 12 in My program runs
Match of Melvin found at 1 in Melvin was here.
```

If *array* is present, it is cleared, and then the zeroth element of *array* is set to the entire portion of *string* matched by *regexp*. If *regexp* contains parentheses, the integer-indexed elements of *array* are set to contain the portion of *string* matching the corresponding parenthesized subexpression. For example:

```
$ echo fooooobazbarrrrr |
> gawk '{ match($0, /(fo+).+(bar*)/, arr)
>         print arr[1], arr[2] }'
⊣ foooo barrrrr
```

In addition, multidimensional subscripts are available providing the start index and length of each matched subexpression:

```
$ echo fooooobazbarrrrr |
> gawk '{ match($0, /(fo+).+(bar*)/, arr)
>           print arr[1], arr[2]
>           print arr[1, "start"], arr[1, "length"]
>           print arr[2, "start"], arr[2, "length"]
> }'
⊣ foooo barrrrr
⊣ 1 5
⊣ 9 7
```

There may not be subscripts for the start and index for every parenthesized subexpression, because they may not all have matched text; thus, they should be tested for with the `in` operator (see Section 8.1.2 [Referring to an Array Element], page 183).

The *array* argument to `match()` is a `gawk` extension. In compatibility mode (see Section 2.2 [Command-Line Options], page 33), using a third argument is a fatal error.

`patsplit(`*`string`*`, `*`array`*` [, `*`fieldpat`*` [, `*`seps`*` ] ]) #`

Divide *string* into pieces (or "fields") defined by *fieldpat* and store the pieces in *array* and the separator strings in the *seps* array. The first piece is stored in `array[1]`, the second piece in `array[2]`, and so forth. The third argument, *fieldpat*, is a regexp describing the fields in *string* (just as `FPAT` is a regexp describing the fields in input records). It may be either a regexp constant or a string. If *fieldpat* is omitted, the value of `FPAT` is used. `patsplit()` returns the number of elements created. `seps[i]` is the possibly null separator string after `array[i]`. The possibly null leading separator will be in `seps[0]`. So a non-null *string* with *n* fields will have *n+1* separators. A null *string* has no fields or separators.

The `patsplit()` function splits strings into pieces in a manner similar to the way input lines are split into fields using `FPAT` (see Section 4.7 [Defining Fields by Content], page 87).

Before splitting the string, `patsplit()` deletes any previously existing elements in the arrays *array* and *seps*.

`split(`*`string`*`, `*`array`*` [, `*`fieldsep`*` [, `*`seps`*` ] ])`

Divide *string* into pieces separated by *fieldsep* and store the pieces in *array* and the separator strings in the *seps* array. The first piece is stored in `array[1]`, the second piece in `array[2]`, and so forth. The string value of the third argument, *fieldsep*, is a regexp describing where to split *string* (much as `FS` can be a regexp describing where to split input records). If *fieldsep* is omitted, the value of `FS` is used. `split()` returns the number of elements created. *seps* is a `gawk` extension, with `seps[i]` being the separator string between `array[i]` and `array[i+1]`. If *fieldsep* is a single space, then any leading whitespace goes into `seps[0]` and any trailing whitespace goes into `seps[n]`, where *n* is the return value of `split()` (i.e., the number of elements in *array*).

The `split()` function splits strings into pieces in the same way that input lines are split into fields. For example:

```
split("cul-de-sac", a, "-", seps)
```

splits the string `"cul-de-sac"` into three fields using '`-`' as the separator. It sets the contents of the array `a` as follows:

```
a[1] = "cul"
a[2] = "de"
a[3] = "sac"
```

and sets the contents of the array `seps` as follows:

```
seps[1] = "-"
seps[2] = "-"
```

The value returned by this call to `split()` is three.

If `gawk` is invoked with `--csv`, then a two-argument call to `split()` splits the string using the CSV parsing rules as described in Section 4.5.4 [Working With Comma Separated Value Files], page 80. With three and four arguments, `split()` works as just described. The four-argument call makes no sense, since each element of *seps* would simply consist of a string containing a comma.

As with input field-splitting, when the value of *fieldsep* is `" "`, leading and trailing whitespace is ignored in values assigned to the elements of *array* but not in *seps*, and the elements are separated by runs of whitespace. Also, as with input field splitting, if *fieldsep* is the null string, each individual character in the string is split into its own array element. (c.e.) Additionally, if *fieldsep* is a single-character string, that string acts as the separator, even if its value is a regular expression metacharacter.

Note, however, that `RS` has no effect on the way `split()` works. Even though '`RS = ""`' causes the newline character to also be an input field separator, this does not affect how `split()` splits strings.

Modern implementations of `awk`, including `gawk`, allow the third argument to be a regexp constant (`/.../`) as well as a string. The POSIX standard allows this as well. See Section 3.6 [Using Dynamic Regexps], page 63, for a discussion of the difference between using a string constant or a regexp constant, and the implications for writing your program correctly.

Before splitting the string, `split()` deletes any previously existing elements in the arrays *array* and *seps*.

If *string* is null, the array has no elements. (So this is a portable way to delete an entire array with one statement. See Section 8.4 [The `delete` Statement], page 190.)

If *string* does not match *fieldsep* at all (but is not null), *array* has one element only. The value of that element is the original *string*.

In POSIX mode (see Section 2.2 [Command-Line Options], page 33), the fourth argument is not allowed.

`sprintf(`*`format`*`, `*`expression1`*`, ...)`

Return (without printing) the string that `printf` would have printed out with the same arguments (see Section 5.5 [Using `printf` Statements for Fancier Printing], page 106). For example:

```
pival = sprintf("pi = %.2f (approx.)", 22/7)
```

assigns the string '`pi = 3.14 (approx.)`' to the variable `pival`.

`strtonum(`*`str`*`)` #

Examine *str* and return its numeric value. If *str* begins with a leading '`0`', `strtonum()` assumes that *str* is an octal number. If *str* begins with a leading '`0x`' or '`0X`', `strtonum()` assumes that *str* is a hexadecimal number. For example:

```
$ echo 0x11 |
> gawk '{ printf "%d\n", strtonum($1) }'
 ⊣ 17
```

Using the `strtonum()` function is *not* the same as adding zero to a string value; the automatic coercion of strings to numbers works only for decimal data, not for octal or hexadecimal.[4]

[4] Unless you use the `--non-decimal-data` option, which isn't recommended. See Section 12.1 [Allowing Nondecimal Input Data], page 343, for more information.

Note also that `strtonum()` uses the current locale's decimal point for recognizing numbers (see Section 6.6 [Where You Are Makes a Difference], page 149).

`sub(`*regexp*`, `*replacement*` [, `*target*`])`

Search *target*, which is treated as a string, for the leftmost, longest substring matched by the regular expression *regexp*. Modify the entire string by replacing the matched text with *replacement*. The modified string becomes the new value of *target*. Return the number of substitutions made (zero or one).

The *regexp* argument may be either a regexp constant (`/...`/) or a string constant (`"..."`). In the latter case, the string is treated as a regexp to be matched. See Section 3.6 [Using Dynamic Regexps], page 63, for a discussion of the difference between the two forms, and the implications for writing your program correctly.

This function is peculiar because *target* is not simply used to compute a value, and not just any expression will do—it must be a variable, field, or array element so that `sub()` can store a modified value there. If this argument is omitted, then the default is to use and alter `$0`.[5] For example:

```
str = "water, water, everywhere"
sub(/at/, "ith", str)
```

sets `str` to '`wither, water, everywhere`', by replacing the leftmost longest occurrence of '`at`' with '`ith`'.

If the special character '`&`' appears in *replacement*, it stands for the precise substring that was matched by *regexp*. (If the regexp can match more than one string, then this precise substring may vary.) For example:

```
{ sub(/candidate/, "& and his wife"); print }
```

changes the first occurrence of '`candidate`' to '`candidate and his wife`' on each input line. Here is another example:

```
$ awk 'BEGIN {
>         str = "daabaaa"
>         sub(/a+/, "C&C", str)
>         print str
> }'
 ⊣ dCaaCbaaa
```

This shows how '`&`' can represent a nonconstant string and also illustrates the "leftmost, longest" rule in regexp matching (see Section 3.5 [How Much Text Matches?], page 62).

The effect of this special character ('`&`') can be turned off by putting a backslash before it in the string. As usual, to insert one backslash in the string, you must write two backslashes. Therefore, write '`\\&`' in a string constant to include a literal '`&`' in the replacement. For example, the following shows how to replace the first '`|`' on each line with an '`&`':

```
{ sub(/\|/, "\\&"); print }
```

[5] Note that this means that the record will first be regenerated using the value of `OFS` if any fields have been changed, and that the fields will be updated after the substitution, even if the operation is a "no-op" such as '`sub(/^/, "")`'.

As mentioned, the third argument to `sub()` must be a variable, field, or array element. Some versions of `awk` allow the third argument to be an expression that is not an lvalue. In such a case, `sub()` still searches for the pattern and returns zero or one, but the result of the substitution (if any) is thrown away because there is no place to put it. Such versions of `awk` accept expressions like the following:

```
sub(/USA/, "United States", "the USA and Canada")
```

For historical compatibility, `gawk` accepts such erroneous code. However, using any other nonchangeable object as the third parameter causes a fatal error and your program will not run.

Finally, if the *regexp* is not a regexp constant, it is converted into a string, and then the value of that string is treated as the regexp to match.

`substr(`*`string`*`,` *`start`* [`,` *`length`*]`)`

Return a *length*-character-long substring of *string*, starting at character number *start*. The first character of a string is character number one.[6] For example, `substr("washington", 5, 3)` returns `"ing"`.

If *length* is not present, `substr()` returns the whole suffix of *string* that begins at character number *start*. For example, `substr("washington", 5)` returns `"ington"`. The whole suffix is also returned if *length* is greater than the number of characters remaining in the string, counting from character *start*.

If *start* is less than one, `substr()` treats it as if it was one. (POSIX doesn't specify what to do in this case: BWK `awk` acts this way, and therefore `gawk` does too.) If *start* is greater than the number of characters in the string, `substr()` returns the null string. Similarly, if *length* is present but less than or equal to zero, the null string is returned.

The string returned by `substr()` *cannot* be assigned. Thus, it is a mistake to attempt to change a portion of a string, as shown in the following example:

```
string = "abcdef"
# try to get "abCDEf", won't work
substr(string, 3, 3) = "CDE"
```

It is also a mistake to use `substr()` as the third argument of `sub()` or `gsub()`:

```
gsub(/xyz/, "pdq", substr($0, 5, 20))  # WRONG
```

(Some commercial versions of `awk` treat `substr()` as assignable, but doing so is not portable.)

If you need to replace bits and pieces of a string, combine `substr()` with string concatenation, in the following manner:

```
string = "abcdef"
...
string = substr(string, 1, 2) "CDE" substr(string, 6)
```

`tolower(`*`string`*`)`

Return a copy of *string*, with each uppercase character in the string replaced with its corresponding lowercase character. Nonalphabetic characters are left

[6] This is different from C and C++, in which the first character is number zero.

unchanged. For example, `tolower("MiXeD cAsE 123")` returns `"mixed case 123"`.

`toupper(`*string*`)`
: Return a copy of *string*, with each lowercase character in the string replaced with its corresponding uppercase character. Nonalphabetic characters are left unchanged. For example, `toupper("MiXeD cAsE 123")` returns `"MIXED CASE 123"`.

At first glance, the `split()` and `patsplit()` functions appear to be mirror images of each other. But there are differences:

- `split()` treats its third argument like `FS`, with all the special rules involved for `FS`.
- Matching of null strings differs. This is discussed in Section 4.7.1 [FS Versus FPAT: A Subtle Difference], page 89.

Matching the Null String

In `awk`, the '`*`' operator can match the null string. This is particularly important for the `sub()`, `gsub()`, and `gensub()` functions. For example:

```
$ echo abc | awk '{ gsub(/m*/, "X"); print }'
⊣ XaXbXcX
```

Although this makes a certain amount of sense, it can be surprising.

9.1.4.1 More about '\' and '&' with `sub()`, `gsub()`, and `gensub()`

I collect spores, molds, and fungus.
—Dr. Egon Spengler ("Ghostbusters," 1984)

CAUTION: This subsubsection has been reported to cause headaches. You might want to skip it upon first reading.

When using `sub()`, `gsub()`, or `gensub()`, and trying to get literal backslashes and ampersands into the replacement text, you need to remember that there are several levels of *escape processing* going on.

First, there is the *lexical* level, which is when `awk` reads your program and builds an internal copy of it to execute. Then there is the runtime level, which is when `awk` actually scans the replacement string to determine what to generate.

At both levels, `awk` looks for a defined set of characters that can come after a backslash. At the lexical level, it looks for the escape sequences listed in Section 3.2 [Escape Sequences], page 52. Thus, for every '\' that `awk` processes at the runtime level, you must type two backslashes at the lexical level. When a character that is not valid for an escape sequence follows the '\', BWK `awk` and `gawk` both simply remove the initial '\' and put the next character into the string. Thus, for example, `"a\qb"` is treated as `"aqb"`.

At the runtime level, the various functions handle sequences of '\' and '`&`' differently. The situation is (sadly) somewhat complex. Historically, the `sub()` and `gsub()` functions treated the two-character sequence '`\&`' specially; this sequence was replaced in the generated text with a single '`&`'. Any other '\' within the *replacement* string that did not precede an '`&`' was passed through unchanged. This is illustrated in Table 9.1.

You type	`sub()` **sees**	`sub()` **generates**
`\&`	`&`	The matched text
`\\&`	`\&`	A literal ‘`&`’
`\\\&`	`\&`	A literal ‘`&`’
`\\\\&`	`\\&`	A literal ‘`\&`’
`\\\\\&`	`\\&`	A literal ‘`\&`’
`\\\\\\&`	`\\\&`	A literal ‘`\\&`’
`\\q`	`\q`	A literal ‘`\q`’

Table 9.1: Historical escape sequence processing for `sub()` and `gsub()`

This table shows the lexical-level processing, where an odd number of backslashes becomes an even number at the runtime level, as well as the runtime processing done by `sub()`. (For the sake of simplicity, the rest of the following tables only show the case of even numbers of backslashes entered at the lexical level.)

The problem with the historical approach is that there is no way to get a literal ‘`\`’ followed by the matched text.

Several editions of the POSIX standard attempted to fix this problem but weren't successful. The details are irrelevant at this point in time.

At one point, the `gawk` maintainer submitted proposed text for a revised standard that reverts to rules that correspond more closely to the original existing practice. The proposed rules have special cases that make it possible to produce a ‘`\`’ preceding the matched text. This is shown in Table 9.2.

You type	`sub()` **sees**	`sub()` **generates**
`\\\\\\&`	`\\\&`	A literal ‘`\&`’
`\\\\&`	`\\&`	A literal ‘`\`’, followed by the matched text
`\\&`	`\&`	A literal ‘`&`’
`\\q`	`\q`	A literal ‘`\q`’
`\\\\`	`\\`	`\\`

Table 9.2: `gawk` rules for `sub()` and backslash

In a nutshell, at the runtime level, there are now three special sequences of characters (‘`\\\&`’, ‘`\\&`’, and ‘`\&`’) whereas historically there was only one. However, as in the historical case, any ‘`\`’ that is not part of one of these three sequences is not special and appears in the output literally.

`gawk` 3.0 and 3.1 follow these rules for `sub()` and `gsub()`. The POSIX standard took much longer to be revised than was expected. In addition, the `gawk` maintainer's proposal was lost during the standardization process. The final rules are somewhat simpler. The results are similar except for one case.

The POSIX rules state that ‘`\&`’ in the replacement string produces a literal ‘`&`’, ‘`\\`’ produces a literal ‘`\`’, and ‘`\`’ followed by anything else is not special; the ‘`\`’ is placed straight into the output. These rules are presented in Table 9.3.

You type	sub() sees	sub() generates
\\\\\\&	\\\&	A literal '\&'
\\\\&	\\&	A literal '\', followed by the matched text
\\&	\&	A literal '&'
\\q	\q	A literal '\q'
\\\\	\\	\

Table 9.3: POSIX rules for `sub()` and `gsub()`

The only case where the difference is noticeable is the last one: '\\\\' is seen as '\\' and produces '\' instead of '\\'.

Starting with version 3.1.4, `gawk` followed the POSIX rules when `--posix` was specified (see Section 2.2 [Command-Line Options], page 33). Otherwise, it continued to follow the proposed rules, as that had been its behavior for many years.

When version 4.0.0 was released, the `gawk` maintainer made the POSIX rules the default, breaking well over a decade's worth of backward compatibility.[7] Needless to say, this was a bad idea, and as of version 4.0.1, `gawk` resumed its historical behavior, and only follows the POSIX rules when `--posix` is given.

The rules for `gensub()` are considerably simpler. At the runtime level, whenever `gawk` sees a '\', if the following character is a digit, then the text that matched the corresponding parenthesized subexpression is placed in the generated output. Otherwise, no matter what character follows the '\', it appears in the generated text and the '\' does not, as shown in Table 9.4.

You type	gensub() sees	gensub() generates
&	&	The matched text
\\&	\&	A literal '&'
\\\\	\\	A literal '\'
\\\\&	\\&	A literal '\', then the matched text
\\\\\\&	\\\&	A literal '\&'
\\q	\q	A literal 'q'

Table 9.4: Escape sequence processing for `gensub()`

Because of the complexity of the lexical- and runtime-level processing and the special cases for `sub()` and `gsub()`, we recommend the use of `gawk` and `gensub()` when you have to do substitutions.

9.1.5 Input/Output Functions

The following functions relate to input/output (I/O). Optional parameters are enclosed in square brackets ([ ]):

`close(`*filename* [`,` *how*]`)`

Close the file *filename* for input or output. Alternatively, the argument may be a shell command that was used for creating a coprocess, or for redirecting to

[7] This was rather naive of him, despite there being a note in this section indicating that the next major version would move to the POSIX rules.

or from a pipe; then the coprocess or pipe is closed. See Section 5.9 [Closing Input and Output Redirections], page 117, for more information.

When closing a coprocess, it is occasionally useful to first close one end of the two-way pipe and then to close the other. This is done by providing a second argument to `close()`. This second argument (*how*) should be one of the two string values `"to"` or `"from"`, indicating which end of the pipe to close. Case in the string does not matter. See Section 12.4 [Two-Way Communications with Another Process], page 351, which discusses this feature in more detail and gives an example.

Note that the second argument to `close()` is a `gawk` extension; it is not available in compatibility mode (see Section 2.2 [Command-Line Options], page 33).

`fflush(`[*filename*]`)`

Flush any buffered output associated with *filename*, which is either a file opened for writing or a shell command for redirecting output to a pipe or coprocess.

Many utility programs *buffer* their output (i.e., they save information to write to a disk file or the screen in memory until there is enough for it to be worthwhile to send the data to the output device). This is often more efficient than writing every little bit of information as soon as it is ready. However, sometimes it is necessary to force a program to *flush* its buffers (i.e., write the information to its destination, even if a buffer is not full). This is the purpose of the `fflush()` function—`gawk` also buffers its output, and the `fflush()` function forces `gawk` to flush its buffers.

Brian Kernighan added `fflush()` to his `awk` in April 1992. For two decades, it was a common extension. In December 2012, it was accepted for inclusion into the POSIX standard. See the Austin Group website.

POSIX standardizes `fflush()` as follows: if there is no argument, or if the argument is the null string (`""`), then `awk` flushes the buffers for *all* open output files and pipes.

> **NOTE:** Prior to version 4.0.2, `gawk` would flush only the standard output if there was no argument, and flush all output files and pipes if the argument was the null string. This was changed in order to be compatible with BWK `awk`, in the hope that standardizing this feature in POSIX would then be easier (which indeed proved to be the case).
>
> With `gawk`, you can use '`fflush("/dev/stdout")`' if you wish to flush only the standard output.

`fflush()` returns zero if the buffer is successfully flushed; otherwise, it returns a nonzero value. (`gawk` returns -1.) In the case where all buffers are flushed, the return value is zero only if all buffers were flushed successfully. Otherwise, it is -1, and `gawk` warns about the problem *filename*.

`gawk` also issues a warning message if you attempt to flush a file or pipe that was opened for reading (such as with `getline`), or if *filename* is not an open file, pipe, or coprocess. In such a case, `fflush()` returns -1, as well.

Interactive Versus Noninteractive Buffering

As a side point, buffering issues can be even more confusing if your program is *interactive* (i.e., communicating with a user sitting at a keyboard).[8]

Interactive programs generally *line buffer* their output (i.e., they write out every line). Noninteractive programs wait until they have a full buffer, which may be many lines of output. Here is an example of the difference:

```
$ awk '{ print $1 + $2 }'
1 1
⊣ 2
2 3
⊣ 5
Ctrl-d
```

Each line of output is printed immediately. Compare that behavior with this example:

```
$ awk '{ print $1 + $2 }' | cat
1 1
2 3
Ctrl-d
⊣ 2
⊣ 5
```

Here, no output is printed until after the *Ctrl-d* is typed, because it is all buffered and sent down the pipe to `cat` in one shot.

`system(`*command*`)`

Execute the operating system command *command* and then return to the `awk` program. Return *command*'s exit status (see further on).

For example, if the following fragment of code is put in your `awk` program:

```
END {
     system("date | mail -s 'awk run done' root")
}
```

the system administrator is sent mail when the `awk` program finishes processing input and begins its end-of-input processing.

Note that redirecting `print` or `printf` into a pipe is often enough to accomplish your task. If you need to run many commands, it is more efficient to simply print them down a pipeline to the shell:

```
while (more stuff to do)
    print command | "/bin/sh"
close("/bin/sh")
```

However, if your `awk` program is interactive, `system()` is useful for running large self-contained programs, such as a shell or an editor. Some operating systems cannot implement the `system()` function. `system()` causes a fatal error if it is not supported.

[8] A program is interactive if the standard output is connected to a terminal device. On modern systems, this means your keyboard and screen.

> **NOTE:** When `--sandbox` is specified, the `system()` function is disabled (see Section 2.2 [Command-Line Options], page 33).

On POSIX systems, a command's exit status is a 16-bit number. The exit value passed to the C `exit()` function is held in the high-order eight bits. The low-order bits indicate if the process was killed by a signal (bit 7) and if so, the guilty signal number (bits 0–6).

In the past, `awk`'s `system()` function simply returned the exit status value divided by 256. In the normal case this gives the exit status but in the case of death-by-signal it yields a fractional floating-point value.[9] POSIX states that `awk`'s `system()` should return the full 16-bit value.

`gawk` steers a middle ground. The return values are summarized in Table 9.5.

Situation	**Return value from `system()`**
`--posix`	C `system()`'s value
Normal exit of command	Command's exit status
Death by signal of command	256 + number of murderous signal
Death by signal of command with core dump	512 + number of murderous signal
Some kind of error	−1

Table 9.5: Return values from `system()`

As of August, 2018, BWK `awk` now follows `gawk`'s behavior for the return value of `system()`.

[9] In private correspondence, Dr. Kernighan has indicated to me that the way this was done was probably a mistake.

Controlling Output Buffering with `system()`

The `fflush()` function provides explicit control over output buffering for individual files and pipes. However, its use is not portable to many older `awk` implementations. An alternative method to flush output buffers is to call `system()` with a null string as its argument:

```
system("")   # flush output
```

`gawk` treats this use of the `system()` function as a special case and is smart enough not to run a shell (or other command interpreter) with the empty command. Therefore, with `gawk`, this idiom is not only useful, it is also efficient. Although this method should work with other `awk` implementations, it does not necessarily avoid starting an unnecessary shell. (Other implementations may only flush the buffer associated with the standard output and not necessarily all buffered output.)

If you think about what a programmer expects, it makes sense that `system()` should flush any pending output. The following program:

```
BEGIN {
     print "first print"
     system("echo system echo")
     print "second print"
}
```

must print:

```
first print
system echo
second print
```

and not:

```
system echo
first print
second print
```

If `awk` did not flush its buffers before calling `system()`, you would see the latter (undesirable) output.

9.1.6 Time Functions

`awk` programs are commonly used to process log files containing timestamp information, indicating when a particular log record was written. Many programs log their timestamps in the form returned by the `time()` system call, which is the number of seconds since a particular epoch. On POSIX-compliant systems, it is the number of seconds since 1970-01-01 00:00:00 UTC, not counting leap seconds.[10] All known POSIX-compliant systems support timestamps from 0 through $2^{31} - 1$, which is sufficient to represent times through 2038-01-19 03:14:07 UTC. Many systems support a wider range of timestamps, including negative timestamps that represent times before the epoch.

In order to make it easier to process such log files and to produce useful reports, `gawk` provides the following functions for working with timestamps. They are `gawk` extensions;

[10] See [Glossary], page 543, especially the entries "Epoch" and "UTC."

they are not specified in the POSIX standard.[11] However, recent versions of `mawk` (see Section B.5 [Other Freely Available `awk` Implementations], page 523) also support these functions. Optional parameters are enclosed in square brackets ([ ]):

`mktime(`*datespec* [`,` *utc-flag*]`)`
: Turn *datespec* into a timestamp in the same form as is returned by `systime()`. It is similar to the function of the same name in ISO C. The argument, *datespec*, is a string of the form `"`*YYYY MM DD HH MM SS* `[`*DST*`]"`. The string consists of six or seven numbers representing, respectively, the full year including century, the month from 1 to 12, the day of the month from 1 to 31, the hour of the day from 0 to 23, the minute from 0 to 59, the second from 0 to 60,[12] and an optional daylight-savings flag.

  The values of these numbers need not be within the ranges specified; for example, an hour of −1 means 1 hour before midnight. The origin-zero Gregorian calendar is assumed, with year 0 preceding year 1 and year −1 preceding year 0. If *utc-flag* is present and is either nonzero or non-null, the time is assumed to be in the UTC time zone; otherwise, the time is assumed to be in the local time zone. If the *DST* daylight-savings flag is positive, the time is assumed to be daylight savings time; if zero, the time is assumed to be standard time; and if negative (the default), `mktime()` attempts to determine whether daylight savings time is in effect for the specified time.

  If *datespec* does not contain enough elements or if the resulting time is out of range, `mktime()` returns −1.

`strftime(`[*format* [`,` *timestamp* [`,` *utc-flag*]]]`)`
: Format the time specified by *timestamp* based on the contents of the *format* string and return the result. It is similar to the function of the same name in ISO C. If *utc-flag* is present and is either nonzero or non-null, the value is formatted as UTC (Coordinated Universal Time, formerly GMT or Greenwich Mean Time). Otherwise, the value is formatted for the local time zone. The *timestamp* is in the same format as the value returned by the `systime()` function. If no *timestamp* argument is supplied, `gawk` uses the current time of day as the timestamp. Without a *format* argument, `strftime()` uses the value of `PROCINFO["strftime"]` as the format string (see Section 7.5 [Predefined Variables], page 167). The default string value is `"%a %b %e %H:%M:%S %Z %Y"`. This format string produces output that is equivalent to that of the `date` utility. You can assign a new value to `PROCINFO["strftime"]` to change the default format; see the following list for the various format directives.

`systime()`
: Return the current time as the number of seconds since the system epoch. On POSIX systems, this is the number of seconds since 1970-01-01 00:00:00 UTC, not counting leap seconds. It may be a different number on other systems.

The `systime()` function allows you to compare a timestamp from a log file with the current time of day. In particular, it is easy to determine how long ago a particular record

[11] The GNU `date` utility can also do many of the things described here. Its use may be preferable for simple time-related operations in shell scripts.

[12] Occasionally there are minutes in a year with a leap second, which is why the seconds can go up to 60.

was logged. It also allows you to produce log records using the "seconds since the epoch" format.

The `mktime()` function allows you to convert a textual representation of a date and time into a timestamp. This makes it easy to do before/after comparisons of dates and times, particularly when dealing with date and time data coming from an external source, such as a log file.

The `strftime()` function allows you to easily turn a timestamp into human-readable information. It is similar in nature to the `sprintf()` function (see Section 9.1.4 [String-Manipulation Functions], page 200), in that it copies nonformat specification characters verbatim to the returned string, while substituting date and time values for format specifications in the *format* string.

`strftime()` is guaranteed by the 1999 ISO C standard[13] to support the following date format specifications:

`%a` The locale's abbreviated weekday name.

`%A` The locale's full weekday name.

`%b` The locale's abbreviated month name.

`%B` The locale's full month name.

`%c` The locale's "appropriate" date and time representation. (This is '`%A %B %d %T %Y`' in the `"C"` locale.)

`%C` The century part of the current year. This is the year divided by 100 and truncated to the next lower integer.

`%d` The day of the month as a decimal number (01–31).

`%D` Equivalent to specifying '`%m/%d/%y`'.

`%e` The day of the month, padded with a space if it is only one digit.

`%F` Equivalent to specifying '`%Y-%m-%d`'. This is the ISO 8601 date format.

`%g` The year modulo 100 of the ISO 8601 week number, as a decimal number (00–99). For example, January 1, 2012, is in week 53 of 2011. Thus, the year of its ISO 8601 week number is 2011, even though its year is 2012. Similarly, December 31, 2012, is in week 1 of 2013. Thus, the year of its ISO week number is 2013, even though its year is 2012.

`%G` The full year of the ISO week number, as a decimal number.

`%h` Equivalent to '`%b`'.

`%H` The hour (24-hour clock) as a decimal number (00–23).

`%I` The hour (12-hour clock) as a decimal number (01–12).

`%j` The day of the year as a decimal number (001–366).

`%m` The month as a decimal number (01–12).

`%M` The minute as a decimal number (00–59).

[13] Unfortunately, not every system's `strftime()` necessarily supports all of the conversions listed here.

`%n` A newline character (ASCII LF).

`%p` The locale's equivalent of the AM/PM designations associated with a 12-hour clock.

`%r` The locale's 12-hour clock time. (This is '`%I:%M:%S %p`' in the `"C"` locale.)

`%R` Equivalent to specifying '`%H:%M`'.

`%S` The second as a decimal number (00–60).

`%t` A TAB character.

`%T` Equivalent to specifying '`%H:%M:%S`'.

`%u` The weekday as a decimal number (1–7). Monday is day one.

`%U` The week number of the year (with the first Sunday as the first day of week one) as a decimal number (00–53).

`%V` The week number of the year (with the first Monday as the first day of week one) as a decimal number (01–53). The method for determining the week number is as specified by ISO 8601. (To wit: if the week containing January 1 has four or more days in the new year, then it is week one; otherwise it is the last week [52 or 53] of the previous year and the next week is week one.)

`%w` The weekday as a decimal number (0–6). Sunday is day zero.

`%W` The week number of the year (with the first Monday as the first day of week one) as a decimal number (00–53).

`%x` The locale's "appropriate" date representation. (This is '`%A %B %d %Y`' in the `"C"` locale.)

`%X` The locale's "appropriate" time representation. (This is '`%T`' in the `"C"` locale.)

`%y` The year modulo 100 as a decimal number (00–99).

`%Y` The full year as a decimal number (e.g., 2015).

`%z` The time zone offset in a '*`+HHMM`*' format (e.g., the format necessary to produce RFC 822/RFC 1036 date headers).

`%Z` The time zone name or abbreviation; no characters if no time zone is determinable.

`%Ec %EC %Ex %EX %Ey %EY %Od %Oe %OH`
`%OI %Om %OM %OS %Ou %OU %OV %Ow %OW %Oy`
"Alternative representations" for the specifications that use only the second letter ('`%c`', '`%C`', and so on).[14] (These facilitate compliance with the POSIX `date` utility.)

`%%` A literal '`%`'.

[14] If you don't understand any of this, don't worry about it; these facilities are meant to make it easier to "internationalize" programs. Other internationalization features are described in Chapter 13 [Internationalization with gawk], page 365.

If a conversion specifier is not one of those just listed, the behavior is undefined.[15]

For systems that are not yet fully standards-compliant, `gawk` supplies a copy of `strftime()` from the GNU C Library. It supports all of the just-listed format specifications. If that version is used to compile `gawk` (see Appendix B [Installing gawk], page 503), then the following additional format specifications are available:

`%k` The hour (24-hour clock) as a decimal number (0–23). Single-digit numbers are padded with a space.

`%l` The hour (12-hour clock) as a decimal number (1–12). Single-digit numbers are padded with a space.

`%s` The time as a decimal timestamp in seconds since the epoch.

Additionally, the alternative representations are recognized but their normal representations are used.

> **NOTE:** Similar to `printf()`, some versions of `strftime()` support the use of flags between the `%` and the format specification letter. Check your local man page for `strftime()` to see if it supports flags or not, and what they are. Be aware, however, that using any such flags is likely to make your script less portable to other systems.

The following example is an `awk` implementation of the POSIX `date` utility. Normally, the `date` utility prints the current date and time of day in a well-known format. However, if you provide an argument to it that begins with a '`+`', `date` copies nonformat specifier characters to the standard output and interprets the current time according to the format specifiers in the string. For example:

```
$ date '+Today is %A, %B %d, %Y.'
⊣ Today is Monday, September 22, 2014.
```

Here is the `gawk` version of the `date` utility. It has a shell "wrapper" to handle the `-u` option, which requires that `date` run as if the time zone is set to UTC:

```
#! /bin/sh
#
# date --- approximate the POSIX 'date' command

case $1 in
-u)  TZ=UTC0     # use UTC
     export TZ
     shift ;;
esac

gawk 'BEGIN  {
    format = PROCINFO["strftime"]
    exitval = 0
```

[15] This is because ISO C leaves the behavior of the C version of `strftime()` undefined and `gawk` uses the system's version of `strftime()` if it's there. Typically, the conversion specifier either does not appear in the returned string or appears literally.

```
    if (ARGC > 2)
        exitval = 1
    else if (ARGC == 2) {
        format = ARGV[1]
        if (format ~ /^\+/)
            format = substr(format, 2)   # remove leading +
    }
    print strftime(format)
    exit exitval
}' "$@"
```

This script was written before the `strftime()` function acquired its third argument, *utc-flag*. Consider how you might modify the program to work entirely in `awk` and process the `-u` option for printing the time in UTC.

9.1.7 Bit-Manipulation Functions

I can explain it for you, but I can't understand it for you.
—Anonymous

Many languages provide the ability to perform *bitwise* operations on two integer numbers. In other words, the operation is performed on each successive pair of bits in the operands. Three common operations are bitwise AND, OR, and XOR. The operations are described in Table 9.6.

	Bit operator					
	AND		OR		XOR	
Operands	0	1	0	1	0	1
0	0	0	0	1	0	1
1	0	1	1	1	1	0

Table 9.6: Bitwise operations

As you can see, the result of an AND operation is 1 only when *both* bits are 1. The result of an OR operation is 1 if *either* bit is 1. The result of an XOR operation is 1 if either bit is 1, but not both. The next operation is the *complement*; the complement of 1 is 0 and the complement of 0 is 1. Thus, this operation "flips" all the bits of a given value.

Finally, two other common operations are to shift the bits left or right. For example, if you have a bit string '`10111001`' and you shift it right by three bits, you end up with '`00010111`'.[16] If you start over again with '`10111001`' and shift it left by three bits, you end up with '`11001000`'. The following list describes `gawk`'s built-in functions that implement the bitwise operations. Optional parameters are enclosed in square brackets ([ ]):

`and(`*v1*`,` *v2* [`, ...`]`)`
: Return the bitwise AND of the arguments. There must be at least two.

`compl(`*val*`)`
: Return the bitwise complement of *val*.

[16] This example shows that zeros come in on the left side. For `gawk`, this is always true, but in some languages, it's possible to have the left side fill with ones.

`lshift(`*val*`, `*count*`)`
: Return the value of *val*, shifted left by *count* bits.

`or(`*v1*`, `*v2*` [, ...])`
: Return the bitwise OR of the arguments. There must be at least two.

`rshift(`*val*`, `*count*`)`
: Return the value of *val*, shifted right by *count* bits.

`xor(`*v1*`, `*v2*` [, ...])`
: Return the bitwise XOR of the arguments. There must be at least two.

> **CAUTION:** Beginning with `gawk` version 4.2, negative operands are not allowed for any of these functions. A negative operand produces a fatal error. See the sidebar "Beware The Smoke and Mirrors!" for more information as to why.
>
> Beginning with `gawk` version 5.4, if not in MPFR mode (see Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399), shifting with `lshift()` or `rshift()` by as many or more bits than are available in the largest unsigned integer returns zero, instead of whatever the underlying C compiler might do.

Here is a user-defined function (see Section 9.2 [User-Defined Functions], page 225) that illustrates the use of these functions:

```
# bits2str --- turn an integer into readable ones and zeros

function bits2str(bits,        data, mask)
{
    if (bits == 0)
        return "0"

    mask = 1
    for (; bits != 0; bits = rshift(bits, 1))
        data = (and(bits, mask) ? "1" : "0") data

    while ((length(data) % 8) != 0)
        data = "0" data

    return data
}

BEGIN {
    printf "123 = %s\n", bits2str(123)
    printf "0123 = %s\n", bits2str(0123)
    printf "0x99 = %s\n", bits2str(0x99)
    comp = compl(0x99)
    printf "compl(0x99) = %#x = %s\n", comp, bits2str(comp)
    shift = lshift(0x99, 2)
    printf "lshift(0x99, 2) = %#x = %s\n", shift, bits2str(shift)
    shift = rshift(0x99, 2)
```

```
        printf "rshift(0x99, 2) = %#x = %s\n", shift, bits2str(shift)
}
```

This program produces the following output when run:

```
$ gawk -f testbits.awk
⊣ 123 = 01111011
⊣ 0123 = 01010011
⊣ 0x99 = 10011001
⊣ compl(0x99) = 0x3fffffffffff66 =
⊣ 00111111111111111111111111111111111111111111111101100110
⊣ lshift(0x99, 2) = 0x264 = 0000001001100100
⊣ rshift(0x99, 2) = 0x26 = 00100110
```

The `bits2str()` function turns a binary number into a string. Initializing `mask` to one creates a binary value where the rightmost bit is set to one. Using this mask, the function repeatedly checks the rightmost bit. ANDing the mask with the value indicates whether the rightmost bit is one or not. If so, a `"1"` is concatenated onto the front of the string. Otherwise, a `"0"` is added. The value is then shifted right by one bit and the loop continues until there are no more one bits.

If the initial value is zero, it returns a simple `"0"`. Otherwise, at the end, it pads the value with zeros to represent multiples of 8-bit quantities. This is typical in modern computers.

The main code in the `BEGIN` rule shows the difference between the decimal and octal values for the same numbers (see Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124), and then demonstrates the results of the `compl()`, `lshift()`, and `rshift()` functions.

Beware The Smoke and Mirrors!

In other languages, bitwise operations are performed on integer values, not floating-point values. As a general statement, such operations work best when performed on unsigned integers.

`gawk` attempts to treat the arguments to the bitwise functions as unsigned integers. For this reason, negative arguments produce a fatal error.

In normal operation, for all of these functions, first the double-precision floating-point value is converted to the widest C unsigned integer type, then the bitwise operation is performed. If the result cannot be represented exactly as a C `double`, leading nonzero bits are removed one by one until it can be represented exactly. The result is then converted back into a C `double`.[17]

However, when using arbitrary precision arithmetic with the `-M` option (see Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399), the results may differ. This is particularly noticeable with the `compl()` function:

```
$ gawk 'BEGIN { print compl(42) }'
⊣ 9007199254740949
$ gawk -M 'BEGIN { print compl(42) }'
⊣ -43
```

What's going on becomes clear when printing the results in hexadecimal:

```
$ gawk 'BEGIN { printf "%#x\n", compl(42) }'
⊣ 0x1fffffffffffd5
$ gawk -M 'BEGIN { printf "%#x\n", compl(42) }'
⊣ 0xffffffffffffffd5
```

When using the `-M` option, under the hood, `gawk` uses GNU MP arbitrary precision integers which have at least 64 bits of precision. When not using `-M`, `gawk` stores integral values in regular double-precision floating point, which only maintain 53 bits of precision. Furthermore, the GNU MP library treats (or at least seems to treat) the leading bit as a sign bit; thus the result with `-M` in this case is a negative number.

In short, using `gawk` for any but the simplest kind of bitwise operations is probably a bad idea; caveat emptor!

9.1.8 Getting Type Information

`gawk` provides two functions that let you distinguish the type of a variable. This is necessary for writing code that traverses every element of an array of arrays (see Section 8.6 [Arrays of Arrays], page 193), and in other contexts.

`isarray(`*x*`)`
: Return a true value if *x* is an array. Otherwise, return false.

`typeof(`*x*`)`
: Return one of the following strings, depending upon the type of *x*:

[17] If you don't understand this paragraph, the upshot is that `gawk` can only store a particular range of integer values; numbers outside that range are reduced to fit within the range.

`"array"` *x* is an array.

`"regexp"` *x* is a strongly typed regexp (see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127).

`"number"` *x* is a number.

`"number|bool"`
x is a Boolean typed value (see Section 12.2 [Boolean Typed Values], page 344).

`"string"` *x* is a string.

`"strnum"` *x* is a number that started life as user input, such as a field or the result of calling `split()`. (I.e., *x* has the strnum attribute; see Section 6.3.2.1 [String Type versus Numeric Type], page 139.)

`"unassigned"`
x is a *scalar* variable that has not been assigned a value yet.

`"untyped"`
x has not yet been used yet at all; it can become a scalar or an array.

`isarray()` is meant for use in two circumstances. The first is when traversing a multidimensional array: you can test if an element is itself an array or not. The second is inside the body of a user-defined function (not discussed yet; see Section 9.2 [User-Defined Functions], page 225), to test if a parameter is an array or not.

> **NOTE:** While you can use `isarray()` at the global level to test variables, doing so makes no sense. Because *you* are the one writing the program, *you* are supposed to know if your variables are arrays or not.

The `typeof()` function is general; it allows you to determine if a variable or function parameter is a scalar (number, string, or strongly typed regexp) or an array.

We delay further discussion of `unassigned` vs. `untyped` to Section 9.3.2 [Dynamic Typing In gawk], page 235.

9.1.9 String-Translation Functions

`gawk` provides facilities for internationalizing `awk` programs. These include the functions described in the following list. The descriptions here are purposely brief. See Chapter 13 [Internationalization with gawk], page 365, for the full story. Optional parameters are enclosed in square brackets ([ ]):

`bindtextdomain(`*`directory`* [`,` *domain*]`)`
Set the directory in which `gawk` will look for message translation files, in case they will not or cannot be placed in the "standard" locations (e.g., during testing). It returns the directory in which *domain* is "bound."

The default *domain* is the value of `TEXTDOMAIN`. If *directory* is the null string (`""`), then `bindtextdomain()` returns the current binding for the given *domain*.

`dcgettext(`*`string`* [`,` *domain* [`,` *category*]]`)`
Return the translation of *string* in text domain *domain* for locale category *category*. The default value for *domain* is the current value of `TEXTDOMAIN`. The default value for *category* is `"LC_MESSAGES"`.

`dcngettext(`*`string1`*`, `*`string2`*`, `*`number`*` [, `*domain*` [, `*category*`] ])`
: Return the plural form used for *number* of the translation of *string1* and *string2* in text domain *domain* for locale category *category*. *string1* is the English singular variant of a message, and *string2* is the English plural variant of the same message. The default value for *domain* is the current value of `TEXTDOMAIN`. The default value for *category* is `"LC_MESSAGES"`.

9.2 User-Defined Functions

Complicated `awk` programs can often be simplified by defining your own functions. User-defined functions can be called just like built-in ones (see Section 6.4 [Function Calls], page 146), but it is up to you to define them (i.e., to tell `awk` what they should do).

9.2.1 Function Definition Syntax

> *It's entirely fair to say that the awk syntax for local variable definitions is appallingly awful.*
>
> —*Brian Kernighan*

Definitions of functions can appear anywhere between the rules of an `awk` program. Thus, the general form of an `awk` program is extended to include sequences of rules *and* user-defined function definitions. There is no need to put the definition of a function before all uses of the function. This is because `awk` reads the entire program before starting to execute any of it.

The definition of a function named *name* looks like this:

```
function name([parameter-list])
{
    body-of-function
}
```

Here, *name* is the name of the function to define. A valid function name is like a valid variable name: a sequence of letters, digits, and underscores that doesn't start with a digit. Here too, only the 52 upper- and lowercase English letters may be used in a function name. Within a single `awk` program, any particular name can only be used as a variable, array, or function.

parameter-list is an optional list of the function's arguments and local variable names, separated by commas. When the function is called, the argument names are used to hold the argument values given in the call.

A function cannot have two parameters with the same name, nor may it have a parameter with the same name as the function itself.

> **CAUTION:** According to the POSIX standard, function parameters cannot have the same name as one of the special predefined variables (see Section 7.5 [Predefined Variables], page 167), nor may a function parameter have the same name as another function.
>
> Not all versions of `awk` enforce these restrictions. `gawk` always enforces the first restriction. With `--posix` (see Section 2.2 [Command-Line Options], page 33), it also enforces the second restriction.

Local variables act like the empty string if referenced where a string value is required, and like zero if referenced where a numeric value is required. This is the same as the behavior of regular variables that have never been assigned a value. (There is more to understand about local variables; see Section 9.3 [Variable Typing Is Dynamic], page 234.)

The *body-of-function* consists of `awk` statements. It is the most important part of the definition, because it says what the function should actually *do*. The argument names exist to give the body a way to talk about the arguments; local variables exist to give the body places to keep temporary values.

Argument names are not distinguished syntactically from local variable names. Instead, the number of arguments supplied when the function is called determines how many argument variables there are. Thus, if three argument values are given, the first three names in *parameter-list* are arguments and the rest are local variables.

It follows that if the number of arguments is not the same in all calls to the function, some of the names in *parameter-list* may be arguments on some occasions and local variables on others. Another way to think of this is that omitted arguments default to the null string.

Usually when you write a function, you know how many names you intend to use for arguments and how many you intend to use as local variables. It is conventional to place some extra space between the arguments and the local variables, in order to document how your function is supposed to be used.

During execution of the function body, the arguments and local variable values hide, or *shadow*, any variables of the same names used in the rest of the program. The shadowed variables are not accessible in the function definition, because there is no way to name them while their names have been taken away for the arguments and local variables. All other variables used in the `awk` program can be referenced or set normally in the function's body. (Also, see Section 9.4 [A Note On Shadowed Variables], page 237.)

The arguments and local variables last only as long as the function body is executing. Once the body finishes, you can once again access the variables that were shadowed while the function was running.

The function body can contain expressions that call functions. They can even call this function, either directly or by way of another function. When this happens, we say the function is *recursive*. The act of a function calling itself is called *recursion*.

All the built-in functions return a value to their caller. User-defined functions can do so also, using the `return` statement, which is described in detail in Section 9.2.4 [The `return` Statement], page 233. Many of the subsequent examples in this section use the `return` statement.

In many `awk` implementations, including `gawk`, the keyword `function` may be abbreviated `func`. (c.e.) However, POSIX only specifies the use of the keyword `function`. This actually has some practical implications. If `gawk` is in POSIX-compatibility mode (see Section 2.2 [Command-Line Options], page 33), then the following statement does *not* define a function:

```
func foo() { a = sqrt($1) ; print a }
```

Instead, it defines a rule that, for each record, concatenates the value of the variable '`func`' with the return value of the function '`foo`'. If the resulting string is non-null, the action

is executed. This is probably not what is desired. (`awk` accepts this input as syntactically valid, because functions may be used before they are defined in `awk` programs.[18])

To ensure that your `awk` programs are portable, always use the keyword `function` when defining a function.

9.2.2 Function Definition Examples

Here is an example of a user-defined function, called `myprint()`, that takes a number and prints it in a specific format:

```
function myprint(num)
{
     printf "%6.3g\n", num
}
```

To illustrate, here is an `awk` rule that uses our `myprint()` function:

```
$3 > 0     { myprint($3) }
```

This program prints, in our special format, all the third fields that contain a positive number in our input. Therefore, when given the following input:

```
 1.2   3.4    5.6   7.8
 9.10 11.12 -13.14 15.16
17.18 19.20  21.22 23.24
```

this program, using our function to format the results, prints:

```
  5.6
 21.2
```

This function deletes all the elements in an array (recall that the extra whitespace signifies the start of the local variable list):

```
function delarray(a,    i)
{
    for (i in a)
        delete a[i]
}
```

When working with arrays, it is often necessary to delete all the elements in an array and start over with a new list of elements (see Section 8.4 [The `delete` Statement], page 190). Instead of having to repeat this loop everywhere that you need to clear out an array, your program can just call `delarray()`. (This guarantees portability. The use of '`delete array`' to delete the contents of an entire array is a relatively recent[19] addition to the POSIX standard.)

The following is an example of a recursive function. It takes a string as an input parameter and returns the string in reverse order. Recursive functions must always have a test that stops the recursion. In this case, the recursion terminates when the input string is already empty:

```
function rev(str)
{
```

[18] This program won't actually run, because `foo()` is undefined.

[19] Late in 2012.

```
    if (str == "")
        return ""

    return (rev(substr(str, 2)) substr(str, 1, 1))
}
```

If this function is in a file named `rev.awk`, it can be tested this way:

```
$ echo "Don't Panic!" |
> gawk -e '{ print rev($0) }' -f rev.awk
⊣ !cinaP t'noD
```

The C `ctime()` function takes a timestamp and returns it as a string, formatted in a well-known fashion. The following example uses the built-in `strftime()` function (see Section 9.1.6 [Time Functions], page 215) to create an `awk` version of `ctime()`:

```
# ctime.awk
#
# awk version of C ctime(3) function

function ctime(ts,    format)
{
    format = "%a %b %e %H:%M:%S %Z %Y"

    if (ts == 0)
        ts = systime()       # use current time as default
    return strftime(format, ts)
}
```

You might think that `ctime()` could use `PROCINFO["strftime"]` for its format string. That would be a mistake, because `ctime()` is supposed to return the time formatted in a standard fashion, and user-level code could have changed `PROCINFO["strftime"]`.

9.2.3 Calling User-Defined Functions

Calling a function means causing the function to run and do its job. A function call is an expression and its value is the value returned by the function.

9.2.3.1 Writing a Function Call

A function call consists of the function name followed by the arguments in parentheses. `awk` expressions are what you write in the call for the arguments. Each time the call is executed, these expressions are evaluated, and the values become the actual arguments. For example, here is a call to `foo()` with three arguments (the first being a string concatenation):

```
foo(x y, "lose", 4 * z)
```

CAUTION: Whitespace characters (spaces and TABs) are not allowed between the function name and the opening parenthesis of the argument list. If you write whitespace by mistake, `awk` might think that you mean to concatenate a variable with an expression in parentheses. However, it notices that you used a function name and not a variable name, and reports an error.

9.2.3.2 Controlling Variable Scope

Unlike in many languages, there is no way to make a variable local to a `{ ... }` block in `awk`, but you can make a variable local to a function. It is good practice to do so whenever a variable is needed only in that function.

To make a variable local to a function, simply declare the variable as an argument after the actual function arguments (see Section 9.2.1 [Function Definition Syntax], page 225). Look at the following example, where variable `i` is a global variable used by both functions `foo()` and `bar()`:

```
function bar()
{
    for (i = 0; i < 3; i++)
        print "bar's i=" i
}

function foo(j)
{
    i = j + 1
    print "foo's i=" i
    bar()
    print "foo's i=" i
}

BEGIN {
      i = 10
      print "top's i=" i
      foo(0)
      print "top's i=" i
}
```

Running this script produces the following, because the `i` in functions `foo()` and `bar()` and at the top level refer to the same variable instance:

```
top's i=10
foo's i=1
bar's i=0
bar's i=1
bar's i=2
foo's i=3
top's i=3
```

If you want `i` to be local to both `foo()` and `bar()`, do as follows (the extra space before `i` is a coding convention to indicate that `i` is a local variable, not an argument):

```
function bar(    i)
{
    for (i = 0; i < 3; i++)
        print "bar's i=" i
}
```

```
function foo(j,    i)
{
    i = j + 1
    print "foo's i=" i
    bar()
    print "foo's i=" i
}

BEGIN {
      i = 10
      print "top's i=" i
      foo(0)
      print "top's i=" i
}
```

Running the corrected script produces the following:

```
top's i=10
foo's i=1
bar's i=0
bar's i=1
bar's i=2
foo's i=1
top's i=10
```

Besides scalar values (strings and numbers), you may also have local arrays. By using a parameter name as an array, `awk` treats it as an array, and it is local to the function. In addition, recursive calls create new arrays. Consider this example:

```
function some_func(p1,      a)
{
    if (p1++ > 3)
        return

    a[p1] = p1

    some_func(p1)

    printf("At level %d, index %d %s found in a\n",
         p1, (p1 - 1), (p1 - 1) in a ? "is" : "is not")
    printf("At level %d, index %d %s found in a\n",
         p1, p1, p1 in a ? "is" : "is not")
    print ""
}

BEGIN {
    some_func(1)
}
```

When run, this program produces the following output:

```
At level 4, index 3 is not found in a
```

```
At level 4, index 4 is found in a

At level 3, index 2 is not found in a
At level 3, index 3 is found in a

At level 2, index 1 is not found in a
At level 2, index 2 is found in a
```

9.2.3.3 Passing Function Arguments by Value Or by Reference

In `awk`, when you declare a function, there is no way to declare explicitly whether the arguments are passed *by value* or *by reference*.

Instead, the passing convention is determined at runtime when the function is called, according to the following rule: if the argument is an array variable, then it is passed by reference. Otherwise, the argument is passed by value.

Passing an argument by value means that when a function is called, it is given a *copy* of the value of this argument. The caller may use a variable as the expression for the argument, but the called function does not know this—it only knows what value the argument had. For example, if you write the following code:

```
foo = "bar"
z = myfunc(foo)
```

then you should not think of the argument to `myfunc()` as being "the variable `foo`." Instead, think of the argument as the string value `"bar"`. If the function `myfunc()` alters the values of its local variables, this has no effect on any other variables. Thus, if `myfunc()` does this:

```
function myfunc(str)
{
   print str
   str = "zzz"
   print str
}
```

to change its first argument variable `str`, it does *not* change the value of `foo` in the caller. The role of `foo` in calling `myfunc()` ended when its value (`"bar"`) was computed. If `str` also exists outside of `myfunc()`, the function body cannot alter this outer value, because it is shadowed during the execution of `myfunc()` and cannot be seen or changed from there.

However, when arrays are the parameters to functions, they are *not* copied. Instead, the array itself is made available for direct manipulation by the function. This is usually termed *call by reference*. Changes made to an array parameter inside the body of a function *are* visible outside that function.

NOTE: Changing an array parameter inside a function can be very dangerous if you do not watch what you are doing. For example:

```
function changeit(array, ind, nvalue)
{
     array[ind] = nvalue
}

BEGIN {
```

```
        a[1] = 1; a[2] = 2; a[3] = 3
        changeit(a, 2, "two")
        printf "a[1] = %s, a[2] = %s, a[3] = %s\n",
                a[1], a[2], a[3]
    }
```

prints ‘`a[1] = 1, a[2] = two, a[3] = 3`’, because `changeit()` stores `"two"` in the second element of `a`.

9.2.3.4 Other Points About Calling Functions

Some `awk` implementations allow you to call a function that has not been defined. They only report a problem at runtime, when the program actually tries to call the function. For example:

```
BEGIN {
    if (0)
        foo()
    else
        bar()
}
function bar() { ... }
# note that `foo' is not defined
```

Because the ‘`if`’ statement will never be true, it is not really a problem that `foo()` has not been defined. Usually, though, it is a problem if a program calls an undefined function.

If `--lint` is specified (see Section 2.2 [Command-Line Options], page 33), `gawk` reports calls to undefined functions.

Some `awk` implementations generate a runtime error if you use either the `next` statement or the `nextfile` statement (see Section 7.4.8 [The `next` Statement], page 164, and see Section 7.4.9 [The `nextfile` Statement], page 165) inside a user-defined function. `gawk` does not have this limitation.

You can call a function and pass it more parameters than it was declared with, like so:

```
function foo(p1, p2)
{
    ...
}

BEGIN {
    foo(1, 2, 3, 4)
}
```

Doing so is bad practice, however. The called function cannot do anything with the additional values being passed to it, so `awk` evaluates the expressions but then just throws them away.

More importantly, such a call is confusing for whoever will next read your program.[20] Function parameters generally are input items that influence the computation performed

[20] Said person might even be you, sometime in the future, at which point you will wonder, “what was I thinking?!?”

by the function. Calling a function with more parameters than it accepts gives the false impression that those values are important to the function, when in fact they are not.

Because this is such a bad practice, `gawk` *unconditionally* issues a warning whenever it executes such a function call. (If you don't like the warning, fix your code! It's incorrect, after all.)

9.2.4 The `return` Statement

As seen in several earlier examples, the body of a user-defined function can contain a `return` statement. This statement returns control to the calling part of the `awk` program. It can also be used to return a value for use in the rest of the `awk` program. It looks like this:

`return` [*expression*]

The *expression* part is optional. Due most likely to an oversight, POSIX does not define what the return value is if you omit the *expression*. Technically speaking, this makes the returned value undefined, and therefore, unpredictable. In practice, though, all versions of `awk` simply return the null string, which acts like zero if used in a numeric context.

A `return` statement without an *expression* is assumed at the end of every function definition. So, if control reaches the end of the function body, then technically the function returns an unpredictable value. In practice, it returns the empty string. `awk` does *not* warn you if you use the return value of such a function.

Sometimes, you want to write a function for what it does, not for what it returns. Such a function corresponds to a `void` function in C, C++, or Java, or to a `procedure` in Ada. Thus, it may be appropriate to not return any value; simply bear in mind that you should not be using the return value of such a function.

The following is an example of a user-defined function that returns a value for the largest number among the elements of an array:

```
function maxelt(vec,   i, ret)
{
     for (i in vec) {
          if (ret == "" || vec[i] > ret)
               ret = vec[i]
     }
     return ret
}
```

You call `maxelt()` with one argument, which is an array name. The local variables `i` and `ret` are not intended to be arguments; there is nothing to stop you from passing more than one argument to `maxelt()` but the results would be strange. The extra space before `i` in the function parameter list indicates that `i` and `ret` are local variables. You should follow this convention when defining functions.

The following program uses the `maxelt()` function. It loads an array, calls `maxelt()`, and then reports the maximum number in that array:

```
function maxelt(vec,   i, ret)
{
     for (i in vec) {
          if (ret == "" || vec[i] > ret)
```

```
                ret = vec[i]
        }
        return ret
}

# Load all fields of each record into nums.
{
        for(i = 1; i <= NF; i++)
                nums[NR, i] = $i
}

END {
        print maxelt(nums)
}
```

Given the following input:

```
 1 5 23 8 16
44 3 5 2 8 26
256 291 1396 2962 100
-6 467 998 1101
99385 11 0 225
```

the program reports (predictably) that 99,385 is the largest value in the array.

9.3 Variable Typing Is Dynamic

It's a desert topping!
It's a floor wax!
—Saturday Night Live (back when it used to be funny)

`awk` is a very fluid language. It is possible that `awk` can't tell if an identifier represents a scalar variable or an array until runtime.

9.3.1 Dynamic Typing In Standard `awk`

Let's first discuss standard `awk`. Here is an annotated sample program:

```
function foo(a)
{
    a[1] = 1   # parameter is an array
}

BEGIN {
    b = 1
    foo(b)  # invalid: fatal type mismatch

    foo(x)  # x uninitialized, becomes an array dynamically
    x = 1   # now not allowed, runtime error
}
```

In this example, the first call to `foo()` generates a fatal error, so `awk` will not report the second error. If you comment out that call, though, then `awk` does report the second error.

Here is a more extreme example:

```
BEGIN {
    funky(a)
    if (A == 0)
        print "<" a ">"
    else
        print a[1]
}

function funky(arr)
{
    if (A == 0)
        arr = 1
    else
        arr[1] = 1
}
```

Here, the function uses its parameter differently depending upon the value of the global variable `A`. If `A` is zero, the parameter `arr` is treated as a scalar. Otherwise it's treated as an array.

There are two ways this program might behave. `awk` could notice that in the main program, `a` is subscripted, and so mark it as an array before the program even begins to run. BWK `awk`, `mawk`, and possibly others do this:

```
$ nawk -v A=0 -f funky.awk
error  nawk: can't assign to a; it's an array name.
error   source line number 11
$ nawk -v A=1 -f funky.awk
⊣ 1
```

Or `awk` could wait until runtime to set the type of `a`. In this case, since `a` was never used before being passed to the function, how the function uses it forces the type to be resolved to either scalar or array. `gawk` and the MKS `awk` do this:

```
$ gawk -v A=0 -f funky.awk
⊣ <>
$ gawk -v A=1 -f funky.awk
⊣ 1
```

POSIX does not specify the correct behavior, so be aware that different implementations work differently.

9.3.2 Dynamic Typing In `gawk`

Hc Svnt Dracones ("Here be dragons")
—*The Lenox Globe*

Things in `gawk` can be a little more unexpected. Because `gawk` allows arrays of arrays, the same dynamic typing can be applied to array elements that have been created but not used.

```
BEGIN {
    funky(a[1])
```

```
    if (A == 0)
        print "<" a[1] ">"
    else
        print a[1][1]
}

function funky(arr)
{
    if (A == 0)
        arr = 1
    else
        arr[1] = 1
}
```

When run, the results are the same as in the earlier case:

```
$ gawk -v A=0 -f funky2.awk
⊣ <>
$ gawk -v A=1 -f funky2.awk
⊣ 1
```

The `typeof()` function provides us a "window" into `gawk`'s inner workings. Let's see how using a variable or array element can change its type dynamically. Let's start with using a variable as a scalar:

```
BEGIN {
    print typeof(a)         # we don't know what a is yet
    printf("a = %d\n", a)   # use it as a scalar
    print typeof(a)         # now we know it's not an array
}
```

When run:

```
$ gawk -f typing1.awk
⊣ untyped
⊣ a = 0
⊣ unassigned
```

Initially, `a` is `untyped`, since we don't know yet if it's an array or scalar. After using it in the call to `printf()`, we know it's a scalar. However, since it was never given a concrete value (number, string, or regexp), its type is `unassigned`.

`gawk` is peculiar in that we can do the same thing, but change `a` into an array:

```
BEGIN {
    print typeof(a)               # we don't know what a is yet
    a[1]                          # make a into an array
    print typeof(a[1])            # but we don't know what a[1] is yet
    printf("a[1] = %d\n", a[1])   # use it as a scalar
    print typeof(a[1])            # now we know it's not an array
}
```

When run:

```
$ gawk -f typing2.awk
```

```
⊣ untyped
⊣ untyped
⊣ a[1] = 0
⊣ unassigned
```

Normally, passing a variable that has never been used to a built-in function causes it to become a scalar variable (`unassigned`). However, `isarray()` and `typeof()` are different; they do not change their arguments from `untyped` to `unassigned`.

As we saw, this applies to both variables denoted by simple identifiers and array elements that come into existence simply by referencing them:

```
$ gawk 'BEGIN { print typeof(x) }'
⊣ untyped
$ gawk 'BEGIN { print typeof(x["foo"]) }'
⊣ untyped
```

Note that prior to version 5.2, array elements that come into existence simply by referencing them were different, they were automatically forced to be scalars:

```
$ gawk-5.1.1 'BEGIN { print typeof(x) }'
⊣ untyped
$ gawk-5.1.1 'BEGIN { print typeof(x["foo"]) }'
⊣ unassigned
```

To sum up, variables and array elements get their nature (array or scalar) "fixed" upon first use. This can lead to some weird cases, and it is best to avoid taking advantage of `gawk`'s dynamic nature, other than in the standard manner of passing untyped variables and array elements as function parameters.

9.4 A Note On Shadowed Variables

This section discusses some aspects of variable shadowing. Feel free to skip it upon first reading.

The "shadowing" concept is important to know for several reasons.

Name confusion
: Using global identifiers (names) locally can lead to very difficult debugging, it complicates writing, reading and maintaining source code, and it decreases the portability, (sharing or reuse) of a library of `awk` functions.

Preventing shadowing in functions
: It is a best practice to consistently use a naming convention, such as "global variable and function names start with a capital letter and local names begin with lowercase one." This also makes programs easier to follow (see Section 10.1 [Naming Library Function Global Variables], page 248).

Circumventing shadow restrictions in functions
: The `gawk` extension `SYMTAB` provides indirect access to global variables that are or may be shadowed (see `SYMTAB` in Section 7.5.2 [Built-in Variables That Convey Information], page 169). For example:

```
...
foo = "global value"
```

```
...

function test(x,   foo)
{
    # use global value of foo as default
    foo = (x > 0) ? SYMTAB["foo"] : "local value"
    ...
}
```

Solving complex shadowing problems

The `gawk` namespace extension provides robust handling of potential name collisions with global variables and functions (see Chapter 15 [Namespaces in gawk], page 391). Namespaces are useful to prevent shadowing by providing identifiers that are common to a group of functions and effectively shadowed from being referenced by global functions (See `FUNCTAB` in Section 7.5.2 [Built-in Variables That Convey Information], page 169.)

Finally, a shadowing caveat: Variables local to a function are *not* "global" to anything. `SYMTAB` elements refer to all *global* variables and arrays, but not to *local* variables and arrays. If a function `A(argA, localA)` calls another function `B()`, the two variables local to `A()` are *not* accessible in function `B()` or any other function. The global/local distinction is also important to remember when passing arguments to a function called indirectly (see Section 9.5 [Indirect Function Calls], page 238).

9.5 Indirect Function Calls

This section describes an advanced, `gawk`-specific extension.

Often, you may wish to defer the choice of function to call until runtime. For example, you may have different kinds of records, each of which should be processed differently.

Normally, you would have to use a series of `if-else` statements to decide which function to call. By using *indirect* function calls, you can specify the name of the function to call as a string variable, and then call the function. Let's look at an example.

Suppose you have a file with your test scores for the classes you are taking, and you wish to get the sum and the average of your test scores. The first field is the class name. The following fields are the functions to call to process the data, up to a "marker" field '`data:`'. Following the marker, to the end of the record, are the various numeric test scores.

Here is the initial file:

```
Biology_101 sum average data: 87.0 92.4 78.5 94.9
Chemistry_305 sum average data: 75.2 98.3 94.7 88.2
English_401 sum average data: 100.0 95.6 87.1 93.4
```

To process the data, you might write initially:

```
{
    class = $1
    for (i = 2; $i != "data:"; i++) {
        if ($i == "sum")
            sum()   # processes the whole record
        else if ($i == "average")
```

```
            average()
        ...             # and so on
    }
}
```

This style of programming works, but can be awkward. With *indirect* function calls, you tell `gawk` to use the *value* of a variable as the *name* of the function to call.

The syntax is similar to that of a regular function call: an identifier immediately followed by an opening parenthesis, any arguments, and then a closing parenthesis, with the addition of a leading '`@`' character:

```
the_function = "sum"
result = @the_function()   # calls the sum() function
```

Here is a full program that processes the previously shown data, using indirect function calls:

```
# indirectcall.awk --- Demonstrate indirect function calls

# average --- return the average of the values in fields $first - $last

function average(first, last,   sum, i)
{
    sum = 0;
    for (i = first; i <= last; i++)
        sum += $i

    return sum / (last - first + 1)
}

# sum --- return the sum of the values in fields $first - $last

function sum(first, last,   ret, i)
{
    ret = 0;
    for (i = first; i <= last; i++)
        ret += $i

    return ret
}
```

These two functions expect to work on fields; thus, the parameters `first` and `last` indicate where in the fields to start and end. Otherwise, they perform the expected computations and are not unusual:

```
# For each record, print the class name and the requested statistics
{
    class_name = $1
    gsub(/_/, " ", class_name)  # Replace _ with spaces

    # find start
```

```
    for (i = 1; i <= NF; i++) {
        if ($i == "data:") {
            start = i + 1
            break
        }
    }

    printf("%s:\n", class_name)
    for (i = 2; $i != "data:"; i++) {
        the_function = $i
        printf("\t%s: <%s>\n", $i, @the_function(start, NF) "")
    }
    print ""
}
```

This is the main processing for each record. It prints the class name (with underscores replaced with spaces). It then finds the start of the actual data, saving it in `start`. The last part of the code loops through each function name (from `$2` up to the marker, '`data:`'), calling the function named by the field. The indirect function call itself occurs as a parameter in the call to `printf`. (The `printf` format string uses '`%s`' as the format specifier so that we can use functions that return strings, as well as numbers. Note that the result from the indirect call is concatenated with the empty string, in order to force it to be a string value.)

Here is the result of running the program:

```
$ gawk -f indirectcall.awk class_data1
⊣ Biology 101:
⊣     sum: <352.8>
⊣     average: <88.2>
⊣
⊣ Chemistry 305:
⊣     sum: <356.4>
⊣     average: <89.1>
⊣
⊣ English 401:
⊣     sum: <376.1>
⊣     average: <94.025>
```

The ability to use indirect function calls is more powerful than you may think at first. The C and C++ languages provide "function pointers," which are a mechanism for calling a function chosen at runtime. One of the most well-known uses of this ability is the C `qsort()` function, which sorts an array using the famous "quicksort" algorithm (see the Wikipedia article for more information). To use this function, you supply a pointer to a comparison function. This mechanism allows you to sort arbitrary data in an arbitrary fashion.

We can do something similar using `gawk`, like this:

```
# quicksort.awk --- Quicksort algorithm, with user-supplied
#                   comparison function
```

```
# quicksort --- C.A.R. Hoare's quicksort algorithm. See Wikipedia
#               or almost any algorithms or computer science text.

function quicksort(data, left, right, less_than,    i, last)
{
    if (left >= right)  # do nothing if array contains fewer
        return          # than two elements

    quicksort_swap(data, left, int((left + right) / 2))
    last = left
    for (i = left + 1; i <= right; i++)
        if (@less_than(data[i], data[left]))
            quicksort_swap(data, ++last, i)
    quicksort_swap(data, left, last)
    quicksort(data, left, last - 1, less_than)
    quicksort(data, last + 1, right, less_than)
}

# quicksort_swap --- helper function for quicksort, should really be inline

function quicksort_swap(data, i, j,      temp)
{
    temp = data[i]
    data[i] = data[j]
    data[j] = temp
}
```

The `quicksort()` function receives the `data` array, the starting and ending indices to sort (`left` and `right`), and the name of a function that performs a "less than" comparison. It then implements the quicksort algorithm.

To make use of the sorting function, we return to our previous example. The first thing to do is write some comparison functions:

```
# num_lt --- do a numeric less than comparison

function num_lt(left, right)
{
    return ((left + 0) < (right + 0))
}

# num_ge --- do a numeric greater than or equal to comparison

function num_ge(left, right)
{
    return ((left + 0) >= (right + 0))
}
```

The `num_ge()` function is needed to perform a descending sort; when used to perform a "less than" test, it actually does the opposite (greater than or equal to), which yields data sorted in descending order.

Next comes a sorting function. It is parameterized with the starting and ending field numbers and the comparison function. It builds an array with the data and calls `quicksort()` appropriately, and then formats the results as a single string:

```
# do_sort --- sort the data according to `compare'
#             and return it as a string

function do_sort(first, last, compare,      data, i, retval)
{
    delete data
    for (i = 1; first <= last; first++) {
        data[i] = $first
        i++
    }

    quicksort(data, 1, i-1, compare)

    retval = data[1]
    for (i = 2; i in data; i++)
        retval = retval " " data[i]

    return retval
}
```

Finally, the two sorting functions call `do_sort()`, passing in the names of the two comparison functions:

```
# sort --- sort the data in ascending order and return it as a string

function sort(first, last)
{
    return do_sort(first, last, "num_lt")
}

# rsort --- sort the data in descending order and return it as a string

function rsort(first, last)
{
    return do_sort(first, last, "num_ge")
}
```

Here is an extended version of the data file:

```
Biology_101 sum average sort rsort data: 87.0 92.4 78.5 94.9
Chemistry_305 sum average sort rsort data: 75.2 98.3 94.7 88.2
English_401 sum average sort rsort data: 100.0 95.6 87.1 93.4
```

Finally, here are the results when the enhanced program is run:

```
$ gawk -f quicksort.awk -f indirectcall.awk class_data2
⊣ Biology 101:
⊣     sum: <352.8>
⊣     average: <88.2>
⊣     sort: <78.5 87.0 92.4 94.9>
⊣     rsort: <94.9 92.4 87.0 78.5>
⊣
⊣ Chemistry 305:
⊣     sum: <356.4>
⊣     average: <89.1>
⊣     sort: <75.2 88.2 94.7 98.3>
⊣     rsort: <98.3 94.7 88.2 75.2>
⊣
⊣ English 401:
⊣     sum: <376.1>
⊣     average: <94.025>
⊣     sort: <87.1 93.4 95.6 100.0>
⊣     rsort: <100.0 95.6 93.4 87.1>
```

Another example where indirect functions calls are useful can be found in processing arrays. This is described in Section 10.7 [Traversing Arrays of Arrays], page 281.

Remember that you must supply a leading '`@`' in front of an indirect function call.

Starting with version 4.1.2 of `gawk`, indirect function calls may also be used with built-in functions and with extension functions (see Chapter 17 [Writing Extensions for gawk], page 415). There are some limitations when calling built-in functions indirectly, as follows.

- You cannot pass a regular expression constant to a built-in function through an indirect function call. This applies to the `sub()`, `gsub()`, `gensub()`, `match()`, `split()` and `patsplit()` functions. However, you can pass a strongly typed regexp constant (see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127).
- If calling `sub()` or `gsub()`, you may only pass two arguments, since those functions are unusual in that they update their third argument. This means that `$0` will be updated.
- You cannot indirectly call built-in functions that can take `$0` as a default parameter; you must supply an argument instead. For example, you must pass an argument to `length()` if calling it indirectly.
- Calling a built-in function indirectly with the wrong number of arguments for that function causes a fatal error. For example, calling `length()` with two arguments. These errors are found at runtime instead of when `gawk` parses your program, since `gawk` doesn't know until runtime if you have passed the correct number of arguments or not.

`gawk` does its best to make indirect function calls efficient. For example, in the following case:

```
for (i = 1; i <= n; i++)
    @the_function()
```

`gawk` looks up the actual function to call only once.

9.6 Summary

- `awk` provides built-in functions and lets you define your own functions.
- POSIX `awk` provides three kinds of built-in functions: numeric, string, and I/O. `gawk` provides functions that sort arrays, work with values representing time, do bit manipulation, determine variable type (array versus scalar), and internationalize and localize programs. `gawk` also provides several extensions to some of standard functions, typically in the form of additional arguments.
- Functions accept zero or more arguments and return a value. The expressions that provide the argument values are completely evaluated before the function is called. Order of evaluation is not defined. The return value can be ignored.
- The handling of backslash in `sub()` and `gsub()` is not simple. It is more straightforward in `gawk`'s `gensub()` function, but that function still requires care in its use.
- User-defined functions provide important capabilities but come with some syntactic inelegancies. In a function call, there cannot be any space between the function name and the opening left parenthesis of the argument list. Also, there is no provision for local variables, so the convention is to add extra parameters, and to separate them visually from the real parameters by extra whitespace.
- User-defined functions may call other user-defined (and built-in) functions and may call themselves recursively. Function parameters "hide" any global variables of the same names. You cannot use the name of a reserved variable (such as `ARGC`) as the name of a parameter in user-defined functions.
- Scalar values are passed to user-defined functions by value. Array parameters are passed by reference; any changes made by the function to array parameters are thus visible after the function has returned.
- Use the `return` statement to return from a user-defined function. An optional expression becomes the function's return value. Only scalar values may be returned by a function.
- If a variable that has never been used is passed to a user-defined function, how that function treats the variable can set its nature: either scalar or array.
- `gawk` is even more fluid in its designation of variables and array elements as scalars or arrays. However, this can lead to weird situations, so you should tread carefully.
- `gawk` provides indirect function calls using a special syntax. By setting a variable to the name of a function, you can determine at runtime what function will be called at that point in the program. This is equivalent to function pointers in C and C++.

Part II:
Problem Solving with `awk`

10 A Library of awk Functions

Section 9.2 [User-Defined Functions], page 225, describes how to write your own `awk` functions. Writing functions is important, because it allows you to encapsulate algorithms and program tasks in a single place. It simplifies programming, making program development more manageable and making programs more readable.

In their seminal 1976 book, *Software Tools*,[1] Brian Kernighan and P.J. Plauger wrote:

> Good Programming is not learned from generalities, but by seeing how significant programs can be made clean, easy to read, easy to maintain and modify, human-engineered, efficient and reliable, by the application of common sense and good programming practices. Careful study and imitation of good programs leads to better writing.

In fact, they felt this idea was so important that they placed this statement on the cover of their book. Because we believe strongly that their statement is correct, this chapter and Chapter 11 [Practical `awk` Programs], page 285, provide a good-sized body of code for you to read and, we hope, to learn from.

This chapter presents a library of useful `awk` functions. Many of the sample programs presented later in this book use these functions. The functions are presented here in a progression from simple to complex.

Section 11.3.7 [Extracting Programs from Texinfo Source Files], page 323, presents a program that you can use to extract the source code for these example library functions and programs from the Texinfo source for this book. (This has already been done as part of the `gawk` distribution.)

If you have written one or more useful, general-purpose `awk` functions and would like to contribute them to the `awk` user community, see [How to Contribute], page 11, for more information.

The programs in this chapter and in Chapter 11 [Practical `awk` Programs], page 285, freely use `gawk`-specific features. Rewriting these programs for different implementations of `awk` is pretty straightforward:

- Diagnostic error messages are sent to `/dev/stderr`. Use '`| "cat 1>&2"`' instead of '`> "/dev/stderr"`' if your system does not have a `/dev/stderr`, or if you cannot use `gawk`.
- Finally, some of the programs choose to ignore upper- and lowercase distinctions in their input. They do so by assigning one to `IGNORECASE`. You can achieve almost the same effect[2] by adding the following rule to the beginning of the program:

  ```
  # ignore case
  { $0 = tolower($0) }
  ```

  Also, verify that all regexp and string constants used in comparisons use only lowercase letters.

[1] Sadly, almost 50 years later, many of the lessons taught by this book have yet to be learned by a vast number of practicing programmers.

[2] The effects are not identical. Output of the transformed record will be in all lowercase, while `IGNORECASE` preserves the original contents of the input record.

10.1 Naming Library Function Global Variables

Due to the way the `awk` language evolved, variables are either *global* (usable by the entire program) or *local* (usable just by a specific function). There is no intermediate state analogous to `static` variables in C.

Library functions often need to have global variables that they can use to preserve state information between calls to the function—for example, `getopt()`'s variable `_opti` (see Section 10.4 [Processing Command-Line Options], page 266). Such variables are called *private*, as the only functions that need to use them are the ones in the library.

When writing a library function, you should try to choose names for your private variables that will not conflict with any variables used by either another library function or a user's main program. For example, a name like `i` or `j` is not a good choice, because user programs often use variable names like these for their own purposes.

The example programs shown in this chapter all start the names of their private variables with an underscore ('_'). Users generally don't use leading underscores in their variable names, so this convention immediately decreases the chances that the variable names will be accidentally shared with the user's program.

In addition, several of the library functions use a prefix that helps indicate what function or set of functions use the variables—for example, `_pw_byname()` in the user database routines (see Section 10.5 [Reading the User Database], page 273). This convention is recommended, as it even further decreases the chance of inadvertent conflict among variable names. Note that this convention is used equally well for variable names and for private function names.[3]

As a final note on variable naming, if a function makes global variables available for use by a main program, it is a good convention to start those variables' names with a capital letter—for example, `getopt()`'s `Opterr` and `Optind` variables (see Section 10.4 [Processing Command-Line Options], page 266). The leading capital letter indicates that it is global, while the fact that the variable name is not all capital letters indicates that the variable is not one of `awk`'s predefined variables, such as `FS`.

It is also important that *all* variables in library functions that do not need to save state are, in fact, declared local.[4] If this is not done, the variables could accidentally be used in the user's program, leading to bugs that are very difficult to track down:

```
function lib_func(x, y,    l1, l2)
{
    ...
    # some_var should be local but by oversight is not
    use variable some_var
    ...
}
```

A different convention, common in the Tcl community, is to use a single associative array to hold the values needed by the library function(s), or "package." This significantly

[3] Although all the library routines could have been rewritten to use this convention, this was not done, in order to show how our own `awk` programming style has evolved and to provide some basis for this discussion.

[4] `gawk`'s `--dump-variables` command-line option is useful for verifying this.

decreases the number of actual global names in use. For example, the functions described in Section 10.5 [Reading the User Database], page 273, might have used array elements `PW_data["inited"]`, `PW_data["total"]`, `PW_data["count"]`, and `PW_data["awklib"]`, instead of `_pw_inited`, `_pw_awklib`, `_pw_total`, and `_pw_count`.

The conventions presented in this section are exactly that: conventions. You are not required to write your programs this way—we merely recommend that you do so.

Beginning with version 5.0, `gawk` provides a powerful mechanism for solving the problems described in this section: *namespaces*. Namespaces and their use are described in detail in Chapter 15 [Namespaces in `gawk`], page 391.

10.2 General Programming

This section presents a number of functions that are of general programming use.

10.2.1 Converting Strings to Numbers

The `strtonum()` function (see Section 9.1.4 [String-Manipulation Functions], page 200) is a `gawk` extension. The following function provides an implementation for other versions of `awk`:

```
# mystrtonum --- convert string to number

function mystrtonum(str,        ret, n, i, k, c)
{
    if (str ~ /^0[0-7]*$/) {
        # octal
        n = length(str)
        ret = 0
        for (i = 1; i <= n; i++) {
            c = substr(str, i, 1)
            # index() returns 0 if c not in string,
            # includes c == "0"
            k = index("1234567", c)

            ret = ret * 8 + k
        }
    } else if (str ~ /^0[xX][[:xdigit:]]+$/) {
        # hexadecimal
        str = substr(str, 3)    # lop off leading 0x
        n = length(str)
        ret = 0
        for (i = 1; i <= n; i++) {
            c = substr(str, i, 1)
            c = tolower(c)
            # index() returns 0 if c not in string,
            # includes c == "0"
            k = index("123456789abcdef", c)
```

```
            ret = ret * 16 + k
        }
    } else if (str ~ \
  /^[-+]?([0-9]+([.][0-9]*([Ee][0-9]+)?)?|([.][0-9]+([Ee][-+]?[0-9]+)?))$/) {
        # decimal number, possibly floating point
        ret = str + 0
    } else
        ret = "NOT-A-NUMBER"

    return ret
}

# BEGIN {     # gawk test harness
#     a[1] = "25"
#     a[2] = ".31"
#     a[3] = "0123"
#     a[4] = "0xdeadBEEF"
#     a[5] = "123.45"
#     a[6] = "1.e3"
#     a[7] = "1.32"
#     a[8] = "1.32E2"
#
#     for (i = 1; i in a; i++)
#         print a[i], strtonum(a[i]), mystrtonum(a[i])
# }
```

The function first looks for C-style octal numbers (base 8). If the input string matches a regular expression describing octal numbers, then `mystrtonum()` loops through each character in the string. It sets `k` to the index in `"1234567"` of the current octal digit. The return value will either be the same number as the digit, or zero if the character is not there, which will be true for a '`0`'. This is safe, because the regexp test in the `if` ensures that only octal values are converted.

Similar logic applies to the code that checks for and converts a hexadecimal value, which starts with '`0x`' or '`0X`'. The use of `tolower()` simplifies the computation for finding the correct numeric value for each hexadecimal digit.

Finally, if the string matches the (rather complicated) regexp for a regular decimal integer or floating-point number, the computation '`ret = str + 0`' lets `awk` convert the value to a number.

A commented-out test program is included, so that the function can be tested with `gawk` and the results compared to the built-in `strtonum()` function.

10.2.2 Assertions

Look both ways before crossing the Atlantic.
—William (Bill) Robbins

When writing large programs, it is often useful to know that a condition or set of conditions is true. Before proceeding with a particular computation, you make a statement about what you believe to be the case. Such a statement is known as an *assertion*. The

C language provides an <assert.h> header file and corresponding assert() macro that a programmer can use to make assertions. If an assertion fails, the assert() macro arranges to print a diagnostic message describing the condition that should have been true but was not, and then it kills the program. In C, using assert() looks this:

```
#include <assert.h>

int myfunc(int a, double b)
{
     assert(a <= 5 && b >= 17.1);
     ...
}
```

If the assertion fails, the program prints a message similar to this:

```
prog.c:5: assertion failed: a <= 5 && b >= 17.1
```

The C language makes it possible to turn the condition into a string for use in printing the diagnostic message. This is not possible in awk, so this assert() function also requires a string version of the condition that is being tested. Following is the function:

```
# assert --- assert that a condition is true. Otherwise, exit.

function assert(condition, string)
{
    if (! condition) {
        printf("%s:%d: assertion failed: %s\n",
            FILENAME, FNR, string) > "/dev/stderr"
        _assert_exit = 1
        exit 1
    }
}

END {
    if (_assert_exit)
        exit 1
}
```

The assert() function tests the condition parameter. If it is false, it prints a message to standard error, using the string parameter to describe the failed condition. It then sets the variable _assert_exit to one and executes the exit statement. The exit statement jumps to the END rule. If the END rule finds _assert_exit to be true, it exits immediately.

The purpose of the test in the END rule is to keep any other END rules from running. When an assertion fails, the program should exit immediately. If no assertions fail, then _assert_exit is still false when the END rule is run normally, and the rest of the program's END rules execute. For all of this to work correctly, assert.awk must be the first source file read by awk. The function can be used in a program in the following way:

```
function myfunc(a, b)
{
     assert(a <= 5 && b >= 17.1, "a <= 5 && b >= 17.1")
     ...
```

```
}
```

If the assertion fails, you see a message similar to the following:

```
mydata:1357: assertion failed: a <= 5 && b >= 17.1
```

There is a small problem with this version of `assert()`. An `END` rule is automatically added to the program calling `assert()`. Normally, if a program consists of just a `BEGIN` rule, the input files and/or standard input are not read. However, now that the program has an `END` rule, `awk` attempts to read the input data files or standard input (see Section 7.1.4.1 [Startup and Cleanup Actions], page 154), most likely causing the program to hang as it waits for input.

There is a simple workaround to this: make sure that such a `BEGIN` rule always ends with an `exit` statement.

10.2.3 Rounding Numbers

The way `printf` and `sprintf()` (see Section 5.5 [Using `printf` Statements for Fancier Printing], page 106) perform rounding often depends upon the system's C `sprintf()` subroutine. On many machines, `sprintf()` rounding is *unbiased*, which means it doesn't always round a trailing .5 up, contrary to naive expectations. In unbiased rounding, .5 rounds to even, rather than always up, so 1.5 rounds to 2 but 4.5 rounds to 4. This means that if you are using a format that does rounding (e.g., `"%.0f"`), you should check what your system does. The following function does traditional rounding; it might be useful if your `awk`'s `printf` does unbiased rounding:

```
# round.awk --- do normal rounding

function round(x,   ival, aval, fraction)
{
   ival = int(x)    # integer part, int() truncates

   # see if fractional part
   if (ival == x)   # no fraction
      return ival   # ensure no decimals

   if (x < 0) {
      aval = -x     # absolute value
      ival = int(aval)
      fraction = aval - ival
      if (fraction >= .5)
         return int(x) - 1   # -2.5 --> -3
      else
         return int(x)       # -2.3 --> -2
   } else {
      fraction = x - ival
      if (fraction >= .5)
         return ival + 1
      else
         return ival
   }
```

```
}
# test harness
# { print $0, round($0) }
```

A different, more compact implementation of this function is suggested by Jason C. Kwan in this message to the bug-gawk@gnu.org mailing list.

10.2.4 The Cliff Random Number Generator

The Cliff random number generator is a very simple random number generator that "passes the noise sphere test for randomness by showing no structure." It is easily programmed, in less than 10 lines of awk code:

```
# cliff_rand.awk --- generate Cliff random numbers

BEGIN { _cliff_seed = 0.1 }

function cliff_rand()
{
    _cliff_seed = (100 * log(_cliff_seed)) % 1
    if (_cliff_seed < 0)
        _cliff_seed = - _cliff_seed
    return _cliff_seed
}
```

This algorithm requires an initial "seed" of 0.1. Each new value uses the current seed as input for the calculation. If the built-in rand() function (see Section 9.1.3 [Numeric Functions], page 198) isn't random enough, you might try using this function instead.

10.2.5 Translating Between Characters and Numbers

One commercial implementation of awk supplies a built-in function, ord(), which takes a character and returns the numeric value for that character in the machine's character set. If the string passed to ord() has more than one character, only the first one is used.

The inverse of this function is chr() (from the function of the same name in Pascal), which takes a number and returns the corresponding character. Both functions are written very nicely in awk; there is no real reason to build them into the awk interpreter:

```
# ord.awk --- do ord and chr

# Global identifiers:
#    _ord_:        numerical values indexed by characters
#    _ord_init:    function to initialize _ord_

BEGIN    { _ord_init() }

function _ord_init(    low, high, i, t)
{
    low = sprintf("%c", 7) # BEL is ascii 7
    if (low == "\a") {    # regular ascii
        low = 0
```

```
        high = 127
    } else if (sprintf("%c", 128 + 7) == "\a") {
        # ascii, mark parity
        low = 128
        high = 255
    } else {        # ebcdic(!)
        low = 0
        high = 255
    }

    for (i = low; i <= high; i++) {
        t = sprintf("%c", i)
        _ord_[t] = i
    }
}
```

Some explanation of the numbers used by `_ord_init()` is worthwhile. The most prominent character set in use today is ASCII.[5] Although an 8-bit byte can hold 256 distinct values (from 0 to 255), ASCII only defines characters that use the values from 0 to 127.[6] In the now distant past, at least one minicomputer manufacturer used ASCII, but with mark parity, meaning that the leftmost bit in the byte is always 1. This means that on those systems, characters have numeric values from 128 to 255. Finally, large mainframe systems use the EBCDIC character set, which uses all 256 values. There are other character sets in use on some older systems, but they are not really worth worrying about:

```
function ord(str,    c)
{
    # only first character is of interest
    c = substr(str, 1, 1)
    return _ord_[c]
}

function chr(c)
{
    # force c to be numeric by adding 0
    return sprintf("%c", c + 0)
}

#### test code ####
# BEGIN {
#    for (;;) {
#        printf("enter a character: ")
#        if (getline var <= 0)
```

[5] This is changing; many systems use Unicode, a very large character set that includes ASCII as a subset. On systems with full Unicode support, a character can occupy up to 32 bits, making simple tests such as used here prohibitively expensive.

[6] ASCII has been extended in many countries to use the values from 128 to 255 for country-specific characters. If your system uses these extensions, you can simplify `_ord_init()` to loop from 0 to 255.

```
#             break
#         printf("ord(%s) = %d\n", var, ord(var))
#     }
# }
```

An obvious improvement to these functions is to move the code for the `_ord_init` function into the body of the `BEGIN` rule. It was written this way initially for ease of development. There is a "test program" in a `BEGIN` rule, to test the function. It is commented out for production use.

10.2.6 Merging an Array into a String

When doing string processing, it is often useful to be able to join all the strings in an array into one long string. The following function, `join()`, accomplishes this task. It is used later in several of the application programs (see Chapter 11 [Practical awk Programs], page 285).

Good function design is important; this function needs to be general, but it should also have a reasonable default behavior. It is called with an array as well as the beginning and ending indices of the elements in the array to be merged. This assumes that the array indices are numeric—a reasonable assumption, as the array was likely created with `split()` (see Section 9.1.4 [String-Manipulation Functions], page 200):

```
# join.awk --- join an array into a string

function join(array, start, end, sep,    result, i)
{
    if (sep == "")
       sep = " "
    else if (sep == SUBSEP) # magic value
       sep = ""
    result = array[start]
    for (i = start + 1; i <= end; i++)
        result = result sep array[i]
    return result
}
```

An optional additional argument is the separator to use when joining the strings back together. If the caller supplies a nonempty value, `join()` uses it; if it is not supplied, it has a null value. In this case, `join()` uses a single space as a default separator for the strings. If the value is equal to `SUBSEP`, then `join()` joins the strings with no separator between them. `SUBSEP` serves as a "magic" value to indicate that there should be no separation between the component strings.[7]

10.2.7 Managing the Time of Day

The `systime()` and `strftime()` functions described in Section 9.1.6 [Time Functions], page 215, provide the minimum functionality necessary for dealing with the time of day in human-readable form. Although `strftime()` is extensive, the control formats are not necessarily easy to remember or intuitively obvious when reading a program.

[7] It would be nice if `awk` had an assignment operator for concatenation. The lack of an explicit operator for concatenation makes string operations more difficult than they really need to be.

The following function, `getlocaltime()`, populates a user-supplied array with preformatted time information. It returns a string with the current time formatted in the same way as the `date` utility:

```
# getlocaltime.awk --- get the time of day in a usable format

# Returns a string in the format of output of date(1)
# Populates the array argument time with individual values:
#    time["second"]       -- seconds (0 - 59)
#    time["minute"]       -- minutes (0 - 59)
#    time["hour"]         -- hours (0 - 23)
#    time["althour"]      -- hours (0 - 12)
#    time["monthday"]     -- day of month (1 - 31)
#    time["month"]        -- month of year (1 - 12)
#    time["monthname"]    -- name of the month
#    time["shortmonth"]   -- short name of the month
#    time["year"]         -- year modulo 100 (0 - 99)
#    time["fullyear"]     -- full year
#    time["weekday"]      -- day of week (Sunday = 0)
#    time["altweekday"]   -- day of week (Monday = 0)
#    time["dayname"]      -- name of weekday
#    time["shortdayname"] -- short name of weekday
#    time["yearday"]      -- day of year (0 - 365)
#    time["timezone"]     -- abbreviation of timezone name
#    time["ampm"]         -- AM or PM designation
#    time["weeknum"]      -- week number, Sunday first day
#    time["altweeknum"]   -- week number, Monday first day

function getlocaltime(time,    ret, now, i)
{
    # get time once, avoids unnecessary system calls
    now = systime()

    # return date(1)-style output
    ret = strftime("%a %b %e %H:%M:%S %Z %Y", now)

    # clear out target array
    delete time

    # fill in values, force numeric values to be
    # numeric by adding 0
    time["second"]       = strftime("%S", now) + 0
    time["minute"]       = strftime("%M", now) + 0
    time["hour"]         = strftime("%H", now) + 0
    time["althour"]      = strftime("%I", now) + 0
    time["monthday"]     = strftime("%d", now) + 0
    time["month"]        = strftime("%m", now) + 0
```

```
    time["monthname"]    = strftime("%B", now)
    time["shortmonth"]   = strftime("%b", now)
    time["year"]         = strftime("%y", now) + 0
    time["fullyear"]     = strftime("%Y", now) + 0
    time["weekday"]      = strftime("%w", now) + 0
    time["altweekday"]   = strftime("%u", now) + 0
    time["dayname"]      = strftime("%A", now)
    time["shortdayname"] = strftime("%a", now)
    time["yearday"]      = strftime("%j", now) + 0
    time["timezone"]     = strftime("%Z", now)
    time["ampm"]         = strftime("%p", now)
    time["weeknum"]      = strftime("%U", now) + 0
    time["altweeknum"]   = strftime("%W", now) + 0

    return ret
}
```

The string indices are easier to use and read than the various formats required by `strftime()`. The `alarm` program presented in Section 11.3.2 [An Alarm Clock Program], page 314, uses this function. A more general design for the `getlocaltime()` function would have allowed the user to supply an optional timestamp value to use instead of the current time.

10.2.8 Reading a Whole File at Once

Often, it is convenient to have the entire contents of a file available in memory as a single string. A straightforward but naive way to do that might be as follows:

```
function readfile1(file,    tmp, contents)
{
    if ((getline tmp < file) < 0)
        return

    contents = tmp RT
    while ((getline tmp < file) > 0)
        contents = contents tmp RT

    close(file)
    return contents
}
```

This function reads from `file` one record at a time, building up the full contents of the file in the local variable `contents`. It works, but is not necessarily efficient.

The following function, based on a suggestion by Denis Shirokov, reads the entire contents of the named file in one shot:

```
# readfile.awk --- read an entire file at once

function readfile(file,     tmp, save_rs)
{
    save_rs = RS
```

```
    RS = "^$"
    getline tmp < file
    close(file)
    RS = save_rs

    return tmp
}
```

It works by setting `RS` to '`^$`', a regular expression that will never match if the file has contents. `gawk` reads data from the file into `tmp`, attempting to match `RS`. The match fails after each read, but fails quickly, such that `gawk` fills `tmp` with the entire contents of the file. (See Section 4.1 [How Input Is Split into Records], page 69, for information on `RT` and `RS`.)

In the case that `file` is empty, the return value is the null string. Thus, calling code may use something like:

```
contents = readfile("/some/path")
if (length(contents) == 0)
    # file was empty ...
```

This tests the result to see if it is empty or not. An equivalent test would be '`contents == ""`'.

See Section 17.7.10 [Reading an Entire File], page 476, for an extension function that also reads an entire file into memory.

10.2.9 Quoting Strings to Pass to the Shell

Michael Brennan offers the following programming pattern, which he uses frequently:

```
#! /bin/sh

awkp='
   ...
   '

input_program | awk "$awkp" | /bin/sh
```

For example, a program of his named `flac-edit` has this form:

```
$ flac-edit -song="Whoope! That's Great" file.flac
```

It generates the following output, which is to be piped to the shell (`/bin/sh`):

```
chmod +w file.flac
metaflac --remove-tag=TITLE file.flac
LANG=en_US.88591 metaflac --set-tag=TITLE='Whoope! That'"'"'s Great' file.flac
chmod -w file.flac
```

Note the need for shell quoting. The function `shell_quote()` does it. `SINGLE` is the one-character string `"'"` and `QSINGLE` is the three-character string `"\"'\""`:

```
# shell_quote --- quote an argument for passing to the shell

function shell_quote(s,             # parameter
    SINGLE, QSINGLE, i, X, n, ret)  # locals
```

```
{
    if (s == "")
        return "\"\""

    SINGLE = "\x27"  # single quote
    QSINGLE = "\"\x27\""
    n = split(s, X, SINGLE)

    ret = SINGLE X[1] SINGLE
    for (i = 2; i <= n; i++)
        ret = ret QSINGLE SINGLE X[i] SINGLE

    return ret
}
```

10.2.10 Checking Whether A Value Is Numeric

A frequent programming question is how to ascertain whether a value is numeric. This can be solved by using this example function `isnumeric()`, which employs the trick of converting a string value to user input by using the `split()` function:

```
# isnumeric --- check whether a value is numeric

function isnumeric(x,  f)
{
    switch (typeof(x)) {
    case "strnum":
    case "number":
        return 1
    case "string":
        return (split(x, f, " ") == 1) && (typeof(f[1]) == "strnum")
    default:
        return 0
    }
}
```

Please note that leading or trailing white space is disregarded in deciding whether a value is numeric or not, so if it matters to you, you may want to add an additional check for that.

Traditionally, it has been recommended to check for numeric values using the test '`x+0 == x`'. This function is superior in two ways: it will not report that unassigned variables contain numeric values; and it recognizes string values with numeric contents where `CONVFMT` does not yield the original string. On the other hand, it uses the `typeof()` function (see Section 9.1.8 [Getting Type Information], page 223), which is specific to `gawk`.

10.2.11 Producing CSV Data

`gawk`'s `--csv` option causes `gawk` to process CSV data (see Section 4.5.4 [Working With Comma Separated Value Files], page 80).

But what if you have regular data that you want to output in CSV format? This section provides functions for doing that.

The first function, `tocsv()`, takes an array of data fields as input. The array should be indexed starting from one. The optional second parameter is the separator to use. If none is supplied, the default is a comma.

The function takes care to quote fields that contain double quotes, newlines, or the separator character. It then builds up the final CSV record and returns it.

```
# tocsv.awk --- convert data to CSV format

function tocsv(fields, sep,     i, j, nfields, result)
{
    if (length(fields) == 0)
        return ""

    if (sep == "")
        sep = ","
    delete nfields
    for (i = 1; i in fields; i++) {
        nfields[i] = fields[i]
        if (nfields[i] ~ /["\n]/ || index(nfields[i], sep) != 0) {
            gsub(/"/, "\"\"", nfields[i])       # double up the double quotes
            nfields[i] = "\"" nfields[i] "\""   # wrap in double quotes
        }
    }

    result = nfields[1]
    j = length(nfields)
    for (i = 2; i <= j; i++)
        result = result sep nfields[i]

    return result
}
```

The next function, `tocsv_rec()` is a wrapper around `tocsv()`. Its intended use is for when you want to convert the current input record to CSV format. The function itself simply copies the fields into an array to pass to `tocsv()` which does the work. It accepts an optional separator character as its first parameter, which it simply passes on to `tocsv()`.

```
function tocsv_rec(sep,     i, fields)
{
    delete fields
    for (i = 1; i <= NF; i++)
        fields[i] = $i

    return tocsv(fields, sep)
}
```

10.3 Data file Management

This section presents functions that are useful for managing command-line data files.

10.3.1 Noting Data file Boundaries

The `BEGIN` and `END` rules are each executed exactly once, at the beginning and end of your `awk` program, respectively (see Section 7.1.4 [The BEGIN and END Special Patterns], page 154). We (the `gawk` authors) once had a user who mistakenly thought that the `BEGIN` rules were executed at the beginning of each data file and the `END` rules were executed at the end of each data file.

When informed that this was not the case, the user requested that we add new special patterns to `gawk`, named `BEGIN_FILE` and `END_FILE`, that would have the desired behavior. He even supplied us the code to do so.

Adding these special patterns to `gawk` wasn't necessary; the job can be done cleanly in `awk` itself, as illustrated by the following library program. It arranges to call two user-supplied functions, `beginfile()` and `endfile()`, at the beginning and end of each data file. Besides solving the problem in only nine(!) lines of code, it does so *portably*; this works with any implementation of `awk`:

```
# transfile.awk
#
# Give the user a hook for filename transitions
#
# The user must supply functions beginfile() and endfile()
# that each take the name of the file being started or
# finished, respectively.

FILENAME != _oldfilename {
    if (_oldfilename != "")
        endfile(_oldfilename)
    _oldfilename = FILENAME
    beginfile(FILENAME)
}

END { endfile(FILENAME) }
```

This file must be loaded before the user's "main" program, so that the rule it supplies is executed first.

This rule relies on `awk`'s `FILENAME` variable, which automatically changes for each new data file. The current file name is saved in a private variable, `_oldfilename`. If `FILENAME` does not equal `_oldfilename`, then a new data file is being processed and it is necessary to call `endfile()` for the old file. Because `endfile()` should only be called if a file has been processed, the program first checks to make sure that `_oldfilename` is not the null string. The program then assigns the current file name to `_oldfilename` and calls `beginfile()` for the file. Because, like all `awk` variables, `_oldfilename` is initialized to the null string, this rule executes correctly even for the first data file.

The program also supplies an `END` rule to do the final processing for the last file. Because this `END` rule comes before any `END` rules supplied in the "main" program, `endfile()` is called first. Once again, the value of multiple `BEGIN` and `END` rules should be clear.

If the same data file occurs twice in a row on the command line, then `endfile()` and `beginfile()` are not executed at the end of the first pass and at the beginning of the second pass. The following version solves the problem:

```
# ftrans.awk --- handle datafile transitions
#
# user supplies beginfile() and endfile() functions

FNR == 1 {
    if (_filename_ != "")
        endfile(_filename_)
    _filename_ = FILENAME
    beginfile(FILENAME)
}

END { endfile(_filename_) }
```

Section 11.2.7 [Counting Things], page 310, shows how this library function can be used and how it simplifies writing the main program.

There is one small catch to how this program works. It relies on the action being executed for the first record in the file. If you happen to process a zero-length file, `FNR` is never set, and `awk` just moves on to the next file in the argument list. If you're worried about this, you'll have to find a workaround.

So Why Does `gawk` Have `BEGINFILE` and `ENDFILE`?

You are probably wondering, if `beginfile()` and `endfile()` functions can do the job, why does `gawk` have `BEGINFILE` and `ENDFILE` patterns?

Good question. Normally, if `awk` cannot open a file, this causes an immediate fatal error. In this case, there is no way for a user-defined function to deal with the problem, as the mechanism for calling it relies on the file being open and at the first record. Thus, the main reason for `BEGINFILE` is to give you a "hook" to catch files that cannot be processed. `ENDFILE` exists for symmetry, and because it provides an easy way to do per-file cleanup processing. For more information, refer to Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155.

One might next ask, so what's the value in `ftrans.awk`? The answer is that it provides a *portable* way to implement beginning-of-file and end-of-file handling. This code should work with any POSIX-compliant version of `awk`.

10.3.2 Rereading the Current File

Another request for a new built-in function was for a function that would make it possible to reread the current file. The requesting user didn't want to have to use `getline` (see Section 4.10 [Explicit Input with `getline`], page 92) inside a loop.

However, as long as you are not in the `END` rule, it is quite easy to arrange to immediately close the current input file and then start over with it from the top. For lack of a better name, we'll call the function `rewind()`:

```
# rewind.awk --- rewind the current file and start over

function rewind(    i)
{
    # shift remaining arguments up
    for (i = ARGC; i > ARGIND; i--)
        ARGV[i] = ARGV[i-1]

    # make sure gawk knows to keep going
    ARGC++

    # make current file next to get done
    ARGV[ARGIND+1] = FILENAME

    # do it
    nextfile
}
```

The `rewind()` function relies on the `ARGIND` variable (see Section 7.5.2 [Built-in Variables That Convey Information], page 169), which is specific to `gawk`. It also relies on the `nextfile` keyword (see Section 7.4.9 [The `nextfile` Statement], page 165). Because of this, you should not call it from an `ENDFILE` rule. (This isn't necessary anyway, because `gawk` goes to the next file as soon as an `ENDFILE` rule finishes!)

You need to be careful calling `rewind()`. You can end up causing infinite recursion if you don't pay attention. Here is an example use:

```
$ cat data
⊣ a
⊣ b
⊣ c
⊣ d
⊣ e

$ cat test.awk
⊣ FNR == 3 && ! rewound {
⊣    rewound = 1
⊣    rewind()
⊣ }
⊣
⊣ { print FILENAME, FNR, $0 }

$ gawk -f rewind.awk -f test.awk data
⊣ data 1 a
⊣ data 2 b
⊣ data 1 a
```

```
⊣ data 2 b
⊣ data 3 c
⊣ data 4 d
⊣ data 5 e
```

10.3.3 Checking for Readable Data files

Normally, if you give `awk` a data file that isn't readable, it stops with a fatal error. There are times when you might want to just ignore such files and keep going.[8] You can do this by prepending the following program to your `awk` program:

```
# readable.awk --- library file to skip over unreadable files

BEGIN {
    for (i = 1; i < ARGC; i++) {
        if (ARGV[i] ~ /^[a-zA-Z_][a-zA-Z0-9_]*=.*/ \
            || ARGV[i] == "-" || ARGV[i] == "/dev/stdin")
            continue    # assignment or standard input
        else if ((getline junk < ARGV[i]) < 0) # unreadable
            delete ARGV[i]
        else
            close(ARGV[i])
    }
}
```

This works, because the `getline` won't be fatal. Removing the element from `ARGV` with `delete` skips the file (because it's no longer in the list). See also Section 7.5.3 [Using ARGC and ARGV], page 177.

Because `awk` variable names only allow the English letters, the regular expression check purposely does not use character classes such as '`[:alpha:]`' and '`[:alnum:]`' (see Section 3.4 [Using Bracket Expressions], page 60).

10.3.4 Checking for Zero-Length Files

All known `awk` implementations silently skip over zero-length files. This is a by-product of `awk`'s implicit read-a-record-and-match-against-the-rules loop: when `awk` tries to read a record from an empty file, it immediately receives an end-of-file indication, closes the file, and proceeds on to the next command-line data file, *without* executing any user-level `awk` program code.

Using `gawk`'s `ARGIND` variable (see Section 7.5 [Predefined Variables], page 167), it is possible to detect when an empty data file has been skipped. Similar to the library file presented in Section 10.3.1 [Noting Data file Boundaries], page 261, the following library file calls a function named `zerofile()` that the user must provide. The arguments passed are the file name and the position in `ARGV` where it was found:

```
# zerofile.awk --- library file to process empty input files
#
```

[8] The `BEGINFILE` special pattern (see Section 7.1.5 [The BEGINFILE and ENDFILE Special Patterns], page 155) provides an alternative mechanism for dealing with files that can't be opened. However, the code here provides a portable solution.

```
# user supplies zerofile() function

BEGIN { Argind = 0 }

ARGIND > Argind + 1 {
    for (Argind++; Argind < ARGIND; Argind++)
        zerofile(ARGV[Argind], Argind)
}

ARGIND != Argind { Argind = ARGIND }

END {
    if (ARGIND > Argind)
        for (Argind++; Argind <= ARGIND; Argind++)
            zerofile(ARGV[Argind], Argind)
}
```

The user-level variable `Argind` allows the `awk` program to track its progress through `ARGV`. Whenever the program detects that `ARGIND` is greater than '`Argind + 1`', it means that one or more empty files were skipped. The action then calls `zerofile()` for each such file, incrementing `Argind` along the way.

The '`Argind != ARGIND`' rule simply keeps `Argind` up to date in the normal case.

Finally, the `END` rule catches the case of any empty files at the end of the command-line arguments. Note that the test in the condition of the `for` loop uses the '`<=`' operator, not '`<`'.

What if you're not using `gawk`? You can write a separate `BEGIN` rule that loops over the files named in `ARGV` and attempts to read a record with `getline`. If `getline` immediately returns zero (end of file), the file exists but is empty. You can then delete it from `ARGV`, issue a warning, or do anything else you think is appropriate.

Also, we note that this library routine was written when `gawk` (like its maintainer) was considerably younger. In modern versions, you could instead write it like this:

```
ENDFILE {
    if (FNR == 0)
            zerofile(FILENAME, ARGIND)
}
```

(With thanks to Andrew Schorr.)

10.3.5 Treating Assignments as File names

Occasionally, you might not want `awk` to process command-line variable assignments (see Section 6.1.3.2 [Assigning Variables on the Command Line], page 129). In particular, if you have a file name that contains an '`=`' character, `awk` treats the file name as an assignment and does not process it.

Some users have suggested an additional command-line option for `gawk` to disable command-line assignments. However, some simple programming with a library file does the trick:

```
# noassign.awk --- library file to avoid the need for a
```

```
# special option that disables command-line assignments

function disable_assigns(argc, argv,    i)
{
    for (i = 1; i < argc; i++)
        if (argv[i] ~ /^[a-zA-Z_][a-zA-Z0-9_]*=.*/)
            argv[i] = ("./" argv[i])
}

BEGIN {
    if (No_command_assign)
        disable_assigns(ARGC, ARGV)
}
```

You then run your program this way:

```
awk -v No_command_assign=1 -f noassign.awk -f yourprog.awk *
```

The function works by looping through the arguments. It prepends '`./`' to any argument that matches the form of a variable assignment, turning that argument into a file name.

The use of `No_command_assign` allows you to disable command-line assignments at invocation time, by giving the variable a true value. When not set, it is initially zero (i.e., false), so the command-line arguments are left alone.

10.4 Processing Command-Line Options

Most utilities on POSIX-compatible systems take options on the command line that can be used to change the way a program behaves. `awk` is an example of such a program (see Section 2.2 [Command-Line Options], page 33). Often, options take *arguments* (i.e., data that the program needs to correctly obey the command-line option). For example, `awk`'s `-F` option requires a string to use as the field separator. The first occurrence on the command line of either `--` or a string that does not begin with '`-`' ends the options.

Modern Unix systems provide a C function named `getopt()` for processing command-line arguments. The programmer provides a string describing the one-letter options. If an option requires an argument, it is followed in the string with a colon. `getopt()` is also passed the count and values of the command-line arguments and is called in a loop. `getopt()` processes the command-line arguments for option letters. Each time around the loop, it returns a single character representing the next option letter that it finds, or '`?`' if it finds an invalid option. When it returns -1, there are no options left on the command line.

When using `getopt()`, options that do not take arguments can be grouped together. Furthermore, options that take arguments require that the argument be present. The argument can immediately follow the option letter, or it can be a separate command-line argument.

Given a hypothetical program that takes three command-line options, `-a`, `-b`, and `-c`, where `-b` requires an argument, all of the following are valid ways of invoking the program:

```
prog -a -b foo -c data1 data2 data3
prog -ac -bfoo -- data1 data2 data3
```

```
prog -acbfoo data1 data2 data3
```

Notice that when the argument is grouped with its option, the rest of the argument is considered to be the option's argument. In this example, `-acbfoo` indicates that all of the `-a`, `-b`, and `-c` options were supplied, and that '`foo`' is the argument to the `-b` option.

`getopt()` provides four external variables that the programmer can use:

`optind` The index in the argument value array (`argv`) where the first nonoption command-line argument can be found.

`optarg` The string value of the argument to an option.

`opterr` Usually `getopt()` prints an error message when it finds an invalid option. Setting `opterr` to zero disables this feature. (An application might want to print its own error message.)

`optopt` The letter representing the command-line option.

The following C fragment shows how `getopt()` might process command-line arguments for `awk`:

```
int
main(int argc, char *argv[])
{
    ...
    /* print our own message */
    opterr = 0;
    while ((c = getopt(argc, argv, "v:f:F:W:")) != -1) {
        switch (c) {
        case 'f':    /* file */
            ...
            break;
        case 'F':    /* field separator */
            ...
            break;
        case 'v':    /* variable assignment */
            ...
            break;
        case 'W':    /* extension */
            ...
            break;
        case '?':
        default:
            usage();
            break;
        }
    }
    ...
}
```

The GNU project's version of the original Unix utilities popularized the use of long command line options. For example, `--help` in addition to `-h`. Arguments to long options

are either provided as separate command line arguments (‘`--source '`*`program-text`*`'`’) or separated from the option with an ‘`=`’ sign (‘`--source='`*`program-text`*`'`’).

As a side point, `gawk` actually uses the GNU `getopt_long()` function to process both normal and GNU-style long options (see Section 2.2 [Command-Line Options], page 33).

The abstraction provided by `getopt()` is very useful and is quite handy in `awk` programs as well. Following is an `awk` version of `getopt()` that accepts both short and long options. (Support for long options was supplied by Greg Minshall. We thank him.)

This function highlights one of the greatest weaknesses in `awk`, which is that it is very poor at manipulating single characters. The function needs repeated calls to `substr()` in order to access individual characters (see Section 9.1.4 [String-Manipulation Functions], page 200).[9]

The discussion that follows walks through the code a bit at a time:

```
# getopt.awk --- Do C library getopt(3) function in awk
#                Also supports long options.

# External variables:
#    Optind -- index in ARGV of first nonoption argument
#    Optarg -- string value of argument to current option
#    Opterr -- if nonzero, print our own diagnostic
#    Optopt -- current option letter

# Returns:
#    -1     at end of options
#    "?"    for unrecognized option
#    <s>    a string representing the current option

# Private Data:
#    _opti  -- index in multiflag option, e.g., -abc
```

The function starts out with comments presenting a list of the global variables it uses, what the return values are, what they mean, and any global variables that are “private” to this library function. Such documentation is essential for any program, and particularly for library functions.

The `getopt()` function first checks that it was indeed called with a string of options (the `options` parameter). If both `options` and `longoptions` have a zero length, `getopt()` immediately returns -1:

```
function getopt(argc, argv, options, longopts,    thisopt, i, j)
{
    if (length(options) == 0 && length(longopts) == 0)
        return -1                   # no options given
```

[9] This function was written before `gawk` acquired the ability to split strings into single characters using `""` as the separator. We have left it alone, as using `substr()` is more portable.

```
if (argv[Optind] == "--") {  # all done
    Optind++
    _opti = 0
    return -1
} else if (argv[Optind] !~ /^-[^:[:space:]]/) {
    _opti = 0
    return -1
}
```

The next thing to check for is the end of the options. A `--` ends the command-line options, as does any command-line argument that does not begin with a '`-`' (unless it is an argument to a preceding option). `Optind` steps through the array of command-line arguments; it retains its value across calls to `getopt()`, because it is a global variable.

The regular expression `/^-[^:[:space:]/` checks for a '`-`' followed by anything that is not whitespace and not a colon. If the current command-line argument does not match this pattern, it is not an option, and it ends option processing. Now, we check to see if we are processing a short (single letter) option, or a long option (indicated by two dashes, e.g., '`--filename`'). If it is a short option, we continue on:

```
if (argv[Optind] !~ /^--/) {        # if this is a short option
    if (_opti == 0)
        _opti = 2
    thisopt = substr(argv[Optind], _opti, 1)
    Optopt = thisopt
    i = index(options, thisopt)
    if (i == 0) {
        if (Opterr)
            printf("%c -- invalid option\n", thisopt) > "/dev/stderr"
        if (_opti >= length(argv[Optind])) {
            Optind++
            _opti = 0
        } else
            _opti++
        return "?"
    }
```

The `_opti` variable tracks the position in the current command-line argument (`argv[Optind]`). If multiple options are grouped together with one '`-`' (e.g., `-abx`), it is necessary to return them to the user one at a time.

If `_opti` is equal to zero, it is set to two, which is the index in the string of the next character to look at (we skip the '`-`', which is at position one). The variable `thisopt` holds the character, obtained with `substr()`. It is saved in `Optopt` for the main program to use.

If `thisopt` is not in the `options` string, then it is an invalid option. If `Opterr` is nonzero, `getopt()` prints an error message on the standard error that is similar to the message from the C version of `getopt()`.

Because the option is invalid, it is necessary to skip it and move on to the next option character. If `_opti` is greater than or equal to the length of the current command-line

argument, it is necessary to move on to the next argument, so `Optind` is incremented and `_opti` is reset to zero. Otherwise, `Optind` is left alone and `_opti` is merely incremented.

In any case, because the option is invalid, `getopt()` returns `"?"`. The main program can examine `Optopt` if it needs to know what the invalid option letter actually is. Continuing on:

```
        if (substr(options, i + 1, 1) == ":") {
            # get option argument
            if (length(substr(argv[Optind], _opti + 1)) > 0)
                Optarg = substr(argv[Optind], _opti + 1)
            else
                Optarg = argv[++Optind]
            _opti = 0
        } else
            Optarg = ""
```

If the option requires an argument, the option letter is followed by a colon in the `options` string. If there are remaining characters in the current command-line argument (`argv[Optind]`), then the rest of that string is assigned to `Optarg`. Otherwise, the next command-line argument is used ('`-xFOO`' versus '`-x FOO`'). In either case, `_opti` is reset to zero, because there are no more characters left to examine in the current command-line argument. Continuing:

```
        if (_opti == 0 || _opti >= length(argv[Optind])) {
            Optind++
            _opti = 0
        } else
            _opti++
        return thisopt
```

Finally, for a short option, if `_opti` is either zero or greater than the length of the current command-line argument, it means this element in `argv` is through being processed, so `Optind` is incremented to point to the next element in `argv`. If neither condition is true, then only `_opti` is incremented, so that the next option letter can be processed on the next call to `getopt()`.

On the other hand, if the earlier test found that this was a long option, we take a different branch:

```
    } else {
        j = index(argv[Optind], "=")
        if (j > 0)
            thisopt = substr(argv[Optind], 3, j - 3)
        else
            thisopt = substr(argv[Optind], 3)
        Optopt = thisopt
```

First, we search this option for a possible embedded equal sign, as the specification of long options allows an argument to an option '`--someopt`' to be specified as '`--someopt=answer`' as well as '`--someopt answer`'.

```
        i = match(longopts, "(^|,)" thisopt "($|[,:])")
        if (i == 0) {
```

```
            if (Opterr)
                 printf("%s -- invalid option\n", thisopt) > "/dev/stderr"
            Optind++
            return "?"
        }
```

Next, we try to find the current option in `longopts`. The regular expression given to `match()`, `"(^|,)" thisopt "($|[,:])"`, matches this option at the beginning of `longopts`, or at the beginning of a subsequent long option (the previous long option would have been terminated by a comma), and, in any case, either at the end of the `longopts` string (‘`$`’), or followed by a comma (separating this option from a subsequent option) or a colon (indicating this long option takes an argument (‘`[,:]`’).

Using this regular expression, we check to see if the current option might possibly be in `longopts` (if `longopts` is not specified, this test will also fail). In case of an error, we possibly print an error message and then return `"?"`. Continuing on:

```
        if (substr(longopts, i-1+RLENGTH, 1) == ":") {
            if (j > 0)
                Optarg = substr(argv[Optind], j + 1)
            else
                Optarg = argv[++Optind]
        } else
            Optarg = ""
```

We now check to see if this option takes an argument and, if so, we set `Optarg` to the value of that argument (either a value after an equal sign specified on the command line, immediately adjoining the long option string, or as the next argument on the command line).

```
        Optind++
        return thisopt
    }
}
```

We increase `Optind` (which we already increased once if a required argument was separated from its option by an equal sign), and return the long option (minus its leading dashes).

The `BEGIN` rule initializes both `Opterr` and `Optind` to one. `Opterr` is set to one, because the default behavior is for `getopt()` to print a diagnostic message upon seeing an invalid option. `Optind` is set to one, because there's no reason to look at the program name, which is in `ARGV[0]`:

```
BEGIN {
    Opterr = 1    # default is to diagnose
    Optind = 1    # skip ARGV[0]

    # test program
    if (_getopt_test) {
        _myshortopts = "ab:cd"
        _mylongopts = "longa,longb:,otherc,otherd"
```

```
        while ((_go_c = getopt(ARGC, ARGV, _myshortopts, _mylongopts)) != -1)
            printf("c = <%s>, Optarg = <%s>\n", _go_c, Optarg)
        printf("non-option arguments:\n")
        for (; Optind < ARGC; Optind++)
            printf("\tARGV[%d] = <%s>\n", Optind, ARGV[Optind])
    }
}
```

The rest of the `BEGIN` rule is a simple test program. Here are the results of some sample runs of the test program:

```
$ awk -f getopt.awk -v _getopt_test=1 -- -a -cbARG bax -x
⊣ c = <a>, Optarg = <>
⊣ c = <c>, Optarg = <>
⊣ c = <b>, Optarg = <ARG>
⊣ non-option arguments:
⊣         ARGV[3] = <bax>
⊣         ARGV[4] = <-x>

$ awk -f getopt.awk -v _getopt_test=1 -- -a -x -- xyz abc
⊣ c = <a>, Optarg = <>
error  x -- invalid option
⊣ c = <?>, Optarg = <>
⊣ non-option arguments:
⊣         ARGV[4] = <xyz>
⊣         ARGV[5] = <abc>

$ awk -f getopt.awk -v _getopt_test=1 -- -a \
> --longa -b xx --longb=foo=bar --otherd --otherc arg1 arg2
⊣ c = <a>, Optarg = <>
⊣ c = <longa>, Optarg = <>
⊣ c = <b>, Optarg = <xx>
⊣ c = <longb>, Optarg = <foo=bar>
⊣ c = <otherd>, Optarg = <>
⊣ c = <otherc>, Optarg = <>
⊣ non-option arguments:
⊣         ARGV[8] = <arg1>
⊣         ARGV[9] = <arg2>
```

In all the runs, the first `--` terminates the arguments to `awk`, so that it does not try to interpret the `-a`, etc., as its own options.

> **NOTE:** After `getopt()` is through, user-level code must clear out all the elements of `ARGV` from 1 to `Optind`, so that `awk` does not try to process the command-line options as file names.

Using '`#!`' with the `-E` option may help avoid conflicts between your program's options and `gawk`'s options, as `-E` causes `gawk` to abandon processing of further options (see Section 1.1.4 [Executable `awk` Programs], page 19, and see Section 2.2 [Command-Line Options], page 33).

Several of the sample programs presented in Chapter 11 [Practical awk Programs], page 285, use getopt() to process their arguments.

10.5 Reading the User Database

The PROCINFO array (see Section 7.5 [Predefined Variables], page 167) provides access to the current user's real and effective user and group ID numbers, and, if available, the user's supplementary group set. However, because these are numbers, they do not provide very useful information to the average user. There needs to be some way to find the user information associated with the user and group ID numbers. This section presents a suite of functions for retrieving information from the user database. See Section 10.6 [Reading the Group Database], page 277, for a similar suite that retrieves information from the group database.

The POSIX standard does not define the file where user information is kept. Instead, it provides the <pwd.h> header file and several C language subroutines for obtaining user information. The primary function is getpwent(), for "get password entry." The "password" comes from the original user database file, /etc/passwd, which stores user information along with the encrypted passwords (hence the name).

Although an awk program could simply read /etc/passwd directly, this file may not contain complete information about the system's set of users.[10] To be sure you are able to produce a readable and complete version of the user database, it is necessary to write a small C program that calls getpwent(). getpwent() is defined as returning a pointer to a struct passwd. Each time it is called, it returns the next entry in the database. When there are no more entries, it returns NULL, the null pointer. When this happens, the C program should call endpwent() to close the database. Following is pwcat, a C program that "cats" the password database:

```
/*
 * pwcat.c
 *
 * Generate a printable version of the password database.
 */
#include <stdio.h>
#include <pwd.h>

int
main(int argc, char **argv)
{
    struct passwd *p;

    while ((p = getpwent()) != NULL)
        printf("%s:%s:%ld:%ld:%s:%s:%s\n",
            p->pw_name, p->pw_passwd, (long) p->pw_uid,
            (long) p->pw_gid, p->pw_gecos, p->pw_dir, p->pw_shell);

    endpwent();
```

[10] It is often the case that password information is stored in a network database.

```
    return 0;
}
```

If you don't understand C, don't worry about it. The output from `pwcat` is the user database, in the traditional `/etc/passwd` format of colon-separated fields. The fields are:

Login name
: The user's login name.

Encrypted password
: The user's encrypted password. This may not be available on some systems.

User-ID
: The user's numeric user ID number. (On some systems, it's a C `long`, and not an `int`. Thus, we cast it to `long` for all cases.)

Group-ID
: The user's numeric group ID number. (Similar comments about `long` versus `int` apply here.)

Full name
: The user's full name, and perhaps other information associated with the user.

Home directory
: The user's login (or "home") directory (familiar to shell programmers as `$HOME`).

Login shell
: The program that is run when the user logs in. This is usually a shell, such as Bash.

A few lines representative of `pwcat`'s output are as follows:

```
$ pwcat
⊣ root:x:0:1:Operator:/:/bin/sh
⊣ nobody:*:65534:65534::/:
⊣ daemon:*:1:1::/:
⊣ sys:*:2:2::/:/bin/csh
⊣ bin:*:3:3::/bin:
⊣ arnold:xyzzy:2076:10:Arnold Robbins:/home/arnold:/bin/sh
⊣ miriam:yxaay:112:10:Miriam Robbins:/home/miriam:/bin/sh
⊣ andy:abcca2:113:10:Andy Jacobs:/home/andy:/bin/sh
...
```

With that introduction, following is a group of functions for getting user information. There are several functions here, corresponding to the C functions of the same names:

```
# passwd.awk --- access password file information

BEGIN {
    # tailor this to suit your system
    _pw_awklib = "/usr/local/libexec/awk/"
}

function _pw_init(    oldfs, oldrs, olddol0, pwcat, using_fw, using_fpat)
{
    if (_pw_inited)
        return
```

```
        oldfs = FS
        oldrs = RS
        olddol0 = $0
        using_fw = (PROCINFO["FS"] == "FIELDWIDTHS")
        using_fpat = (PROCINFO["FS"] == "FPAT")
        FS = ":"
        RS = "\n"

        pwcat = _pw_awklib "pwcat"
        while ((pwcat | getline) > 0) {
            _pw_byname[$1] = $0
            _pw_byuid[$3] = $0
            _pw_bycount[++_pw_total] = $0
        }
        close(pwcat)
        _pw_count = 0
        _pw_inited = 1
        FS = oldfs
        if (using_fw)
            FIELDWIDTHS = FIELDWIDTHS
        else if (using_fpat)
            FPAT = FPAT
        RS = oldrs
        $0 = olddol0
    }
```

The `BEGIN` rule sets a private variable to the directory where `pwcat` is stored. Because it is used to help out an `awk` library routine, we have chosen to put it in `/usr/local/libexec/awk`; however, you might want it to be in a different directory on your system.

The function `_pw_init()` fills three copies of the user information into three associative arrays. The arrays are indexed by username (`_pw_byname`), by user ID number (`_pw_byuid`), and by order of occurrence (`_pw_bycount`). The variable `_pw_inited` is used for efficiency, as `_pw_init()` needs to be called only once.

Because this function uses `getline` to read information from `pwcat`, it first saves the values of `FS`, `RS`, and `$0`. It notes in the variable `using_fw` whether field splitting with `FIELDWIDTHS` is in effect or not. Doing so is necessary, as these functions could be called from anywhere within a user's program, and the user may have his or her own way of splitting records and fields. This makes it possible to restore the correct field-splitting mechanism later. The test can only be true for `gawk`. It is false if using `FS` or `FPAT`, or on some other `awk` implementation.

The code that checks for using `FPAT`, using `using_fpat` and `PROCINFO["FS"]`, is similar.

The main part of the function uses a loop to read database lines, split the lines into fields, and then store the lines into each array as necessary. When the loop is done, `_pw_init()` cleans up by closing the pipeline, setting `_pw_inited` to one, and restoring

`FS` (and `FIELDWIDTHS` or `FPAT` if necessary), `RS`, and `$0`. The use of `_pw_count` is explained shortly.

The `getpwnam()` function takes a username as a string argument. If that user is in the database, it returns the appropriate line. Otherwise, it relies on the array reference to a nonexistent element to create the element with the null string as its value:

```
function getpwnam(name)
{
    _pw_init()
    return _pw_byname[name]
}
```

Similarly, the `getpwuid()` function takes a user ID number argument. If that user number is in the database, it returns the appropriate line. Otherwise, it returns the null string:

```
function getpwuid(uid)
{
    _pw_init()
    return _pw_byuid[uid]
}
```

The `getpwent()` function simply steps through the database, one entry at a time. It uses `_pw_count` to track its current position in the `_pw_bycount` array:

```
function getpwent()
{
    _pw_init()
    if (_pw_count < _pw_total)
        return _pw_bycount[++_pw_count]
    return ""
}
```

The `endpwent()` function resets `_pw_count` to zero, so that subsequent calls to `getpwent()` start over again:

```
function endpwent()
{
    _pw_count = 0
}
```

A conscious design decision in this suite is that each subroutine calls `_pw_init()` to initialize the database arrays. The overhead of running a separate process to generate the user database, and the I/O to scan it, are only incurred if the user's main program actually calls one of these functions. If this library file is loaded along with a user's program, but none of the routines are ever called, then there is no extra runtime overhead. (The alternative is move the body of `_pw_init()` into a `BEGIN` rule, which always runs `pwcat`. This simplifies the code but runs an extra process that may never be needed.)

In turn, calling `_pw_init()` is not too expensive, because the `_pw_inited` variable keeps the program from reading the data more than once. If you are worried about squeezing every last cycle out of your `awk` program, the check of `_pw_inited` could be moved out of `_pw_init()` and duplicated in all the other functions. In practice, this is not necessary, as most `awk` programs are I/O-bound, and such a change would clutter up the code.

The id program in Section 11.2.3 [Printing Out User Information], page 294, uses these functions.

10.6 Reading the Group Database

Much of the discussion presented in Section 10.5 [Reading the User Database], page 273, applies to the group database as well. Although there has traditionally been a well-known file (/etc/group) in a well-known format, the POSIX standard only provides a set of C library routines (<grp.h> and getgrent()) for accessing the information. Even though this file may exist, it may not have complete information. Therefore, as with the user database, it is necessary to have a small C program that generates the group database as its output. grcat, a C program that "cats" the group database, is as follows:

```
/*
 * grcat.c
 *
 * Generate a printable version of the group database.
 */
#include <stdio.h>
#include <grp.h>

int
main(int argc, char **argv)
{
    struct group *g;
    int i;

    while ((g = getgrent()) != NULL) {
        printf("%s:%s:%ld:", g->gr_name, g->gr_passwd,
                                    (long) g->gr_gid);
        for (i = 0; g->gr_mem[i] != NULL; i++) {
            printf("%s", g->gr_mem[i]);
            if (g->gr_mem[i+1] != NULL)
                putchar(',');
        }
        putchar('\n');
    }
    endgrent();
    return 0;
}
```

Each line in the group database represents one group. The fields are separated with colons and represent the following information:

Group Name
: The group's name.

Group Password
: The group's encrypted password. In practice, this field is never used; it is usually empty or set to '*'.

Group ID Number
: The group's numeric group ID number; the association of name to number must be unique within the file. (On some systems it's a C `long`, and not an `int`. Thus, we cast it to `long` for all cases.)

Group Member List
: A comma-separated list of usernames. These users are members of the group. Modern Unix systems allow users to be members of several groups simultaneously. If your system does, then there are elements `"group1"` through `"group`*N*`"` in `PROCINFO` for those group ID numbers. (Note that `PROCINFO` is a `gawk` extension; see Section 7.5 [Predefined Variables], page 167.)

Here is what running `grcat` might produce:

```
$ grcat
⊣ wheel:*:0:arnold
⊣ nogroup:*:65534:
⊣ daemon:*:1:
⊣ kmem:*:2:
⊣ staff:*:10:arnold,miriam,andy
⊣ other:*:20:
...
```

Here are the functions for obtaining information from the group database. There are several, modeled after the C library functions of the same names:

```
# group.awk --- functions for dealing with the group file

BEGIN {
    # Change to suit your system
    _gr_awklib = "/usr/local/libexec/awk/"
}

function _gr_init(    oldfs, oldrs, olddol0, grcat,
                      using_fw, using_fpat, n, a, i)
{
    if (_gr_inited)
        return

    oldfs = FS
    oldrs = RS
    olddol0 = $0
    using_fw = (PROCINFO["FS"] == "FIELDWIDTHS")
    using_fpat = (PROCINFO["FS"] == "FPAT")
    FS = ":"
    RS = "\n"

    grcat = _gr_awklib "grcat"
    while ((grcat | getline) > 0) {
        if ($1 in _gr_byname)
```

```
            _gr_byname[$1] = _gr_byname[$1] "," $4
        else
            _gr_byname[$1] = $0
        if ($3 in _gr_bygid)
            _gr_bygid[$3] = _gr_bygid[$3] "," $4
        else
            _gr_bygid[$3] = $0

        n = split($4, a, "[ \t]*,[ \t]*")
        for (i = 1; i <= n; i++)
            if (a[i] in _gr_groupsbyuser)
                _gr_groupsbyuser[a[i]] = _gr_groupsbyuser[a[i]] " " $1
            else
                _gr_groupsbyuser[a[i]] = $1

        _gr_bycount[++_gr_count] = $0
    }
    close(grcat)
    _gr_count = 0
    _gr_inited++
    FS = oldfs
    if (using_fw)
        FIELDWIDTHS = FIELDWIDTHS
    else if (using_fpat)
        FPAT = FPAT
    RS = oldrs
    $0 = olddol0
}
```

The `BEGIN` rule sets a private variable to the directory where `grcat` is stored. Because it is used to help out an `awk` library routine, we have chosen to put it in `/usr/local/libexec/awk`. You might want it to be in a different directory on your system.

These routines follow the same general outline as the user database routines (see Section 10.5 [Reading the User Database], page 273). The `_gr_inited` variable is used to ensure that the database is scanned no more than once. The `_gr_init()` function first saves `FS`, `RS`, and `$0`, and then sets `FS` and `RS` to the correct values for scanning the group information. It also takes care to note whether `FIELDWIDTHS` or `FPAT` is being used, and to restore the appropriate field-splitting mechanism.

The group information is stored in several associative arrays. The arrays are indexed by group name (`_gr_byname`), by group ID number (`_gr_bygid`), and by position in the database (`_gr_bycount`). There is an additional array indexed by username (`_gr_groupsbyuser`), which is a space-separated list of groups to which each user belongs.

Unlike in the user database, it is possible to have multiple records in the database for the same group. This is common when a group has a large number of members. A pair of such entries might look like the following:

```
tvpeople:*:101:johnny,jay,arsenio
```

```
tvpeople:*:101:david,conan,tom,joan
```

For this reason, `_gr_init()` looks to see if a group name or group ID number is already seen. If so, the usernames are simply concatenated onto the previous list of users.[11]

Finally, `_gr_init()` closes the pipeline to `grcat`, restores `FS` (and `FIELDWIDTHS` or `FPAT`, if necessary), `RS`, and `$0`, initializes `_gr_count` to zero (it is used later), and makes `_gr_inited` nonzero.

The `getgrnam()` function takes a group name as its argument, and if that group exists, it is returned. Otherwise, it relies on the array reference to a nonexistent element to create the element with the null string as its value:

```
function getgrnam(group)
{
    _gr_init()
    return _gr_byname[group]
}
```

The `getgrgid()` function is similar; it takes a numeric group ID and looks up the information associated with that group ID:

```
function getgrgid(gid)
{
    _gr_init()
    return _gr_bygid[gid]
}
```

The `getgruser()` function does not have a C counterpart. It takes a username and returns the list of groups that have the user as a member:

```
function getgruser(user)
{
    _gr_init()
    return _gr_groupsbyuser[user]
}
```

The `getgrent()` function steps through the database one entry at a time. It uses `_gr_count` to track its position in the list:

```
function getgrent()
{
    _gr_init()
    if (++_gr_count in _gr_bycount)
        return _gr_bycount[_gr_count]
    return ""
}
```

The `endgrent()` function resets `_gr_count` to zero so that `getgrent()` can start over again:

```
function endgrent()
{
    _gr_count = 0
```

[11] There is a subtle problem with the code just presented. Suppose that the first time there were no names. This code adds the names with a leading comma. It also doesn't check that there is a `$4`.

```
}
```

As with the user database routines, each function calls `_gr_init()` to initialize the arrays. Doing so only incurs the extra overhead of running `grcat` if these functions are used (as opposed to moving the body of `_gr_init()` into a `BEGIN` rule).

Most of the work is in scanning the database and building the various associative arrays. The functions that the user calls are themselves very simple, relying on `awk`'s associative arrays to do work.

The `id` program in Section 11.2.3 [Printing Out User Information], page 294, uses these functions.

10.7 Traversing Arrays of Arrays

Section 8.6 [Arrays of Arrays], page 193, described how `gawk` provides arrays of arrays. In particular, any element of an array may be either a scalar or another array. The `isarray()` function (see Section 9.1.8 [Getting Type Information], page 223) lets you distinguish an array from a scalar. The following function, `walk_array()`, recursively traverses an array, printing the element indices and values. You call it with the array and a string representing the name of the array:

```
function walk_array(arr, name,      i)
{
    for (i in arr) {
        if (isarray(arr[i]))
            walk_array(arr[i], (name "[" i "]"))
        else
            printf("%s[%s] = %s\n", name, i, arr[i])
    }
}
```

It works by looping over each element of the array. If any given element is itself an array, the function calls itself recursively, passing the subarray and a new string representing the current index. Otherwise, the function simply prints the element's name, index, and value. Here is a main program to demonstrate:

```
BEGIN {
    a[1] = 1
    a[2][1] = 21
    a[2][2] = 22
    a[3] = 3
    a[4][1][1] = 411
    a[4][2] = 42

    walk_array(a, "a")
}
```

When run, the program produces the following output:

```
$ gawk -f walk_array.awk
⊣ a[1] = 1
⊣ a[2][1] = 21
```

```
⊣ a[2][2] = 22
⊣ a[3] = 3
⊣ a[4][1][1] = 411
⊣ a[4][2] = 42
```

The function just presented simply prints the name and value of each scalar array element. However, it is easy to generalize it, by passing in the name of a function to call when walking an array. The modified function looks like this:

```
function process_array(arr, name, process, do_arrays,   i, new_name)
{
    for (i in arr) {
        new_name = (name "[" i "]")
        if (isarray(arr[i])) {
            if (do_arrays)
                @process(new_name, arr[i])
            process_array(arr[i], new_name, process, do_arrays)
        } else
            @process(new_name, arr[i])
    }
}
```

The arguments are as follows:

`arr` The array.

`name` The name of the array (a string).

`process` The name of the function to call.

`do_arrays`
If this is true, the function can handle elements that are subarrays.

If subarrays are to be processed, that is done before walking them further.

When run with the following scaffolding, the function produces the same results as does the earlier version of `walk_array()`:

```
BEGIN {
    a[1] = 1
    a[2][1] = 21
    a[2][2] = 22
    a[3] = 3
    a[4][1][1] = 411
    a[4][2] = 42

    process_array(a, "a", "do_print", 0)
}

function do_print(name, element)
{
    printf "%s = %s\n", name, element
}
```

10.8 Summary

- Reading programs is an excellent way to learn Good Programming. The functions and programs provided in this chapter and the next are intended to serve that purpose.
- When writing general-purpose library functions, put some thought into how to name any global variables so that they won't conflict with variables from a user's program.
- The functions presented here fit into the following categories:

  General problems
  : Number-to-string conversion, testing assertions, rounding, random number generation, converting characters to numbers, joining strings, getting easily usable time-of-day information, and reading a whole file in one shot

  Managing data files
  : Noting data file boundaries, rereading the current file, checking for readable files, checking for zero-length files, and treating assignments as file names

  Processing command-line options
  : An `awk` version of the standard C `getopt()` function

  Reading the user and group databases
  : Two sets of routines that parallel the C library versions

  Traversing arrays of arrays
  : Two functions that traverse an array of arrays to any depth

10.9 Exercises

1. In Section 10.3.4 [Checking for Zero-Length Files], page 264, we presented the `zerofile.awk` program, which made use of `gawk`'s `ARGIND` variable. Can this problem be solved without relying on `ARGIND`? If so, how?
2. As a related challenge, revise that code to handle the case where an intervening value in `ARGV` is a variable assignment.

11 Practical awk Programs

Chapter 10 [A Library of awk Functions], page 247, presents the idea that reading programs in a language contributes to learning that language. This chapter continues that theme, presenting a potpourri of awk programs for your reading enjoyment. There are three sections. The first describes how to run the programs presented in this chapter.

The second presents awk versions of several common POSIX utilities. These are programs that you are hopefully already familiar with, and therefore whose problems are understood. By reimplementing these programs in awk, you can focus on the awk-related aspects of solving the programming problems.

The third is a grab bag of interesting programs. These solve a number of different data-manipulation and management problems. Many of the programs are short, which emphasizes awk's ability to do a lot in just a few lines of code.

Many of these programs use library functions presented in Chapter 10 [A Library of awk Functions], page 247.

11.1 Running the Example Programs

To run a given program, you would typically do something like this:

```
awk -f program -- options files
```

Here, *program* is the name of the awk program (such as cut.awk), *options* are any command-line options for the program that start with a '-', and *files* are the actual data files.

If your system supports the '#!' executable interpreter mechanism (see Section 1.1.4 [Executable awk Programs], page 19), you can instead run your program directly:

```
cut.awk -c1-8 myfiles > results
```

If your awk is not gawk, you may instead need to use this:

```
cut.awk -- -c1-8 myfiles > results
```

11.2 Reinventing Wheels for Fun and Profit

This section presents a number of POSIX utilities implemented in awk. Reinventing these programs in awk is often enjoyable, because the algorithms can be very clearly expressed, and the code is usually very concise and simple. This is true because awk does so much for you.

It should be noted that these programs are not necessarily intended to replace the installed versions on your system. Nor may all of these programs be fully compliant with the most recent POSIX standard. This is not a problem; their purpose is to illustrate awk language programming for "real-world" tasks.

The programs are presented in alphabetical order.

11.2.1 Cutting Out Fields and Columns

The cut utility selects, or "cuts," characters or fields from its standard input and sends them to its standard output. Fields are separated by TABs by default, but you may supply a command-line option to change the field *delimiter* (i.e., the field-separator character). cut's definition of fields is less general than awk's.

A common use of `cut` might be to pull out just the login names of logged-on users from the output of `who`. For example, the following pipeline generates a sorted, unique list of the logged-on users:

```
who | cut -c1-8 | sort | uniq
```

The options for `cut` are:

`-c` *`list`* Use *list* as the list of characters to cut out. Items within the list may be separated by commas, and ranges of characters can be separated with dashes. The list '`1-8,15,22-35`' specifies characters 1 through 8, 15, and 22 through 35.

`-d` *`delim`* Use *delim* as the field-separator character instead of the TAB character.

`-f` *`list`* Use *list* as the list of fields to cut out.

`-s` Suppress printing of lines that do not contain the field delimiter.

The `awk` implementation of `cut` uses the `getopt()` library function (see Section 10.4 [Processing Command-Line Options], page 266) and the `join()` library function (see Section 10.2.6 [Merging an Array into a String], page 255).

The current POSIX version of `cut` has options to cut fields based on both bytes and characters. This version does not attempt to implement those options, as `awk` works exclusively in terms of characters.

The program begins with a comment describing the options, the library functions needed, and a `usage()` function that prints out a usage message and exits. `usage()` is called if invalid arguments are supplied:

```
# cut.awk --- implement cut in awk

# Options:
#    -c list     Cut characters
#    -f list     Cut fields
#    -d c        Field delimiter character
#
#    -s          Suppress lines without the delimiter
#
# Requires getopt() and join() library functions

function usage()
{
    print("usage: cut [-f list] [-d c] [-s] [files...]") > "/dev/stderr"
    print("       cut [-c list] [files...]") > "/dev/stderr"
    exit 1
}
```

Next comes a `BEGIN` rule that parses the command-line options. It sets `FS` to a single TAB character, because that is `cut`'s default field separator. The rule then sets the output field separator to be the same as the input field separator. A loop using `getopt()` steps through the command-line options. Exactly one of the variables `by_fields` or `by_chars` is

set to true, to indicate that processing should be done by fields or by characters, respectively. When cutting by characters, the output field separator is set to the null string:

```
BEGIN {
    FS = "\t"    # default
    OFS = FS
    while ((c = getopt(ARGC, ARGV, "sf:c:d:")) != -1) {
        if (c == "f") {
            by_fields = 1
            fieldlist = Optarg
        } else if (c == "c") {
            by_chars = 1
            fieldlist = Optarg
            OFS = ""
        } else if (c == "d") {
            if (length(Optarg) > 1) {
                printf("cut: using first character of %s" \
                       " for delimiter\n", Optarg) > "/dev/stderr"
                Optarg = substr(Optarg, 1, 1)
            }
            fs = FS = Optarg
            OFS = FS
            if (FS == " ")    # defeat awk semantics
                FS = "[ ]"
        } else if (c == "s")
            suppress = 1
        else
            usage()
    }

    # Clear out options
    for (i = 1; i < Optind; i++)
        ARGV[i] = ""
```

The code must take special care when the field delimiter is a space. Using a single space (`" "`) for the value of `FS` is incorrect—`awk` would separate fields with runs of spaces, TABs, and/or newlines, and we want them to be separated with individual spaces. To this end, we save the original space character in the variable `fs` for later use; after setting `FS` to `"[ ]"` we can't use it directly to see if the field delimiter character is in the string.

Also remember that after `getopt()` is through (as described in Section 10.4 [Processing Command-Line Options], page 266), we have to clear out all the elements of `ARGV` from 1 to `Optind`, so that `awk` does not try to process the command-line options as file names.

After dealing with the command-line options, the program verifies that the options make sense. Only one or the other of `-c` and `-f` should be used, and both require a field list. Then the program calls either `set_fieldlist()` or `set_charlist()` to pull apart the list of fields or characters:

```
    if (by_fields && by_chars)
        usage()
```

```
    if (by_fields == 0 && by_chars == 0)
        by_fields = 1    # default

    if (fieldlist == "") {
        print "cut: needs list for -c or -f" > "/dev/stderr"
        exit 1
    }

    if (by_fields)
        set_fieldlist()
    else
        set_charlist()
}
```

`set_fieldlist()` splits the field list apart at the commas into an array. Then, for each element of the array, it looks to see if the element is actually a range, and if so, splits it apart. The function checks the range to make sure that the first number is smaller than the second. Each number in the list is added to the `flist` array, which simply lists the fields that will be printed. Normal field splitting is used. The program lets `awk` handle the job of doing the field splitting:

```
function set_fieldlist(        n, m, i, j, k, f, g)
{
    n = split(fieldlist, f, ",")
    j = 1    # index in flist
    for (i = 1; i <= n; i++) {
        if (index(f[i], "-") != 0) { # a range
            m = split(f[i], g, "-")
            if (m != 2 || g[1] >= g[2]) {
                printf("cut: bad field list: %s\n",
                                    f[i]) > "/dev/stderr"
                exit 1
            }
            for (k = g[1]; k <= g[2]; k++)
                flist[j++] = k
        } else
            flist[j++] = f[i]
    }
    nfields = j - 1
}
```

The `set_charlist()` function is more complicated than `set_fieldlist()`. The idea here is to use `gawk`'s `FIELDWIDTHS` variable (see Section 4.6 [Reading Fixed-Width Data], page 84), which describes constant-width input. When using a character list, that is exactly what we have.

Setting up `FIELDWIDTHS` is more complicated than simply listing the fields that need to be printed. We have to keep track of the fields to print and also the intervening characters that have to be skipped. For example, suppose you wanted characters 1 through 8, 15, and

22 through 35. You would use '`-c 1-8,15,22-35`'. The necessary value for `FIELDWIDTHS` is `"8 6 1 6 14"`. This yields five fields, and the fields to print are `$1`, `$3`, and `$5`. The intermediate fields are *filler*, which is stuff in between the desired data. `flist` lists the fields to print, and `t` tracks the complete field list, including filler fields:

```
function set_charlist(    field, i, j, f, g, n, m, t,
                          filler, last, len)
{
    field = 1   # count total fields
    n = split(fieldlist, f, ",")
    j = 1       # index in flist
    for (i = 1; i <= n; i++) {
        if (index(f[i], "-") != 0) { # range
            m = split(f[i], g, "-")
            if (m != 2 || g[1] >= g[2]) {
                printf("cut: bad character list: %s\n",
                               f[i]) > "/dev/stderr"
                exit 1
            }
            len = g[2] - g[1] + 1
            if (g[1] > 1)  # compute length of filler
                filler = g[1] - last - 1
            else
                filler = 0
            if (filler)
                t[field++] = filler
            t[field++] = len  # length of field
            last = g[2]
            flist[j++] = field - 1
        } else {
            if (f[i] > 1)
                filler = f[i] - last - 1
            else
                filler = 0
            if (filler)
                t[field++] = filler
            t[field++] = 1
            last = f[i]
            flist[j++] = field - 1
        }
    }
    FIELDWIDTHS = join(t, 1, field - 1)
    nfields = j - 1
}
```

Next is the rule that processes the data. If the `-s` option is given, then `suppress` is true. The first `if` statement makes sure that the input record does have the field separator. If

cut is processing fields, suppress is true, and the field separator character is not in the record, then the record is skipped.

If the record is valid, then gawk has split the data into fields, either using the character in FS or using fixed-length fields and FIELDWIDTHS. The loop goes through the list of fields that should be printed. The corresponding field is printed if it contains data. If the next field also has data, then the separator character is written out between the fields:

```
{
    if (by_fields && suppress && index($0, fs) == 0)
        next

    for (i = 1; i <= nfields; i++) {
        if ($flist[i] != "") {
            printf "%s", $flist[i]
            if (i < nfields && $flist[i+1] != "")
                printf "%s", OFS
        }
    }
    print ""
}
```

This version of cut relies on gawk's FIELDWIDTHS variable to do the character-based cutting. It is possible in other awk implementations to use substr() (see Section 9.1.4 [String-Manipulation Functions], page 200), but it is also extremely painful. The FIELDWIDTHS variable supplies an elegant solution to the problem of picking the input line apart by characters.

11.2.2 Searching for Regular Expressions in Files

The grep family of programs searches files for patterns. These programs have an unusual history. Initially there was grep (Global Regular Expression Print), which used what are now called Basic Regular Expressions (BREs). Later there was egrep (Extended grep) which used what are now called Extended Regular Expressions (EREs). (These are almost identical to those available in awk; see Chapter 3 [Regular Expressions], page 51). There was also fgrep (Fast grep), which searched for matches of one or more fixed strings.

POSIX chose to combine these three programs into one, simply named grep. On a POSIX system, grep's default behavior is to search using BREs. You use -E to specify the use of EREs, and -F to specify searching for fixed strings.

In practice, systems continue to come with separate egrep and fgrep utilities, for backwards compatibility. This section provides an awk implementation of egrep, which supports all of the POSIX-mandated options. You invoke it as follows:

egrep [*options*] '*pattern*' *files* ...

The *pattern* is a regular expression. In typical usage, the regular expression is quoted to prevent the shell from expanding any of the special characters as file name wildcards. Normally, egrep prints the lines that matched. If multiple file names are provided on the command line, each output line is preceded by the name of the file and a colon.

The options to egrep are as follows:

`-c` Print a count of the lines that matched the pattern, instead of the lines themselves.

`-e` *pattern*
Use *pattern* as the regexp to match. The purpose of the `-e` option is to allow patterns that start with a '`-`'.

`-i` Ignore case distinctions in both the pattern and the input data.

`-l` Only print (list) the names of the files that matched, not the lines that matched.

`-q` Be quiet. No output is produced and the exit value indicates whether the pattern was matched.

`-s` Be silent. Do not print error messages for files that could not be opened.

`-v` Invert the sense of the test. `egrep` prints the lines that do *not* match the pattern and exits successfully if the pattern is not matched.

`-x` Match the entire input line in order to consider the match as having succeeded.

This version uses the `getopt()` library function (see Section 10.4 [Processing Command-Line Options], page 266) and `gawk`'s `BEGINFILE` and `ENDFILE` special patterns (see Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155).

The program begins with descriptive comments and then a `BEGIN` rule that processes the command-line arguments with `getopt()`. The `-i` (ignore case) option is particularly easy with `gawk`; we just use the `IGNORECASE` predefined variable (see Section 7.5 [Predefined Variables], page 167):

```
# egrep.awk --- simulate egrep in awk

# Options:
#    -c    count of lines
#    -e    argument is pattern
#    -i    ignore case
#    -l    print filenames only
#    -n    add line number to output
#    -q    quiet - use exit value
#    -s    silent - don't print errors
#    -v    invert test, success if no match
#    -x    the entire line must match
#
# Requires getopt library function
# Uses IGNORECASE, BEGINFILE and ENDFILE
# Invoke using gawk -f egrep.awk -- options ...

BEGIN {
    while ((c = getopt(ARGC, ARGV, "ce:ilnqsvx")) != -1) {
        if (c == "c")
            count_only++
        else if (c == "e")
            pattern = Optarg
```

```
            else if (c == "i")
                IGNORECASE = 1
            else if (c == "l")
                filenames_only++
            else if (c == "n")
                line_numbers++
            else if (c == "q")
                no_print++
            else if (c == "s")
                no_errors++
            else if (c == "v")
                invert++
            else if (c == "x")
                full_line++
            else
                usage()
        }
```

Note the comment about invocation: Because several of the options overlap with `gawk`'s, a `--` is needed to tell `gawk` to stop looking for options.

Next comes the code that handles the `egrep`-specific behavior. `egrep` uses the first nonoption on the command line if no pattern is supplied with `-e`. If the pattern is empty, that means no pattern was supplied, so it's necessary to print an error message and exit. The command-line arguments up to `ARGV[Optind]` are cleared, so that `gawk` won't try to process them as files. If no files are specified, the standard input is used, and if multiple files are specified, we make sure to note this so that the file names can precede the matched lines in the output:

```
        if (pattern == "")
            pattern = ARGV[Optind++]

        if (pattern == "")
          usage()

        for (i = 1; i < Optind; i++)
            ARGV[i] = ""

        if (Optind >= ARGC) {
            ARGV[1] = "-"
            ARGC = 2
        } else if (ARGC - Optind > 1)
            do_filenames++
    }
```

The `BEGINFILE` rule executes when each new file is processed. In this case, it is fairly simple; it initializes a variable `fcount` to zero. `fcount` tracks how many lines in the current file matched the pattern.

Here also is where we implement the `-s` option. We check if `ERRNO` has been set, and if `-s` was supplied. In that case, it's necessary to move on to the next file. Otherwise `gawk` would exit with an error:

```
BEGINFILE {
    fcount = 0
    if (ERRNO && no_errors)
        nextfile
}
```

The `ENDFILE` rule executes after each file has been processed. It affects the output only when the user wants a count of the number of lines that matched. `no_print` is true only if the exit status is desired. `count_only` is true if line counts are desired. `egrep` therefore only prints line counts if printing and counting are enabled. The output format must be adjusted depending upon the number of files to process. Finally, `fcount` is added to `total`, so that we know the total number of lines that matched the pattern:

```
ENDFILE {
    if (! no_print && count_only) {
        if (do_filenames)
            print file ":" fcount
        else
            print fcount
    }

    total += fcount
}
```

The following rule does most of the work of matching lines. The variable `matches` is true (non-zero) if the line matched the pattern. If the user specified that the entire line must match (with `-x`), the code checks this condition by looking at the values of `RSTART` and `RLENGTH`. If those indicate that the match is not over the full line, `matches` is set to zero (false).

If the user wants lines that did not match, we invert the sense of `matches` using the '`!`' operator. We then increment `fcount` with the value of `matches`, which is either one or zero, depending upon a successful or unsuccessful match. If the line does not match, the `next` statement just moves on to the next input line.

We make a number of additional tests, but only if we are not counting lines. First, if the user only wants the exit status (`no_print` is true), then it is enough to know that *one* line in this file matched, and we can skip on to the next file with `nextfile`. Similarly, if we are only printing file names, we can print the file name, and then skip to the next file with `nextfile`. Finally, each line is printed, with a leading file name, optional colon and line number, and the final colon if necessary:

```
{
    matches = match($0, pattern)
    if (matches && full_line && (RSTART != 1 || RLENGTH != length()))
         matches = 0

    if (invert)
```

```
            matches = ! matches

        fcount += matches    # 1 or 0

        if (! matches)
            next

        if (! count_only) {
            if (no_print)
                nextfile

            if (filenames_only) {
                print FILENAME
                nextfile
            }

            if (do_filenames)
                if (line_numbers)
                   print FILENAME ":" FNR ":" $0
                else
                   print FILENAME ":" $0
            else
                print
        }
    }
```

The `END` rule takes care of producing the correct exit status. If there are no matches, the exit status is one; otherwise, it is zero:

```
END {
    exit (total == 0)
}
```

The `usage()` function prints a usage message in case of invalid options, and then exits:

```
function usage()
{
    print("Usage:\tegrep [-cilnqsvx] [-e pat] [files ...]") > "/dev/stderr"
    print("\tegrep [-cilnqsvx] pat [files ...]") > "/dev/stderr"
    exit 1
}
```

11.2.3 Printing Out User Information

The `id` utility lists a user's real and effective user ID numbers, real and effective group ID numbers, and the user's group set, if any. `id` only prints the effective user ID and group ID if they are different from the real ones. If possible, `id` also supplies the corresponding user and group names. The output might look like this:

```
$ id
⊣ uid=1000(arnold) gid=1000(arnold) groups=1000(arnold),4(adm),7(lp),27(sudo)
```

This information is part of what is provided by gawk's PROCINFO array (see Section 7.5 [Predefined Variables], page 167). However, the id utility provides a more palatable output than just individual numbers.

The POSIX version of id takes several options that give you control over the output's format, such as printing only real ids, or printing only numbers or only names. Additionally, you can print the information for a specific user, instead of that of the current user.

Here is a version of POSIX id written in awk. It uses the getopt() library function (see Section 10.4 [Processing Command-Line Options], page 266), the user database library functions (see Section 10.5 [Reading the User Database], page 273), and the group database library functions (see Section 10.6 [Reading the Group Database], page 277) from Chapter 10 [A Library of awk Functions], page 247.

The program is moderately straightforward. All the work is done in the BEGIN rule. It starts with explanatory comments, a list of options, and then a usage() function:

```
# id.awk --- implement id in awk
#
# Requires user and group library functions and getopt

# output is:
# uid=12(foo) euid=34(bar) gid=3(baz) \
#             egid=5(blat) groups=9(nine),2(two),1(one)

# Options:
#   -G Output all group ids as space separated numbers (ruid, euid, groups)
#   -g Output only the euid as a number
#   -n Output name instead of the numeric value (with -g/-G/-u)
#   -r Output ruid/rguid instead of effective id
#   -u Output only effective user id, as a number

function usage()
{
    printf("Usage:\n" \
           "\tid [user]\n" \
           "\tid -G [-n] [user]\n" \
           "\tid -g [-nr] [user]\n" \
           "\tid -u [-nr] [user]\n") > "/dev/stderr"

    exit 1
}
```

The first step is to parse the options using getopt(), and to set various flag variables according to the options given:

```
BEGIN {
    # parse args
    while ((c = getopt(ARGC, ARGV, "Ggnru")) != -1) {
        if (c == "G")
            groupset_only++
```

```
        else if (c == "g")
            egid_only++
        else if (c == "n")
            names_not_groups++
        else if (c == "r")
            real_ids_only++
        else if (c == "u")
            euid_only++
        else
            usage()
    }
```

The next step is to check that no conflicting options were provided. `-G` and `-r` are mutually exclusive. It is also not allowed to provide more than one user name on the command line:

```
    if (groupset_only && real_ids_only)
        usage()
    else if (ARGC - Optind > 1)
        usage()
```

The user and group ID numbers are obtained from `PROCINFO` for the current user, or from the user and password databases for a user supplied on the command line. In the latter case, `real_ids_only` is set, since it's not possible to print information about the effective user and group IDs:

```
    if (ARGC - Optind == 0) {
        # gather info for current user
        uid = PROCINFO["uid"]
        euid = PROCINFO["euid"]
        gid = PROCINFO["gid"]
        egid = PROCINFO["egid"]
        for (i = 1; ("group" i) in PROCINFO; i++)
            groupset[i] = PROCINFO["group" i]
    } else {
        fill_info_for_user(ARGV[ARGC-1])
        real_ids_only++
    }
```

The test in the `for` loop is worth noting. Any supplementary groups in the `PROCINFO` array have the indices `"group1"` through `"group`*N*`"` for some *N* (i.e., the total number of supplementary groups). However, we don't know in advance how many of these groups there are.

This loop works by starting at one, concatenating the value with `"group"`, and then using `in` to see if that value is in the array (see Section 8.1.2 [Referring to an Array Element], page 183). Eventually, `i` increments past the last group in the array and the loop exits.

The loop is also correct if there are *no* supplementary groups; then the condition is false the first time it's tested, and the loop body never executes.

Now, based on the options, we decide what information to print. For `-G` (print just the group set), we then select whether to print names or numbers. In either case, when done we exit:

```
if (groupset_only) {
    if (names_not_groups) {
        for (i = 1; i in groupset; i++) {
            entry = getgrgid(groupset[i])
            name = get_first_field(entry)
            printf("%s", name)
            if ((i + 1) in groupset)
                printf(" ")
        }
    } else {
        for (i = 1; i in groupset; i++) {
            printf("%u", groupset[i])
            if ((i + 1) in groupset)
                printf(" ")
        }
    }

    print ""    # final newline
    exit 0
}
```

Otherwise, for `-g` (effective group ID only), we check if `-r` was also provided, in which case we use the real group ID. Then based on `-n`, we decide whether to print names or numbers. Here too, when done, we exit:

```
else if (egid_only) {
    id = real_ids_only ? gid : egid
    if (names_not_groups) {
        entry = getgrgid(id)
        name = get_first_field(entry)
        printf("%s\n", name)
    } else {
        printf("%u\n", id)
    }

    exit 0
}
```

The `get_first_field()` function extracts the group name from the group database entry for the given group ID.

Similar processing logic applies to `-u` (effective user ID only), combined with `-r` and `-n`:

```
else if (euid_only) {
    id = real_ids_only ? uid : euid
    if (names_not_groups) {
        entry = getpwuid(id)
```

```
            name = get_first_field(entry)
            printf("%s\n", name)
        } else {
            printf("%u\n", id)
        }

        exit 0
    }
```

At this point, we haven't exited yet, so we print the regular, default output, based either on the current user's information, or that of the user whose name was provided on the command line. We start with the real user ID:

```
    printf("uid=%d", uid)
    pw = getpwuid(uid)
    print_first_field(pw)
```

The `print_first_field()` function prints the user's login name from the password file entry, surrounded by parentheses. It is shown soon. Printing the effective user ID is next:

```
    if (euid != uid && ! real_ids_only) {
        printf(" euid=%d", euid)
        pw = getpwuid(euid)
        print_first_field(pw)
    }
```

Similar logic applies to the real and effective group IDs:

```
    printf(" gid=%d", gid)
    pw = getgrgid(gid)
    print_first_field(pw)

    if (egid != gid && ! real_ids_only) {
        printf(" egid=%d", egid)
        pw = getgrgid(egid)
        print_first_field(pw)
    }
```

Finally, we print the group set and the terminating newline:

```
    for (i = 1; i in groupset; i++) {
        if (i == 1)
            printf(" groups=")
        group = groupset[i]
        printf("%d", group)
        pw = getgrgid(group)
        print_first_field(pw)
        if ((i + 1) in groupset)
            printf(",")
    }

    print ""
}
```

The `get_first_field()` function extracts the first field from a password or group file entry for use as a user or group name. Fields are separated by ':' characters:

```
function get_first_field(str,  a)
{
    if (str != "") {
        split(str, a, ":")
        return a[1]
    }
}
```

This function is then used by `print_first_field()` to output the given name surrounded by parentheses:

```
function print_first_field(str)
{
    first = get_first_field(str)
    printf("(%s)", first)
}
```

These two functions simply isolate out some code that is used repeatedly, making the whole program shorter and cleaner. In particular, moving the check for the empty string into `get_first_field()` saves several lines of code.

Finally, `fill_info_for_user()` fetches user, group, and group set information for the user named on the command. The code is fairly straightforward, merely requiring that we exit if the given user doesn't exist:

```
function fill_info_for_user(user,
                            pwent, fields, groupnames, grent, groups, i)
{
    pwent = getpwnam(user)
    if (pwent == "") {
        printf("id: '%s': no such user\n", user) > "/dev/stderr"
        exit 1
    }

    split(pwent, fields, ":")
    uid = fields[3] + 0
    gid = fields[4] + 0
```

Getting the group set is a little awkward. The library routine `getgruser()` returns a list of group *names*. These have to be gone through and turned back into group numbers, so that the rest of the code will work as expected:

```
    groupnames = getgruser(user)
    split(groupnames, groups, " ")
    for (i = 1; i in groups; i++) {
        grent = getgrnam(groups[i])
        split(grent, fields, ":")
        groupset[i] = fields[3] + 0
    }
}
```

11.2.4 Splitting a Large File into Pieces

The `split` utility splits large text files into smaller pieces. The usage follows the POSIX standard for `split` and is as follows:

```
split [-l count] [-a suffix-len] [file [outname]]
split -b N[k|m]] [-a suffix-len] [file [outname]]
```

By default, the output files are named `xaa`, `xab`, and so on. Each file has 1,000 lines in it, with the likely exception of the last file.

The `split` program has evolved over time, and the current POSIX version is more complicated than the original Unix version. The options and what they do are as follows:

`-a` *suffix-len*
: Use *suffix-len* characters for the suffix. For example, if *suffix-len* is four, the output files would range from `xaaaa` to `xzzzz`.

`-b` *N*[`k`|`m`]]
: Instead of each file containing a specified number of lines, each file should have (at most) *N* bytes. Supplying a trailing '`k`' multiplies *N* by 1,024, yielding kilobytes. Supplying a trailing '`m`' multiplies *N* by 1,048,576 ($1,024 \times 1,024$) yielding megabytes. (This option is mutually exclusive with `-l`).

`-l` *count*
: Each file should have at most *count* lines, instead of the default 1,000. (This option is mutually exclusive with `-b`).

If supplied, *file* is the input file to read. Otherwise standard input is processed. If supplied, *outname* is the leading prefix to use for file names, instead of '`x`'.

In order to use the `-b` option, `gawk` should be invoked with its `-b` option (see Section 2.2 [Command-Line Options], page 33), or with the environment variable `LC_ALL` set to '`C`', so that each input byte is treated as a separate character.[1]

Here is an implementation of `split` in `awk`. It uses the `getopt()` function presented in Section 10.4 [Processing Command-Line Options], page 266.

The program begins with a standard descriptive comment and then a `usage()` function describing the options. The variable `common` keeps the function's lines short so that they look nice on the page:

```
# split.awk --- do split in awk
#
# Requires getopt() library function.

function usage(     common)
{
    common = "[-a suffix-len] [file [outname]]"
    printf("usage: split [-l count]  %s\n", common) > "/dev/stderr"
    printf("       split [-b N[k|m]] %s\n", common) > "/dev/stderr"
    exit 1
}
```

[1] Using `-b` twice requires separating `gawk`'s options from those of the program. For example: '`gawk -f getopt.awk -f split.awk -b -- -b 42m large-file.txt split-`'.

Next, in a `BEGIN` rule we set the default values and parse the arguments. After that we initialize the data structures used to cycle the suffix from '`aa...`' to '`zz...`'. Finally we set the name of the first output file:

```
BEGIN {
    # Set defaults:
    Suffix_length = 2
    Line_count = 1000
    Byte_count = 0
    Outfile = "x"

    parse_arguments()

    init_suffix_data()

    Output = (Outfile compute_suffix())
}
```

Parsing the arguments is straightforward. The program follows our convention (see Section 10.1 [Naming Library Function Global Variables], page 248) of having important global variables start with an uppercase letter:

```
function parse_arguments(   i, c, l, modifier)
{
    while ((c = getopt(ARGC, ARGV, "a:b:l:")) != -1) {
        if (c == "a")
            Suffix_length = Optarg + 0
        else if (c == "b") {
            Byte_count = Optarg + 0
            Line_count = 0

            l = length(Optarg)
            modifier = substr(Optarg, l, 1)
            if (modifier == "k")
                Byte_count *= 1024
            else if (modifier == "m")
                Byte_count *= 1024 * 1024
        } else if (c == "l") {
            Line_count = Optarg + 0
            Byte_count = 0
        } else
            usage()
    }

    # Clear out options
    for (i = 1; i < Optind; i++)
        ARGV[i] = ""

    # Check for filename
```

```
        if (ARGV[Optind]) {
            Optind++

            # Check for different prefix
            if (ARGV[Optind]) {
                Outfile = ARGV[Optind]
                ARGV[Optind] = ""

                if (++Optind < ARGC)
                    usage()
            }
        }
    }
```

Managing the file name suffix is interesting. Given a suffix of length three, say, the values go from '`aaa`', '`aab`', '`aac`' and so on, all the way to '`zzx`', '`zzy`', and finally '`zzz`'. There are two important aspects to this:

- We have to be able to easily generate these suffixes, and in particular easily handle "rolling over"; for example, going from '`abz`' to '`aca`'.
- We have to tell when we've finished with the last file, so that if we still have more input data we can print an error message and exit. The trick is to handle this *after* using the last suffix, and not when the final suffix is created.

The computation is handled by `compute_suffix()`. This function is called every time a new file is opened.

The flow here is messy, because we want to generate '`zzzz`' (say), and use it, and only produce an error after all the file name suffixes have been used up. The logical steps are as follows:

1. Generate the suffix, saving the value in `result` to return. To do this, the supplementary array `Suffix_ind` contains one element for each letter in the suffix. Each element ranges from 1 to 26, acting as the index into a string containing all the lowercase letters of the English alphabet. It is initialized by `init_suffix_data()`. `result` is built up one letter at a time, using each `substr()`.
2. Prepare the data structures for the next time `compute_suffix()` is called. To do this, we loop over `Suffix_ind`, *backwards*. If the current element is less than 26, it's incremented and the loop breaks ('`abq`' goes to '`abr`'). Otherwise, the element is reset to one and we move down the list ('`abz`' to '`aca`'). Thus, the `Suffix_ind` array is always "one step ahead" of the actual file name suffix to be returned.
3. Check if we've gone past the limit of possible file names. If `Reached_last` is true, print a message and exit. Otherwise, check if `Suffix_ind` describes a suffix where all the letters are '`z`'. If that's the case we're about to return the final suffix. If so, we set `Reached_last` to true so that the *next* call to `compute_suffix()` will cause a failure.

Physically, the steps in the function occur in the order 3, 1, 2:

```
function compute_suffix(    i, result, letters)
{
    # Logical step 3
```

```
    if (Reached_last) {
        printf("split: too many files!\n") > "/dev/stderr"
        exit 1
    } else if (on_last_file())
        Reached_last = 1    # fail when wrapping after 'zzz'

    # Logical step 1
    result = ""
    letters = "abcdefghijklmnopqrstuvwxyz"
    for (i = 1; i <= Suffix_length; i++)
        result = result substr(letters, Suffix_ind[i], 1)

    # Logical step 2
    for (i = Suffix_length; i >= 1; i--) {
        if (++Suffix_ind[i] > 26) {
            Suffix_ind[i] = 1
        } else
            break
    }

    return result
}
```

The `Suffix_ind` array and `Reached_last` are initialized by `init_suffix_data()`:

```
function init_suffix_data(  i)
{
    for (i = 1; i <= Suffix_length; i++)
        Suffix_ind[i] = 1

    Reached_last = 0
}
```

The function `on_last_file()` returns true if `Suffix_ind` describes a suffix where all the letters are '`z`' by checking that all the elements in the array are equal to 26:

```
function on_last_file(  i, on_last)
{
    on_last = 1
    for (i = 1; i <= Suffix_length; i++) {
        on_last = on_last && (Suffix_ind[i] == 26)
    }

    return on_last
}
```

The actual work of splitting the input file is done by the next two rules. Since splitting by line count and splitting by byte count are mutually exclusive, we simply use two separate rules, one for when `Line_count` is greater than zero, and another for when `Byte_count` is greater than zero.

The variable `tcount` counts how many lines have been processed so far. When it exceeds `Line_count`, it's time to close the previous file and switch to a new one:

```
Line_count > 0 {
    if (++tcount > Line_count) {
        close(Output)
        Output = (Outfile compute_suffix())
        tcount = 1
    }
    print > Output
}
```

The rule for handling bytes is more complicated. Since lines most likely vary in length, the `Byte_count` boundary may be hit in the middle of an input record. In that case, `split` has to write enough of the first bytes of the input record to finish up `Byte_count` bytes, close the file, open a new file, and write the rest of the record to the new file. The logic here does all that:

```
Byte_count > 0 {
    # `+ 1' is for the final newline
    if (tcount + length($0) + 1 > Byte_count) { # would overflow
        # compute leading bytes
        leading_bytes = Byte_count - tcount

        # write leading bytes
        printf("%s", substr($0, 1, leading_bytes)) > Output

        # close old file, open new file
        close(Output)
        Output = (Outfile compute_suffix())

        # set up first bytes for new file
        $0 = substr($0, leading_bytes + 1)  # trailing bytes
        tcount = 0
    }

    # write full record or trailing bytes
    tcount += length($0) + 1
    print > Output
}
```

Finally, the `END` rule cleans up by closing the last output file:

```
END {
    close(Output)
}
```

11.2.5 Duplicating Output into Multiple Files

The `tee` program is known as a "pipe fitting." `tee` copies its standard input to its standard output and also duplicates it to the files named on the command line. Its usage is as follows:

`tee` [`-a`] *file* ...

The `-a` option tells `tee` to append to the named files, instead of truncating them and starting over.

The `BEGIN` rule first makes a copy of all the command-line arguments into an array named `copy`. `ARGV[0]` is not needed, so it is not copied. `tee` cannot use `ARGV` directly, because `awk` attempts to process each file name in `ARGV` as input data.

If the first argument is `-a`, then the flag variable `append` is set to true, and both `ARGV[1]` and `copy[1]` are deleted. If `ARGC` is less than two, then no file names were supplied and `tee` prints a usage message and exits. Finally, `awk` is forced to read the standard input by setting `ARGV[1]` to `"-"` and `ARGC` to two:

```
# tee.awk --- tee in awk
#
# Copy standard input to all named output files.
# Append content if -a option is supplied.

BEGIN {
    for (i = 1; i < ARGC; i++)
        copy[i] = ARGV[i]

    if (ARGV[1] == "-a") {
        append = 1
        delete ARGV[1]
        delete copy[1]
        ARGC--
    }
    if (ARGC < 2) {
        print "usage: tee [-a] file ..." > "/dev/stderr"
        exit 1
    }
    ARGV[1] = "-"
    ARGC = 2
}
```

The following single rule does all the work. Because there is no pattern, it is executed for each line of input. The body of the rule simply prints the line into each file on the command line, and then to the standard output:

```
{
    # moving the if outside the loop makes it run faster
    if (append)
        for (i in copy)
            print >> copy[i]
    else
        for (i in copy)
            print > copy[i]
    print
}
```

It is also possible to write the loop this way:

```
for (i in copy)
    if (append)
        print >> copy[i]
    else
        print > copy[i]
```

This is more concise, but it is also less efficient. The '`if`' is tested for each record and for each output file. By duplicating the loop body, the '`if`' is only tested once for each input record. If there are N input records and M output files, the first method only executes N '`if`' statements, while the second executes $N*M$ '`if`' statements.

Finally, the `END` rule cleans up by closing all the output files:

```
END {
    for (i in copy)
        close(copy[i])
}
```

11.2.6 Printing Nonduplicated Lines of Text

The `uniq` utility reads sorted lines of data on its standard input, and by default removes duplicate lines. In other words, it only prints unique lines—hence the name. `uniq` has a number of options. The usage is as follows:

`uniq` [`-udc` [`-f` *n*] [`-s` *n*]] [*inputfile* [*outputfile*]]

The options for `uniq` are:

`-d`
: Print only repeated (duplicated) lines.

`-u`
: Print only nonrepeated (unique) lines.

`-c`
: Count lines. This option overrides `-d` and `-u`. Both repeated and nonrepeated lines are counted.

`-f` *n*
: Skip *n* fields before comparing lines. The definition of fields is similar to `awk`'s default: nonwhitespace characters separated by runs of spaces and/or TABs.

`-s` *n*
: Skip *n* characters before comparing lines. Any fields specified with `-f` are skipped first.

inputfile
: Data is read from the input file named on the command line, instead of from the standard input.

outputfile
: The generated output is sent to the named output file, instead of to the standard output.

Normally `uniq` behaves as if both the `-d` and `-u` options are provided.

`uniq` uses the `getopt()` library function (see Section 10.4 [Processing Command-Line Options], page 266) and the `join()` library function (see Section 10.2.6 [Merging an Array into a String], page 255).

The program begins with a `usage()` function and then a brief outline of the options and their meanings in comments:

```
# uniq.awk --- do uniq in awk
#
# Requires getopt() and join() library functions

function usage()
{
    print("Usage: uniq [-udc [-f fields] [-s chars]] " \
          "[ in [ out ]]") > "/dev/stderr"
    exit 1
}

# -c    count lines. overrides -d and -u
# -d    only repeated lines
# -u    only nonrepeated lines
# -f n  skip n fields
# -s n  skip n characters, skip fields first
```

The POSIX standard for `uniq` allows options to start with '`+`' as well as with '`-`'. An initial `BEGIN` rule traverses the arguments changing any leading '`+`' to '`-`' so that the `getopt()` function can parse the options:

```
# As of 2020, '+' can be used as the option character in addition to '-'
# Previously allowed use of -N to skip fields and +N to skip
# characters is no longer allowed, and not supported by this version.

BEGIN {
    # Convert + to - so getopt can handle things
    for (i = 1; i < ARGC; i++) {
        first = substr(ARGV[i], 1, 1)
        if (ARGV[i] == "--" || (first != "-" && first != "+"))
            break
        else if (first == "+")
            # Replace "+" with "-"
            ARGV[i] = "-" substr(ARGV[i], 2)
    }
}
```

The next `BEGIN` rule deals with the command-line arguments and options. If no options are supplied, then the default is taken, to print both repeated and nonrepeated lines. The output file, if provided, is assigned to `outputfile`. Early on, `outputfile` is initialized to the standard output, `/dev/stdout`:

```
BEGIN {
    count = 1
    outputfile = "/dev/stdout"
    opts = "udcf:s:"
    while ((c = getopt(ARGC, ARGV, opts)) != -1) {
        if (c == "u")
            non_repeated_only++
        else if (c == "d")
```

```
            repeated_only++
        else if (c == "c")
            do_count++
        else if (c == "f")
            fcount = Optarg + 0
        else if (c == "s")
            charcount = Optarg + 0
        else
            usage()
    }

    for (i = 1; i < Optind; i++)
        ARGV[i] = ""

    if (repeated_only == 0 && non_repeated_only == 0)
        repeated_only = non_repeated_only = 1

    if (ARGC - Optind == 2) {
        outputfile = ARGV[ARGC - 1]
        ARGV[ARGC - 1] = ""
    }
}
```

The following function, `are_equal()`, compares the current line, `$0`, to the previous line, `last`. It handles skipping fields and characters. If no field count and no character count are specified, `are_equal()` returns one or zero depending upon the result of a simple string comparison of `last` and `$0`.

Otherwise, things get more complicated. If fields have to be skipped, each line is broken into an array using `split()` (see Section 9.1.4 [String-Manipulation Functions], page 200); the desired fields are then joined back into a line using `join()`. The joined lines are stored in `clast` and `cline`. If no fields are skipped, `clast` and `cline` are set to `last` and `$0`, respectively. Finally, if characters are skipped, `substr()` is used to strip off the leading `charcount` characters in `clast` and `cline`. The two strings are then compared and `are_equal()` returns the result:

```
function are_equal(    n, m, clast, cline, alast, aline)
{
    if (fcount == 0 && charcount == 0)
        return (last == $0)

    if (fcount > 0) {
        n = split(last, alast)
        m = split($0, aline)
        clast = join(alast, fcount+1, n)
        cline = join(aline, fcount+1, m)
    } else {
        clast = last
        cline = $0
```

```
    }
    if (charcount) {
        clast = substr(clast, charcount + 1)
        cline = substr(cline, charcount + 1)
    }

    return (clast == cline)
}
```

The following two rules are the body of the program. The first one is executed only for the very first line of data. It sets `last` equal to `$0`, so that subsequent lines of text have something to be compared to.

The second rule does the work. The variable `equal` is one or zero, depending upon the results of `are_equal()`'s comparison. If `uniq` is counting repeated lines, and the lines are equal, then it increments the `count` variable. Otherwise, it prints the line and resets `count`, because the two lines are not equal.

If `uniq` is not counting, and if the lines are equal, `count` is incremented. Nothing is printed, as the point is to remove duplicates. Otherwise, if `uniq` is counting repeated lines and more than one line is seen, or if `uniq` is counting nonrepeated lines and only one line is seen, then the line is printed, and `count` is reset.

Finally, similar logic is used in the `END` rule to print the final line of input data:

```
NR == 1 {
    last = $0
    next
}

{
    equal = are_equal()

    if (do_count) {    # overrides -d and -u
        if (equal)
            count++
        else {
            printf("%4d %s\n", count, last) > outputfile
            last = $0
            count = 1    # reset
        }
        next
    }

    if (equal)
        count++
    else {
        if ((repeated_only && count > 1) ||
            (non_repeated_only && count == 1))
                print last > outputfile
        last = $0
```

```
            count = 1
        }
    }

    END {
        if (do_count)
            printf("%4d %s\n", count, last) > outputfile
        else if ((repeated_only && count > 1) ||
                 (non_repeated_only && count == 1))
            print last > outputfile
        close(outputfile)
    }
```

As a side note, this program does not follow our recommended convention of naming global variables with a leading capital letter. Doing that would make the program a little easier to follow.

11.2.7 Counting Things

The `wc` (word count) utility counts lines, words, characters and bytes in one or more input files.

11.2.7.1 Modern Character Sets

In the early days of computing, single bytes were used for storing characters. The most common character sets were ASCII and EBCDIC, which each provided all the English upper- and lowercase letters, the 10 Hindu-Arabic numerals from 0 through 9, and a number of other standard punctuation and control characters.

Today, the most popular character set in use is Unicode (of which ASCII is a pure subset). Unicode provides tens of thousands of unique characters (called *code points*) to cover most existing human languages, living and dead. (Sadly, proposals to add some nonhuman ones, such as Klingon and J.R.R. Tolkien's Elvish languages, were not accepted).

To save space in files, Unicode code points are *encoded*, where each character takes from one to four bytes in the file. UTF-8 is possibly the most popular of such *multibyte encodings*.

The POSIX standard requires that `awk` function in terms of characters, not bytes. Thus in `gawk`, `length()`, `substr()`, `split()`, `match()` and the other string functions (see Section 9.1.4 [String-Manipulation Functions], page 200) all work in terms of characters in the local character set, and not in terms of bytes. (Not all `awk` implementations do so, though).

There is no standard, built-in way to distinguish characters from bytes in an `awk` program. For an `awk` implementation of `wc`, which needs to make such a distinction, we will have to use an external extension.

11.2.7.2 A Brief Introduction To Extensions

Loadable extensions are presented in full detail in Chapter 17 [Writing Extensions for gawk], page 415. They provide a way to add functions to `gawk` which can call out to other facilities written in C or C++.

For the purposes of `wc.awk`, it's enough to know that the extension is loaded with the `@load` directive, and the additional function we will use is called `mbs_length()`. This function returns the number of bytes in a string, not the number of characters.

The `"mbs"` extension comes from the `gawkextlib` project. See Section 17.8 [The gawkextlib Project], page 478, for more information.

11.2.7.3 Code for `wc.awk`

The usage for `wc` is as follows:

```
wc [-lwcm] [files ...]
```

If no files are specified on the command line, `wc` reads its standard input. If there are multiple files, it also prints total counts for all the files. The options and their meanings are as follows:

`-c` Count only bytes. Once upon a time, the 'c' in this option stood for "characters." But, as explained earlier, bytes and character are no longer synonymous with each other.

`-l` Count only lines.

`-m` Count only characters.

`-w` Count only words. A "word" is a contiguous sequence of nonwhitespace characters, separated by spaces and/or TABs. Luckily, this is the normal way `awk` separates fields in its input data.

Implementing `wc` in `awk` is particularly elegant, because `awk` does a lot of the work for us; it splits lines into words (i.e., fields) and counts them, it counts lines (i.e., records), and it can easily tell us how long a line is in characters.

This program uses the `getopt()` library function (see Section 10.4 [Processing Command-Line Options], page 266) and the file-transition functions (see Section 10.3.1 [Noting Data file Boundaries], page 261).

This version has one notable difference from older versions of `wc`: it always prints the counts in the order lines, words, characters and bytes. Older versions note the order of the `-l`, `-w`, and `-c` options on the command line, and print the counts in that order. POSIX does not mandate this behavior, though.

The `BEGIN` rule does the argument processing. The variable `print_total` is true if more than one file is named on the command line:

```
# wc.awk --- count lines, words, characters, bytes

# Options:
#    -l    only count lines
#    -w    only count words
#    -c    only count bytes
#    -m    only count characters
#
# Default is to count lines, words, bytes
#
# Requires getopt() and file transition library functions
```

```
# Requires mbs extension from gawkextlib

@load "mbs"

BEGIN {
    # let getopt() print a message about
    # invalid options. we ignore them
    while ((c = getopt(ARGC, ARGV, "lwcm")) != -1) {
        if (c == "l")
            do_lines = 1
        else if (c == "w")
            do_words = 1
        else if (c == "c")
            do_bytes = 1
        else if (c == "m")
            do_chars = 1
    }
    for (i = 1; i < Optind; i++)
        ARGV[i] = ""

    # if no options, do lines, words, bytes
    if (! do_lines && ! do_words && ! do_chars && ! do_bytes)
        do_lines = do_words = do_bytes = 1

    print_total = (ARGC - i > 1)
}
```

The `beginfile()` function is simple; it just resets the counts of lines, words, characters and bytes to zero, and saves the current file name in `fname`:

```
function beginfile(file)
{
    lines = words = chars = bytes = 0
    fname = FILENAME
}
```

The `endfile()` function adds the current file's numbers to the running totals of lines, words, and characters. It then prints out those numbers for the file that was just read. It relies on `beginfile()` to reset the numbers for the following data file:

```
function endfile(file)
{
    tlines += lines
    twords += words
    tchars += chars
    tbytes += bytes
    if (do_lines)
        printf "\t%d", lines
    if (do_words)
        printf "\t%d", words
```

```
    if (do_chars)
        printf "\t%d", chars
    if (do_bytes)
        printf "\t%d", bytes
    printf "\t%s\n", fname
}
```

There is one rule that is executed for each line. It adds the length of the record, plus one, to `chars`. Adding one plus the record length is needed because the newline character separating records (the value of `RS`) is not part of the record itself, and thus not included in its length. Similarly, it adds the length of the record in bytes, plus one, to `bytes`. Next, `lines` is incremented for each line read, and `words` is incremented by the value of `NF`, which is the number of "words" on this line:

```
# do per line
{
    chars += length($0) + 1    # get newline
    bytes += mbs_length($0) + 1
    lines++
    words += NF
}
```

Finally, the `END` rule simply prints the totals for all the files:

```
END {
    if (print_total) {
        if (do_lines)
            printf "\t%d", tlines
        if (do_words)
            printf "\t%d", twords
        if (do_chars)
            printf "\t%d", tchars
        if (do_bytes)
            printf "\t%d", tbytes
        print "\ttotal"
    }
}
```

11.3 A Grab Bag of awk Programs

This section is a large "grab bag" of miscellaneous programs. We hope you find them both interesting and enjoyable.

11.3.1 Finding Duplicated Words in a Document

A common error when writing large amounts of prose is to accidentally duplicate words. Typically you will see this in text as something like "the the program does the following. . ." When the text is online, often the duplicated words occur at the end of one line and at the the beginning of another, making them very difficult to spot.

This program, `dupword.awk`, scans through a file one line at a time and looks for adjacent occurrences of the same word. It also saves the last word on a line (in the variable `prev`) for comparison with the first word on the next line.

The first two statements make sure that the line is all lowercase, so that, for example, "The" and "the" compare equal to each other. The next statement replaces nonalphanumeric and nonwhitespace characters with spaces, so that punctuation does not affect the comparison either. The characters are replaced with spaces so that formatting controls don't create nonsense words (e.g., the Texinfo '`@code{NF}`' becomes '`codeNF`' if punctuation is simply deleted). The record is then resplit into fields, yielding just the actual words on the line, and ensuring that there are no empty fields.

If there are no fields left after removing all the punctuation, the current record is skipped. Otherwise, the program loops through each word, comparing it to the previous one:

```
# dupword.awk --- find duplicate words in text

{
    $0 = tolower($0)
    gsub(/[^[:alnum:][:blank:]]/, " ");
    $0 = $0         # re-split
    if (NF == 0)
        next
    if ($1 == prev)
        printf("%s:%d: duplicate %s\n",
            FILENAME, FNR, $1)
    for (i = 2; i <= NF; i++)
        if ($i == $(i-1))
            printf("%s:%d: duplicate %s\n",
                FILENAME, FNR, $i)
    prev = $NF
}
```

11.3.2 An Alarm Clock Program

Nothing cures insomnia like a ringing alarm clock.
—*Arnold Robbins*

Sleep is for web developers.
—*Erik Quanstrom*

The following program is a simple "alarm clock" program. You give it a time of day and an optional message. At the specified time, it prints the message on the standard output. In addition, you can give it the number of times to repeat the message as well as a delay between repetitions.

This program uses the `getlocaltime()` function from Section 10.2.7 [Managing the Time of Day], page 255.

All the work is done in the `BEGIN` rule. The first part is argument checking and setting of defaults: the delay, the count, and the message to print. If the user supplied a message without the ASCII BEL character (known as the "alert" character, `"\a"`), then it is added to the message. (On many systems, printing the ASCII BEL generates an audible alert.

Thus, when the alarm goes off, the system calls attention to itself in case the user is not looking at the computer.) Just for a change, this program uses a `switch` statement (see Section 7.4.5 [The `switch` Statement], page 161), but the processing could be done with a series of `if-else` statements instead. Here is the program:

```
# alarm.awk --- set an alarm
#
# Requires getlocaltime() library function

# usage: alarm time [ "message" [ count [ delay ] ] ]

BEGIN {
    # Initial argument sanity checking
    usage1 = "usage: alarm time ['message' [count [delay]]]"
    usage2 = sprintf("\t(%s) time ::= hh:mm", ARGV[1])

    if (ARGC < 2) {
        print usage1 > "/dev/stderr"
        print usage2 > "/dev/stderr"
        exit 1
    }
    switch (ARGC) {
    case 5:
        delay = ARGV[4] + 0
        # fall through
    case 4:
        count = ARGV[3] + 0
        # fall through
    case 3:
        message = ARGV[2]
        break
    default:
        if (ARGV[1] !~ /[[:digit:]]?[[:digit:]]:[[:digit:]]{2}/) {
            print usage1 > "/dev/stderr"
            print usage2 > "/dev/stderr"
            exit 1
        }
        break
    }

    # set defaults for once we reach the desired time
    if (delay == 0)
        delay = 180    # 3 minutes
    if (count == 0)
        count = 5
    if (message == "")
        message = sprintf("\aIt is now %s!\a", ARGV[1])
```

```
else if (index(message, "\a") == 0)
    message = "\a" message "\a"
```

The next section of code turns the alarm time into hours and minutes, converts it (if necessary) to a 24-hour clock, and then turns that time into a count of the seconds since midnight. Next it turns the current time into a count of seconds since midnight. The difference between the two is how long to wait before setting off the alarm:

```
# split up alarm time
split(ARGV[1], atime, ":")
hour = atime[1] + 0    # force numeric
minute = atime[2] + 0  # force numeric

# get current broken down time
getlocaltime(now)

# if time given is 12-hour hours and it's after that
# hour, e.g., `alarm 5:30' at 9 a.m. means 5:30 p.m.,
# then add 12 to real hour
if (hour < 12 && now["hour"] > hour)
    hour += 12

# set target time in seconds since midnight
target = (hour * 60 * 60) + (minute * 60)

# get current time in seconds since midnight
current = (now["hour"] * 60 * 60) + \
           (now["minute"] * 60) + now["second"]

# how long to sleep for
naptime = target - current
if (naptime <= 0) {
    print "alarm: time is in the past!" > "/dev/stderr"
    exit 1
}
```

Finally, the program uses the `system()` function (see Section 9.1.5 [Input/Output Functions], page 211) to call the `sleep` utility. The `sleep` utility simply pauses for the given number of seconds. If the exit status is not zero, the program assumes that `sleep` was interrupted and exits. If `sleep` exited with an OK status (zero), then the program prints the message in a loop, again using `sleep` to delay for however many seconds are necessary:

```
# zzzzzz..... go away if interrupted
if (system(sprintf("sleep %d", naptime)) != 0)
    exit 1

# time to notify!
command = sprintf("sleep %d", delay)
for (i = 1; i <= count; i++) {
    print message
```

```
            # if sleep command interrupted, go away
            if (system(command) != 0)
                break
        }

        exit 0
    }
```

11.3.3 Transliterating Characters

The system `tr` utility transliterates characters. For example, it is often used to map uppercase letters into lowercase for further processing:

```
generate data | tr 'A-Z' 'a-z' | process data ...
```

`tr` requires two lists of characters.[2] When processing the input, the first character in the first list is replaced with the first character in the second list, the second character in the first list is replaced with the second character in the second list, and so on. If there are more characters in the "from" list than in the "to" list, the last character of the "to" list is used for the remaining characters in the "from" list.

Once upon a time, a user proposed adding a transliteration function to `gawk`. The following program was written to prove that character transliteration could be done with a user-level function. This program is not as complete as the system `tr` utility, but it does most of the job.

The `translate` program was written long before `gawk` acquired the ability to split each character in a string into separate array elements. Thus, it makes repeated use of the `substr()`, `index()`, and `gsub()` built-in functions (see Section 9.1.4 [String-Manipulation Functions], page 200). There are two functions. The first, `stranslate()`, takes three arguments:

`from` A list of characters from which to translate

`to` A list of characters to which to translate

`target` The string on which to do the translation

Associative arrays make the translation part fairly easy. `t_ar` holds the "to" characters, indexed by the "from" characters. Then a simple loop goes through `from`, one character at a time. For each character in `from`, if the character appears in `target`, it is replaced with the corresponding `to` character.

The `translate()` function calls `stranslate()`, using `$0` as the target. The main program sets two global variables, `FROM` and `TO`, from the command line, and then changes `ARGV` so that `awk` reads from the standard input.

Finally, the processing rule simply calls `translate()` for each record:

```
# translate.awk --- do tr-like stuff

# Bugs: does not handle things like tr A-Z a-z; it has
```

[2] On some older systems, including Solaris, the system version of `tr` may require that the lists be written as range expressions enclosed in square brackets (‘`[a-z]`’) and quoted, to prevent the shell from attempting a file name expansion. This is not a feature.

```
# to be spelled out. However, if `to' is shorter than `from',
# the last character in `to' is used for the rest of `from'.

function stranslate(from, to, target,     lf, lt, ltarget, t_ar, i, c,
                                                                result)
{
    lf = length(from)
    lt = length(to)
    ltarget = length(target)
    for (i = 1; i <= lt; i++)
        t_ar[substr(from, i, 1)] = substr(to, i, 1)
    if (lt < lf)
        for (; i <= lf; i++)
            t_ar[substr(from, i, 1)] = substr(to, lt, 1)
    for (i = 1; i <= ltarget; i++) {
        c = substr(target, i, 1)
        if (c in t_ar)
            c = t_ar[c]
        result = result c
    }
    return result
}

function translate(from, to)
{
    return $0 = stranslate(from, to, $0)
}

# main program
BEGIN {
    if (ARGC < 3) {
        print "usage: translate from to" > "/dev/stderr"
        exit
    }
    FROM = ARGV[1]
    TO = ARGV[2]
    ARGC = 2
    ARGV[1] = "-"
}

{
    translate(FROM, TO)
    print
}
```

It is possible to do character transliteration in a user-level function, but it is not necessarily efficient, and we (the `gawk` developers) started to consider adding a built-in function.

However, shortly after writing this program, we learned that Brian Kernighan had added the `toupper()` and `tolower()` functions to his `awk` (see Section 9.1.4 [String-Manipulation Functions], page 200). These functions handle the vast majority of the cases where character transliteration is necessary, and so we chose to simply add those functions to `gawk` as well and then leave well enough alone.

An obvious improvement to this program would be to set up the `t_ar` array only once, in a `BEGIN` rule. However, this assumes that the "from" and "to" lists will never change throughout the lifetime of the program.

Another obvious improvement is to enable the use of ranges, such as '`a-z`', as allowed by the `tr` utility. Look at the code for `cut.awk` (see Section 11.2.1 [Cutting Out Fields and Columns], page 285) for inspiration.

11.3.4 Printing Mailing Labels

Here is a "real-world"[3] program. This script reads lists of names and addresses and generates mailing labels. Each page of labels has 20 labels on it, two across and 10 down. The addresses are guaranteed to be no more than five lines of data. Each address is separated from the next by a blank line.

The basic idea is to read 20 labels' worth of data. Each line of each label is stored in the `line` array. The single rule takes care of filling the `line` array and printing the page when 20 labels have been read.

The `BEGIN` rule simply sets `RS` to the empty string, so that `awk` splits records at blank lines (see Section 4.1 [How Input Is Split into Records], page 69). It sets `MAXLINES` to 100, because 100 is the maximum number of lines on the page ($20 \cdot 5 = 100$).

Most of the work is done in the `printpage()` function. The label lines are stored sequentially in the `line` array. But they have to print horizontally: `line[1]` next to `line[6]`, `line[2]` next to `line[7]`, and so on. Two loops accomplish this. The outer loop, controlled by `i`, steps through every 10 lines of data; this is each row of labels. The inner loop, controlled by `j`, goes through the lines within the row. As `j` goes from 0 to 4, '`i+j`' is the `j`th line in the row, and '`i+j+5`' is the entry next to it. The output ends up looking something like this:

```
line 1          line 6
line 2          line 7
line 3          line 8
line 4          line 9
line 5          line 10
...
```

The `printf` format string '`%-41s`' left-aligns the data and prints it within a fixed-width field.

As a final note, an extra blank line is printed at lines 21 and 61, to keep the output lined up on the labels. This is dependent on the particular brand of labels in use when the program was written. You will also note that there are two blank lines at the top and two blank lines at the bottom.

[3] "Real world" is defined as "a program actually used to get something done."

The `END` rule arranges to flush the final page of labels; there may not have been an even multiple of 20 labels in the data:

```
# labels.awk --- print mailing labels

# Each label is 5 lines of data that may have blank lines.
# The label sheets have 2 blank lines at the top and 2 at
# the bottom.

BEGIN    { RS = "" ; MAXLINES = 100 }

function printpage(    i, j)
{
    if (Nlines <= 0)
        return

    printf "\n\n"        # header

    for (i = 1; i <= Nlines; i += 10) {
        if (i == 21 || i == 61)
            print ""
        for (j = 0; j < 5; j++) {
            if (i + j > MAXLINES)
                break
            printf "   %-41s %s\n", line[i+j], line[i+j+5]
        }
        print ""
    }

    printf "\n\n"        # footer

    delete line
}

# main rule
{
    if (Count >= 20) {
        printpage()
        Count = 0
        Nlines = 0
    }
    n = split($0, a, "\n")
    for (i = 1; i <= n; i++)
        line[++Nlines] = a[i]
    for (; i <= 5; i++)
        line[++Nlines] = ""
    Count++
```

```
}

END {
    printpage()
}
```

11.3.5 Generating Word-Usage Counts

When working with large amounts of text, it can be interesting to know how often different words appear. For example, an author may overuse certain words, in which case he or she might wish to find synonyms to substitute for words that appear too often. This subsection develops a program for counting words and presenting the frequency information in a useful format.

At first glance, a program like this would seem to do the job:

```
# wordfreq-first-try.awk --- print list of word frequencies

{
    for (i = 1; i <= NF; i++)
        freq[$i]++
}

END {
    for (word in freq)
        printf "%s\t%d\n", word, freq[word]
}
```

The program relies on `awk`'s default field-splitting mechanism to break each line up into "words" and uses an associative array named `freq`, indexed by each word, to count the number of times the word occurs. In the `END` rule, it prints the counts.

This program has several problems that prevent it from being useful on real text files:

- The `awk` language considers upper- and lowercase characters to be distinct. Therefore, "bartender" and "Bartender" are not treated as the same word. This is undesirable, because words are capitalized if they begin sentences in normal text, and a frequency analyzer should not be sensitive to capitalization.
- Words are detected using the `awk` convention that fields are separated just by whitespace. Other characters in the input (except newlines) don't have any special meaning to `awk`. This means that punctuation characters count as part of words.
- The output does not come out in any useful order. You're more likely to be interested in which words occur most frequently or in having an alphabetized table of how frequently each word occurs.

The first problem can be solved by using `tolower()` to remove case distinctions. The second problem can be solved by using `gsub()` to remove punctuation characters. Finally, we solve the third problem by using the system `sort` utility to process the output of the `awk` script. Here is the new version of the program:

```
# wordfreq.awk --- print list of word frequencies
```

```
{
    $0 = tolower($0)    # remove case distinctions
    # remove punctuation
    gsub(/[^[:alnum:]_[:blank:]]/, "", $0)
    for (i = 1; i <= NF; i++)
        freq[$i]++
}

END {
    for (word in freq)
        printf "%s\t%d\n", word, freq[word]
}
```

The regexp `/[^[:alnum:]_[:blank:]]/` might have been written `/[[:punct:]]/`, but then underscores would also be removed, and we want to keep them.

Assuming we have saved this program in a file named `wordfreq.awk`, and that the data is in `file1`, the following pipeline:

```
awk -f wordfreq.awk file1 | sort -k 2nr
```

produces a table of the words appearing in `file1` in order of decreasing frequency.

The `awk` program suitably massages the data and produces a word frequency table, which is not ordered. The `awk` script's output is then sorted by the `sort` utility and printed on the screen.

The options given to `sort` specify a sort that uses the second field of each input line (skipping one field), that the sort keys should be treated as numeric quantities (otherwise '`15`' would come before '`5`'), and that the sorting should be done in descending (reverse) order.

The `sort` could even be done from within the program, by changing the `END` action to:

```
END {
    sort = "sort -k 2nr"
    for (word in freq)
        printf "%s\t%d\n", word, freq[word] | sort
    close(sort)
}
```

This way of sorting must be used on systems that do not have true pipes at the command-line (or batch-file) level. See the general operating system documentation for more information on how to use the `sort` program.

11.3.6 Removing Duplicates from Unsorted Text

The `uniq` program (see Section 11.2.6 [Printing Nonduplicated Lines of Text], page 306) removes duplicate lines from *sorted* data.

Suppose, however, you need to remove duplicate lines from a data file but that you want to preserve the order the lines are in. A good example of this might be a shell history file. The history file keeps a copy of all the commands you have entered, and it is not unusual to repeat a command several times in a row. Occasionally you might want to compact the history by removing duplicate entries. Yet it is desirable to maintain the order of the original commands.

This simple program does the job. It uses two arrays. The `data` array is indexed by the text of each line. For each line, `data[$0]` is incremented. If a particular line has not been seen before, then `data[$0]` is zero. In this case, the text of the line is stored in `lines[count]`. Each element of `lines` is a unique command, and the indices of `lines` indicate the order in which those lines are encountered. The `END` rule simply prints out the lines, in order:

```
# histsort.awk --- compact a shell history file
# Thanks to Byron Rakitzis for the general idea

{
    if (data[$0]++ == 0)
        lines[++count] = $0
}

END {
    for (i = 1; i <= count; i++)
        print lines[i]
}
```

This program also provides a foundation for generating other useful information. For example, using the following `print` statement in the `END` rule indicates how often a particular command is used:

```
print data[lines[i]], lines[i]
```

This works because `data[$0]` is incremented each time a line is seen.

Rick van Rein offers the following one-liner to do the same job of removing duplicates from unsorted text:

```
awk '{ if (! seen[$0]++) print }'
```

This can be simplified even further, at the risk of becoming almost too obscure:

```
awk '! seen[$0]++'
```

This version uses the expression as a pattern, relying on `awk`'s default action of printing the line when the pattern is true.

11.3.7 Extracting Programs from Texinfo Source Files

Both this chapter and the previous chapter (Chapter 10 [A Library of awk Functions], page 247) present a large number of `awk` programs. If you want to experiment with these programs, it is tedious to type them in by hand. Here we present a program that can extract parts of a Texinfo input file into separate files.

This book is written in Texinfo, the GNU Project's document formatting language. A single Texinfo source file can be used to produce both printed documentation, with TEX, and online documentation. (Texinfo is fully documented in the book *Texinfo—The GNU Documentation Format*, available from the Free Software Foundation, and also available online.)

For our purposes, it is enough to know three things about Texinfo input files:

- The "at" symbol ('`@`') is special in Texinfo, much as the backslash ('\') is in C or `awk`. Literal '`@`' symbols are represented in Texinfo source files as '`@@`'.

- Comments start with either '`@c`' or '`@comment`'. The file-extraction program works by using special comments that start at the beginning of a line.
- Lines containing '`@group`' and '`@end group`' commands bracket example text that should not be split across a page boundary. (Unfortunately, TEX isn't always smart enough to do things exactly right, so we have to give it some help.)

The following program, `extract.awk`, reads through a Texinfo source file and does two things, based on the special comments. Upon seeing '`@c system ...`', it runs a command, by extracting the command text from the control line and passing it on to the `system()` function (see Section 9.1.5 [Input/Output Functions], page 211). Upon seeing '`@c file` *`filename`*', each subsequent line is sent to the file *filename*, until '`@c endfile`' is encountered. The rules in `extract.awk` match either '`@c`' or '`@comment`' by letting the '`omment`' part be optional. Lines containing '`@group`' and '`@end group`' are simply removed. `extract.awk` uses the `join()` library function (see Section 10.2.6 [Merging an Array into a String], page 255).

The example programs in the online Texinfo source for *GAWK: Effective AWK Programming* (`gawk.texi`) have all been bracketed inside '`file`' and '`endfile`' lines. The `gawk` distribution uses a copy of `extract.awk` to extract the sample programs and install many of them in a standard directory where `gawk` can find them. The Texinfo file looks something like this:

```
...
This program has a @code{BEGIN} rule
that prints a nice message:

@example
@c file examples/messages.awk
BEGIN @{ print "Don't panic!" @}
@c endfile
@end example

It also prints some final advice:

@example
@c file examples/messages.awk
END @{ print "Always avoid bored archaeologists!" @}
@c endfile
@end example
...
```

`extract.awk` begins by setting `IGNORECASE` to one, so that mixed upper- and lowercase letters in the directives won't matter.

The first rule handles calling `system()`, checking that a command is given (`NF` is at least three) and also checking that the command exits with a zero exit status, signifying OK:

```
# extract.awk --- extract files and run programs from Texinfo files

BEGIN    { IGNORECASE = 1 }
```

```
/^@c(omment)?[ \t]+system/ {
    if (NF < 3) {
        e = ("extract: " FILENAME ":" FNR)
        e = (e  ": badly formed `system' line")
        print e > "/dev/stderr"
        next
    }
    $1 = ""
    $2 = ""
    stat = system($0)
    if (stat != 0) {
        e = ("extract: " FILENAME ":" FNR)
        e = (e ": warning: system returned " stat)
        print e > "/dev/stderr"
    }
}
```

The variable `e` is used so that the rule fits nicely on the page.

The second rule handles moving data into files. It verifies that a file name is given in the directive. If the file named is not the current file, then the current file is closed. Keeping the current file open until a new file is encountered allows the use of the '`>`' redirection for printing the contents, keeping open-file management simple.

The `for` loop does the work. It reads lines using `getline` (see Section 4.10 [Explicit Input with `getline`], page 92). For an unexpected end-of-file, it calls the `unexpected_eof()` function. If the line is an "endfile" line, then it breaks out of the loop. If the line is an '`@group`' or '`@end group`' line, then it ignores it and goes on to the next line. Similarly, comments within examples are also ignored.

Most of the work is in the following few lines. If the line has no '`@`' symbols, the program can print it directly. Otherwise, each leading '`@`' must be stripped off. To remove the '`@`' symbols, the line is split into separate elements of the array `a`, using the `split()` function (see Section 9.1.4 [String-Manipulation Functions], page 200). The '`@`' symbol is used as the separator character. Each element of `a` that is empty indicates two successive '`@`' symbols in the original line. For each two empty elements ('`@@`' in the original file), we have to add a single '`@`' symbol back in.

When the processing of the array is finished, `join()` is called with the value of `SUBSEP` (see Section 8.5 [Multidimensional Arrays], page 192), to rejoin the pieces back into a single line. That line is then printed to the output file:

```
/^@c(omment)?[ \t]+file/ {
    if (NF != 3) {
        e = ("extract: " FILENAME ":" FNR ": badly formed `file' line")
        print e > "/dev/stderr"
        next
    }
    if ($3 != curfile) {
        if (curfile != "")
            filelist[curfile] = 1   # save to close later
```

```
            curfile = $3
        }

        for (;;) {
            if ((getline line) <= 0)
                unexpected_eof()
            if (line ~ /^@c(omment)?[ \t]+endfile/)
                break
            else if (line ~ /^@(end[ \t]+)?group/)
                continue
            else if (line ~ /^@c(omment+)?[ \t]+/)
                continue
            if (index(line, "@") == 0) {
                print line > curfile
                continue
            }
            n = split(line, a, "@")
            # if a[1] == "", means leading @,
            # don't add one back in.
            for (i = 2; i <= n; i++) {
                if (a[i] == "") { # was an @@
                    a[i] = "@"
                    if (a[i+1] == "")
                        i++
                }
            }
            print join(a, 1, n, SUBSEP) > curfile
        }
    }
```

An important thing to note is the use of the '`>`' redirection. Output done with '`>`' only opens the file once; it stays open and subsequent output is appended to the file (see Section 5.6 [Redirecting Output of `print` and `printf`], page 112). This makes it easy to mix program text and explanatory prose for the same sample source file (as has been done here!) without any hassle. The file is only closed when a new data file name is encountered or at the end of the input file.

When a new file name is encountered, instead of closing the file, the program saves the name of the current file in `filelist`. This makes it possible to interleave the code for more than one file in the Texinfo input file. (Previous versions of this program *did* close the file. But because of the '`>`' redirection, a file whose parts were not all one after the other ended up getting clobbered.) An `END` rule then closes all the open files when processing is finished:

```
END {
    close(curfile)          # close the last one
    for (f in filelist)     # close all the rest
        close(f)
}
```

Finally, the function `unexpected_eof()` prints an appropriate error message and then exits:

```
function unexpected_eof()
{
    printf("extract: %s:%d: unexpected EOF or error\n",
                     FILENAME, FNR) > "/dev/stderr"
    exit 1
}
```

11.3.8 A Simple Stream Editor

The `sed` utility is a *stream editor*, a program that reads a stream of data, makes changes to it, and passes it on. It is often used to make global changes to a large file or to a stream of data generated by a pipeline of commands. Although `sed` is a complicated program in its own right, its most common use is to perform global substitutions in the middle of a pipeline:

```
command1 < orig.data | sed 's/old/new/g' | command2 > result
```

Here, '`s/old/new/g`' tells `sed` to look for the regexp '`old`' on each input line and globally replace it with the text '`new`' (i.e., all the occurrences on a line). This is similar to `awk`'s `gsub()` function (see Section 9.1.4 [String-Manipulation Functions], page 200).

The following program, `awksed.awk`, accepts at least two command-line arguments: the pattern to look for and the text to replace it with. Any additional arguments are treated as data file names to process. If none are provided, the standard input is used:

```
# awksed.awk --- do s/foo/bar/g using just print
#     Thanks to Michael Brennan for the idea

function usage()
{
    print "usage: awksed pat repl [files...]" > "/dev/stderr"
    exit 1
}

BEGIN {
    # validate arguments
    if (ARGC < 3)
        usage()

    RS = ARGV[1]
    ORS = ARGV[2]

    # don't use arguments as files
    ARGV[1] = ARGV[2] = ""
}
```

```
# look ma, no hands!
{
    if (RT == "")
        printf "%s", $0
    else
        print
}
```

The program relies on `gawk`'s ability to have `RS` be a regexp, as well as on the setting of `RT` to the actual text that terminates the record (see Section 4.1 [How Input Is Split into Records], page 69).

The idea is to have `RS` be the pattern to look for. `gawk` automatically sets `$0` to the text between matches of the pattern. This is text that we want to keep, unmodified. Then, by setting `ORS` to the replacement text, a simple `print` statement outputs the text we want to keep, followed by the replacement text.

There is one wrinkle to this scheme, which is what to do if the last record doesn't end with text that matches `RS`. Using a `print` statement unconditionally prints the replacement text, which is not correct. However, if the file did not end in text that matches `RS`, `RT` is set to the null string. In this case, we can print `$0` using `printf` (see Section 5.5 [Using `printf` Statements for Fancier Printing], page 106).

The `BEGIN` rule handles the setup, checking for the right number of arguments and calling `usage()` if there is a problem. Then it sets `RS` and `ORS` from the command-line arguments and sets `ARGV[1]` and `ARGV[2]` to the null string, so that they are not treated as file names (see Section 7.5.3 [Using `ARGC` and `ARGV`], page 177).

The `usage()` function prints an error message and exits. Finally, the single rule handles the printing scheme outlined earlier, using `print` or `printf` as appropriate, depending upon the value of `RT`.

11.3.9 An Easy Way to Use Library Functions

In Section 2.7 [Including Other Files into Your Program], page 46, we saw how `gawk` provides a built-in file-inclusion capability. However, this is a `gawk` extension. This section provides the motivation for making file inclusion available for standard `awk`, and shows how to do it using a combination of shell and `awk` programming.

Using library functions in `awk` can be very beneficial. It encourages code reuse and the writing of general functions. Programs are smaller and therefore clearer. However, using library functions is only easy when writing `awk` programs; it is painful when running them, requiring multiple `-f` options. If `gawk` is unavailable, then so too is the `AWKPATH` environment variable and the ability to put `awk` functions into a library directory (see Section 2.2 [Command-Line Options], page 33). It would be nice to be able to write programs in the following manner:

```
# library functions
@include getopt.awk
@include join.awk
...

# main program
```

```
BEGIN {
    while ((c = getopt(ARGC, ARGV, "a:b:cde")) != -1)
        ...
    ...
}
```

The following program, `igawk.sh`, provides this service. It simulates `gawk`'s searching of the `AWKPATH` variable and also allows *nested* includes (i.e., a file that is included with `@include` can contain further `@include` directives). `igawk` makes an effort to only include files once, so that nested includes don't accidentally include a library function twice.

`igawk` should behave just like `gawk` externally. This means it should accept all of `gawk`'s command-line arguments, including the ability to have multiple source files specified via `-f` and the ability to mix command-line and library source files.

The program is written using the POSIX Shell (`sh`) command language.[4] It works as follows:

1. Loop through the arguments, saving anything that doesn't represent `awk` source code for later, when the expanded program is run.
2. For any arguments that do represent `awk` text, put the arguments into a shell variable that will be expanded. There are two cases:
   a. Literal text, provided with `-e` or `--source`. This text is just appended directly.
   b. Source file names, provided with `-f`. We use a neat trick and append '`@include` *`filename`*' to the shell variable's contents. Because the file-inclusion program works the way `gawk` does, this gets the text of the file included in the program at the correct point.
3. Run an `awk` program (naturally) over the shell variable's contents to expand `@include` directives. The expanded program is placed in a second shell variable.
4. Run the expanded program with `gawk` and any other original command-line arguments that the user supplied (such as the data file names).

This program uses shell variables extensively: for storing command-line arguments and the text of the `awk` program that will expand the user's program, for the user's original program, and for the expanded program. Doing so removes some potential problems that might arise were we to use temporary files instead, at the cost of making the script somewhat more complicated.

The initial part of the program turns on shell tracing if the first argument is '`debug`'.

The next part loops through all the command-line arguments. There are several cases of interest:

`--` This ends the arguments to `igawk`. Anything else should be passed on to the user's `awk` program without being evaluated.

`-W` This indicates that the next option is specific to `gawk`. To make argument processing easier, the `-W` is appended to the front of the remaining arguments and the loop continues. (This is an `sh` programming trick. Don't worry about it if you are not familiar with `sh`.)

[4] Fully explaining the `sh` language is beyond the scope of this book. We provide some minimal explanations, but see a good shell programming book if you wish to understand things in more depth.

`-v`, `-F`
: These are saved and passed on to `gawk`.

`-f`, `--file`, `--file=`, `-Wfile=`
: The file name is appended to the shell variable `program` with an `@include` directive. The `expr` utility is used to remove the leading option part of the argument (e.g., '`--file=`'). (Typical `sh` usage would be to use the `echo` and `sed` utilities to do this work. Unfortunately, some versions of `echo` evaluate escape sequences in their arguments, possibly mangling the program text. Using `expr` avoids this problem.)

`--source`, `--source=`, `-Wsource=`
: The source text is appended to `program`.

`--version`, `-Wversion`
: `igawk` prints its version number, runs '`gawk --version`' to get the `gawk` version information, and then exits.

If none of the `-f`, `--file`, `-Wfile`, `--source`, or `-Wsource` arguments are supplied, then the first nonoption argument should be the `awk` program. If there are no command-line arguments left, `igawk` prints an error message and exits. Otherwise, the first argument is appended to `program`. In any case, after the arguments have been processed, the shell variable `program` contains the complete text of the original `awk` program.

The program is as follows:

```
#! /bin/sh
# igawk --- like gawk but do @include processing

if [ "$1" = debug ]
then
    set -x
    shift
fi

# A literal newline, so that program text is formatted correctly
n='
'

# Initialize variables to empty
program=
opts=

while [ $# -ne 0 ] # loop over arguments
do
    case $1 in
    --)     shift
            break ;;

    -W)     shift
            # The ${x?'message here'} construct prints a
            # diagnostic if $x is the null string
```

```
            set -- -W"${@?'missing operand'}"
            continue ;;

    -[vF])  opts="$opts $1 '${2?'missing operand'}'"
            shift ;;

    -[vF]*) opts="$opts '$1'" ;;

    -f)     program="$program$n@include ${2?'missing operand'}"
            shift ;;

    -f*)    f=$(expr "$1" : '-f\(.*\)')
            program="$program$n@include $f" ;;

    -[W-]file=*)
            f=$(expr "$1" : '-.file=\(.*\)')
            program="$program$n@include $f" ;;

    -[W-]file)
            program="$program$n@include ${2?'missing operand'}"
            shift ;;

    -[W-]source=*)
            t=$(expr "$1" : '-.source=\(.*\)')
            program="$program$n$t" ;;

    -[W-]source)
            program="$program$n${2?'missing operand'}"
            shift ;;

    -[W-]version)
            echo igawk: version 3.0 1>&2
            gawk --version
            exit 0 ;;

    -[W-]*) opts="$opts '$1'" ;;

    *)      break ;;
    esac
    shift
done

if [ -z "$program" ]
then
     program=${1?'missing program'}
     shift
fi
```

```
# At this point, `program' has the program.
```

The `awk` program to process `@include` directives is stored in the shell variable `expand_prog`. Doing this keeps the shell script readable. The `awk` program reads through the user's program, one line at a time, using `getline` (see Section 4.10 [Explicit Input with `getline`], page 92). The input file names and `@include` directives are managed using a stack. As each `@include` is encountered, the current file name is "pushed" onto the stack and the file named in the `@include` directive becomes the current file name. As each file is finished, the stack is "popped," and the previous input file becomes the current input file again. The process is started by making the original file the first one on the stack.

The `pathto()` function does the work of finding the full path to a file. It simulates `gawk`'s behavior when searching the `AWKPATH` environment variable (see Section 2.5.1 [The `AWKPATH` Environment Variable], page 42). If a file name has a '`/`' in it, no path search is done. Similarly, if the file name is `"-"`, then that string is used as-is. Otherwise, the file name is concatenated with the name of each directory in the path, and an attempt is made to open the generated file name. The only way to test if a file can be read in `awk` is to go ahead and try to read it with `getline`; this is what `pathto()` does.[5] If the file can be read, it is closed and the file name is returned:

```
expand_prog='

function pathto(file,    i, t, junk)
{
    if (index(file, "/") != 0)
        return file

    if (file == "-")
        return file

    for (i = 1; i <= ndirs; i++) {
        t = (pathlist[i] "/" file)
        if ((getline junk < t) > 0) {
            # found it
            close(t)
            return t
        }
    }
    return ""
}
```

The main program is contained inside one `BEGIN` rule. The first thing it does is set up the `pathlist` array that `pathto()` uses. After splitting the path on '`:`', null elements are replaced with `"."`, which represents the current directory:

```
BEGIN {
    path = ENVIRON["AWKPATH"]
```

[5] On some very old versions of `awk`, the test '`getline junk < t`' can loop forever if the file exists but is empty.

```
        ndirs = split(path, pathlist, ":")
        for (i = 1; i <= ndirs; i++) {
            if (pathlist[i] == "")
                pathlist[i] = "."
        }
```

The stack is initialized with `ARGV[1]`, which will be `"/dev/stdin"`. The main loop comes next. Input lines are read in succession. Lines that do not start with `@include` are printed verbatim. If the line does start with `@include`, the file name is in `$2`. `pathto()` is called to generate the full path. If it cannot, then the program prints an error message and continues.

The next thing to check is if the file is included already. The `processed` array is indexed by the full file name of each included file and it tracks this information for us. If the file is seen again, a warning message is printed. Otherwise, the new file name is pushed onto the stack and processing continues.

Finally, when `getline` encounters the end of the input file, the file is closed and the stack is popped. When `stackptr` is less than zero, the program is done:

```
        stackptr = 0
        input[stackptr] = ARGV[1] # ARGV[1] is first file

        for (; stackptr >= 0; stackptr--) {
            while ((getline < input[stackptr]) > 0) {
                if (tolower($1) != "@include") {
                    print
                    continue
                }
                fpath = pathto($2)
                if (fpath == "") {
                    printf("igawk: %s:%d: cannot find %s\n",
                        input[stackptr], FNR, $2) > "/dev/stderr"
                    continue
                }
                if (! (fpath in processed)) {
                    processed[fpath] = input[stackptr]
                    input[++stackptr] = fpath  # push onto stack
                } else
                    print $2, "included in", input[stackptr],
                        "already included in",
                        processed[fpath] > "/dev/stderr"
            }
            close(input[stackptr])
        }
    }'  # closing single quote ends `expand_prog' variable

    processed_program=$(gawk -- "$expand_prog" /dev/stdin << EOF
    $program
    EOF
```

```
)
```

The shell construct '*command* `<<` *marker*' is called a *here document*. Everything in the shell script up to the *marker* is fed to *command* as input. The shell processes the contents of the here document for variable and command substitution (and possibly other things as well, depending upon the shell).

The shell construct '`$(...)`' is called *command substitution*. The output of the command inside the parentheses is substituted into the command line. Because the result is used in a variable assignment, it is saved as a single string, even if the results contain whitespace.

The expanded program is saved in the variable `processed_program`. It's done in these steps:

1. Run `gawk` with the `@include`-processing program (the value of the `expand_prog` shell variable) reading standard input.
2. Standard input is the contents of the user's program, from the shell variable `program`. Feed its contents to `gawk` via a here document.
3. Save the results of this processing in the shell variable `processed_program` by using command substitution.

The last step is to call `gawk` with the expanded program, along with the original options and command-line arguments that the user supplied:

```
eval gawk $opts -- '"$processed_program"' '"$@"'
```

The `eval` command is a shell construct that reruns the shell's parsing process. This keeps things properly quoted.

This version of `igawk` represents the fifth version of this program. There are four key simplifications that make the program work better:

- Using `@include` even for the files named with `-f` makes building the initial collected `awk` program much simpler; all the `@include` processing can be done once.
- Not trying to save the line read with `getline` in the `pathto()` function when testing for the file's accessibility for use with the main program simplifies things considerably.
- Using a `getline` loop in the `BEGIN` rule does it all in one place. It is not necessary to call out to a separate loop for processing nested `@include` directives.
- Instead of saving the expanded program in a temporary file, putting it in a shell variable avoids some potential security problems. This has the disadvantage that the script relies upon more features of the `sh` language, making it harder to follow for those who aren't familiar with `sh`.

Also, this program illustrates that it is often worthwhile to combine `sh` and `awk` programming together. You can usually accomplish quite a lot, without having to resort to low-level programming in C or C++, and it is frequently easier to do certain kinds of string and argument manipulation using the shell than it is in `awk`.

Finally, `igawk` shows that it is not always necessary to add new features to a program; they can often be layered on top.[6]

[6] `gawk` does `@include` processing itself in order to support the use of `awk` programs as Web CGI scripts.

Before gawk acquired its built-in @include mechanism, igawk and its manual page were installed as part of the regular gawk installation ('make install'). This is no longer done, because it's no longer necessary. But we've kept the program in this book for its educational value.

11.3.10 Finding Anagrams from a Dictionary

An interesting programming challenge is to search for *anagrams* in a word list (such as /usr/share/dict/words on many GNU/Linux systems). One word is an anagram of another if both words contain the same letters (e.g., "babbling" and "blabbing").

Column 2, Problem C, of Jon Bentley's *Programming Pearls*, Second Edition, presents an elegant algorithm. The idea is to give words that are anagrams a common signature, sort all the words together by their signatures, and then print them. Dr. Bentley observes that taking the letters in each word and sorting them produces those common signatures.

The following program uses arrays of arrays to bring together words with the same signature and array sorting to print the words in sorted order:

```
# anagram.awk --- An implementation of the anagram-finding algorithm
#                 from Jon Bentley's "Programming Pearls," 2nd edition.
#                 Addison Wesley, 2000, ISBN-10: 0-201-65788-0,
#                 ISBN-13: 978-0-201-65788-3.
#                 Column 2, Problem C, section 2.8, pp 18-20.

/'s$/   { next }        # Skip possessives
```

The program starts with a header, and then a rule to skip possessives in the dictionary file. The next rule builds up the data structure. The first dimension of the array is indexed by the signature; the second dimension is the word itself:

```
{
    key = word2key($1)  # Build signature
    data[key][$1] = $1  # Store word with signature
}
```

The word2key() function creates the signature. It splits the word apart into individual letters, sorts the letters, and then joins them back together:

```
# word2key --- split word apart into letters, sort, and join back together

function word2key(word,     a, i, n, result)
{
    n = split(word, a, "")
    asort(a)

    for (i = 1; i <= n; i++)
        result = result a[i]

    return result
}
```

Finally, the `END` rule traverses the array and prints out the anagram lists. It sends the output to the system `sort` command because otherwise the anagrams would appear in arbitrary order:

```
END {
    sort = "sort"
    for (key in data) {
        # Sort words with same key
        nwords = asorti(data[key], words)
        if (nwords == 1)
            continue

        # And print. Minor glitch: trailing space at end of each line
        for (j = 1; j <= nwords; j++)
            printf("%s ", words[j]) | sort
        print "" | sort
    }
    close(sort)
}
```

Here is some partial output when the program is run:

```
$ gawk -f anagram.awk /usr/share/dict/words | grep '^b'
...
babbled blabbed
babbler blabber brabble
babblers blabbers brabbles
babbling blabbing
babbly blabby
babel bable
babels beslab
babery yabber
...
```

11.3.11 And Now for Something Completely Different

The following program was written by Davide Brini and is published on his website. It serves as his signature in the Usenet group `comp.lang.awk`. He supplies the following copyright terms:

> Copyright © 2008 Davide Brini
>
> Copying and distribution of the code published in this page, with or without modification, are permitted in any medium without royalty provided the copyright notice and this notice are preserved.

Here is the program:

```
awk 'BEGIN{O="~"~"~";o="=="=="==";o+=+o;x=O""O;while(X++<=x+o+o)c=c"%c";
printf c,(x-O)*(x-O),x*(x-o)-o,x*(x-O)+x-O-o,+x*(x-O)-x+o,X*(o*o+O)+x-O,
X*(X-x)-o*o,(x+X)*o*o+o,x*(X-x)-O-O,x-O+(O+o+X+x)*(o+O),X*X-X*(x-O)-x+O,
O+X*(o*(o+O)+O),+x+O+X*o,x*(x-o),(o+X+x)*o*o-(x-O-O),O+(X-x)*(X+O),x-O}'
```

We leave it to you to determine what the program does. (If you are truly desperate to understand it, see Chris Johansen's explanation, which is embedded in the Texinfo source file for this book.)

11.3.12 Demonstrating Shortest and Longest Match Operators

In Section 3.3.3 [Shortest Match, or "Non-greedy" Regexp Operators], page 58, we described the POSIX 2024 shortest-match operators, and show the output of a program that demonstrated the differences. Here is the program, `shortest-match.awk`:

```
# shortest-match.awk --- Demonstrate shortest match operators

BEGIN {
    text[1] = "aaaxxxzzz";
        shortpat[1] = @/x+?/
        longpat[1] = @/x+/
    text[2] = "aaaxxxyzzz";
        shortpat[2] = @/x+?y/
        longpat[2] = @/x+y/
    text[3] = "aaaxxxxxxxxxxxxxxxxzzz";
        shortpat[3] = @/(x+?)(x+)(x+?)(x+)/
        longpat[3] = @/(x+)(x+)(x+)(x+)/
    text[4] = "aaaxyxxyxxyxzzz"
        shortpat[4] = @/((x+)(y+?)(x+))+/
        longpat[4] = @/((x+)(y+)(x+))+/
    text[5] = "aaaxyxxyxxyxzzz"
        shortpat[5] = @/((x+)(y+?)(x+)){2}/
        longpat[5] = @/((x+)(y+)(x+)){2}/

    count = length(text)
    for (i = 1; i <= count; i++) {
        show(text[i], shortpat[i], longpat[i])
    }
}

# show --- show the results of using shortest- and longest-match operators

function show(text, shortpat, longpat,
          s_offsets, l_offsets, i, n)   # locals
{
    printf("\"%s\"\n", text)

    match(text, shortpat, s_offsets)
    subresult = gensub(shortpat, "X", 1, text)
    printf("\tshortpat: /%s/, result: \"%s\"\n", shortpat, subresult)
    dump(text, s_offsets)

    match(text, longpat, l_offsets)
```

```
    subresult = gensub(longpat, "X", 1, text)
    printf("\tlongpat: /%s/, result: \"%s\"\n", longpat, subresult)
    dump(text, l_offsets)
}

# dump --- dump out the start and length of subpattern matches

function dump(text, offsets,    i, n, s, l)
{
    n = length(offsets)
    for (i = 0; i <= n; i++) {
        if ((i, "start") in offsets) {
            s = offsets[i, "start"]
            l = offsets[i, "length"]
            printf("\t\t%d: (s: %d, l: %d) -> \"%s\"\n", i,
                s, l, substr(text, s, l))
        }
    }
}
```

The program makes use of strongly typed regexp constants (see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127), the optional fourth argument to the `match()` function, and the `gensub()` and `substr()` functions (see Section 9.1.4 [String-Manipulation Functions], page 200).

11.4 Summary

- The programs provided in this chapter continue on the theme that reading programs is an excellent way to learn Good Programming.
- Using '`#!`' to make `awk` programs directly runnable makes them easier to use. Otherwise, invoke the program using '`awk -f ...`'.
- Reimplementing standard POSIX programs in `awk` is a pleasant exercise; `awk`'s expressive power lets you write such programs in relatively few lines of code, yet they are functionally complete and usable.
- One of standard `awk`'s weaknesses is working with individual characters. The ability to use `split()` with the empty string as the separator can considerably simplify such tasks.
- The examples here demonstrate the usefulness of the library functions from Chapter 10 [A Library of `awk` Functions], page 247, for a number of real (if small) programs.
- Besides reinventing POSIX wheels, other programs solved a selection of interesting problems, such as finding duplicate words in text, printing mailing labels, and finding anagrams.

11.5 Exercises

1. Rewrite `cut.awk` (see Section 11.2.1 [Cutting Out Fields and Columns], page 285) using `split()` with `""` as the separator.

2. In Section 11.2.2 [Searching for Regular Expressions in Files], page 290, we mentioned that '`egrep -i`' could be simulated in versions of `awk` without `IGNORECASE` by using `tolower()` on the line and the pattern. In a footnote there, we also mentioned that this solution has a bug: the translated line is output, and not the original one. Fix this problem.
3. POSIX versions of `grep` accept a `-F` option which causes `grep` to match fixed strings. Add support for this to `egrep.awk`.
4. Similarly, POSIX versions of `grep` allow you to provide multiple patterns to match, in either of two ways. You may provide a quoted string on the command line where the patterns are separated by newlines. Or you may use the `-f` option to provide a file containing the patterns, one per line. Implement both of these features.
5. The POSIX version of `id` takes options that control which information is printed. Modify the `awk` version (see Section 11.2.3 [Printing Out User Information], page 294) to accept the same arguments and perform in the same way.
6. The `split.awk` program (see Section 11.2.4 [Splitting a Large File into Pieces], page 300) assumes that letters are contiguous in the character set, which isn't true for EBCDIC systems. Fix this problem. (Hint: Consider a different way to work through the alphabet, without relying on `ord()` and `chr()`.)
7. In `uniq.awk` (see Section 11.2.6 [Printing Nonduplicated Lines of Text], page 306, the logic for choosing which lines to print represents a *state machine*, which is "a device which can be in one of a set number of stable conditions depending on its previous condition and on the present values of its inputs."[7] Brian Kernighan suggests that "an alternative approach to state machines is to just read the input into an array, then use indexing. It's almost always easier code, and for most inputs where you would use this, just as fast." Rewrite the logic to follow this suggestion.
8. Why can't the `wc.awk` program (see Section 11.2.7 [Counting Things], page 310) just use the value of `FNR` in `endfile()`? Hint: Examine the code in Section 10.3.1 [Noting Data file Boundaries], page 261.
9. Manipulation of individual characters in the `translate` program (see Section 11.3.3 [Transliterating Characters], page 317) is painful using standard `awk` functions. Given that `gawk` can split strings into individual characters using `""` as the separator, how might you use this feature to simplify the program?
10. The `extract.awk` program (see Section 11.3.7 [Extracting Programs from Texinfo Source Files], page 323) was written before `gawk` had the `gensub()` function. Use it to simplify the code.
11. Compare the performance of the `awksed.awk` program (see Section 11.3.8 [A Simple Stream Editor], page 327) with the more straightforward:

```
BEGIN {
    pat = ARGV[1]
    repl = ARGV[2]
    ARGV[1] = ARGV[2] = ""
}
```

[7] This definition is from https://www.lexico.com/en/definition/state_machine.

```
{ gsub(pat, repl); print }
```

12. What are the advantages and disadvantages of `awksed.awk` versus the real `sed` utility?
13. In Section 11.3.9 [An Easy Way to Use Library Functions], page 328, we mentioned that not trying to save the line read with `getline` in the `pathto()` function when testing for the file's accessibility for use with the main program simplifies things considerably. What problem does this engender though?
14. As an additional example of the idea that it is not always necessary to add new features to a program, consider the idea of having two files in a directory in the search path:

    `default.awk`
    : This file contains a set of default library functions, such as `getopt()` and `assert()`.

    `site.awk`
    : This file contains library functions that are specific to a site or installation; i.e., locally developed functions. Having a separate file allows `default.awk` to change with new `gawk` releases, without requiring the system administrator to update it each time by adding the local functions.

    One user suggested that `gawk` be modified to automatically read these files upon startup. Instead, it would be very simple to modify `igawk` to do this. Since `igawk` can process nested `@include` directives, `default.awk` could simply contain `@include` directives for the desired library functions. Make this change.
15. Modify `anagram.awk` (see Section 11.3.10 [Finding Anagrams from a Dictionary], page 335), to avoid the use of the external `sort` utility.

Part III:
Moving Beyond Standard `awk` with `gawk`

12 Advanced Features of gawk

> *Write documentation as if whoever reads it is a violent psychopath who knows where you live.*
>
> —*Steve English, as quoted by Peter Langston*

This chapter discusses advanced features in gawk. It's a bit of a "grab bag" of items that are otherwise unrelated to each other. First, we look at a command-line option that allows gawk to recognize nondecimal numbers in input data, not just in awk programs. Then, gawk's special features for sorting arrays are presented. Next, two-way I/O, discussed briefly in earlier parts of this book, is described in full detail, along with the basics of TCP/IP networking. We then see how gawk can *profile* an awk program, making it possible to tune it for performance. Next, we present an experimental feature that allows you to preserve the values of awk variables and arrays between runs of gawk. Finally, we discuss the philosophy behind gawk's extension mechanism.

Additional advanced features are discussed in separate chapters of their own:

- Chapter 13 [Internationalization with gawk], page 365, discusses how to internationalize your awk programs, so that they can speak multiple national languages.
- Chapter 14 [Debugging awk Programs], page 375, describes gawk's built-in command-line debugger for debugging awk programs.
- Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399, describes how you can use gawk to perform arbitrary-precision arithmetic.
- Chapter 17 [Writing Extensions for gawk], page 415, discusses the ability to dynamically add new built-in functions to gawk.

12.1 Allowing Nondecimal Input Data

If you run gawk with the --non-decimal-data option, you can have nondecimal values in your input data:

```
$ echo 0123 123 0x123 |
> gawk --non-decimal-data '{ printf "%d, %d, %d\n", $1, $2, $3 }'
⊣ 83, 123, 291
```

For this feature to work, write your program so that gawk treats your data as numeric:

```
$ echo 0123 123 0x123 | gawk '{ print $1, $2, $3 }'
⊣ 0123 123 0x123
```

The print statement treats its expressions as strings. Although the fields can act as numbers when necessary, they are still strings, so print does not try to treat them numerically. You need to add zero to a field to force it to be treated as a number. For example:

```
$ echo 0123 123 0x123 | gawk --non-decimal-data '
> { print $1, $2, $3
>   print $1 + 0, $2 + 0, $3 + 0 }'
⊣ 0123 123 0x123
⊣ 83 123 291
```

In Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124, we described how octal and hexadecimal values may be used in program source code to represent numeric values. That section also discussed hexadecimal floating-point values.

As of version 5.4 of `gawk`, the `--non-decimal-data` option and the `strtonum()` function accept such values and convert them correctly. For example:

```
$ echo 0x1p-3 | ./gawk -n '{ print $1 + 0 }'
⊣ 0.125
```

Because it is common to have decimal data with leading zeros, and because allowing nondecimal data could lead to surprising results, the default is to leave it disabled. If you want it, you must explicitly request it.

> **CAUTION:** *Use of this option is not recommended.* It can break old programs very badly. Instead, use the `strtonum()` function to convert your data (see Section 9.1.4 [String-Manipulation Functions], page 200). This makes your programs easier to write and easier to read, and leads to less surprising results.

12.2 Boolean Typed Values

Scalar values in `awk` are either numbers or strings. `gawk` also supports values of type `regexp` (see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127).

As described in Section 6.3.1 [True and False in `awk`], page 139, Boolean values in `awk` don't have a separate type: a value counts as "true" if it is nonzero or non-null, and as "false" otherwise.

When interchanging data with languages that do have a real Boolean type, using a standard format such as JSON or XML, the lack of a true Boolean type in `awk` is problematic. (See, for example, the `json` extension provided by the `gawkextlib` project.)

It's easy to import Boolean data into `awk`, but then the fact that it was originally Boolean is lost. Exporting data is even harder; there's no way to indicate that a value is really Boolean.

To solve this problem, `gawk` provides a function named `mkbool()`. It takes one argument, which is any `awk` expression, and it returns a value of Boolean type.

The returned values are normal `awk` numeric values, with values of either one or zero, depending upon the truth value of the original expression passed in the call to `mkbool()`.

The `typeof()` function (see Section 9.1.8 [Getting Type Information], page 223) returns `"number|bool"` for these values.

Thus Boolean-typed values *are* numbers as far as `gawk` is concerned, except that extension code can treat them as Booleans if desired.

While it would have been possible to add two new built-in variables of Boolean type named `TRUE` and `FALSE`, doing so would undoubtedly have broken many existing `awk` programs. Instead, having a "generator" function that creates Boolean values gives flexibility, without breaking as much existing code.

12.3 Controlling Array Traversal and Array Sorting

`gawk` lets you control the order in which a '`for (`*`indx`* `in` *`array`*`)`' loop traverses an array.

In addition, two built-in functions, `asort()` and `asorti()`, let you sort arrays based on the array values and indices, respectively. These two functions also provide control over the sorting criteria used to order the elements during sorting.

12.3.1 Controlling Array Traversal

By default, the order in which a '`for (`*`indx`* `in` *`array`*`)`' loop scans an array is not defined; it is generally based upon the internal implementation of arrays inside `awk`.

Often, though, it is desirable to be able to loop over the elements in a particular order that you, the programmer, choose. `gawk` lets you do this.

Section 8.1.6 [Using Predefined Array Scanning Orders with gawk], page 186, describes how you can assign special, predefined values to `PROCINFO["sorted_in"]` in order to control the order in which `gawk` traverses an array during a `for` loop.

In addition, the value of `PROCINFO["sorted_in"]` can be a function name.[1] This lets you traverse an array based on any custom criterion. The array elements are ordered according to the return value of this function. The comparison function should be defined with at least four arguments:

```
function comp_func(i1, v1, i2, v2)
{
    compare elements 1 and 2 in some fashion
    return < 0; 0; or > 0
}
```

Here, `i1` and `i2` are the indices, and `v1` and `v2` are the corresponding values of the two elements being compared. Either `v1` or `v2`, or both, can be arrays if the array being traversed contains subarrays as values. (See Section 8.6 [Arrays of Arrays], page 193, for more information about subarrays.) The three possible return values are interpreted as follows:

`comp_func(i1, v1, i2, v2) < 0`
: Index `i1` comes before index `i2` during loop traversal.

`comp_func(i1, v1, i2, v2) == 0`
: Indices `i1` and `i2` come together, but the relative order with respect to each other is undefined.

`comp_func(i1, v1, i2, v2) > 0`
: Index `i1` comes after index `i2` during loop traversal.

Our first comparison function can be used to scan an array in numerical order of the indices:

```
function cmp_num_idx(i1, v1, i2, v2)
{
    # numerical index comparison, ascending order
    return (i1 - i2)
}
```

Our second function traverses an array based on the string order of the element values rather than by indices:

```
function cmp_str_val(i1, v1, i2, v2)
{
    # string value comparison, ascending order
```

[1] This is why the predefined sorting orders start with an '`@`' character, which cannot be part of an identifier.

```
    v1 = v1 ""
    v2 = v2 ""
    if (v1 < v2)
        return -1
    return (v1 != v2)
}
```

The third comparison function makes all numbers, and numeric strings without any leading or trailing spaces, come out first during loop traversal:

```
function cmp_num_str_val(i1, v1, i2, v2,   n1, n2)
{
     # numbers before string value comparison, ascending order
     n1 = v1 + 0
     n2 = v2 + 0
     if (n1 == v1)
         return (n2 == v2) ? (n1 - n2) : -1
     else if (n2 == v2)
         return 1
     return (v1 < v2) ? -1 : (v1 != v2)
}
```

Here is a main program to demonstrate how `gawk` behaves using each of the previous functions:

```
BEGIN {
    data["one"] = 10
    data["two"] = 20
    data[10] = "one"
    data[100] = 100
    data[20] = "two"

    f[1] = "cmp_num_idx"
    f[2] = "cmp_str_val"
    f[3] = "cmp_num_str_val"
    for (i = 1; i <= 3; i++) {
        printf("Sort function: %s\n", f[i])
        PROCINFO["sorted_in"] = f[i]
        for (j in data)
            printf("\tdata[%s] = %s\n", j, data[j])
        print ""
    }
}
```

Here are the results when the program is run:

```
$ gawk -f compdemo.awk
⊣ Sort function: cmp_num_idx       Sort by numeric index
⊣     data[two] = 20
⊣     data[one] = 10               Both strings are numerically zero
⊣     data[10] = one
```

```
⊣     data[20] = two
⊣     data[100] = 100
⊣
⊣ Sort function: cmp_str_val       Sort by element values as strings
⊣     data[one] = 10
⊣     data[100] = 100              String 100 is less than string 20
⊣     data[two] = 20
⊣     data[10] = one
⊣     data[20] = two
⊣
⊣ Sort function: cmp_num_str_val   Sort all numeric values before all strings
⊣     data[one] = 10
⊣     data[two] = 20
⊣     data[100] = 100
⊣     data[10] = one
⊣     data[20] = two
```

Consider sorting the entries of a GNU/Linux system password file according to login name. The following program sorts records by a specific field position and can be used for this purpose:

```
# passwd-sort.awk --- simple program to sort by field position
# field position is specified by the global variable POS

function cmp_field(i1, v1, i2, v2)
{
    # comparison by value, as string, and ascending order
    return v1[POS] < v2[POS] ? -1 : (v1[POS] != v2[POS])
}

{
    for (i = 1; i <= NF; i++)
        a[NR][i] = $i
}

END {
    PROCINFO["sorted_in"] = "cmp_field"
    if (POS < 1 || POS > NF)
        POS = 1

    for (i in a) {
        for (j = 1; j <= NF; j++)
            printf("%s%c", a[i][j], j < NF ? ":" : "")
        print ""
    }
}
```

The first field in each entry of the password file is the user's login name, and the fields are separated by colons. Each record defines a subarray, with each field as an element in the subarray. Running the program produces the following output:

```
$ gawk -v POS=1 -F: -f sort.awk /etc/passwd
⊣ adm:x:3:4:adm:/var/adm:/sbin/nologin
⊣ apache:x:48:48:Apache:/var/www:/sbin/nologin
⊣ avahi:x:70:70:Avahi daemon:/:/sbin/nologin
...
```

The comparison should normally always return the same value when given a specific pair of array elements as its arguments. If inconsistent results are returned, then the order is undefined. This behavior can be exploited to introduce random order into otherwise seemingly ordered data:

```
function cmp_randomize(i1, v1, i2, v2)
{
    # random order (caution: this may never terminate!)
    return (2 - 4 * rand())
}
```

As already mentioned, the order of the indices is arbitrary if two elements compare equal. This is usually not a problem, but letting the tied elements come out in arbitrary order can be an issue, especially when comparing item values. The partial ordering of the equal elements may change the next time the array is traversed, if other elements are added to or removed from the array. One way to resolve ties when comparing elements with otherwise equal values is to include the indices in the comparison rules. Note that doing this may make the loop traversal less efficient, so consider it only if necessary. The following comparison functions force a deterministic order, and are based on the fact that the (string) indices of two elements are never equal:

```
function cmp_numeric(i1, v1, i2, v2)
{
    # numerical value (and index) comparison, descending order
    return (v1 != v2) ? (v2 - v1) : (i2 - i1)
}

function cmp_string(i1, v1, i2, v2)
{
    # string value (and index) comparison, descending order
    v1 = v1 i1
    v2 = v2 i2
    return (v1 > v2) ? -1 : (v1 != v2)
}
```

A custom comparison function can often simplify ordered loop traversal, and the sky is really the limit when it comes to designing such a function.

When string comparisons are made during a sort, either for element values where one or both aren't numbers, or for element indices handled as strings, the value of `IGNORECASE` (see Section 7.5 [Predefined Variables], page 167) controls whether the comparisons treat corresponding upper- and lowercase letters as equivalent or distinct.

Another point to keep in mind is that in the case of subarrays, the element values can themselves be arrays; a production comparison function should use the `isarray()` function (see Section 9.1.8 [Getting Type Information], page 223) to check for this, and choose a defined sorting order for subarrays.

All sorting based on `PROCINFO["sorted_in"]` is disabled in POSIX mode, because the `PROCINFO` array is not special in that case.

As a side note, sorting the array indices before traversing the array has been reported to add a 15% to 20% overhead to the execution time of `awk` programs. For this reason, sorted array traversal is not the default.

12.3.2 Sorting Array Values and Indices with gawk

In most `awk` implementations, sorting an array requires writing a `sort()` function. This can be educational for exploring different sorting algorithms, but usually that's not the point of the program. `gawk` provides the built-in `asort()` and `asorti()` functions (see Section 9.1.4 [String-Manipulation Functions], page 200) for sorting arrays. For example:

```
populate the array data
n = asort(data)
for (i = 1; i <= n; i++)
    do something with data[i]
```

After the call to `asort()`, the array `data` is indexed from 1 to some number n, the total number of elements in `data`. (This count is `asort()`'s return value.) `data[1]` $\leq$ `data[2]` $\leq$ `data[3]`, and so on. The default comparison is based on the type of the elements (see Section 6.3.2 [Variable Typing and Comparison Expressions], page 139). All numeric values come before all string values, which in turn come before all subarrays.

An important side effect of calling `asort()` is that *the array's original indices are irrevocably lost*. As this isn't always desirable, `asort()` accepts a second argument:

```
populate the array source
n = asort(source, dest)
for (i = 1; i <= n; i++)
    do something with dest[i]
```

In this case, `gawk` copies the `source` array into the `dest` array and then sorts `dest`, destroying its indices. However, the `source` array is not affected.

Often, what's needed is to sort on the values of the *indices* instead of the values of the elements. To do that, use the `asorti()` function. The interface and behavior are identical to that of `asort()`, except that the index values are used for sorting and become the values of the result array:

```
{ source[$0] = some_func($0) }

END {
    n = asorti(source, dest)
    for (i = 1; i <= n; i++) {
        Work with sorted indices directly:
        do something with dest[i]
        ...
        Access original array via sorted indices:
```

```
            do something with source[dest[i]]
        }
    }
```

So far, so good. Now it starts to get interesting. Both `asort()` and `asorti()` accept a third string argument to control comparison of array elements. When we introduced `asort()` and `asorti()` in Section 9.1.4 [String-Manipulation Functions], page 200, we ignored this third argument; however, now is the time to describe how this argument affects these two functions.

Basically, the third argument specifies how the array is to be sorted. There are two possibilities. As with `PROCINFO["sorted_in"]`, this argument may be one of the predefined names that `gawk` provides (see Section 8.1.6 [Using Predefined Array Scanning Orders with gawk], page 186), or it may be the name of a user-defined function (see Section 12.3.1 [Controlling Array Traversal], page 345).

In the latter case, *the function can compare elements in any way it chooses*, taking into account just the indices, just the values, or both. This is extremely powerful.

Once the array is sorted, `asort()` takes the *values* in their final order and uses them to fill in the result array, whereas `asorti()` takes the *indices* in their final order and uses them to fill in the result array.

> **NOTE:** Copying array indices and elements isn't expensive in terms of memory. Internally, `gawk` maintains *reference counts* to data. For example, when `asort()` copies the first array to the second one, there is only one copy of the original array elements' data, even though both arrays use the values.

You may use the same array for both the first and second arguments to `asort()` and `asorti()`. Doing so only makes sense if you are also supplying the third argument, since `awk` doesn't provide a way to pass that third argument without also passing the first and second ones.

Because `IGNORECASE` affects string comparisons, the value of `IGNORECASE` also affects sorting for both `asort()` and `asorti()`. Note also that the locale's sorting order does *not* come into play; comparisons are based on character values only.[2]

The following example demonstrates the use of a comparison function with `asort()`. The comparison function, `case_fold_compare()`, maps both values to lowercase in order to compare them ignoring case.

```
# case_fold_compare --- compare as strings, ignoring case

function case_fold_compare(i1, v1, i2, v2,    l, r)
{
    l = tolower(v1)
    r = tolower(v2)

    if (l < r)
        return -1
    else if (l == r)
```

[2] This is true because locale-based comparison occurs only when in POSIX-compatibility mode, and because `asort()` and `asorti()` are `gawk` extensions, they are not available in that case.

```
        return 0
    else
        return 1
}
```

And here is the test program for it:

```
# Test program

BEGIN {
    Letters = "abcdefghijklmnopqrstuvwxyz" \
              "ABCDEFGHIJKLMNOPQRSTUVWXYZ"
    split(Letters, data, "")

    asort(data, result, "case_fold_compare")

    j = length(result)
    for (i = 1; i <= j; i++) {
        printf("%s", result[i])
        if (i % (j/2) == 0)
            printf("\n")
        else
            printf(" ")
    }
}
```

When run, we get the following:

```
$ gawk -f case_fold_compare.awk
⊣ A a B b c C D d e E F f g G H h i I J j k K l L M m
⊣ n N O o p P Q q r R S s t T u U V v w W X x y Y z Z
```

NOTE: "Under the hood," `gawk` uses the C library `qsort()` function to manage the sorting. `qsort()` can call itself recursively. This means that when you write a comparison function, you should be careful to avoid the use of global variables and arrays; use only local variables and arrays that you declare as additional parameters to the comparison function. Otherwise, you are likely to cause unintentional memory corruption in your global arrays and possibly cause `gawk` itself to fail.

12.4 Two-Way Communications with Another Process

It is often useful to be able to send data to a separate program for processing and then read the result. This can always be done with temporary files:

```
# Write the data for processing
tempfile = ("mydata." PROCINFO["pid"])
while (not done with data)
    print data | ("subprogram > " tempfile)
close("subprogram > " tempfile)

# Read the results, remove tempfile when done
```

```
while ((getline newdata < tempfile) > 0)
    process newdata appropriately
close(tempfile)
system("rm " tempfile)
```

This works, but not elegantly. Among other things, it requires that the program be run in a directory that cannot be shared among users; for example, `/tmp` will not do, as another user might happen to be using a temporary file with the same name.[3]

However, with `gawk`, it is possible to open a *two-way* pipe to another process. The second process is termed a *coprocess*, as it runs in parallel with `gawk`. The two-way connection is created using the '`|&`' operator (borrowed from the Korn shell, `ksh`):[4]

```
do {
    print data |& "subprogram"
    "subprogram" |& getline results
} while (data left to process)
close("subprogram")
```

The first time an I/O operation is executed using the '`|&`' operator, `gawk` creates a two-way pipeline to a child process that runs the other program. Output created with `print` or `printf` is written to the program's standard input, and output from the program's standard output can be read by the `gawk` program using `getline`. As is the case with processes started by '`|`', the subprogram can be any program, or pipeline of programs, that can be started by the shell.

There are some cautionary items to be aware of:

- As the code inside `gawk` currently stands, the coprocess's standard error goes to the same place that the parent `gawk`'s standard error goes. It is not possible to read the child's standard error separately.
- I/O buffering may be a problem. `gawk` automatically flushes all output down the pipe to the coprocess. However, if the coprocess does not flush its output, `gawk` may hang when doing a `getline` in order to read the coprocess's results. This could lead to a situation known as *deadlock*, where each process is waiting for the other one to do something.

It is possible to close just one end of the two-way pipe to a coprocess, by supplying a second argument to the `close()` function of either `"to"` or `"from"` (see Section 5.9 [Closing Input and Output Redirections], page 117). These strings tell `gawk` to close the end of the pipe that sends data to the coprocess or the end that reads from it, respectively.

This is particularly necessary in order to use the system `sort` utility as part of a coprocess; `sort` must read *all* of its input data before it can produce any output. The `sort` program does not receive an end-of-file indication until `gawk` closes the write end of the pipe.

When you have finished writing data to the `sort` utility, you can close the `"to"` end of the pipe, and then start reading sorted data via `getline`. For example:

```
BEGIN {
```

[3] Michael Brennan suggests the use of `rand()` to generate unique file names. This is a valid point; nevertheless, temporary files remain more difficult to use than two-way pipes.

[4] This is very different from the same operator in the C shell and in Bash.

```
    command = "LC_ALL=C sort"
    n = split("abcdefghijklmnopqrstuvwxyz", a, "")

    for (i = n; i > 0; i--)
        print a[i] |& command
    close(command, "to")

    while ((command |& getline line) > 0)
        print "got", line
    close(command)
}
```

This program writes the letters of the alphabet in reverse order, one per line, down the two-way pipe to `sort`. It then closes the write end of the pipe, so that `sort` receives an end-of-file indication. This causes `sort` to sort the data and write the sorted data back to the `gawk` program. Once all of the data has been read, `gawk` terminates the coprocess and exits.

As a side note, the assignment '`LC_ALL=C`' in the `sort` command ensures traditional Unix (ASCII) sorting from `sort`. This is not strictly necessary here, but it's good to know how to do this.

Be careful when closing the `"from"` end of a two-way pipe; in this case `gawk` waits for the child process to exit, which may cause your program to hang. (Thus, this particular feature is of much less use in practice than being able to close the `"to"` end.)

> **CAUTION:** Normally, it is a fatal error to write to the `"to"` end of a two-way pipe which has been closed, and it is also a fatal error to read from the `"from"` end of a two-way pipe that has been closed.
>
> You may set `PROCINFO["`*`command`*`", "NONFATAL"]` to make such operations become nonfatal. If you do so, you then need to check `ERRNO` after each `print`, `printf`, or `getline`. See Section 5.11 [Enabling Nonfatal Output], page 120, for more information.

You may also use pseudo-ttys (ptys) for two-way communication instead of pipes, if your system supports them. This is done on a per-command basis, by setting a special element in the `PROCINFO` array (see Section 7.5.2 [Built-in Variables That Convey Information], page 169), like so:

```
command = "sort -nr"           # command, save in convenience variable
PROCINFO[command, "pty"] = 1   # update PROCINFO
print ... |& command           # start two-way pipe
...
```

If your system does not have ptys, or if all the system's ptys are in use, `gawk` automatically falls back to using regular pipes.

Using ptys usually avoids the buffer deadlock issues described earlier, at some loss in performance. This is because the tty driver buffers and sends data line-by-line. On systems with the `stdbuf` (part of the GNU Coreutils package), you can use that program instead of ptys.

Note also that ptys are not fully transparent. Certain binary control codes, such *`Ctrl-d`* for end-of-file, are interpreted by the tty driver and not passed through.

> **CAUTION:** Finally, coprocesses open up the possibility of *deadlock* between `gawk` and the program running in the coprocess. This can occur if you send "too much" data to the coprocess before reading any back; each process is blocked writing data with no one available to read what they've already written. There is no workaround for deadlock; careful programming and knowledge of the behavior of the coprocess are required.

The following example, due to Andrew Schorr, demonstrates how using ptys can help deal with buffering deadlocks.

Suppose `gawk` were unable to add numbers. You could use a coprocess to do it. Here's an exceedingly simple program written for that purpose:

```
$ cat add.c
#include <stdio.h>

int
main(void)
{
    int x, y;
    while (scanf("%d %d", & x, & y) == 2)
        printf("%d\n", x + y);
    return 0;
}
$ cc -O add.c -o add       Compile the program
```

You could then write an exceedingly simple `gawk` program to add numbers by passing them to the coprocess:

```
$ echo 1 2 |
> gawk -v cmd=./add '{ print |& cmd; cmd |& getline x; print x }'
```

And it would deadlock, because `add.c` fails to call '`setlinebuf(stdout)`'. The `add` program freezes.

Now try instead:

```
$ echo 1 2 |
> gawk -v cmd=add 'BEGIN { PROCINFO[cmd, "pty"] = 1 }
>                  { print |& cmd; cmd |& getline x; print x }'
⊣ 3
```

By using a pty, `gawk` fools the standard I/O library into thinking it has an interactive session, so it defaults to line buffering. And now, magically, it works!

12.5 Using `gawk` for Network Programming

EMRED:

> *A host is a host from coast to coast,*
> *and nobody talks to a host that's close,*
> *unless the host that isn't close*
> *is busy, hung, or dead.*
>
> —*Mike O'Brien (aka Mr. Protocol)*

In addition to being able to open a two-way pipeline to a coprocess on the same system (see Section 12.4 [Two-Way Communications with Another Process], page 351), it is possible to make a two-way connection to another process on another system across an IP network connection.

You can think of this as just a *very long* two-way pipeline to a coprocess. The way `gawk` decides that you want to use TCP/IP networking is by recognizing special file names that begin with one of '`/inet/`', '`/inet4/`', or '`/inet6/`'.

The full syntax of the special file name is *`/net-type/protocol/local-port/remote-host/remote-port`*. The components are:

net-type Specifies the kind of Internet connection to make. Use '`/inet4/`' to force IPv4, and '`/inet6/`' to force IPv6. Plain '`/inet/`' (which used to be the only option) uses the system default, most likely IPv4.

protocol The protocol to use over IP. This must be either '`tcp`', or '`udp`', for a TCP or UDP IP connection, respectively. TCP should be used for most applications. As of version 5.4 of `gawk`, use of UDP is considered obsolete, as it never worked very well. `gawk` issues a warning if UDP is used. Support for it will be removed in version 6.0.

local-port The local TCP or UDP port number to use. Use a port number of '`0`' when you want the system to pick a port. This is what you should do when writing a TCP or UDP client. You may also use a well-known service name, such as '`smtp`' or '`http`', in which case `gawk` attempts to determine the predefined port number using the C `getaddrinfo()` function.

remote-host
The IP address or fully qualified domain name of the Internet host to which you want to connect.

remote-port
The TCP or UDP port number to use on the given *remote-host*. Again, use '`0`' if you don't care, or else a well-known service name.

> **NOTE:** Failure in opening a two-way socket will result in a nonfatal error being returned to the calling code. The value of `ERRNO` indicates the error (see Section 7.5.2 [Built-in Variables That Convey Information], page 169).

Consider the following very simple example:

```
BEGIN {
    Service = "/inet/tcp/0/localhost/daytime"
    Service |& getline
    print $0
    close(Service)
}
```

This program reads the current date and time from the local system's TCP `daytime` server. It then prints the results and closes the connection.

Because this topic is extensive, the use of `gawk` for TCP/IP programming is documented separately. See *TCP/IP Internetworking with* `gawk`, which comes as part of the `gawk`

distribution, for a much more complete introduction and discussion, as well as extensive examples.

> **NOTE:** `gawk` can only open direct sockets. There is currently no way to access services available over Secure Socket Layer (SSL); this includes any web service whose URL starts with '`https://`'.

12.6 Profiling Your `awk` Programs

You may produce execution traces of your `awk` programs. This is done by passing the option `--profile` to `gawk`. When `gawk` has finished running, it creates a profile of your program in a file named `awkprof.out`. Because it is profiling, it also executes up to 45% slower than `gawk` normally does.

As shown in the following example, the `--profile` option can be used to change the name of the file where `gawk` will write the profile:

```
gawk --profile=myprog.prof -f myprog.awk data1 data2
```

In the preceding example, `gawk` places the profile in `myprog.prof` instead of in `awkprof.out`.

Here is a sample session showing a simple `awk` program, its input data, and the results from running `gawk` with the `--profile` option. First, the `awk` program:

```
BEGIN { print "First BEGIN rule" }

END { print "First END rule" }

/foo/ {
    print "matched /foo/, gosh"
    for (i = 1; i <= 3; i++)
        sing()
}

{
    if (/foo/)
        print "if is true"
    else
        print "else is true"
}

BEGIN { print "Second BEGIN rule" }

END { print "Second END rule" }

function sing(    dummy)
{
    print "I gotta be me!"
}
```

Following is the input data:

```
foo
```

```
bar
baz
foo
junk
```

Here is the `awkprof.out` that results from running the `gawk` profiler on this program and data (this example also illustrates that `awk` programmers sometimes get up very early in the morning to work):

```
        # gawk profile, created Mon Sep 29 05:16:21 2014

        # BEGIN rule(s)

        BEGIN {
    1           print "First BEGIN rule"
        }

        BEGIN {
    1           print "Second BEGIN rule"
        }

        # Rule(s)

    5   /foo/ { # 2
    2           print "matched /foo/, gosh"
    6           for (i = 1; i <= 3; i++) {
    6                   sing()
                }
        }

    5   {
    5           if (/foo/) { # 2
    2                   print "if is true"
    3           } else {
    3                   print "else is true"
                }
        }

        # END rule(s)

        END {
    1           print "First END rule"
        }

        END {
    1           print "Second END rule"
        }
```

```
      # Functions, listed alphabetically

6     function sing(dummy)
      {
6             print "I gotta be me!"
      }
```

This example illustrates many of the basic features of profiling output. They are as follows:

- The program is printed in the order `BEGIN` rules, `BEGINFILE` rules, pattern–action rules, `ENDFILE` rules, `END` rules, and functions, listed alphabetically. Multiple `BEGIN` and `END` rules retain their separate identities, as do multiple `BEGINFILE` and `ENDFILE` rules.
- Pattern–action rules have two counts. The first count, to the left of the rule, shows how many times the rule's pattern was *tested*. The second count, to the right of the rule's opening left brace in a comment, shows how many times the rule's action was *executed*. The difference between the two indicates how many times the rule's pattern evaluated to false.
- Similarly, the count for an `if-else` statement shows how many times the condition was tested. To the right of the opening left brace for the `if`'s body is a count showing how many times the condition was true. The count for the `else` indicates how many times the test failed.
- The count for a loop header (such as `for` or `while`) shows how many times the loop test was executed. (Because of this, you can't just look at the count on the first statement in a rule to determine how many times the rule was executed. If the first statement is a loop, the count is misleading.)
- For user-defined functions, the count next to the `function` keyword indicates how many times the function was called. The counts next to the statements in the body show how many times those statements were executed.
- The layout uses "K&R" style with TABs. Braces are used everywhere, even when the body of an `if`, `else`, or loop is only a single statement.
- Parentheses are used only where needed, as indicated by the structure of the program and the precedence rules. For example, '`(3 + 5) * 4`' means add three and five, then multiply the total by four. However, '`3 + 5 * 4`' has no parentheses, and means '`3 + (5 * 4)`'. However, explicit parentheses in the source program are retained.
- Parentheses are used around the arguments to `print` and `printf` only when the `print` or `printf` statement is followed by a redirection. Similarly, if the target of a redirection isn't a scalar, it gets parenthesized.
- `gawk` supplies leading comments in front of the `BEGIN` and `END` rules, the `BEGINFILE` and `ENDFILE` rules, the pattern–action rules, and the functions.
- Functions are listed alphabetically. All functions in the `awk` namespace are listed first, in alphabetical order. Then come the functions in namespaces. The namespaces are listed in alphabetical order, and the functions within each namespace are listed alphabetically.

The profiled version of your program may not look exactly like what you typed when you wrote it. This is because `gawk` creates the profiled version by "pretty-printing" its internal

representation of the program. The advantage to this is that `gawk` can produce a standard representation. Also, things such as:

```
/foo/
```

come out as:

```
/foo/   {
    print
}
```

which is correct, but possibly unexpected. (If a program uses both '`print $0`' and plain '`print`', that distinction is retained.)

Besides creating profiles when a program has completed, `gawk` can produce a profile while it is running. This is useful if your `awk` program goes into an infinite loop and you want to see what has been executed. To use this feature, run `gawk` with the `--profile` option in the background:

```
$ gawk --profile -f myprog &
[1] 13992
```

The shell prints a job number and process ID number; in this case, 13992. Use the `kill` command to send the `USR1` signal to `gawk`:

```
$ kill -USR1 13992
```

As usual, the profiled version of the program is written to `awkprof.out`, or to a different file if one was specified with the `--profile` option.

Along with the regular profile, as shown earlier, the profile file includes a trace of any active functions:

```
# Function Call Stack:

#   3. baz
#   2. bar
#   1. foo
# -- main --
```

You may send `gawk` the `USR1` signal as many times as you like. Each time, the profile and function call trace are appended to the output profile file.

If you use the `HUP` signal instead of the `USR1` signal, `gawk` produces the profile and the function call trace and then exits.

When `gawk` runs on MS-Windows systems, it uses the `INT` and `QUIT` signals for producing the profile, and in the case of the `INT` signal, `gawk` exits. This is because these systems don't support the `kill` command, so the only signals you can deliver to a program are those generated by the keyboard. The `INT` signal is generated by the *`Ctrl-c`* or *`Ctrl-BREAK`* key, while the `QUIT` signal is generated by the *`Ctrl-\`* key.

Finally, `gawk` also accepts another option, `--pretty-print`. When called this way, `gawk` "pretty-prints" the program into `awkprof.out`, without any execution counts.

> **NOTE:** Once upon a time, the `--pretty-print` option would also run your program. This is no longer the case.

There is a significant difference between the output created when profiling, and that created when pretty-printing. Pretty-printed output preserves the original comments that

were in the program, although their placement may not correspond exactly to their original locations in the source code. However, no comments should be lost. Also, `gawk` does the best it can to preserve the distinction between comments at the end of a statement and comments on lines by themselves. This isn't always perfect, though.

However, as a deliberate design decision, profiling output *omits* the original program's comments. This allows you to focus on the execution count data and helps you avoid the temptation to use the profiler for pretty-printing.

Additionally, pretty-printed output does not have the leading indentation that the profiling output does. This makes it easy to pretty-print your code once development is completed, and then use the result as the final version of your program.

Because the internal representation of your program is formatted to recreate an `awk` program, profiling and pretty-printing automatically disable `gawk`'s default optimizations.

Profiling and pretty-printing also preserve the original format of numeric constants; if you used an octal or hexadecimal value in your source code, it will appear that way in the output.

12.7 Preserving Data Between Runs

Starting with version 5.2, `gawk` supports *persistent memory*. This feature stores the values of all of `gawk`'s variables, arrays and user-defined functions in a persistent heap, which resides in a file in the filesystem. When persistent memory is not in use (the normal case), `gawk`'s data resides in ephemeral system memory.

Persistent memory is enabled on certain 64-bit systems supporting the `mmap()` and `munmap()` system calls. Since the persistent store ends up holding pointers to functions held within the `gawk` executable, in order to use persistent memory, you must use the same `gawk` executable from run to run.

You can see if your version of `gawk` supports persistent memory like so:

```
$ gawk --version
⊣ GNU Awk 5.4.0, API 4.1, PMA Avon 8-g1, (GNU MPFR 4.2.1, GNU MP 6.3.0)
⊣ Copyright (C) 1989, 1991-2026 Free Software Foundation.
...
```

If you see the '`PMA`' with a version indicator, then it's supported.

As of this writing, persistent memory has only been tested on GNU/Linux, Cygwin, FreeBSD 12–16, macOS, MidnightBSD 3 and 4, NetBSD 10 and 11, OpenBSD 7, and Solaris 2.11. On all others, persistent memory is disabled by default. You can force it to be enabled by exporting the shell variable `REALLY_USE_PERSIST_MALLOC` with a nonempty value before running `configure` (see Section B.2.1 [Compiling gawk for Unix-Like Systems], page 507). If you do so and all the tests pass, please let the maintainer know.

To use persistent memory, follow these steps:

1. Create a new, empty sparse file of the desired size. For example, four gigabytes. On a GNU/Linux system, you can use the `truncate` utility:

   ```
   $ truncate -s 4G data.pma
   ```

2. It is recommended (but not required) to change the permissions on the file so that only the owner can read and write it:

   ```
   $ chmod 0600 data.pma
   ```

3. Provide the path to the data file in the `GAWK_PERSIST_FILE` environment variable. This is best done by placing the value in the environment just for the run of `gawk`, like so:

```
$ GAWK_PERSIST_FILE=data.pma gawk 'BEGIN { print ++i }'
1
```

4. Use the same data file in subsequent runs to use the preserved data values:

```
$ GAWK_PERSIST_FILE=data.pma gawk 'BEGIN { print ++i }'
2
$ GAWK_PERSIST_FILE=data.pma gawk 'BEGIN { print ++i }'
3
```

   As shown, in subsequent runs using the same data file, the values of `gawk`'s variables are preserved. However, `gawk`'s special variables, such as `NR`, are reset upon each run. Only the variables defined by the program are preserved across runs.

Interestingly, the `awk` program that you execute need not be the same from run to run; the persistent store only maintains the values of variables, arrays, and user-defined functions, not the totality of `gawk`'s internal state. This lets you share data between unrelated `awk` programs, eliminating the need for scripts to communicate via text files.

Terence Kelly, the author of the persistent memory allocator `gawk` uses, provides the following advice about the backing file:

> Regarding backing file size, I recommend making it far larger than all of the data that will ever reside in it, assuming that the file system supports sparse files. The "pay only for what you use" aspect of sparse files ensures that the actual storage resource footprint of the backing file will meet the application's needs but will be as small as possible. If the file system does *not* support sparse files, there's a dilemma: Making the backing file too large is wasteful, but making it too small risks memory exhaustion, i.e., `pma_malloc()` returns `NULL`. But persistent `gawk` should still work even without sparse files.

You can disable the use of the persistent memory allocator in `gawk` with the `--disable-pma` option to the `configure` command at the time that you build `gawk` (see Section B.2 [Compiling and Installing gawk on Unix-Like Systems], page 507).

You can set the `PMA_VERBOSITY` environment variable to a value between zero and three to control how much debugging and error information the persistent memory allocator will print. `gawk` sets the default to one. See the `support/pma.c` source code to understand what the different verbosity levels are.

There are a few constraints on the use of persistent memory:

- If you use MPFR mode (the `-M` option) on the first run of a program using persistent memory, you *must* continue to use it on all subsequent runs. Similarly, if you don't use `-M` on the first run, do not use it on any subsequent runs.

  Mixing and matching MPFR mode and regular mode with the same backing file is not allowed. `gawk` detects such a situation and issues a fatal error message.
- The GNU/Linux CIFS filesystem is known to not work well with the PMA allocator. Don't use a backing file on a CIFS filesystem.
- If `gawk` is run by the `root` user, then persistent memory is not allowed. This is to avoid the possibility of private data "leaking" into the backing file and being recovered later by an attacker.

- Over time, the backing file will be filled with memory "leaked" by `gawk` as it runs. Most notably this is the memory used to compile your program into an internal form before running it, which happens each time, but there are other leakages as well. (For an extreme example of this, see this thread in the `bug-gawk@gnu-org` mailing list archives.) It is up to you to use '`du -sh` *`pmafile`*' occasionally to monitor how full the file is, and arrange to dump any data you may need before the backing file becomes full.
- You can use dynamically loaded extensions (see Chapter 17 [Writing Extensions for gawk], page 415) with persistent memory. However, `gawk` notices if an extension is being loaded from a different path than previously, and in such a case it generates a fatal error.
- `gawk` produces a warning if the current version of `gawk` doesn't match the one that was first used with a particular backing storage file.

Terence Kelly has provided a separate *Persistent-Memory* `gawk` *User Manual* document, which is included in the `gawk` distribution. It is worth reading.

Here are additional articles and web links that provide more information about persistent memory and why it's useful in a scripting language like `gawk`.

`https://web.eecs.umich.edu/~tpkelly/pma/`
: This is the canonical source for Terence Kelly's Persistent Memory Allocator (PMA). The latest source code and user manual will always be available at this location. Kelly may be reached directly at any of the following email addresses: `tpkelly@acm.org`, `tpkelly@cs.princeton.edu`, or `tpkelly@eecs.umich.edu`.

Persistent Memory Allocation
: Terence Kelly, Zi Fan Tan, Jianan Li, and Haris Volos, ACM *Queue* magazine, Vol. 20 No. 2 (March/April 2022), PDF, HTML. This paper explains the design of the PMA allocator used in persistent `gawk`.

Persistent Scripting
: Zi Fan Tan, Jianan Li, Haris Volos, and Terence Kelly, Non-Volatile Memory Workshop (NVMW) 2022, `http://nvmw.ucsd.edu/program/`. This paper motivates and describes a research prototype of persistent `gawk` and presents performance evaluations on Intel Optane non-volatile memory; note that the interface differs slightly.

Persistent Memory Programming on Conventional Hardware
: Terence Kelly, ACM *Queue* magazine Vol. 17 No. 4 (July/Aug 2019), PDF, HTML. This paper describes simple techniques for persistent memory for C/C++ code on conventional computers that lack non-volatile memory hardware.

Is Persistent Memory Persistent?
: Terence Kelly, ACM *Queue* magazine Vol. 18 No. 2 (March/April 2020), PDF, HTML. This paper describes a simple and robust testbed for testing software against real power failures.

Crashproofing the Original NoSQL Key/Value Store
: Terence Kelly, ACM *Queue* magazine Vol. 19 No. 4 (July/Aug 2021), PDF, HTML. This paper describes a crash-tolerance feature added to GNU DBM' (`gdbm`).

When Terence Kelly published his papers, his collaborators produced a prototype integration of PMA with `gawk`. That version used a (mandatory!) option `--persist=`*`file`* to specify the file for storing the persistent heap. If this option is given to `gawk`, it produces a fatal error message instructing the user to use the `GAWK_PERSIST_FILE` environment variable instead. Except for this paragraph, that option is otherwise undocumented.

The prototype only supported persistent data; it did not support persistent functions.

> **NOTE:** The maintainer reserves the right to remove the persistent memory feature should it become burdensome.[5]

12.8 Builtin Features versus Extensions

As this and subsequent chapters show, `gawk` has a large number of extensions over standard `awk` built-in to the program. These have developed over time. More recently, the focus has moved to using the extension mechanism (see Chapter 17 [Writing Extensions for gawk], page 415) for adding features. This section discusses the "guiding philosophy" behind what should be added to the interpreter as a built-in feature versus what should be done in extensions.

There are several goals:

1. Keep the language `awk`; it should not become unrecognizable, even if programs in it will only run on `gawk`.
2. Keep the core from getting any larger unless absolutely necessary.
3. Add new functionality either in `awk` scripts (`-f`, `@include`) or in loadable extensions written in C or C++ (`-l`, `@load`).
4. Extend the core interpreter only if some feature is:
   A. Truly desirable.
   B. Cannot be done via library files or loadable extensions.
   C. Can be implemented without too much pain in the core.

Combining modules with `awk` files is a powerful technique. Some of the sample extensions demonstrate this.

Loading extensions and library files should not be done automatically, because then there's overhead that most users don't want or need.

12.9 Summary

- The `--non-decimal-data` option causes `gawk` to treat octal- and hexadecimal-looking input data as octal and hexadecimal. This option should be used with caution or not at all; use of `strtonum()` is preferable. Note that this option may disappear in a future version of `gawk`.

[5] Meaning, there are too many bug reports, or too many strange differences in behavior from when `gawk` is run normally.

- You can take over complete control of sorting in '`for (`*`indx`* `in` *`array`*`)`' array traversal by setting `PROCINFO["sorted_in"]` to the name of a user-defined function that does the comparison of array elements based on index and value.
- Similarly, you can supply the name of a user-defined comparison function as the third argument to either `asort()` or `asorti()` to control how those functions sort arrays. Or you may provide one of the predefined control strings that work for `PROCINFO["sorted_in"]`.
- You can use the '`|&`' operator to create a two-way pipe to a coprocess. You read from the coprocess with `getline` and write to it with `print` or `printf`. Use `close()` to close off the coprocess completely, or optionally, close off one side of the two-way communications.
- By using special file names with the '`|&`' operator, you can open a TCP/IP (or UDP/IP) connection to remote hosts on the Internet. `gawk` supports both IPv4 and IPv6.
- You can generate statement count profiles of your program. This can help you determine which parts of your program may be taking the most time and let you tune them more easily. Sending the `USR1` signal while profiling causes `gawk` to dump the profile and keep going, including a function call stack.
- You can also just "pretty-print" the program.
- Persistent memory allows you to preserve the values of variables and arrays between runs of `gawk`. This feature is currently experimental.
- New features should be developed using the extension mechanism if possible; they should be added to the core interpreter only as a last resort.

13 Internationalization with gawk

Moon... Gorgeous... MEDITATION!
—*Pretty Guardian Sailor Moon Eternal, The Movie*

It probably sounded better in Japanese.
—*Malka Robbins*

Once upon a time, computer makers wrote software that worked only in English. Eventually, hardware and software vendors noticed that if their systems worked in the native languages of non-English-speaking countries, they were able to sell more systems. As a result, internationalization and localization of programs and software systems became a common practice.

For many years, the ability to provide internationalization was largely restricted to programs written in C and C++. This chapter describes the underlying library `gawk` uses for internationalization, as well as how `gawk` makes internationalization features available at the `awk` program level. Having internationalization available at the `awk` level gives software developers additional flexibility—they are no longer forced to write in C or C++ when internationalization is a requirement.

13.1 Internationalization and Localization

Internationalization means writing (or modifying) a program once, in such a way that it can use multiple languages without requiring further source code changes. *Localization* means providing the data necessary for an internationalized program to work in a particular language. Most typically, these terms refer to features such as the language used for printing error messages, the language used to read responses, and information related to how numerical and monetary values are printed and read.

13.2 GNU gettext

`gawk` uses GNU `gettext` to provide its internationalization features. The facilities in GNU `gettext` focus on messages: strings printed by a program, either directly or via formatting with `printf` or `sprintf()`.[1]

When using GNU `gettext`, each application has its own *text domain*. This is a unique name, such as '`kpilot`' or '`gawk`', that identifies the application. A complete application may have multiple components—programs written in C or C++, as well as scripts written in `sh` or `awk`. All of the components use the same text domain.

To make the discussion concrete, assume we're writing an application named `guide`. Internationalization consists of the following steps, in this order:

1. The programmer reviews the source for all of `guide`'s components and marks each string that is a candidate for translation. For example, "`` `-F': option required `" is a good candidate for translation. A table with strings of option names is not (e.g., `gawk`'s `--profile` option should remain the same, no matter what the local language).
2. The programmer indicates the application's text domain ("`guide`") to the `gettext` library, by calling the `textdomain()` function.

[1] For some operating systems, the `gawk` port doesn't support GNU `gettext`. Therefore, these features are not available if you are using one of those operating systems. Sorry.

3. Messages from the application are extracted from the source code and collected into a portable object template file (`guide.pot`), which lists the strings and their translations. The translations are initially empty. The original (usually English) messages serve as the key for lookup of the translations.
4. For each language with a translator, `guide.pot` is copied to a portable object file (`.po`) and translations are created and shipped with the application. For example, there might be a `fr.po` for a French translation.
5. Each language's `.po` file is converted into a binary message object (`.gmo`) file. A message object file contains the original messages and their translations in a binary format that allows fast lookup of translations at runtime.
6. When `guide` is built and installed, the binary translation files are installed in a standard place.
7. For testing and development, it is possible to tell `gettext` to use `.gmo` files in a different directory than the standard one by using the `bindtextdomain()` function.
8. At runtime, `guide` looks up each string via a call to `gettext()`. The returned string is the translated string if available, or the original string if not.
9. If necessary, it is possible to access messages from a different text domain than the one belonging to the application, without having to switch the application's default text domain back and forth.

In C (or C++), the string marking and dynamic translation lookup are accomplished by wrapping each string in a call to `gettext()`:

```
printf("%s", gettext("Don't Panic!\n"));
```

The tools that extract messages from source code pull out all strings enclosed in calls to `gettext()`.

The GNU `gettext` developers, recognizing that typing '`gettext(...)`' over and over again is both painful and ugly to look at, use the macro '`_`' (an underscore) to make things easier:

```
/* In the standard header file: */
#define _(str) gettext(str)

/* In the program text: */
printf("%s", _("Don't Panic!\n"));
```

This reduces the typing overhead to just three extra characters per string and is considerably easier to read as well.

There are locale *categories* for different types of locale-related information. The defined locale categories that `gettext` knows about are:

`LC_MESSAGES`
: Text messages. This is the default category for `gettext` operations, but it is possible to supply a different one explicitly, if necessary. (It is almost never necessary to supply a different category.)

`LC_COLLATE`
: Text-collation information (i.e., how different characters and/or groups of characters sort in a given language).

`LC_CTYPE` Character-type information (alphabetic, digit, upper- or lowercase, and so on) as well as character encoding. This information is accessed via the POSIX character classes in regular expressions, such as `/[[:alnum:]]/` (see Section 3.4 [Using Bracket Expressions], page 60).

`LC_MONETARY`
Monetary information, such as the currency symbol, and whether the symbol goes before or after a number.

`LC_NUMERIC`
Numeric information, such as which characters to use for the decimal point and the thousands separator.[2]

`LC_TIME` Time- and date-related information, such as 12- or 24-hour clock, month printed before or after the day in a date, local month abbreviations, and so on.

`LC_ALL` All of the above. (Not too useful in the context of `gettext`.)

NOTE: As described in Section 6.6 [Where You Are Makes a Difference], page 149, environment variables with the same name as the locale categories (`LC_CTYPE`, `LC_ALL`, etc.) influence `gawk`'s behavior (and that of other utilities).

Normally, these variables also affect how the `gettext` library finds translations. However, the `LANGUAGE` environment variable overrides the `LC_xxx` variables. Many GNU/Linux systems may define this variable without your knowledge, causing `gawk` to not find the correct translations. If this happens to you, look to see if `LANGUAGE` is defined, and if so, use the shell's `unset` command to remove it.

For testing translations of `gawk` itself, you can set the `GAWK_LOCALE_DIR` environment variable. See the documentation for the C `bindtextdomain()` function and also see Section 2.5.3 [Other Environment Variables], page 44.

13.3 Internationalizing `awk` Programs

`gawk` provides the following variables for internationalization:

`TEXTDOMAIN`
This variable indicates the application's text domain. For compatibility with GNU `gettext`, the default value is `"messages"`.

`_"your message here"`
String constants marked with a leading underscore are candidates for translation at runtime. String constants without a leading underscore are not translated.

`gawk` provides the following functions for internationalization:

`dcgettext(`*`string`*` [, `*`domain`*` [, `*`category`*`]])`
Return the translation of *string* in text domain *domain* for locale category *category*. The default value for *domain* is the current value of `TEXTDOMAIN`. The default value for *category* is `"LC_MESSAGES"`.

[2] Americans use a comma every three decimal places and a period for the decimal point, while many Europeans do exactly the opposite: 1,234.56 versus 1.234,56.

If you supply a value for *category*, it must be a string equal to one of the known locale categories described in the previous section. You must also supply a text domain. Use `TEXTDOMAIN` if you want to use the current domain.

> **CAUTION:** The order of arguments to the `awk` version of the `dcgettext()` function is purposely different from the order for the C version. The `awk` version's order was chosen to be simple and to allow for reasonable `awk`-style default arguments.

`dcngettext(`*`string1`*`, `*`string2`*`, `*`number`*` [, `*`domain`*` [, `*`category`*`]])`
: Return the plural form used for *number* of the translation of *string1* and *string2* in text domain *domain* for locale category *category*. *string1* is the English singular variant of a message, and *string2* is the English plural variant of the same message. The default value for *domain* is the current value of `TEXTDOMAIN`. The default value for *category* is `"LC_MESSAGES"`.

  The same remarks about argument order as for the `dcgettext()` function apply.

`bindtextdomain(`*`directory`*` [, `*`domain`*` ])`
: Change the directory in which `gettext` looks for `.gmo` files, in case they will not or cannot be placed in the standard locations (e.g., during testing). Return the directory in which *domain* is "bound."

  The default *domain* is the value of `TEXTDOMAIN`. If *directory* is the null string (`""`), then `bindtextdomain()` returns the current binding for the given *domain*.

To use these facilities in your `awk` program, follow these steps:

1. Set the variable `TEXTDOMAIN` to the text domain of your program. This is best done in a `BEGIN` rule (see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154), or it can also be done via the `-v` command-line option (see Section 2.2 [Command-Line Options], page 33):

   ```
   BEGIN {
       TEXTDOMAIN = "guide"
       ...
   }
   ```

2. Mark all translatable strings with a leading underscore ('`_`') character. It *must* be adjacent to the opening double quote of the string. For example:

   ```
   print _"hello, world"
   x = _"you goofed"
   printf(_"Number of users is %d\n", nusers)
   ```

3. If you are creating strings dynamically, you can still translate them, using the `dcgettext()` built-in function:[3]

   ```
   if (groggy)
       message = dcgettext("%d customers disturbing me\n", "adminprog")
   else
       message = dcgettext("enjoying %d customers\n", "adminprog")
   printf(message, ncustomers)
   ```

[3] Thanks to Bruno Haible for this example.

Here, the call to `dcgettext()` supplies a different text domain (`"adminprog"`) in which to find the message, but it uses the default `"LC_MESSAGES"` category.

The previous example only works if `ncustomers` is greater than one. This example would be better done with `dcngettext()`:

```
if (groggy)
    message = dcngettext("%d customer disturbing me\n",
                         "%d customers disturbing me\n",
                         ncustomers, "adminprog")
else
    message = dcngettext("enjoying %d customer\n",
                         "enjoying %d customers\n",
                         ncustomers, "adminprog")
printf(message, ncustomers)
```

4. During development, you might want to put the `.gmo` file in a private directory for testing. This is done with the `bindtextdomain()` built-in function:

```
BEGIN {
   TEXTDOMAIN = "guide"   # our text domain
   if (Testing) {
       # where to find our files
       bindtextdomain("testdir")
       # joe is in charge of adminprog
       bindtextdomain("../joe/testdir", "adminprog")
   }
   ...
}
```

See Section 13.5 [A Simple Internationalization Example], page 372, for an example program showing the steps to create and use translations from `awk`.

13.4 Translating `awk` Programs

Once a program's translatable strings have been marked, they must be extracted to create the initial `.pot` file. As part of translation, it is often helpful to rearrange the order in which arguments to `printf` are output.

`gawk`'s `--gen-pot` command-line option extracts the messages and is discussed next. After that, `printf`'s ability to rearrange the order for `printf` arguments at runtime is covered.

13.4.1 Extracting Marked Strings

Once your `awk` program is working, and all the strings have been marked and you've set (and perhaps bound) the text domain, it is time to produce translations. First, use the `--gen-pot` command-line option to create the initial `.pot` file:

```
gawk --gen-pot -f guide.awk > guide.pot
```

When run with `--gen-pot`, `gawk` does not execute your program. Instead, it parses it as usual and prints all marked strings to standard output in the format of a GNU `gettext` Portable Object file. Also included in the output are any constant strings that appear as the

first argument to `dcgettext()` or as the first and second argument to `dcngettext()`.[4] You should distribute the generated `.pot` file with your `awk` program; translators will eventually use it to provide you translations that you can also then distribute. See Section 13.5 [A Simple Internationalization Example], page 372, for the full list of steps to go through to create and test translations for `guide`.

13.4.2 Rearranging `printf` Arguments

Format strings for `printf` and `sprintf()` (see Section 5.5 [Using `printf` Statements for Fancier Printing], page 106) present a special problem for translation. Consider the following:[5]

```
printf(_"String `%s' has %d characters\n",
          string, length(string)))
```

A possible German translation for this might be:

```
"%d Zeichen lang ist die Zeichenkette `%s'\n"
```

The problem should be obvious: the order of the format specifications is different from the original! Even though `gettext()` can return the translated string at runtime, it cannot change the argument order in the call to `printf`.

To solve this problem, `printf` format specifiers may have an additional optional element, which we call a *positional specifier*. For example:

```
"%2$d Zeichen lang ist die Zeichenkette `%1$s'\n"
```

Here, the positional specifier consists of an integer count, which indicates which argument to use, and a '`$`'. Counts are one-based, and the format string itself is *not* included. Thus, in the following example, '`string`' is the first argument and '`length(string)`' is the second:

```
$ gawk 'BEGIN {
>     string = "Don\47t Panic"
>     printf "%2$d characters live in \"%1$s\"\n",
>                         string, length(string)
> }'
⊣ 11 characters live in "Don't Panic"
```

If present, positional specifiers come first in the format specification, before the flags, the field width, and/or the precision.

Positional specifiers can be used with the dynamic field width and precision capability:

```
$ gawk 'BEGIN {
>    printf("%*.*s\n", 10, 20, "hello")
>    printf("%3$*2$.*1$s\n", 20, 10, "hello")
> }'
⊣      hello
⊣      hello
```

NOTE: When using '`*`' with a positional specifier, the '`*`' comes first, then the integer position, and then the '`$`'. This is somewhat counterintuitive.

---

[4] The `xgettext` utility that comes with GNU `gettext` can handle `.awk` files.

[5] This example is borrowed from the GNU `gettext` manual.

gawk does not allow you to mix regular format specifiers and those with positional specifiers in the same string:

```
$ gawk 'BEGIN { printf "%d %3$s\n", 1, 2, "hi" }'
error  gawk: cmd. line:1: fatal: must use `count$' on all formats or none
```

NOTE: There are some pathological cases that gawk may fail to diagnose. In such cases, the output may not be what you expect. It's still a bad idea to try mixing them, even if gawk doesn't detect it.

Although positional specifiers can be used directly in awk programs, their primary purpose is to help in producing correct translations of format strings into languages different from the one in which the program is first written.

13.4.3 awk Portability Issues

gawk's internationalization features were purposely chosen to have as little impact as possible on the portability of awk programs that use them to other versions of awk. Consider this program:

```
BEGIN {
    TEXTDOMAIN = "guide"
    if (Test_Guide)   # set with -v
        bindtextdomain("/test/guide/messages")
    print _"don't panic!"
}
```

As written, it won't work on other versions of awk. However, it is actually almost portable, requiring very little change:

- Assignments to TEXTDOMAIN won't have any effect, because TEXTDOMAIN is not special in other awk implementations.
- Non-GNU versions of awk treat marked strings as the concatenation of a variable named _ with the string following it.[6] Typically, the variable _ has the null string ("") as its value, leaving the original string constant as the result.
- By defining "dummy" functions to replace dcgettext(), dcngettext(), and bindtextdomain(), the awk program can be made to run, but all the messages are output in the original language. For example:

```
function bindtextdomain(dir, domain)
{
    return dir
}

function dcgettext(string, domain, category)
{
    return string
}

function dcngettext(string1, string2, number, domain, category)
{
```

[6] This is good fodder for an "Obfuscated awk" contest.

```
        return (number == 1 ? string1 : string2)
    }
```

- The use of positional specifications in `printf` or `sprintf()` is *not* portable. To support `gettext()` at the C level, many systems' C versions of `sprintf()` do support positional specifiers. But it works only if enough arguments are supplied in the function call. Many versions of `awk` pass `printf` formats and arguments unchanged to the underlying C library version of `sprintf()`, but only one format and argument at a time. What happens if a positional specification is used is anybody's guess. However, because the positional specifications are primarily for use in *translated* format strings, and because non-GNU `awk`s never retrieve the translated string, this should not be a problem in practice.

13.5 A Simple Internationalization Example

Now let's look at a step-by-step example of how to internationalize and localize a simple `awk` program, using `guide.awk` as our original source:

```
BEGIN {
    TEXTDOMAIN = "guide"
    bindtextdomain(".")  # for testing
    print _"Don't Panic"
    print _"The Answer Is", 42
    print "Pardon me, Zaphod who?"
}
```

Run '`gawk --gen-pot`' to create the `.pot` file:

```
$ gawk --gen-pot -f guide.awk > guide.pot
```

This produces:

```
#: guide.awk:4
msgid "Don't Panic"
msgstr ""

#: guide.awk:5
msgid "The Answer Is"
msgstr ""
```

This original portable object template file is saved and reused for each language into which the application is translated. The `msgid` is the original string and the `msgstr` is the translation.

> **NOTE:** Strings not marked with a leading underscore do not appear in the `guide.pot` file.

Next, the messages must be translated. Here is a translation to a hypothetical dialect of English, called "Mellow":[7]

```
$ cp guide.pot guide-mellow.po
Add translations to guide-mellow.po ...
```

[7] Perhaps it would be better if it were called "Hippy." Ah, well.

Following are the translations:

```
#: guide.awk:4
msgid "Don't Panic"
msgstr "Hey man, relax!"

#: guide.awk:5
msgid "The Answer Is"
msgstr "Like, the scoop is"
```

> **NOTE:** The following instructions apply to GNU/Linux with the GNU C Library. Be aware that the actual steps may change over time, that the following description may not be accurate for all GNU/Linux distributions, and that things may work entirely differently on other operating systems.

The next step is to make the directory to hold the binary message object file and then to create the `guide.mo` file. The directory has the form *`locale`*`/LC_MESSAGES`, where *locale* is a locale name known to the C `gettext` routines.

How do we know which locale to use? It turns out that there are four different environment variables used by the C `gettext` routines. In order, they are `$LANGUAGE`, `$LC_ALL`, `$LANG`, and `$LC_MESSAGES`.[8] Thus, we check the value of `$LANGUAGE`:

```
$ echo $LANGUAGE
⊣ en_US.UTF-8
```

We next make the directories:

```
$ mkdir en_US.UTF-8 en_US.UTF-8/LC_MESSAGES
```

The `msgfmt` utility converts the human-readable `.po` file into a machine-readable `.mo` file. By default, `msgfmt` creates a file named `messages`. This file must be renamed and placed in the proper directory (using the `-o` option) so that `gawk` can find it:

```
$ msgfmt guide-mellow.po -o en_US.UTF-8/LC_MESSAGES/guide.mo
```

Finally, we run the program to test it:

```
$ gawk -f guide.awk
⊣ Hey man, relax!
⊣ Like, the scoop is 42
⊣ Pardon me, Zaphod who?
```

If the three replacement functions for `dcgettext()`, `dcngettext()`, and `bindtextdomain()` (see Section 13.4.3 [awk Portability Issues], page 371) are in a file named `libintl.awk`, then we can run `guide.awk` unchanged as follows:

```
$ gawk --posix -f guide.awk -f libintl.awk
⊣ Don't Panic
⊣ The Answer Is 42
⊣ Pardon me, Zaphod who?
```

[8] Well, sort of. It seems that if `$LC_ALL` is set to '`C`', then no translations are done. Go figure.

13.6 gawk Can Speak Your Language

gawk itself has been internationalized using the GNU gettext package. (GNU gettext is described in complete detail in *GNU gettext utilities*.) As of this writing, the latest version of GNU gettext is version 0.19.8.1.

If a translation of gawk's messages exists, then gawk produces usage messages, warnings, and fatal errors in the local language.

13.7 Summary

- Internationalization means writing a program such that it can use multiple languages without requiring source code changes. Localization means providing the data necessary for an internationalized program to work in a particular language.
- gawk uses GNU gettext to let you internationalize and localize awk programs. A program's text domain identifies the program for grouping all messages and other data together.
- You mark a program's strings for translation by preceding them with an underscore. Once that is done, the strings are extracted into a .pot file. This file is copied for each language into a .po file, and the .po files are compiled into .gmo files for use at runtime.
- You can use positional specifications with sprintf() and printf to rearrange the placement of argument values in formatted strings and output. This is useful for the translation of format control strings.
- The internationalization features have been designed so that they can be easily worked around in a standard awk.
- gawk itself has been internationalized and ships with a number of translations for its messages.

14 Debugging awk Programs

It would be nice if computer programs worked perfectly the first time they were run, but in real life, this rarely happens for programs of any complexity. Thus, most programming languages have facilities available for "debugging" programs, and `awk` is no exception.

The `gawk` debugger is purposely modeled after the GNU Debugger (GDB) command-line debugger. If you are familiar with GDB, learning how to use `gawk` for debugging your programs is easy.

14.1 Introduction to the gawk Debugger

This section introduces debugging in general and begins the discussion of debugging in `gawk`.

14.1.1 Debugging in General

(If you have used debuggers in other languages, you may want to skip ahead to Section 14.1.3 [awk Debugging], page 376.)

Of course, a debugging program cannot remove bugs for you, because it has no way of knowing what you or your users consider a "bug" versus a "feature." (Sometimes, we humans have a hard time with this ourselves.) In that case, what can you expect from such a tool? The answer to that depends on the language being debugged, but in general, you can expect at least the following:

- The ability to watch a program execute its instructions one by one, giving you, the programmer, the opportunity to think about what is happening on a time scale of seconds, minutes, or hours, rather than the nanosecond time scale at which the code usually runs.
- The opportunity to not only passively observe the operation of your program, but to control it and try different paths of execution, without having to change your source files.
- The chance to see the values of data in the program at any point in execution, and also to change that data on the fly, to see how that affects what happens afterward. (This often includes the ability to look at internal data structures besides the variables you actually defined in your code.)
- The ability to obtain additional information about your program's state or even its internal structure.

All of these tools provide a great amount of help in using your own skills and understanding of the goals of your program to find where it is going wrong (or, for that matter, to better comprehend a perfectly functional program that you or someone else wrote).

14.1.2 Debugging Concepts

Before diving in to the details, we need to introduce several important concepts that apply to just about all debuggers. The following list defines terms used throughout the rest of this chapter:

Stack frame

Programs generally call functions during the course of their execution. One function can call another, or a function can call itself (recursion). You can

view the chain of called functions (main program calls A, which calls B, which calls C), as a stack of executing functions: the currently running function is the topmost one on the stack, and when it finishes (returns), the next one down then becomes the active function. Such a stack is termed a *call stack*.

For each function on the call stack, the system maintains a data area that contains the function's parameters, local variables, and return value, as well as any other "bookkeeping" information needed to manage the call stack. This data area is termed a *stack frame*.

`gawk` also follows this model, and gives you access to the call stack and to each stack frame. You can see the call stack, as well as from where each function on the stack was invoked. Commands that print the call stack print information about each stack frame (as detailed later on).

Breakpoint

During debugging, you often wish to let the program run until it reaches a certain point, and then continue execution from there one statement (or instruction) at a time. The way to do this is to set a *breakpoint* within the program. A breakpoint is where the execution of the program should break off (stop), so that you can take over control of the program's execution. You can add and remove as many breakpoints as you like.

Watchpoint

A watchpoint is similar to a breakpoint. The difference is that breakpoints are oriented around the code: stop when a certain point in the code is reached. A watchpoint, however, specifies that program execution should stop when a *data value* is changed. This is useful, as sometimes it happens that a variable receives an erroneous value, and it's hard to track down where this happens just by looking at the code. By using a watchpoint, you can stop whenever a variable is assigned to, and usually find the errant code quite quickly.

14.1.3 `awk` Debugging

Debugging an `awk` program has some specific aspects that are not shared with programs written in other languages.

First of all, the fact that `awk` programs usually take input line by line from a file or files and operate on those lines using specific rules makes it especially useful to organize viewing the execution of the program in terms of these rules. As we will see, each `awk` rule is treated almost like a function call, with its own specific block of instructions.

In addition, because `awk` is by design a very concise language, it is easy to lose sight of everything that is going on "inside" each line of `awk` code. The debugger provides the opportunity to look at the individual primitive instructions carried out by the higher-level `awk` commands.[1]

[1] The "primitive instructions" are defined by `gawk` itself; the debugger does not work at the level of machine instructions.

14.2 Sample gawk Debugging Session

In order to illustrate the use of `gawk` as a debugger, let's look at a sample debugging session. We will use the `awk` implementation of the POSIX `uniq` command presented earlier (see Section 11.2.6 [Printing Nonduplicated Lines of Text], page 306) as our example.

14.2.1 How to Start the Debugger

Starting the debugger is almost exactly like running `gawk` normally, except you have to pass an additional option, `--debug`, or the corresponding short option, `-D`. The file(s) containing the program and any supporting code are given on the command line as arguments to one or more `-f` options. (`gawk` is not designed to debug command-line programs, only programs contained in files.) In our case, we invoke the debugger like this:

```
$ gawk -D -f getopt.awk -f join.awk -f uniq.awk -- -1 inputfile
```

where both `getopt.awk` and `uniq.awk` are in `$AWKPATH`. (Experienced users of GDB or similar debuggers should note that this syntax is slightly different from what you are used to. With the `gawk` debugger, you give the arguments for running the program in the command line to the debugger rather than as part of the `run` command at the debugger prompt.) The `--` ends `gawk`'s command line options. It's not strictly necessary here, but it is needed if an option to the `awk` program conflicts with a `gawk` option. The `-1` is an option to `uniq.awk`.

Instead of immediately running the program on `inputfile`, as `gawk` would ordinarily do, the debugger merely loads all the program source files, compiles them internally, and then gives us a prompt:

```
gawk>
```

from which we can issue commands to the debugger. At this point, no code has been executed.

14.2.2 Finding the Bug

Let's say that we are having a problem using (a faulty version of) `uniq.awk` in "field-skipping" mode, and it doesn't seem to be catching lines which should be identical when skipping the first field, such as:

```
awk is a wonderful program!
gawk is a wonderful program!
```

This could happen if we were thinking (C-like) of the fields in a record as being numbered in a zero-based fashion, so instead of the lines:

```
clast = join(alast, fcount+1, n)
cline = join(aline, fcount+1, m)
```

we wrote:

```
clast = join(alast, fcount, n)
cline = join(aline, fcount, m)
```

The first thing we usually want to do when trying to investigate a problem like this is to put a breakpoint in the program so that we can watch it at work and catch what it is doing wrong. A reasonable spot for a breakpoint in `uniq.awk` is at the beginning of the

function `are_equal()`, which compares the current line with the previous one. To set the breakpoint, use the `b` (breakpoint) command:

```
gawk> b are_equal
⊣ Breakpoint 1 set at file `awklib/eg/prog/uniq.awk', line 63
```

The debugger tells us the file and line number where the breakpoint is. Now type '`r`' or '`run`' and the program runs until it hits the breakpoint for the first time:

```
gawk> r
⊣ Starting program:
⊣ Stopping in Rule ...
⊣ Breakpoint 1, are_equal(n, m, clast, cline, alast, aline)
        at `awklib/eg/prog/uniq.awk':63
⊣ 63          if (fcount == 0 && charcount == 0)
gawk>
```

Now we can look at what's going on inside our program. First of all, let's see how we got to where we are. At the prompt, we type '`bt`' (short for "backtrace"), and the debugger responds with a listing of the current stack frames:

```
gawk> bt
⊣ #0  are_equal(n, m, clast, cline, alast, aline)
        at `awklib/eg/prog/uniq.awk':68
⊣ #1  in main() at `awklib/eg/prog/uniq.awk':88
```

This tells us that `are_equal()` was called by the main program at line 88 of `uniq.awk`. (This is not a big surprise, because this is the only call to `are_equal()` in the program, but in more complex programs, knowing who called a function and with what parameters can be the key to finding the source of the problem.)

Now that we're in `are_equal()`, we can start looking at the values of some variables. Let's say we type '`p n`' (`p` is short for "print"). We would expect to see the value of `n`, a parameter to `are_equal()`. Actually, the debugger gives us:

```
gawk> p n
⊣ n = untyped variable
```

In this case, `n` is an uninitialized local variable, because the function was called without arguments (see Section 6.4 [Function Calls], page 146).

A more useful variable to display might be the current record:

```
gawk> p $0
⊣ $0 = "gawk is a wonderful program!"
```

This might be a bit puzzling at first, as this is the second line of our test input. Let's look at `NR`:

```
gawk> p NR
⊣ NR = 2
```

So we can see that `are_equal()` was only called for the second record of the file. Of course, this is because our program contains a rule for '`NR == 1`':

```
NR == 1 {
    last = $0
    next
```

```
}
```

OK, let's just check that that rule worked correctly:

```
gawk> p last
⊣ last = "awk is a wonderful program!"
```

Everything we have done so far has verified that the program has worked as planned, up to and including the call to `are_equal()`, so the problem must be inside this function. To investigate further, we must begin "stepping through" the lines of `are_equal()`. We start by typing '`n`' (for "next"):

```
gawk> n
⊣ 66          if (fcount > 0) {
```

This tells us that `gawk` is now ready to execute line 66, which decides whether to give the lines the special "field-skipping" treatment indicated by the `-1` command-line option. (Notice that we skipped from where we were before, at line 63, to here, because the condition in line 63, '`if (fcount == 0 && charcount == 0)`', was false.)

Continuing to step, we now get to the splitting of the current and last records:

```
gawk> n
⊣ 67              n = split(last, alast)
gawk> n
⊣ 68              m = split($0, aline)
```

At this point, we should be curious to see what our records were split into, so we try to look:

```
gawk> p n m alast aline
⊣ n = 5
⊣ m = untyped variable
⊣ alast = array, 5 elements
⊣ aline = untyped variable
```

(The `p` command can take more than one argument, similar to `awk`'s `print` statement.)

This is kind of disappointing, though. All we found out is that there are five elements in `alast`; `m` and `aline` don't have values because we are at line 68 but haven't executed it yet. This information is useful enough (we now know that none of the words were accidentally left out), but what if we want to see inside the array?

The first choice would be to use subscripts:

```
gawk> p alast[0]
⊣ "0" not in array `alast'
```

Oops!

```
gawk> p alast[1]
⊣ alast["1"] = "awk"
```

This would be kind of slow for a 100-member array, though, so `gawk` provides a shortcut (reminiscent of another language not to be mentioned):

```
gawk> p @alast
⊣ alast["1"] = "awk"
⊣ alast["2"] = "is"
⊣ alast["3"] = "a"
```

```
⊣ alast["4"] = "wonderful"
⊣ alast["5"] = "program!"
```

It looks like we got this far OK. Let's take another step or two:

```
gawk> n
⊣ 69              clast = join(alast, fcount, n)
gawk> n
⊣ 70              cline = join(aline, fcount, m)
```

Well, here we are at our error (sorry to spoil the suspense). What we had in mind was to join the fields starting from the second one to make the virtual record to compare, and if the first field were numbered zero, this would work. Let's look at what we've got:

```
gawk> p cline clast
⊣ cline = "gawk is a wonderful program!"
⊣ clast = "awk is a wonderful program!"
```

Hey, those look pretty familiar! They're just our original, unaltered input records. A little thinking (the human brain is still the best debugging tool), and we realize that we were off by one!

We get out of the debugger:

```
gawk> q
⊣ The program is running. Exit anyway (y/n)? y
```

Then we get into an editor:

```
clast = join(alast, fcount+1, n)
cline = join(aline, fcount+1, m)
```

and problem solved!

14.3 Main Debugger Commands

The `gawk` debugger command set can be divided into the following categories:

- Breakpoint control
- Execution control
- Viewing and changing data
- Working with the stack
- Getting information
- Miscellaneous

Each of these are discussed in the following subsections. In the following descriptions, commands that may be abbreviated show the abbreviation on a second description line. A debugger command name may also be truncated if that partial name is unambiguous. The debugger has the built-in capability to automatically repeat the previous command just by hitting *`Enter`*. This works for the commands `list`, `next`, `nexti`, `step`, `stepi`, and `continue` executed without any argument.

14.3.1 Control of Breakpoints

As we saw earlier, the first thing you probably want to do in a debugging session is to get your breakpoints set up, because your program will otherwise just run as if it was not under the debugger. The commands for controlling breakpoints are:

`break` [[*filename*`:`]*n* | *function*] [`"`*expression*`"`]
`b` [[*filename*`:`]*n* | *function*] [`"`*expression*`"`]

Without any argument, set a breakpoint at the next instruction to be executed in the selected stack frame. Arguments can be one of the following:

n Set a breakpoint at line number *n* in the current source file.

filename`:`*n*
Set a breakpoint at line number *n* in source file *filename*.

function Set a breakpoint at entry to (the first instruction of) function *function*.

Each breakpoint is assigned a number that can be used to delete it from the breakpoint list using the `delete` command.

With a breakpoint, you may also supply a condition. This is an `awk` expression (enclosed in double quotes) that the debugger evaluates whenever the breakpoint is reached. If the condition is true, then the debugger stops execution and prompts for a command. Otherwise, it continues executing the program.

`clear` [[*filename*`:`]*n* | *function*]

Without any argument, delete any breakpoint at the next instruction to be executed in the selected stack frame. If the program stops at a breakpoint, this deletes that breakpoint so that the program does not stop at that location again. Arguments can be one of the following:

n Delete breakpoint(s) set at line number *n* in the current source file.

filename`:`*n*
Delete breakpoint(s) set at line number *n* in source file *filename*.

function Delete breakpoint(s) set at entry to function *function*.

`condition` *n* `"`*expression*`"`

Add a condition to existing breakpoint or watchpoint *n*. The condition is an `awk` expression *enclosed in double quotes* that the debugger evaluates whenever the breakpoint or watchpoint is reached. If the condition is true, then the debugger stops execution and prompts for a command. Otherwise, the debugger continues executing the program. If the condition expression is not specified, any existing condition is removed (i.e., the breakpoint or watchpoint is made unconditional).

`delete` [*n1 n2* ...] [*n*–*m*]
`d` [*n1 n2* ...] [*n*–*m*]

Delete specified breakpoints or a range of breakpoints. Delete all defined breakpoints if no argument is supplied.

`disable` [*n1 n2* ... | *n*–*m*]

Disable specified breakpoints or a range of breakpoints. Without any argument, disable all breakpoints.

`enable` [`del | once`] [*n1 n2 ...*] [*n–m*]
`e` [`del | once`] [*n1 n2 ...*] [*n–m*]
: Enable specified breakpoints or a range of breakpoints. Without any argument, enable all breakpoints. Optionally, you can specify how to enable the breakpoints:

  `del` — Enable the breakpoints temporarily, then delete each one when the program stops at it.

  `once` — Enable the breakpoints temporarily, then disable each one when the program stops at it.

`ignore` *n count*
: Ignore breakpoint number *n* the next *count* times it is hit.

`tbreak` [[*filename*`:`]*n* | *function*]
`t` [[*filename*`:`]*n* | *function*]
: Set a temporary breakpoint (enabled for only one stop). The arguments are the same as for `break`.

14.3.2 Control of Execution

Now that your breakpoints are ready, you can start running the program and observing its behavior. There are more commands for controlling execution of the program than we saw in our earlier example:

`commands` [*n*]
`silent`
`...`
`end`
: Set a list of commands to be executed upon stopping at a breakpoint or watchpoint. *n* is the breakpoint or watchpoint number. Without a number, the last one set is used. The actual commands follow, starting on the next line, and terminated by the `end` command. If the command `silent` is in the list, the usual messages about stopping at a breakpoint and the source line are not printed. Any command in the list that resumes execution (e.g., `continue`) terminates the list (an implicit `end`), and subsequent commands are ignored. For example:

```
gawk> commands
> silent
> printf "A silent breakpoint; i = %d\n", i
> info locals
> set i = 10
> continue
> end
gawk>
```

`continue` [*count*]
`c` [*count*]
: Resume program execution. If continued from a breakpoint and *count* is specified, ignore the breakpoint at that location the next *count* times before stopping.

`finish`
: Execute until the selected stack frame returns. Print the returned value.

`next` [*count*]
`n` [*count*] Continue execution to the next source line, stepping over function calls. The argument *count* controls how many times to repeat the action, as in `step`.

`nexti` [*count*]
`ni` [*count*] Execute one (or *count*) instruction(s), stepping over function calls.

`return` [*value*]
Cancel execution of a function call. If *value* (either a string or a number) is specified, it is used as the function's return value. If used in a frame other than the innermost one (the currently executing function; i.e., frame number 0), discard all inner frames in addition to the selected one, and the caller of that frame becomes the innermost frame.

`run`
`r` Start/restart execution of the program. When restarting, the debugger retains the current breakpoints, watchpoints, command history, automatic display variables, and debugger options.

`step` [*count*]
`s` [*count*] Continue execution until control reaches a different source line in the current stack frame, stepping inside any function called within the line. If the argument *count* is supplied, steps that many times before stopping, unless it encounters a breakpoint or watchpoint.

`stepi` [*count*]
`si` [*count*] Execute one (or *count*) instruction(s), stepping inside function calls. (For illustration of what is meant by an "instruction" in `gawk`, see the output shown under `dump` in Section 14.3.6 [Miscellaneous Commands], page 387.)

`until` [[*filename*`:`]*n* | *function*]
`u` [[*filename*`:`]*n* | *function*]
Without any argument, continue execution until a line past the current line in the current stack frame is reached. With an argument, continue execution until the specified location is reached, or the current stack frame returns.

14.3.3 Viewing and Changing Data

The commands for viewing and changing variables inside of `gawk` are:

`display` [*var* | `$`*n*]
Add variable *var* (or field `$`*n*) to the display list. The value of the variable or field is displayed each time the program stops. Each variable added to the list is identified by a unique number:

```
gawk> display x
⊣ 10: x = 1
```

This displays the assigned item number, the variable name, and its current value. If the display variable refers to a function parameter, it is silently deleted from the list as soon as the execution reaches a context where no such variable of the given name exists. Without argument, `display` displays the current values of items on the list.

`eval "`*awk statements*`"`
: Evaluate *awk statements* in the context of the running program. You can do anything that an `awk` program would do: assign values to variables, call functions, and so on.

  > **NOTE:** You cannot use `eval` to execute a statement containing any of the following: `exit`, `getline`, `next`, `nextfile`, or `return`.

`eval` *param*, ...
awk statements
`end`
: This form of `eval` is similar, but it allows you to define "local variables" that exist in the context of the *awk statements*, instead of using variables or function parameters defined by the program.

`print` *var1*[`,` *var2* ...]
`p` *var1*[`,` *var2* ...]
: Print the value of a `gawk` variable or field. Fields must be referenced by constants:

  ```
  gawk> print $3
  ```

  This prints the third field in the input record (if the specified field does not exist, it prints '`Null field`'). A variable can be an array element, with the subscripts being constant string values. To print the contents of an array, prefix the name of the array with the '`@`' symbol:

  ```
  gawk> print @a
  ```

  This prints the indices and the corresponding values for all elements in the array `a`.

`printf` *format* [`,` *arg* ...]
: Print formatted text. The *format* may include escape sequences, such as '`\n`' (see Section 3.2 [Escape Sequences], page 52). No newline is printed unless one is specified.

`set` *var*`=`*value*
: Assign a constant (number or string) value to an `awk` variable or field. String values must be enclosed between double quotes (`"..."`).

  You can also set special `awk` variables, such as `FS`, `NF`, `NR`, and so on.

`watch` *var* `|` `$`*n* [`"`*expression*`"`]
`w` *var* `|` `$`*n* [`"`*expression*`"`]
: Add variable *var* (or field `$`*n*) to the watch list. The debugger then stops whenever the value of the variable or field changes. Each watched item is assigned a number that can be used to delete it from the watch list using the `unwatch` command.

  With a watchpoint, you may also supply a condition. This is an `awk` expression (enclosed in double quotes) that the debugger evaluates whenever the watchpoint is reached. If the condition is true, then the debugger stops execution and prompts for a command. Otherwise, `gawk` continues executing the program.

`undisplay` [*n*]
: Remove item number *n* (or all items, if no argument) from the automatic display list.

`unwatch` [*n*]
: Remove item number *n* (or all items, if no argument) from the watch list.

14.3.4 Working with the Stack

Whenever you run a program that contains any function calls, `gawk` maintains a stack of all of the function calls leading up to where the program is right now. You can see how you got to where you are, and also move around in the stack to see what the state of things was in the functions that called the one you are in. The commands for doing this are:

`backtrace` [*count*]
`bt` [*count*]
`where` [*count*]
: Print a backtrace of all function calls (stack frames), or innermost *count* frames if *count* > 0. Print the outermost *count* frames if *count* < 0. The backtrace displays the name and arguments to each function, the source file name, and the line number. The alias `where` for `backtrace` is provided for longtime GDB users who may be used to that command.

`down` [*count*]
: Move *count* (default 1) frames down the stack toward the innermost frame. Then select and print the frame.

`frame` [*n*]
`f` [*n*]
: Select and print stack frame *n*. Frame 0 is the currently executing, or *innermost*, frame (function call); frame 1 is the frame that called the innermost one. The highest-numbered frame is the one for the main program. The printed information consists of the frame number, function and argument names, source file, and the source line.

`up` [*count*]
: Move *count* (default 1) frames up the stack toward the outermost frame. Then select and print the frame.

14.3.5 Obtaining Information About the Program and the Debugger State

Besides looking at the values of variables, there is often a need to get other sorts of information about the state of your program and of the debugging environment itself. The `gawk` debugger has one command that provides this information, appropriately called `info`. `info` is used with one of a number of arguments that tell it exactly what you want to know:

`info` *what*
`i` *what*
: The value for *what* should be one of the following:

  `args`
  : List arguments of the selected frame.

  `break`
  : List all currently set breakpoints.

  `display`
  : List all items in the automatic display list.

  `frame`
  : Give a description of the selected stack frame.

  `functions`
  : List all function definitions including source file names and line numbers.

`locals` List local variables of the selected frame.

`source` Print the name of the current source file. Each time the program stops, the current source file is the file containing the current instruction. When the debugger first starts, the current source file is the first file included via the `-f` option. The '`list` *`filename`*`:`*`lineno`*' command can be used at any time to change the current source.

`sources` List all program sources.

`variables`
List all global variables.

`watch` List all items in the watch list.

Additional commands give you control over the debugger, the ability to save the debugger's state, and the ability to run debugger commands from a file. The commands are:

`option` [*name*[`=`*value*]]
`o` [*name*[`=`*value*]]
Without an argument, display the available debugger options and their current values. '`option` *`name`*' shows the current value of the named option. '`option` *`name`*`=`*`value`*' assigns a new value to the named option. The available options are:

`history_size`
Set the maximum number of lines to keep in the history file `./.gawk_history`. The default is 100.

`listsize` Specify the number of lines that `list` prints. The default is 15.

`outfile` Send `gawk` output to a file; debugger output still goes to standard output. An empty string (`""`) resets output to standard output.

`prompt` Change the debugger prompt. The default is '`gawk>` '.

`save_history` [`on` | `off`]
Save command history to file `./.gawk_history`. The default is `on`.

`save_options` [`on` | `off`]
Save current options to file `./.gawkrc` upon exit. The default is `on`. Options are read back into the next session upon startup.

`trace` [`on` | `off`]
Turn instruction tracing on or off. The default is `off`.

`save` *filename*
Save the commands from the current session to the given file name, so that they can be replayed using the `source` command.

`source` *filename*
Run command(s) from a file; an error in any command does not terminate execution of subsequent commands. Comments (lines starting with '`#`') are

allowed in a command file. Empty lines are ignored; they do *not* repeat the last command. You can't restart the program by having more than one `run` command in the file. Also, the list of commands may include additional `source` commands; however, the `gawk` debugger will not source the same file more than once in order to avoid infinite recursion.

In addition to, or instead of, the `source` command, you can use the `-D` *`file`* or `--debug=`*`file`* command-line options to execute commands from a file non-interactively (see Section 2.2 [Command-Line Options], page 33).

14.3.6 Miscellaneous Commands

There are a few more commands that do not fit into the previous categories, as follows:

`dump` [*filename*]
: Dump byte code of the program to standard output or to the file named in *filename*. This prints a representation of the internal instructions that `gawk` executes to implement the `awk` commands in a program. This can be very enlightening, as the following partial dump of Davide Brini's obfuscated code (see Section 11.3.11 [And Now for Something Completely Different], page 336) demonstrates:

```
gawk> dump
 ⊣        # BEGIN
 ⊣
 ⊣ [  1:0xfcd340] Op_rule           : [in_rule = BEGIN] [source_file = brini.awk]
 ⊣ [  1:0xfcc240] Op_push_i         : "~" [MALLOC|STRING|STRCUR]
 ⊣ [  1:0xfcc2a0] Op_push_i         : "~" [MALLOC|STRING|STRCUR]
 ⊣ [  1:0xfcc280] Op_match          :
 ⊣ [  1:0xfcc1e0] Op_store_var      : 0
 ⊣ [  1:0xfcc2e0] Op_push_i         : "==" [MALLOC|STRING|STRCUR]
 ⊣ [  1:0xfcc340] Op_push_i         : "==" [MALLOC|STRING|STRCUR]
 ⊣ [  1:0xfcc320] Op_equal          :
 ⊣ [  1:0xfcc200] Op_store_var      : o
 ⊣ [  1:0xfcc380] Op_push           : o
 ⊣ [  1:0xfcc360] Op_plus_i         : 0 [MALLOC|NUMCUR|NUMBER]
 ⊣ [  1:0xfcc220] Op_push_lhs       : o [do_reference = true]
 ⊣ [  1:0xfcc300] Op_assign_plus    :
 ⊣ [   :0xfcc2c0] Op_pop            :
 ⊣ [  1:0xfcc400] Op_push           : 0
 ⊣ [  1:0xfcc420] Op_push_i         : "" [MALLOC|STRING|STRCUR]
 ⊣ [   :0xfcc4a0] Op_no_op          :
 ⊣ [  1:0xfcc480] Op_push           : 0
 ⊣ [   :0xfcc4c0] Op_concat         : [expr_count = 3] [concat_flag = 0]
 ⊣ [  1:0xfcc3c0] Op_store_var      : x
 ⊣ [  1:0xfcc440] Op_push_lhs       : X [do_reference = true]
 ⊣ [  1:0xfcc3a0] Op_postincrement  :
 ⊣ [  1:0xfcc4e0] Op_push           : x
 ⊣ [  1:0xfcc540] Op_push           : o
 ⊣ [  1:0xfcc500] Op_plus           :
 ⊣ [  1:0xfcc580] Op_push           : o
 ⊣ [  1:0xfcc560] Op_plus           :
 ⊣ [  1:0xfcc460] Op_leq            :
 ⊣ [   :0xfcc5c0] Op_jmp_false      : [target_jmp = 0xfcc5e0]
 ⊣ [  1:0xfcc600] Op_push_i         : "%c" [MALLOC|STRING|STRCUR]
 ⊣ [   :0xfcc660] Op_no_op          :
 ⊣ [  1:0xfcc520] Op_assign_concat  : c
```

```
 ⊣ [   :0xfcc620] Op_jmp            : [target_jmp = 0xfcc440]
...
 ⊣ [     2:0xfcc5a0] Op_K_printf         : [expr_count = 17] [redir_type = ""]
 ⊣ [      :0xfcc140] Op_no_op            :
 ⊣ [      :0xfcc1c0] Op_atexit           :
 ⊣ [      :0xfcc640] Op_stop             :
 ⊣ [      :0xfcc180] Op_no_op            :
 ⊣ [      :0xfcd150] Op_after_beginfile  :
 ⊣ [      :0xfcc160] Op_no_op            :
 ⊣ [      :0xfcc1a0] Op_after_endfile    :
gawk>
```

`exit` Exit the debugger. See the entry for '`quit`', later in this list.

`help`
`h` Print a list of all of the `gawk` debugger commands with a short summary of their usage. '`help` *`command`*' prints the information about the command *command*.

`list` [`-` | `+` | *n* | *filename*`:`*n* | *n*–*m* | *function*]
`l` [`-` | `+` | *n* | *filename*`:`*n* | *n*–*m* | *function*]
Print the specified lines (default 15) from the current source file or the file named *filename*. The possible arguments to `list` are as follows:

`-` (Minus) Print lines before the lines last printed.

`+` Print lines after the lines last printed. `list` without any argument does the same thing.

n Print lines centered around line number *n*.

n–*m* Print lines from *n* to *m*.

filename`:`*n*
Print lines centered around line number *n* in source file *filename*. This command may change the current source file.

function Print lines centered around the beginning of the function *function*. This command may change the current source file.

`quit`
`q` Exit the debugger. Debugging is great fun, but sometimes we all have to tend to other obligations in life, and sometimes we find the bug and are free to go on to the next one! As we saw earlier, if you are running a program, the debugger warns you when you type '`q`' or '`quit`', to make sure you really want to quit.

`trace` [`on` | `off`]
Turn on or off continuous printing of the instructions that are about to be executed, along with the `awk` lines they implement. The default is `off`.

It is to be hoped that most of the "opcodes" in these instructions are fairly self-explanatory, and using `stepi` and `nexti` while `trace` is on will make them into familiar friends.

14.4 Readline Support

If gawk is compiled with the GNU Readline library, you can take advantage of that library's command completion and history expansion features. The following types of completion are available:

Command completion
: Command names.

Source file name completion
: Source file names. Relevant commands are `break`, `clear`, `list`, `tbreak`, and `until`.

Argument completion
: Non-numeric arguments to a command. Relevant commands are `enable` and `info`.

Variable name completion
: Global variable names, and function arguments in the current context if the program is running. Relevant commands are `display`, `print`, `set`, and `watch`.

14.5 Limitations

We hope you find the gawk debugger useful and enjoyable to work with, but as with any program, especially in its early releases, it still has some limitations. A few that it's worth being aware of are:

- At this point, the debugger does not give a detailed explanation of what you did wrong when you type in something it doesn't like. Rather, it just responds '`syntax error`'. When you do figure out what your mistake was, though, you'll feel like a real guru.
- If you perused the dump of opcodes in Section 14.3.6 [Miscellaneous Commands], page 387, (or if you are already familiar with gawk internals), you will realize that much of the internal manipulation of data in gawk, as in many interpreters, is done on a stack. `Op_push`, `Op_pop`, and the like are the "bread and butter" of most gawk code.

  Unfortunately, as of now, the gawk debugger does not allow you to examine the stack's contents. That is, the intermediate results of expression evaluation are on the stack, but cannot be printed. Rather, only variables that are defined in the program can be printed. Of course, a workaround for this is to use more explicit variables at the debugging stage and then change back to obscure, perhaps more optimal code later.
- There is no way to look "inside" the process of compiling regular expressions to see if you got it right. As an awk programmer, you are expected to know the meaning of `/[^[:alnum:][:blank:]]/`.
- The gawk debugger is designed to be used by running a program (with all its parameters) on the command line, as described in Section 14.2.1 [How to Start the Debugger], page 377. There is no way (as of now) to attach or "break into" a running program. This seems reasonable for a language that is used mainly for quickly executing, short programs.
- The gawk debugger only accepts source code supplied with the `-f` option. If you have a shell script that provides an awk program as a command line parameter, and you need

to use the debugger, you can write the script to a temporary file, and use that as the program, with the `-f` option. This might look like this:

```
cat << \EOF > /tmp/script.$$
...                                    Your program here
EOF
gawk -D -f /tmp/script.$$
rm /tmp/script.$$
```

14.6 Summary

- Programs rarely work correctly the first time. Finding bugs is called debugging, and a program that helps you find bugs is a debugger. `gawk` has a built-in debugger that works very similarly to the GNU Debugger, GDB.
- Debuggers let you step through your program one statement at a time, examine and change variable and array values, and do a number of other things that let you understand what your program is actually doing (as opposed to what it is supposed to do).
- Like most debuggers, the `gawk` debugger works in terms of stack frames, and lets you set both breakpoints (stop at a point in the code) and watchpoints (stop when a data value changes).
- The debugger command set is fairly complete, providing control over breakpoints, execution, viewing and changing data, working with the stack, getting information, and other tasks.
- If the GNU Readline library is available when `gawk` is compiled, it is used by the debugger to provide command-line history and editing.
- Usually, the debugger does not affect the program being debugged, but occasionally it can.

15 Namespaces in gawk

This chapter describes a feature that is specific to gawk.

> **CAUTION:** This feature described in this chapter is new. It is entirely possible, and even likely, that there are dark corners (if not bugs) still lurking within the implementation. If you find any such, please report them (See Section B.4 [Reporting Problems and Bugs], page 518).

15.1 Standard awk's Single Namespace

In standard awk, there is a single, global, *namespace*. This means that *all* function names and global variable names must be unique. For example, two different awk source files cannot both define a function named min(), or define the same identifier, used as a scalar in one and as an array in the other.

This situation is okay when programs are small, say a few hundred lines, or even a few thousand, but it prevents the development of reusable libraries of awk functions, and can inadvertently cause independently-developed library files to accidentally step on each other's "private" global variables (see Section 10.1 [Naming Library Function Global Variables], page 248).

Most other programming languages solve this issue by providing some kind of namespace control: a way to say "this function is in namespace *xxx*, and that function is in namespace *yyy*." (Of course, there is then still a single namespace for the namespaces, but the hope is that there are much fewer namespaces in use by any given program, and thus much less chance for collisions.) These facilities are sometimes referred to as *packages* or *modules*.

Starting with version 5.0, gawk provides a simple mechanism to put functions and global variables into separate namespaces.

15.2 Qualified Names

A *qualified name* is an identifier that includes a namespace name, the namespace separator ::, and a *component* name. For example, one might have a function named posix::getpid(). Here, the namespace is posix and the function name within the namespace (the component) is getpid(). The namespace and component names are separated by a double-colon. Only one such separator is allowed in a qualified name.

> **NOTE:** Unlike C++, the :: is *not* an operator. No spaces are allowed between the namespace name, the ::, and the component name.

You must use qualified names from one namespace to access variables and functions in another. This is especially important when using variable names to index the special SYMTAB array (see Section 7.5.2 [Built-in Variables That Convey Information], page 169), and when making indirect function calls (see Section 9.5 [Indirect Function Calls], page 238).

15.3 The Default Namespace

The default namespace, not surprisingly, is awk. All of the predefined awk and gawk variables are in this namespace, and thus have qualified names like awk::ARGC, awk::NF, and so on.

Furthermore, even when you have changed the namespace for your current source file (see Section 15.4 [Changing The Namespace], page 392), gawk forces unqualified identifiers

whose names are all uppercase letters to be in the `awk` namespace. This makes it possible for you to easily reference `gawk`'s global variables from different namespaces. It also keeps your code looking natural.

15.4 Changing The Namespace

In order to set the current namespace, use an `@namespace` directive at the top level of your program:

```
@namespace "passwd"

BEGIN { ... }
...
```

After this directive, all simple non-completely-uppercase identifiers are placed into the `passwd` namespace.

You can change the namespace multiple times within a single source file, although this is likely to become confusing if you do it too much.

> **NOTE:** Association of unqualified identifiers to a namespace is handled while `gawk` parses your program, *before* it starts to run. There is no concept of a "current" namespace once your program starts executing. Be sure you understand this.

Each source file for `-i` and `-f` starts out with an implicit '`@namespace "awk"`'. Similarly, each chunk of command-line code supplied with `-e` has such an implicit initial statement (see Section 2.2 [Command-Line Options], page 33).

Files included with `@include` (see Section 2.7 [Including Other Files into Your Program], page 46) "push" and "pop" the current namespace. That is, each `@include` saves the current namespace and starts over with an implicit '`@namespace "awk"`' which remains in effect until an explicit `@namespace` directive is seen. When `gawk` finishes processing the included file, the saved namespace is restored and processing continues where it left off in the original file.

The use of `@namespace` has no influence upon the order of execution of `BEGIN`, `BEGINFILE`, `END`, and `ENDFILE` rules.

15.5 Namespace and Component Naming Rules

A number of rules apply to the namespace and component names, as follows.

- It is a syntax error to use qualified names for function parameter names.
- It is a syntax error to use any standard `awk` reserved word (such as `if` or `for`), or the name of any standard built-in function (such as `sin()` or `gsub()`) as either part of a qualified name. Thus, the following produces a syntax error:

  ```
  @namespace "example"

  function gsub(str, pat, result) { ... }
  ```

- Outside the `awk` namespace, the names of the additional `gawk` built-in functions (such as `gensub()` or `strftime()`) *may* be used as component names (see [Gawk Extension Functions], page 486). The same set of names may be used as namespace names, although this has the potential to be confusing.

- The additional gawk built-in functions may still be called from outside the awk namespace by qualifying them. For example, awk::systime(). Here is a somewhat silly example demonstrating this rule and the previous one:

```
BEGIN {
    print "in awk namespace, systime() =", systime()
}

@namespace "testing"

function systime()
{
    print "in testing namespace, systime() =", awk::systime()
}

BEGIN {
    systime()
}
```

  When run, it produces output like this:

```
$ gawk -f systime.awk
⊣ in awk namespace, systime() = 1500488503
⊣ in testing namespace, systime() = 1500488503
```

- gawk pre-defined variable names may be used: NF::NR is valid, if possibly not all that useful.

15.6 Internal Name Management

For backwards compatibility, all identifiers in the awk namespace are stored internally as unadorned identifiers (that is, without a leading 'awk::'). This is mainly relevant when using such identifiers as indices for SYMTAB, FUNCTAB, and PROCINFO["identifiers"] (see Section 7.5.2 [Built-in Variables That Convey Information], page 169), and for use in indirect function calls (see Section 9.5 [Indirect Function Calls], page 238).

In program code, to refer to variables and functions in the awk namespace from another namespace, you must still use the 'awk::' prefix. For example:

```
@namespace "awk"            This is the default namespace

BEGIN {
    Title = "My Report"     Qualified name is awk::Title
}

@namespace "report"         Now in report namespace

function compute()          This is really report::compute()
{
    print awk::Title        But would be SYMTAB["Title"]
    ...
}
```

15.7 Namespace Example

The following example is a revised version of the suite of routines developed in Section 10.5 [Reading the User Database], page 273. See there for an explanation of how the code works.

The formulation here, due mainly to Andrew Schorr, is rather elegant. All of the implementation functions and variables are in the `passwd` namespace, whereas the main interface functions are defined in the `awk` namespace.

```
# ns_passwd.awk --- access password file information

@namespace "passwd"

BEGIN {
    # tailor this to suit your system
    Awklib = "/usr/local/libexec/awk/"
}

function Init(    oldfs, oldrs, olddol0, pwcat, using_fw, using_fpat)
{
    if (Inited)
        return

    oldfs = FS
    oldrs = RS
    olddol0 = $0
    using_fw = (PROCINFO["FS"] == "FIELDWIDTHS")
    using_fpat = (PROCINFO["FS"] == "FPAT")
    FS = ":"
    RS = "\n"

    pwcat = Awklib "pwcat"
    while ((pwcat | getline) > 0) {
        Byname[$1] = $0
        Byuid[$3] = $0
        Bycount[++Total] = $0
    }
    close(pwcat)
    Count = 0
    Inited = 1
    FS = oldfs
    if (using_fw)
        FIELDWIDTHS = FIELDWIDTHS
    else if (using_fpat)
        FPAT = FPAT
    RS = oldrs
    $0 = olddol0
}
```

```
function awk::getpwnam(name)
{
    Init()
    return Byname[name]
}

function awk::getpwuid(uid)
{
    Init()
    return Byuid[uid]
}

function awk::getpwent()
{
    Init()
    if (Count < Total)
        return Bycount[++Count]
    return ""
}

function awk::endpwent()
{
    Count = 0
}
```

As you can see, this version also follows the convention mentioned in Section 10.1 [Naming Library Function Global Variables], page 248, whereby global variable and function names start with a capital letter.

Here is a simple test program. Since it's in a separate file, unadorned identifiers are sought for in the `awk` namespace:

```
BEGIN {
    while ((p = getpwent()) != "")
        print p
}
```

Here's what happens when it's run:

```
$ gawk -f ns_passwd.awk -f testpasswd.awk
⊣ root:x:0:0:root:/root:/bin/bash
⊣ daemon:x:1:1:daemon:/usr/sbin:/usr/sbin/nologin
⊣ bin:x:2:2:bin:/bin:/usr/sbin/nologin
⊣ sys:x:3:3:sys:/dev:/usr/sbin/nologin
...
```

15.8 Including A File Without Changing The Namespace

As mentioned at the end of Section 2.7 [Including Other Files into Your Program], page 46, files included with `@include` are treated as if they had '`@namespace "awk"`' at their beginning. Sometimes, though, this behavior is undesirable.

Consider, for example, the case where you have some significant functions in one namespace:

```
@namespace "mylib"

function major_func1(a, b, c) { ... }
function major_func2(a, b, c) { ... }
...
```

From another namespace, you want to call these functions, frequently:

```
@namespace "myproj1"
function job1(a, b, c) {
    ...
    if (mylib::major_func1(a, b, c))
        ...
    else if (mylib::major_func2(a, b, c))
        ...
    ...
}
... and so on ...
```

Using the '`mylib::`' prefix everywhere starts to get painful.

You might then try to write some *forwarding functions*, which you would `@include` in each namespace. For example, something like this in a file named `mylib_forward.awk`:

```
function major_func1(a, b, c)
{
    return mylib::major_func1(a, b, c)
}

function major_func2(a, b, c)
{
    return mylib::major_func2(a, b, c)
}
```

You might then try to `@include` this file in each namespace:

```
@namespace "myproj1"
@include "mylib_forward.awk"

function job1(a, b, c) {
    ...
    if (major_func1(a, b, c))       # calls forwarding function
        ...
    else if (major_func2(a, b, c))  # ditto
        ...
    ...
}
...

@namespace "myproj2"
```

```
@include "mylib_forward.awk"
...
```

But this won't work, since `@include` resets the namespace to 'awk'.

For this reason, `@nsinclude` was added. It works exactly the same as `@include`, but it does not change the namespace:

```
@namespace "myproj1"
@nsinclude "mylib_forward.awk"

function job1(a, b, c) {
    ...
    if (major_func1(a, b, c))       # calls forwarding function
        ...
    else if (major_func2(a, b, c))  # ditto
        ...
    ...
}
...

@namespace "myproj2"
@nsinclude "mylib_forward.awk"
...
```

This will work the way we want it to.

15.9 Namespaces and Other gawk Features

This section looks briefly at how the namespace facility interacts with other important `gawk` features.

The profiler and pretty-printer (see Section 12.6 [Profiling Your `awk` Programs], page 356) have been enhanced to understand namespaces and the namespace naming rules presented in Section 15.5 [Namespace and Component Naming Rules], page 392. In particular, the output groups functions in the same namespace together, and has `@namespace` directives in front of rules as necessary. This allows component names to be simple identifiers, instead of using qualified identifiers everywhere.

Interaction with the debugger (see Section 14.1 [Introduction to the `gawk` Debugger], page 375) has not had to change (at least as of this writing). Some of the internal byte codes changed in order to accommodate namespaces, and the debugger's `dump` command was adjusted to match.

The extension API (see Chapter 17 [Writing Extensions for `gawk`], page 415) has always allowed for placing functions into a different namespace, although this was not previously implemented. However, the symbol lookup and symbol update routines did not have provision for including a namespace. That has now been corrected (see Section 17.4.11.1 [Variable Access and Update by Name], page 439). See Section 17.7.4 [Enabling In-Place File Editing], page 472, for a nice example of an extension that leverages a namespace shared by cooperating `awk` and C code.

15.10 Summary

- Standard `awk` provides a single namespace for all global identifiers (scalars, arrays, and functions). This is limiting when one wants to develop libraries of reusable functions or function suites.
- `gawk` provides multiple namespaces by using qualified names: names consisting of a namespace name, a double colon, `::`, and a component name. Namespace names might still possibly conflict, but this is true of any language providing namespaces, modules, or packages.
- The default namespace is `awk`. The rules for namespace and component names are provided in Section 15.5 [Namespace and Component Naming Rules], page 392. The rules are designed in such a way as to make namespace-aware code continue to look and work naturally while still providing the necessary power and flexibility.
- Other parts of `gawk` have been extended as necessary to integrate namespaces smoothly with their operation. This applies most notably to the profiler / pretty-printer (see Section 12.6 [Profiling Your `awk` Programs], page 356) and to the extension facility (see Chapter 17 [Writing Extensions for `gawk`], page 415).
- Overall, the namespace facility was designed and implemented such that backwards compatibility is paramount. Programs that don't use namespaces should see absolutely no difference in behavior when run by a namespace-capable version of `gawk`.

16 Arithmetic and Arbitrary-Precision Arithmetic with gawk

This chapter introduces some basic concepts relating to how computers do arithmetic and defines some important terms. It then proceeds to describe floating-point arithmetic, which is what `awk` uses for all its computations, including a discussion of arbitrary-precision floating-point arithmetic, which is a feature available only in `gawk`. It continues on to present arbitrary-precision integers, and concludes with a description of some points where `gawk` and the POSIX standard are not quite in agreement.

> **NOTE:** Most users of `gawk` can safely skip this chapter. But if you want to do scientific calculations with `gawk`, this is the place to be.

16.1 A General Description of Computer Arithmetic

> Have you ever considered that the plural of "half" is "whole"?
>
> —*Allan Sherman*

Until now, we have worked with data as either numbers or strings. Ultimately, however, computers represent everything in terms of *binary digits*, or *bits*. A decimal digit can take on any of 10 values: zero through nine. A binary digit can take on any of two values, zero or one. Using binary, computers (and computer software) can represent and manipulate numerical and character data. In general, the more bits you can use to represent a particular thing, the greater the range of possible values it can take on.

Modern computers support at least two, and often more, ways to do arithmetic. Each kind of arithmetic uses a different representation (organization of the bits) for the numbers. The kinds of arithmetic that interest us are:

Decimal arithmetic

> This is the kind of arithmetic you learned in elementary school, using paper and pencil (and/or a calculator). In theory, numbers can have an arbitrary number of digits on either side (or both sides) of the decimal point, and the results of a computation are always exact.
>
> Some modern systems can do decimal arithmetic in hardware, but usually you need a special software library to provide access to these instructions. There are also libraries that do decimal arithmetic entirely in software.
>
> Despite the fact that some users expect `gawk` to be performing decimal arithmetic,[1] it does not do so.

Integer arithmetic

> In school, integer values were referred to as "whole" numbers—that is, numbers without any fractional part, such as 1, 42, or −17. The advantage to integer numbers is that they represent values exactly. The disadvantage is that their range is limited.
>
> In computers, integer values come in two flavors: *signed* and *unsigned*. Signed values may be negative or positive, whereas unsigned values are always greater than or equal to zero.
>
> In computer systems, integer arithmetic is exact, but the possible range of values is limited. Integer arithmetic is generally faster than floating-point arithmetic.

[1] We don't know why they expect this, but they do.

Floating-point arithmetic

> Floating-point numbers represent what were called in school "real" numbers (i.e., those that have a fractional part, such as 3.1415927). The advantage to floating-point numbers is that they can represent a much larger range of values than can integers. The disadvantage is that there are numbers that they cannot represent exactly.
>
> Modern systems support floating-point arithmetic in hardware, with a limited range of values. There are software libraries that allow the use of arbitrary-precision floating-point calculations.
>
> POSIX `awk` uses *double-precision* floating-point numbers, which can hold more digits than *single-precision* floating-point numbers. `gawk` has facilities for performing arbitrary-precision floating-point arithmetic, which we describe in more detail shortly.

Computers work with integer and floating-point values of different ranges. Integer values are usually either 32 or 64 bits in size. Single-precision floating-point values occupy 32 bits, whereas double-precision floating-point values occupy 64 bits. (Quadruple-precision floating point values also exist. They occupy 128 bits, but such numbers are not available in `awk`.) Floating-point values are always signed. The possible ranges of values are shown in Table 16.1 and Table 16.2.

Representation	**Minimum value**	**Maximum value**
32-bit signed integer	−2,147,483,648	2,147,483,647
32-bit unsigned integer	0	4,294,967,295
64-bit signed integer	−9,223,372,036,854,775,808	9,223,372,036,854,775,807
64-bit unsigned integer	0	18,446,744,073,709,551,615

Table 16.1: Value ranges for integer representations

Representation	**Minimum positive nonzero value**	**Minimum finite value**	**Maximum finite value**
Single-precision floating-point	$1.175494 \cdot 10^{-38}$	$-3.402823 \cdot 10^{38}$	$3.402823 \cdot 10^{38}$
Double-precision floating-point	$2.225074 \cdot 10^{-308}$	$-1.797693 \cdot 10^{308}$	$1.797693 \cdot 10^{308}$
Quadruple-precision floating-point	$3.362103 \cdot 10^{-4932}$	$-1.189731 \cdot 10^{4932}$	$1.189731 \cdot 10^{4932}$

Table 16.2: Approximate value ranges for floating-point number representations

16.2 Other Stuff to Know

The rest of this chapter uses a number of terms. Here are some informal definitions that should help you work your way through the material here:

Accuracy A floating-point calculation's accuracy is how close it comes to the real (paper and pencil) value.

Error The difference between what the result of a computation "should be" and what it actually is. It is best to minimize error as much as possible.

Exponent The order of magnitude of a value; some number of bits in a floating-point value store the exponent.

Inf A special value representing infinity. Operations involving another number and infinity produce infinity.

NaN "Not a number." A special value that results from attempting a calculation that has no answer as a real number. See Section 16.4.1.4 [Floating Point Values They Didn't Talk About In School], page 405, for more information about infinity and not-a-number values.

Normalized
How the significand (see later in this list) is usually stored. The value is adjusted so that the first bit is one, and then that leading one is assumed instead of physically stored. This provides one extra bit of precision.

Precision The number of bits used to represent a floating-point number. The more bits, the more digits you can represent. Binary and decimal precisions are related approximately, according to the formula:

$$prec = 3.322 \cdot dps$$

Here, *prec* denotes the binary precision (measured in bits) and *dps* (short for decimal places) is the decimal digits.

Rounding mode
How numbers are rounded up or down when necessary. More details are provided later.

Significand
A floating-point value consists of the significand multiplied by 10 to the power of the exponent. For example, in `1.2345e67`, the significand is `1.2345`.

Stability From the Wikipedia article on numerical stability: "Calculations that can be proven not to magnify approximation errors are called *numerically stable*."

See the Wikipedia article on accuracy and precision for more information on some of those terms.

On modern systems, floating-point hardware uses the representation and operations defined by the IEEE 754 standard. Three of the standard IEEE 754 types are 32-bit single precision, 64-bit double precision, and 128-bit quadruple precision. The standard also specifies extended precision formats to allow greater precisions and larger exponent ranges. (`awk` uses only the 64-bit double-precision format.)

Table 16.3 lists the precision and exponent field values for the basic IEEE 754 binary formats.

Name	**Total bits**	**Precision**	**Minimum exponent**	**Maximum exponent**
Single	32	24	−126	+127
Double	64	53	−1022	+1023
Quadruple	128	113	−16382	+16383

Table 16.3: Basic IEEE format values

NOTE: The precision numbers include the implied leading one that gives them one extra bit of significand.

16.3 Arbitrary-Precision Arithmetic Features in gawk

This section briefly describes arbitrary-precision arithmetic in gawk.

16.3.1 Arbitrary Precision Arithmetic is On Parole!

As of version 5.2, arbitrary precision arithmetic in gawk is "on parole." The primary gawk maintainer is no longer maintaining it. Fortunately, a volunteer from the development team has agreed to take it over.

This feature is on parole because its inclusion was a mistake. It has led to endless bug reports, misuse of the feature and public abuse of the maintainer, for no real increased value.

If the situation with support changes, the feature will be removed from gawk.

If you use this feature, you should consider finding a different toolset with which to accomplish your goals.[2]

16.3.2 Arbitrary Precision Introduction

By default, gawk uses the double-precision floating-point values supplied by the hardware of the system it runs on. However, if it was compiled to do so, and the -M command-line option is supplied, gawk uses the GNU MPFR and GNU MP (GMP) libraries for arbitrary-precision arithmetic on numbers. You can see if MPFR support is available like so:

```
$ gawk --version
⊣ GNU Awk 5.3.1, API 4.0, PMA Avon 8-g1, (GNU MPFR 4.1.0, GNU MP 6.2.1)
⊣ Copyright (C) 1989, 1991-2024 Free Software Foundation.
...
```

(You may see different version numbers than what's shown here. That's OK; what's important is to see that GNU MPFR and GNU MP are listed in the output.)

Additionally, there are a few elements available in the PROCINFO array to provide information about the MPFR and GMP libraries (see Section 7.5.2 [Built-in Variables That Convey Information], page 169).

The MPFR library provides precise control over precisions and rounding modes, and gives correctly rounded, reproducible, platform-independent results. With the -M command-line option, all floating-point arithmetic operators and numeric functions can yield results to any desired precision level supported by MPFR.

Two predefined variables, PREC and ROUNDMODE, provide control over the working precision and the rounding mode. The precision and the rounding mode are set globally for every operation to follow. See Section 16.4.4 [Setting the Precision], page 407, and Section 16.4.5 [Setting the Rounding Mode], page 408, for more information.

16.4 Floating-Point Arithmetic: Caveat Emptor!

Math class is tough!
—*Teen Talk Barbie, July 1992*

[2] Of course, you can always continue to use a version of gawk that still supports arbitrary precision arithmetic. It simply will be unmaintained.

This section provides a high-level overview of the issues involved when doing lots of floating-point arithmetic.[3] The discussion applies to both hardware and arbitrary-precision floating-point arithmetic.

> **CAUTION:** The material here is purposely general. If you need to do serious computer arithmetic, you should do some research first, and not rely just on what we tell you.

16.4.1 Floating-Point Arithmetic Is Not Exact

Binary floating-point representations and arithmetic are inexact. Simple values like 0.1 cannot be precisely represented using binary floating-point numbers, and the limited precision of floating-point numbers means that slight changes in the order of operations or the precision of intermediate storage can change the result. To make matters worse, with arbitrary-precision floating-point arithmetic, you can set the precision before starting a computation, but then you cannot be sure of the number of significant decimal places in the final result.

16.4.1.1 Many Numbers Cannot Be Represented Exactly

So, before you start to write any code, you should think about what you really want and what's really happening. Consider the two numbers in the following example:

```
x = 0.875               # 1/2 + 1/4 + 1/8
y = 0.425
```

Unlike the number in `y`, the number stored in `x` is exactly representable in binary because it can be written as a finite sum of one or more fractions whose denominators are all powers of two. When `gawk` reads a floating-point number from program source, it automatically rounds that number to whatever precision your machine supports. If you try to print the numeric content of a variable using an output format string of `"%.17g"`, it may not produce the same number as you assigned to it:

```
$ gawk 'BEGIN { x = 0.875; y = 0.425
>               printf("%0.17g, %0.17g\n", x, y) }'
 ⊣ 0.875, 0.42499999999999999
```

Often the error is so small you do not even notice it, and if you do, you can always specify how much precision you would like in your output. Usually this is a format string like `"%.15g"`, which, when used in the previous example, produces an output identical to the input.

16.4.1.2 Be Careful Comparing Values

Because the underlying representation can be a little bit off from the exact value, comparing floating-point values to see if they are exactly equal is generally a bad idea. Here is an example where it does not work like you would expect:

```
$ gawk 'BEGIN { print (0.1 + 12.2 == 12.3) }'
 ⊣ 0
```

[3] There is a very nice paper on floating-point arithmetic by David Goldberg, "What Every Computer Scientist Should Know About Floating-Point Arithmetic," *ACM Computing Surveys* **23**, 1 (1991-03): 5-48. This is worth reading if you are interested in the details, but it does require a background in computer science.

The general wisdom when comparing floating-point values is to see if they are within some small range of each other (called a *delta*, or *tolerance*). You have to decide how small a delta is important to you. Code to do this looks something like the following:

```
delta = 0.00001                 # for example
difference = abs(a - b)         # subtract the two values
if (difference < delta)
    # all ok
else
    # not ok
```

(We assume that you have a simple absolute value function named `abs()` defined elsewhere in your program.) If you write a function to compare values with a delta, you should be sure to use '`difference < abs(delta)`' in case someone passes in a negative delta value.

16.4.1.3 Errors Accumulate

The loss of accuracy during a single computation with floating-point numbers usually isn't enough to worry about. However, if you compute a value that is the result of a sequence of floating-point operations, the error can accumulate and greatly affect the computation itself. Here is an attempt to compute the value of π using one of its many series representations:

```
BEGIN {
    x = 1.0 / sqrt(3.0)
    n = 6
    for (i = 1; i < 30; i++) {
        n = n * 2.0
        x = (sqrt(x * x + 1) - 1) / x
        printf("%.15f\n", n * x)
    }
}
```

When run, the early errors propagate through later computations, causing the loop to terminate prematurely after attempting to divide by zero:

```
$ gawk -f pi.awk
⊣ 3.215390309173475
⊣ 3.159659942097510
⊣ 3.146086215131467
⊣ 3.142714599645573
...
⊣ 3.224515243534819
⊣ 2.791117213058638
⊣ 0.000000000000000
error  gawk: pi.awk:6: fatal: division by zero attempted
```

Here is an additional example where the inaccuracies in internal representations yield an unexpected result:

```
$ gawk 'BEGIN {
>   for (d = 1.1; d <= 1.5; d += 0.1)    # loop five times (?)
>       i++
>   print i
```

```
> }'
 ⊣ 4
```

16.4.1.4 Floating Point Values They Didn't Talk About In School

Both IEEE 754 floating-point hardware, and MPFR, support two kinds of values that you probably didn't learn about in school. The first is *infinity*, a special value, that can be either negative or positive, and which is either smaller than any other value (negative infinity), or larger than any other value (positive infinity). When such values are generated, `gawk` prints them as either '`-inf`' or '`+inf`', respectively. It accepts those strings as data input and converts them to the proper floating-point values internally.

Infinity values of the same sign compare as equal to each other. Otherwise, operations (addition, subtraction, etc.) involving another number and infinity produce mathematically reasonable results.

The second kind of value is "not a number", or NaN for short.[4] This is a special value that results from attempting a calculation that has no answer as a real number. In such a case, programs can either receive a floating-point exception, or get NaN back as the result. The IEEE 754 standard recommends that systems return NaN. Some examples:

`sqrt(-1)` The $\sqrt{-1}$ makes sense in the range of complex numbers, but not in the range of real numbers, so the result is NaN.

`log(-8)` -8 is out of the domain of `log()`, so the result is NaN.

NaN values are strange. In particular, they cannot be compared with other floating point values; any such comparison, except for "is not equal to", returns false. NaN values are so much unequal to other values that even comparing two identical NaN values with `!=` returns true!

NaN values can also be signed, although it depends upon the implementation as to which sign you get for any operation that returns a NaN. For example, on some systems, `sqrt(-1)` returns a negative NaN. On others, it returns a positive NaN.

When such values are generated, `gawk` prints them as either '`-nan`' or '`+nan`', respectively. Here too, `gawk` accepts those strings as data input and converts them to the proper floating-point values internally.

If you want to dive more deeply into this topic, you can find test programs in C, `awk` and Python in the directory `awklib/eg/test-programs` in the `gawk` distribution. These programs enable comparison among programming languages as to how they handle NaN and infinity values.

16.4.2 Getting the Accuracy You Need

Can arbitrary-precision arithmetic give exact results? There are no easy answers. The standard rules of algebra often do not apply when using floating-point arithmetic. Among other things, the distributive and associative laws do not hold completely, and order of operation may be important for your computation. Rounding error, cumulative precision loss, and underflow are often troublesome.

When `gawk` tests the expressions '`0.1 + 12.2`' and '`12.3`' for equality using the machine double-precision arithmetic, it decides that they are not equal! (See Section 16.4.1.2 [Be

[4] Thanks to Michael Brennan for this description, which we have paraphrased, and for the examples.

Careful Comparing Values], page 403.) You can get the result you want by increasing the precision; 56 bits in this case does the job:

```
$ gawk -M -v PREC=56 'BEGIN { print (0.1 + 12.2 == 12.3) }'
⊣ 1
```

If adding more bits is good, perhaps adding even more bits of precision is better? Here is what happens if we use an even larger value of `PREC`:

```
$ gawk -M -v PREC=201 'BEGIN { print (0.1 + 12.2 == 12.3) }'
⊣ 0
```

This is not a bug in `gawk` or in the MPFR library. It is easy to forget that the finite number of bits used to store the value is often just an approximation after proper rounding. The test for equality succeeds if and only if *all* bits in the two operands are exactly the same. Because this is not necessarily true after floating-point computations with a particular precision and effective rounding mode, a straight test for equality may not work. Instead, compare the two numbers to see if they are within the desirable delta of each other.

In applications where 15 or fewer decimal places suffice, hardware double-precision arithmetic can be adequate, and is usually much faster. But you need to keep in mind that every floating-point operation can suffer a new rounding error with catastrophic consequences, as illustrated by our earlier attempt to compute the value of π. Extra precision can greatly enhance the stability and the accuracy of your computation in such cases.

Additionally, you should understand that repeated addition is not necessarily equivalent to multiplication in floating-point arithmetic. In the example in Section 16.4.1.3 [Errors Accumulate], page 404:

```
$ gawk 'BEGIN {
>   for (d = 1.1; d <= 1.5; d += 0.1)    # loop five times (?)
>       i++
>   print i
> }'
⊣ 4
```

you may or may not succeed in getting the correct result by choosing an arbitrarily large value for `PREC`. Reformulation of the problem at hand is often the correct approach in such situations.

16.4.3 Try a Few Extra Bits of Precision and Rounding

Instead of arbitrary-precision floating-point arithmetic, often all you need is an adjustment of your logic or a different order for the operations in your calculation. The stability and the accuracy of the computation of π in the earlier example can be enhanced by using the following simple algebraic transformation:

```
(sqrt(x * x + 1) - 1) / x ≡ x / (sqrt(x * x + 1) + 1)
```

After making this change, the program converges to π in under 30 iterations:

```
$ gawk -f pi2.awk
⊣ 3.215390309173473
⊣ 3.159659942097501
⊣ 3.146086215131436
⊣ 3.142714599645370
```

```
⊣ 3.141873049979825
...
⊣ 3.141592653589797
⊣ 3.141592653589797
```

16.4.4 Setting the Precision

gawk uses a global working precision; it does not keep track of the precision or accuracy of individual numbers. Performing an arithmetic operation or calling a built-in function rounds the result to the current working precision. The default working precision is 53 bits, which you can modify using the predefined variable PREC. You can also set the value to one of the predefined case-insensitive strings shown in Table 16.4, to emulate an IEEE 754 binary format.

PREC	**IEEE 754 binary format**
"half"	16-bit half-precision
"single"	Basic 32-bit single precision
"double"	Basic 64-bit double precision
"quad"	Basic 128-bit quadruple precision
"oct"	256-bit octuple precision

Table 16.4: Predefined precision strings for PREC

The following example illustrates the effects of changing precision on arithmetic operations:

```
$ gawk -M -v PREC=100 'BEGIN { x = 1.0e-400; print x + 0
>   PREC = "double"; print x + 0 }'
⊣ 1e-400
⊣ 0
```

CAUTION: Be wary of floating-point constants! When reading a floating-point constant from program source code, gawk uses the default precision (that of a C double), unless overridden by an assignment to the special variable PREC on the command line, to store it internally as an MPFR number. Changing the precision using PREC in the program text does *not* change the precision of a constant.

If you need to represent a floating-point constant at a higher precision than the default and cannot use a command-line assignment to PREC, you should either specify the constant as a string, or as a rational number, whenever possible. The following example illustrates the differences among various ways to print a floating-point constant:

```
$ gawk -M 'BEGIN { PREC = 113; printf("%0.25f\n", 0.1) }'
⊣ 0.1000000000000000055511151
$ gawk -M -v PREC=113 'BEGIN { printf("%0.25f\n", 0.1) }'
⊣ 0.1000000000000000000000000
$ gawk -M 'BEGIN { PREC = 113; printf("%0.25f\n", "0.1") }'
⊣ 0.1000000000000000000000000
$ gawk -M 'BEGIN { PREC = 113; printf("%0.25f\n", 1/10) }'
⊣ 0.1000000000000000000000000
```

16.4.5 Setting the Rounding Mode

The `ROUNDMODE` variable provides program-level control over the rounding mode. The correspondence between `ROUNDMODE` and the IEEE rounding modes is shown in Table 16.5.

Rounding mode	IEEE name	ROUNDMODE
Round to nearest, ties to even	`roundTiesToEven`	`"N"` or `"n"`
Round toward positive infinity	`roundTowardPositive`	`"U"` or `"u"`
Round toward negative infinity	`roundTowardNegative`	`"D"` or `"d"`
Round toward zero	`roundTowardZero`	`"Z"` or `"z"`
Round away from zero		`"A"` or `"a"`

Table 16.5: `gawk` rounding modes

`ROUNDMODE` has the default value `"N"`, which selects the IEEE 754 rounding mode `roundTiesToEven`. In Table 16.5, the value `"A"` selects rounding away from zero. This is only available if your version of the MPFR library supports it; otherwise, setting `ROUNDMODE` to `"A"` has no effect.

The default mode `roundTiesToEven` is the most preferred, but the least intuitive. This method does the obvious thing for most values, by rounding them up or down to the nearest digit. For example, rounding 1.132 to two digits yields 1.13, and rounding 1.157 yields 1.16.

However, when it comes to rounding a value that is exactly halfway between, things do not work the way you probably learned in school. In this case, the number is rounded to the nearest even digit. So rounding 0.125 to two digits rounds down to 0.12, but rounding 0.6875 to three digits rounds up to 0.688. You probably have already encountered this rounding mode when using `printf` to format floating-point numbers. For example:

```
BEGIN {
    x = -4.5
    for (i = 1; i < 10; i++) {
        x += 1.0
        printf("%4.1f => %2.0f\n", x, x)
    }
}
```

produces the following output when run on the author's system:[5]

```
-3.5 => -4
-2.5 => -2
-1.5 => -2
-0.5 => 0
 0.5 => 0
 1.5 => 2
 2.5 => 2
 3.5 => 4
 4.5 => 4
```

The theory behind `roundTiesToEven` is that it more or less evenly distributes upward and downward rounds of exact halves, which might cause any accumulating round-off error

[5] It is possible for the output to be completely different if the C library in your system does not use the IEEE 754 even-rounding rule to round halfway cases for `printf()`.

to cancel itself out. This is the default rounding mode for IEEE 754 computing functions and operators.

Rounding Modes and Conversion

It's important to understand that, along with `CONVFMT` and `OFMT`, the rounding mode affects how numbers are converted to strings. For example, consider the following program:

```
BEGIN {
    pi = 3.1416
    OFMT = "%.f"        # Print value as integer
    print pi            # ROUNDMODE = "N" by default.
    ROUNDMODE = "U"     # Now change ROUNDMODE
    print pi
}
```

Running this program produces this output:

```
$ gawk -M -f roundmode.awk
⊣ 3
⊣ 4
```

The other rounding modes are rarely used. Rounding toward positive infinity (`roundTowardPositive`) and toward negative infinity (`roundTowardNegative`) are often used to implement interval arithmetic, where you adjust the rounding mode to calculate upper and lower bounds for the range of output. The `roundTowardZero` mode can be used for converting floating-point numbers to integers. When rounding away from zero, the nearest number with magnitude greater than or equal to the value is selected.

Some numerical analysts will tell you that your choice of rounding style has tremendous impact on the final outcome, and advise you to wait until final output for any rounding. Instead, you can often avoid round-off error problems by setting the precision initially to some value sufficiently larger than the final desired precision, so that the accumulation of round-off error does not influence the outcome. If you suspect that results from your computation are sensitive to accumulation of round-off error, look for a significant difference in output when you change the rounding mode to be sure.

16.5 Arbitrary-Precision Integer Arithmetic with gawk

When given the `-M` option, `gawk` performs all integer arithmetic using GMP arbitrary-precision integers. Any number that looks like an integer in a source or data file is stored as an arbitrary-precision integer. The size of the integer is limited only by the available memory. For example, the following computes $5^{4^{3^2}}$, the result of which is beyond the limits of ordinary hardware double-precision floating-point values:

```
$ gawk -M 'BEGIN {
>   x = 5^4^3^2
>   print "number of digits =", length(x)
>   print substr(x, 1, 20), "...", substr(x, length(x) - 19, 20)
> }'
⊣ number of digits = 183231
⊣ 62060698786608744707 ... 92256259918212890625
```

If instead you were to compute the same value using arbitrary-precision floating-point values, the precision needed for correct output (using the formula $prec = 3.322 \cdot dps$) would be $3.322 \cdot 183231$, or 608693.

The result from an arithmetic operation with an integer and a floating-point value is a floating-point value with a precision equal to the working precision. The following program calculates the eighth term in Sylvester's sequence[6] using a recurrence:

```
$ gawk -M 'BEGIN {
>   s = 2.0
>   for (i = 1; i <= 7; i++)
>       s = s * (s - 1) + 1
>   print s
> }'
 ⊣ 113423713055421845118910464
```

The output differs from the actual number, 113,423,713,055,421,844,361,000,443, because the default precision of 53 bits is not enough to represent the floating-point results exactly. You can either increase the precision (100 bits is enough in this case), or replace the floating-point constant '`2.0`' with an integer, to perform all computations using integer arithmetic to get the correct output.

Sometimes `gawk` must implicitly convert an arbitrary-precision integer into an arbitrary-precision floating-point value. This is primarily because the MPFR library does not always provide the relevant interface to process arbitrary-precision integers or mixed-mode numbers as needed by an operation or function. In such a case, the precision is set to the minimum value necessary for exact conversion, and the working precision is not used for this purpose. If this is not what you need or want, you can employ a subterfuge and convert the integer to floating point first, like this:

```
gawk -M 'BEGIN { n = 13; print (n + 0.0) % 2.0 }'
```

You can avoid this issue altogether by specifying the number as a floating-point value to begin with:

```
gawk -M 'BEGIN { n = 13.0; print n % 2.0 }'
```

Note that for this particular example, it is likely best to just use the following:

```
gawk -M 'BEGIN { n = 13; print n % 2 }'
```

When dividing two arbitrary precision integers with either '`/`' or '`%`', the result is typically an arbitrary precision floating point value (unless the denominator evenly divides into the numerator).

16.6 How To Check If MPFR Is Available

Occasionally, you might like to be able to check if `gawk` was invoked with the `-M` option, enabling arbitrary-precision arithmetic. You can do so with the following function, contributed by Andrew Schorr:

```
# adequate_math_precision --- return true if we have enough bits
```

[6] Weisstein, Eric W. *Sylvester's Sequence*. From MathWorld—A Wolfram Web Resource (https://mathworld.wolfram.com/SylvestersSequence.html).

```
function adequate_math_precision(n)
{
    return (1 != (1+(1/(2^(n-1)))))
}
```

Here is code that invokes the function in order to check if arbitrary-precision arithmetic is available:

```
BEGIN {
    # How many bits of mantissa precision are required
    # for this program to function properly?
    fpbits = 123

    # We hope that we were invoked with MPFR enabled. If so, the
    # following statement should configure calculations to our desired
    # precision.
    PREC = fpbits

    if (! adequate_math_precision(fpbits)) {
        print("Error: insufficient computation precision available.\n" \
              "Try again with the -M argument?") > "/dev/stderr"
        # Note: you may need to set a flag here to bail out of END rules
        exit 1
    }
}
```

Please be aware that `exit` will jump to the `END` rules, if present (see Section 7.4.10 [The `exit` Statement], page 166).

16.7 Standards Versus Existing Practice

Historically, `awk` has converted any nonnumeric-looking string to the numeric value zero, when required. Furthermore, the original definition of the language and the original POSIX standards specified that `awk` only understands decimal numbers (base 10), and not octal (base 8) or hexadecimal numbers (base 16).

Changes in the language of the 2001 and 2004 POSIX standards can be interpreted to imply that `awk` should support additional features. These features are:

- Interpretation of floating-point data values specified in hexadecimal notation (e.g., `0xDEADBEEF`). (Note: data values, *not* source code constants.)
- Support for the special IEEE 754 floating-point values "not a number" (NaN), positive infinity ("inf"), and negative infinity ("−inf"). In particular, the format for these values is as specified by the ISO 1999 C standard, which ignores case and can allow implementation-dependent additional characters after the '`nan`' and allow either '`inf`' or '`infinity`'.

The first problem is that both of these are clear changes to historical practice:

- The `gawk` maintainer feels that supporting hexadecimal floating-point values, in particular, is ugly, and was never intended by the original designers to be part of the language.

- Allowing completely alphabetic strings to have valid numeric values is also a very severe departure from historical practice.

The second problem is that the `gawk` maintainer feels that this interpretation of the standard, which required a certain amount of "language lawyering" to arrive at in the first place, was not even intended by the standard developers. In other words, "We see how you got where you are, but we don't think that that's where you want to be."

Recognizing these issues, but attempting to provide compatibility with the earlier versions of the standard, the 2008 POSIX standard added explicit wording to allow, but not require, that `awk` support hexadecimal floating-point values and special values for "not a number" and infinity.

Although the `gawk` maintainer continues to feel that providing those features is inadvisable, nevertheless, on systems that support IEEE floating point, it seems reasonable to provide *some* way to support NaN and infinity values. The solution implemented in `gawk` is as follows:

- With the `--posix` command-line option, `gawk` becomes "hands off." String values are passed directly to the system library's `strtod()` function, and if it successfully returns a numeric value, that is what's used.[7] By definition, the results are not portable across different systems. They are also a little surprising:

```
$ echo nanny | gawk --posix '{ print $1 + 0 }'
⊣ nan
$ echo 0xDeadBeef | gawk --posix '{ print $1 + 0 }'
⊣ 3735928559
```

- Without `--posix`, `gawk` interprets the four string values '`+inf`', '`-inf`', '`+nan`', and '`-nan`' specially, producing the corresponding special numeric values. The leading sign acts a signal to `gawk` (and the user) that the value is really numeric. Hexadecimal floating point is not supported (unless you also use `--non-decimal-data`, which is *not* recommended). For example:

```
$ echo nanny | gawk '{ print $1 + 0 }'
⊣ 0
$ echo +nan | gawk '{ print $1 + 0 }'
⊣ +nan
$ echo 0xDeadBeef | gawk '{ print $1 + 0 }'
⊣ 0
```

  `gawk` ignores case in the four special values. Thus, '`+nan`' and '`+NaN`' are the same.

Besides handling input, `gawk` also needs to print "correct" values on output when a value is either NaN or infinity. Starting with version 4.2.2, for such values `gawk` prints one of the four strings just described: '`+inf`', '`-inf`', '`+nan`', or '`-nan`'. Similarly, in POSIX mode, `gawk` prints the result of the system's C `printf()` function using the `%g` format string for the value, whatever that may be.

16.8 Summary

- Most computer arithmetic is done using either integers or floating-point values. Standard `awk` uses double-precision floating-point values.

[7] You asked for it, you got it.

- In the early 1990s Barbie mistakenly said, "Math class is tough!" Although math isn't tough, floating-point arithmetic isn't the same as pencil-and-paper math, and care must be taken:
  - Not all numbers can be represented exactly.
  - Comparing values should use a delta, instead of being done directly with '`==`' and '`!=`'.
  - Errors accumulate.
  - Operations are not always truly associative or distributive.
- Increasing the accuracy can help, but it is not a panacea.
- Often, increasing the accuracy and then rounding to the desired number of digits produces reasonable results.
- Use `-M` (or `--bignum`) to enable MPFR arithmetic. Use `PREC` to set the precision in bits, and `ROUNDMODE` to set the IEEE 754 rounding mode.
- With `-M`, `gawk` performs arbitrary-precision integer arithmetic using the GMP library. This is faster and more space-efficient than using MPFR for the same calculations.
- There are several areas with respect to floating-point numbers where `gawk` disagrees with the POSIX standard. It pays to be aware of them.
- Overall, there is no need to be unduly suspicious about the results from floating-point arithmetic. The lesson to remember is that floating-point arithmetic is always more complex than arithmetic using pencil and paper. In order to take advantage of the power of floating-point arithmetic, you need to know its limitations and work within them. For most casual use of floating-point arithmetic, you will often get the expected result if you simply round the display of your final results to the correct number of significant decimal digits.
- As general advice, avoid presenting numerical data in a manner that implies better precision than is actually the case.

17 Writing Extensions for gawk

It is possible to add new functions written in C or C++ to gawk using dynamically loaded libraries. This facility is available on systems that support the C dlopen() and dlsym() functions. This chapter describes how to create extensions using code written in C or C++.

If you don't know anything about C programming, you can safely skip this chapter, although you may wish to review the documentation on the extensions that come with gawk (see Section 17.7 [The Sample Extensions in the gawk Distribution], page 467), and the information on the gawkextlib project (see Section 17.8 [The gawkextlib Project], page 478). The sample extensions are automatically built and installed when gawk is.

> **NOTE:** When --sandbox is specified, extensions are disabled (see Section 2.2 [Command-Line Options], page 33).

17.1 Introduction

An *extension* (sometimes called a *plug-in*) is a piece of external compiled code that gawk can load at runtime to provide additional functionality, over and above the built-in capabilities described in the rest of this book.

Extensions are useful because they allow you (of course) to extend gawk's functionality. For example, they can provide access to system calls (such as chdir() to change directory) and to other C library routines that could be of use. As with most software, "the sky is the limit"; if you can imagine something that you might want to do and can write in C or C++, you can write an extension to do it!

Extensions are written in C or C++, using the *application programming interface* (API) defined for this purpose by the gawk developers. The rest of this chapter explains the facilities that the API provides and how to use them, and presents a small example extension. In addition, it documents the sample extensions included in the gawk distribution and describes the gawkextlib project. See Section C.5 [Extension API Design], page 535, for a discussion of the extension mechanism goals and design.

17.2 Extension Licensing

Every dynamic extension must be distributed under a license that is compatible with the GNU GPL (see [GNU General Public License], page 557).

In order for the extension to tell gawk that it is properly licensed, the extension must define the global symbol plugin_is_GPL_compatible. If this symbol does not exist, gawk emits a fatal error and exits when it tries to load your extension.

The declared type of the symbol should be int. It does not need to be in any allocated section, though. The code merely asserts that the symbol exists in the global scope. Something like this is enough:

```
int plugin_is_GPL_compatible;
```

17.3 How It Works at a High Level

Communication between gawk and an extension is two-way. First, when an extension is loaded, gawk passes it a pointer to a struct whose fields are function pointers. This is shown in Figure 17.1.

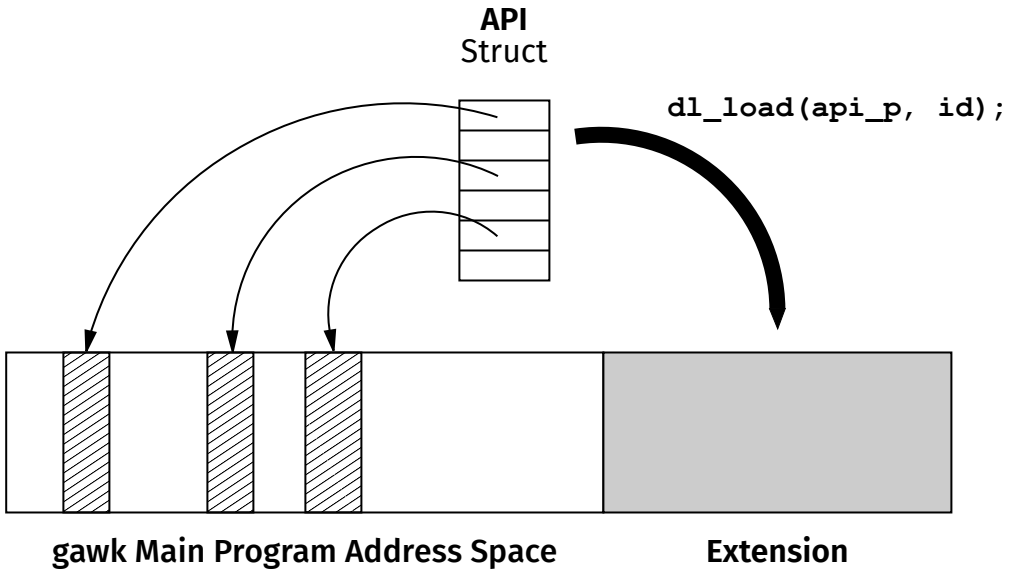

Figure 17.1: Loading the extension

The extension can call functions inside `gawk` through these function pointers, at runtime, without needing (link-time) access to `gawk`'s symbols. One of these function pointers is to a function for "registering" new functions. This is shown in Figure 17.2.

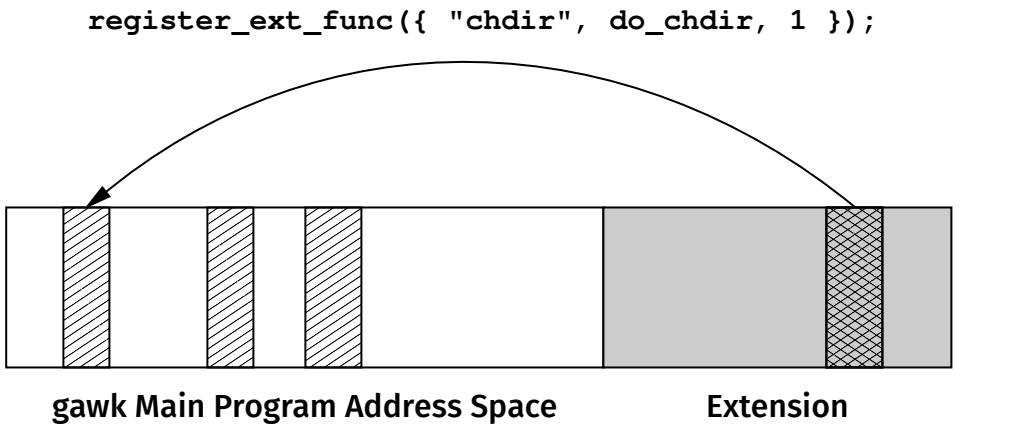

Figure 17.2: Registering a new function

In the other direction, the extension registers its new functions with `gawk` by passing function pointers to the functions that provide the new feature (`do_chdir()`, for example). `gawk` associates the function pointer with a name and can then call it, using a defined calling convention. This is shown in Figure 17.3.

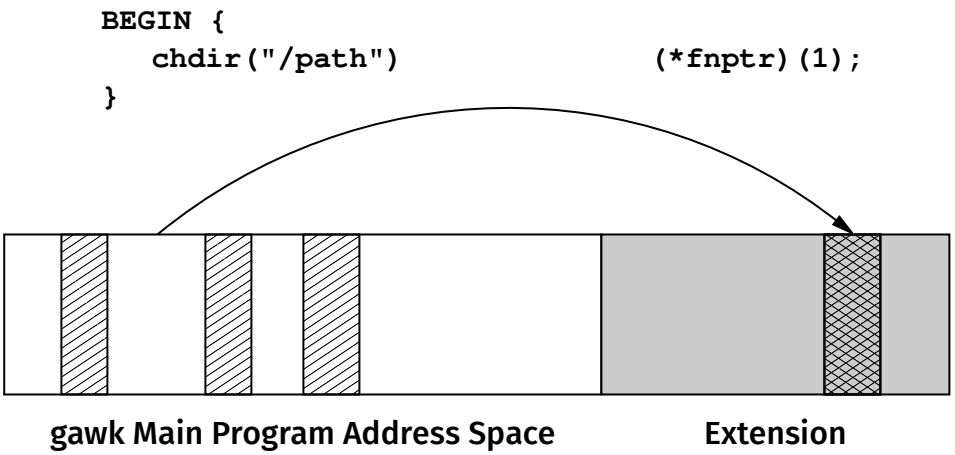

Figure 17.3: Calling the new function

The `do_xxx()` function, in turn, then uses the function pointers in the API `struct` to do its work, such as updating variables or arrays, printing messages, setting `ERRNO`, and so on.

Convenience macros make calling through the function pointers look like regular function calls so that extension code is quite readable and understandable.

Although all of this sounds somewhat complicated, the result is that extension code is quite straightforward to write and to read. You can see this in the sample extension `filefuncs.c` (see Section 17.6 [Example: Some File Functions], page 458) and also in the `testext.c` code for testing the APIs.

Some other bits and pieces:

- The API provides access to `gawk`'s `do_xxx` values, reflecting command-line options, like `do_lint`, `do_profiling`, and so on (see Section 17.4.14 [API Variables], page 453). These are informational: an extension cannot affect their values inside `gawk`. In addition, attempting to assign to them produces a compile-time error.
- The API also provides major and minor version numbers, so that an extension can check if the `gawk` it is loaded with supports the facilities it was compiled with. (Version mismatches "shouldn't" happen, but we all know how *that* goes.) See Section 17.4.14.1 [API Version Constants and Variables], page 453, for details.

17.4 API Description

C or C++ code for an extension must include the header file `gawkapi.h`, which declares the functions and defines the data types used to communicate with `gawk`. This (rather large) section describes the API in detail.

17.4.1 Introduction

Access to facilities within `gawk` is achieved by calling through function pointers passed into your extension.

API function pointers are provided for the following kinds of operations:

- Allocating, reallocating, and releasing memory.
- Registration functions. You may register:
  - Extension functions
  - Exit callbacks
  - A version string
  - Input parsers
  - Output wrappers
  - Two-way processors

  All of these are discussed in detail later in this chapter.
- Printing fatal, warning, and "lint" warning messages.
- Updating `ERRNO`, or unsetting it.
- Accessing parameters, including converting an undefined parameter into an array.
- Symbol table access: retrieving a global variable, creating one, or changing one.
- Creating and releasing cached values; this provides an efficient way to use values for multiple variables and can be a big performance win.
- Manipulating arrays:
  - Retrieving, adding, deleting, and modifying elements
  - Getting the count of elements in an array
  - Creating a new array
  - Clearing an array
  - Flattening an array for easy C-style looping over all its indices and elements
- Accessing and manipulating redirections.

Some points about using the API:

- The following types, macros, and/or functions are referenced in `gawkapi.h`. For correct use, you must therefore include the corresponding standard header file *before* including `gawkapi.h`. The list of macros and related header files is shown in Table 17.1.

C entity	**Header file**
`EOF`	`<stdio.h>`
Values for `errno`	`<errno.h>`
`FILE`	`<stdio.h>`
`NULL`	`<stddef.h>`
`memcpy()`	`<string.h>`
`memset()`	`<string.h>`
`size_t`	`<sys/types.h>`
`struct stat`	`<sys/stat.h>`

Table 17.1: Standard header files needed by API

Due to portability concerns, especially to systems that are not fully standards-compliant, it is your responsibility to include the correct files in the correct way. This requirement is necessary in order to keep `gawkapi.h` clean, instead of becoming a portability hodge-podge as can be seen in some parts of the `gawk` source code.

- If your extension uses MPFR facilities, and you wish to receive such values from `gawk` and/or pass such values to it, you must include the `<mpfr.h>` header before including `<gawkapi.h>`.
- The `gawkapi.h` file may be included more than once without ill effect. Doing so, however, is poor coding practice.
- Although the API only uses ISO C 90 features, there is an exception; the "constructor" functions use the `inline` keyword. If your compiler does not support this keyword, you should either place '`-Dinline=''`' on your command line or use the GNU Autotools and include a `config.h` file in your extensions.
- All pointers filled in by `gawk` point to memory managed by `gawk` and should be treated by the extension as read-only.

  Memory for *all* strings passed into `gawk` from the extension *must* come from calling one of `gawk_malloc()`, `gawk_calloc()`, or `gawk_realloc()`, and is managed by `gawk` from then on.

  Memory for MPFR/GMP values that come from `gawk` should also be treated as read-only. However, unlike strings, memory for MPFR/GMP values allocated by an extension and passed into `gawk` is *copied* by `gawk`; the extension should then free the values itself to avoid memory leaks. This is discussed further in Section 17.4.5 [Managing MPFR and GMP Values], page 426.
- The API defines several simple `struct`s that map values as seen from `awk`. A value can be a `double`, a string, or an array (as in multidimensional arrays, or when creating a new array).

  String values maintain both pointer and length, because embedded NUL characters are allowed.

  > **NOTE:** By intent, `gawk` maintains strings using the current multibyte encoding (as defined by `LC_xxx` environment variables) and not using wide characters. This matches how `gawk` stores strings internally and also how characters are likely to be input into and output from files.
  >
  > **NOTE:** String values passed to an extension by `gawk` are always NUL-terminated. Thus it is safe to pass such string values to standard library and system routines. However, because `gawk` allows embedded NUL characters in string data, before using the data as a regular C string, you should check that the length for that string passed to the extension matches the return value of `strlen()` for it.
- When retrieving a value (such as a parameter or that of a global variable or array element), the extension requests a specific type (number, string, scalar, value cookie, array, or "undefined"). When the request is "undefined," the returned value will have the real underlying type.

  However, if the request and actual type don't match, the access function returns "false" and fills in the type of the actual value that is there, so that the extension can, e.g., print an error message (such as "scalar passed where array expected").

You may call the API functions by using the function pointers directly, but the interface is not so pretty. To make extension code look more like regular code, the `gawkapi.h` header file defines several macros that you should use in your code. This section presents the macros as if they were functions.

17.4.2 General-Purpose Data Types

I have a true love/hate relationship with unions.
—*Arnold Robbins*

That's the thing about unions: the compiler will arrange things so they can accommodate both love and hate.
—*Chet Ramey*

The extension API defines a number of simple types and structures for general-purpose use. Additional, more specialized, data structures are introduced in subsequent sections, together with the functions that use them.

The general-purpose types and structures are as follows:

```
typedef void *awk_ext_id_t;
```
A value of this type is received from `gawk` when an extension is loaded. That value must then be passed back to `gawk` as the first parameter of each API function.

```
#define awk_const ...
```
This macro expands to '`const`' when compiling an extension, and to nothing when compiling `gawk` itself. This makes certain fields in the API data structures unwritable from extension code, while allowing `gawk` to use them as it needs to.

```
typedef enum awk_bool {
    awk_false = 0,
    awk_true
} awk_bool_t;
```
A simple Boolean type.

```
typedef struct awk_string {
    char *str;      /* data */
    size_t len;     /* length thereof, in chars */
} awk_string_t;
```
This represents a mutable string. `gawk` owns the memory pointed to if it supplied the value. Otherwise, it takes ownership of the memory pointed to. *Such memory must come from calling one of the* `gawk_malloc()`, `gawk_calloc()`, *or* `gawk_realloc()` *functions!*

As mentioned earlier, strings are maintained using the current multibyte encoding.

```
typedef enum {
    AWK_UNDEFINED,
    AWK_NUMBER,
    AWK_STRING,
    AWK_REGEX,
    AWK_STRNUM,
    AWK_ARRAY,
    AWK_SCALAR,         /* opaque access to a variable */
    AWK_VALUE_COOKIE,   /* for updating a previously created value */
    AWK_BOOL
} awk_valtype_t;
```

This `enum` indicates the type of a value. It is used in the following `struct`.

```
typedef struct awk_value {
    awk_valtype_t val_type;
    union {
        awk_string_t       s;
        awknum_t           n;
        awk_array_t        a;
        awk_scalar_t       scl;
        awk_value_cookie_t vc;
        awk_bool_t         b;
    } u;
} awk_value_t;
```

An "awk value." The `val_type` member indicates what kind of value the `union` holds, and each member is of the appropriate type.

```
#define str_value      u.s
#define strnum_value   str_value
#define regex_value    str_value
#define num_value      u.n.d
#define num_type       u.n.type
#define num_ptr        u.n.ptr
#define array_cookie   u.a
#define scalar_cookie  u.scl
#define value_cookie   u.vc
#define bool_value     u.b
```

Using these macros makes accessing the fields of the `awk_value_t` more readable.

```
enum AWK_NUMBER_TYPE {
    AWK_NUMBER_TYPE_DOUBLE,
    AWK_NUMBER_TYPE_MPFR,
    AWK_NUMBER_TYPE_MPZ
};
```

This `enum` is used in the following structure for defining the type of numeric value that is being worked with. It is declared at the top level of the file so that it works correctly for C++ as well as for C.

```
typedef struct awk_number {
    double d;
    enum AWK_NUMBER_TYPE type;
    void *ptr;
} awk_number_t;
```

This represents a numeric value. Internally, `gawk` stores every number as either a C `double`, a GMP integer, or an MPFR arbitrary-precision floating-point value. In order to allow extensions to also support GMP and MPFR values, numeric values are passed in this structure.

The double-precision `d` element is always populated in data received from `gawk`. In addition, by examining the `type` member, an extension can determine if the `ptr` member is either a GMP integer (type `mpz_ptr`), or an MPFR floating-point value (type `mpfr_ptr_t`), and cast it appropriately.

> **CAUTION:** Any MPFR or MPZ values that you create and pass to `gawk` to save are *copied*. This means you are responsible to release the storage once you're done with it. See the sample `intdiv` extension for some example code.

```
typedef void *awk_scalar_t;
```

Scalars can be represented as an opaque type. These values are obtained from `gawk` and then passed back into it. This is discussed in a general fashion in the text following this list, and in more detail in Section 17.4.11.2 [Variable Access and Update by Cookie], page 440.

```
typedef void *awk_value_cookie_t;
```

A "value cookie" is an opaque type representing a cached value. This is also discussed in a general fashion in the text following this list, and in more detail in Section 17.4.11.3 [Creating and Using Cached Values], page 442.

Scalar values in `awk` are numbers, strings, strnums, or typed regexps. The `awk_value_t` struct represents values. The `val_type` member indicates what is in the `union`.

Representing numbers is easy—the API uses a C `double`. Strings require more work. Because `gawk` allows embedded NUL bytes in string values, a string must be represented as a pair containing a data pointer and length. This is the `awk_string_t` type.

A strnum (numeric string) value is represented as a string and consists of user input data that appears to be numeric. When an extension creates a strnum value, the result is a string flagged as user input. Subsequent parsing by `gawk` then determines whether it looks like a number and should be treated as a strnum, or as a regular string.

This is useful in cases where an extension function would like to do something comparable to the `split()` function which sets the strnum attribute on the array elements it creates. For example, an extension that implements CSV splitting would want to use this feature. This is also useful for a function that retrieves a data item from a database. The PostgreSQL `PQgetvalue()` function, for example, returns a string that may be numeric or textual depending on the contents.

Typed regexp values (see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127) are not of much use to extension functions. Extension functions can tell that they've received them, and create them for scalar values. Otherwise, they can examine the text of the regexp through `regex_value.str` and `regex_value.len`.

Identifiers (i.e., the names of global variables) can be associated with either scalar values or with arrays. In addition, gawk provides true arrays of arrays, where any given array element can itself be an array. Discussion of arrays is delayed until Section 17.4.12 [Array Manipulation], page 444.

The various macros listed earlier make it easier to use the elements of the union as if they were fields in a struct; this is a common coding practice in C. Such code is easier to write and to read, but it remains *your* responsibility to make sure that the val_type member correctly reflects the type of the value in the awk_value_t struct.

Conceptually, the first three members of the union (number, string, and array) are all that is needed for working with awk values. However, because the API provides routines for accessing and changing the value of a global scalar variable only by using the variable's name, there is a performance penalty: gawk must find the variable each time it is accessed and changed. This turns out to be a real issue, not just a theoretical one.

Thus, if you know that your extension will spend considerable time reading and/or changing the value of one or more scalar variables, you can obtain a *scalar cookie*[1] object for that variable, and then use the cookie for getting the variable's value or for changing the variable's value. The awk_scalar_t type holds a scalar cookie, and the scalar_cookie macro provides access to the value of that type in the awk_value_t struct. Given a scalar cookie, gawk can directly retrieve or modify the value, as required, without having to find it first.

The awk_value_cookie_t type and value_cookie macro are similar. If you know that you wish to use the same numeric or string *value* for one or more variables, you can create the value once, retaining a *value cookie* for it, and then pass in that value cookie whenever you wish to set the value of a variable. This saves storage space within the running gawk process and reduces the time needed to create the value.

17.4.3 Memory Allocation Functions and Convenience Macros

The API provides a number of *memory allocation* functions for allocating memory that can be passed to gawk, as well as a number of convenience macros. This subsection presents them all as function prototypes, in the way that extension code would use them:

`void *gawk_malloc(size_t size);`
: Call the correct version of malloc() to allocate storage that may be passed to gawk.

`void *gawk_calloc(size_t nmemb, size_t size);`
: Call the correct version of calloc() to allocate storage that may be passed to gawk.

`void *gawk_realloc(void *ptr, size_t size);`
: Call the correct version of realloc() to allocate storage that may be passed to gawk.

`void gawk_free(void *ptr);`
: Call the correct version of free() to release storage that was allocated with gawk_malloc(), gawk_calloc(), or gawk_realloc().

[1] See the "cookie" entry in the Jargon file for a definition of *cookie*, and the "magic cookie" entry in the Jargon file for a nice example. See also the entry for "Cookie" in the [Glossary], page 543.

The API has to provide these functions because it is possible for an extension to be compiled and linked against a different version of the C library than was used for the `gawk` executable.[2] If `gawk` were to use its version of `free()` when the memory came from an unrelated version of `malloc()`, unexpected behavior would likely result.

Three convenience macros may be used for allocating storage from `gawk_malloc()`, `gawk_calloc`, and `gawk_realloc()`. If the allocation fails, they cause `gawk` to exit with a fatal error message. They should be used as if they were procedure calls that do not return a value:

`#define emalloc(pointer, type, size, message) ...`

The arguments to this macro are as follows:

`pointer` The pointer variable to point at the allocated storage.

`type` The type of the pointer variable. This is used to create a cast for the call to `gawk_malloc()`.

`size` The total number of bytes to be allocated.

`message` A message to be prefixed to the fatal error message. Typically this is the name of the function using the macro.

For example, you might allocate a string value like so:

```
awk_value_t result;
char *message;
const char greet[] = "Don't Panic!";

emalloc(message, char *, sizeof(greet), "myfunc");
strcpy(message, greet);
make_malloced_string(message, strlen(message), & result);
```

`#define ezalloc(pointer, type, size, message) ...`

This is like `emalloc()`, but it calls `gawk_calloc()` instead of `gawk_malloc()`. The arguments are the same as for the `emalloc()` macro, but this macro guarantees that the memory returned is initialized to zero.

`#define erealloc(pointer, type, size, message) ...`

This is like `emalloc()`, but it calls `gawk_realloc()` instead of `gawk_malloc()`. The arguments are the same as for the `emalloc()` macro.

Two additional functions allocate MPFR and GMP objects for use by extension functions that need to create and then return such values.

> **NOTE:** These functions are obsolete. Extension functions that need local MPFR and GMP values should simply allocate them on the stack and clear them, as any other code would.

The functions are:

`void *get_mpfr_ptr();`

Allocate and initialize an MPFR object and return a pointer to it. If the allocation fails, `gawk` exits with a fatal "out of memory" error. If `gawk` was compiled without MPFR support, calling this function causes a fatal error.

[2] This is more common on MS-Windows systems, but it can happen on Unix-like systems as well.

`void *get_mpz_ptr();`
: Allocate and initialize a GMP object and return a pointer to it. If the allocation fails, `gawk` exits with a fatal "out of memory" error. If `gawk` was compiled without MPFR support, calling this function causes a fatal error.

Both of these functions return '`void *`', since the `gawkapi.h` header file should not have dependency upon `<mpfr.h>` (and `<gmp.h>`, which is included from `<mpfr.h>`). The actual return values are of types `mpfr_ptr` and `mpz_ptr` respectively, and you should cast the return values appropriately before assigning the results to variables of the correct types.

The memory allocated by these functions should be freed with `gawk_free()`.

17.4.4 Constructor Functions

The API provides a number of *constructor* functions for creating string and numeric values, as well as a number of convenience macros. This subsection presents them all as function prototypes, in the way that extension code would use them:

```
static inline awk_value_t *
make_const_string(const char *string, size_t length, awk_value_t *result);
```
: This function creates a string value in the `awk_value_t` variable pointed to by `result`. It expects `string` to be a C string constant (or other string data), and automatically creates a *copy* of the data for storage in `result`. It returns `result`.

```
static inline awk_value_t *
make_malloced_string(const char *string, size_t length, awk_value_t *result);
```
: This function creates a string value in the `awk_value_t` variable pointed to by `result`. It expects `string` to be a '`char *`' value pointing to data previously obtained from `gawk_malloc()`, `gawk_calloc()`, or `gawk_realloc()`. The idea here is that the data is passed directly to `gawk`, which assumes responsibility for it. It returns `result`.

```
static inline awk_value_t *
make_null_string(awk_value_t *result);
```
: This specialized function creates a null string (the "undefined" value) in the `awk_value_t` variable pointed to by `result`. It returns `result`.

```
static inline awk_value_t *
make_number(double num, awk_value_t *result);
```
: This function simply creates a numeric value in the `awk_value_t` variable pointed to by `result`.

```
static inline awk_value_t *
make_number_mpz(void *mpz, awk_value_t *result);
```
: This function creates a GMP number value in `result`. The `mpz` must be from a call to `get_mpz_ptr()` (and thus be of real underlying type `mpz_ptr`).

```
static inline awk_value_t *
make_number_mpfr(void *mpfr, awk_value_t *result);
```
: This function creates an MPFR number value in `result`. The `mpfr` must be from a call to `get_mpfr_ptr()`.

```
static inline awk_value_t *
make_const_user_input(const char *string, size_t length, awk_value_t
*result);
```

This function is identical to `make_const_string()`, but the string is flagged as user input that should be treated as a strnum value if the contents of the string are numeric.

```
static inline awk_value_t *
make_malloced_user_input(const char *string, size_t length, awk_value_t
*result);
```

This function is identical to `make_malloced_string()`, but the string is flagged as user input that should be treated as a strnum value if the contents of the string are numeric.

```
static inline awk_value_t *
make_const_regex(const char *string, size_t length, awk_value_t *result);
```

This function creates a strongly typed regexp value by allocating a copy of the string. `string` is the regular expression of length `len`.

```
static inline awk_value_t *
make_malloced_regex(const char *string, size_t length, awk_value_t *result);
```

This function creates a strongly typed regexp value. `string` is the regular expression of length `len`. It expects `string` to be a '`char *`' value pointing to data previously obtained from `gawk_malloc()`, `gawk_calloc()`, or `gawk_realloc()`.

```
static inline awk_value_t *
make_bool(awk_bool_t boolval, awk_value_t *result);
```

This function creates a boolean value in the `awk_value_t` variable pointed to by `result`.

17.4.5 Managing MPFR and GMP Values

MPFR and GMP values are different from string values, where you can "take ownership" of the value simply by assigning pointers. For example:

```
char *p = gawk_malloc(42);      p "owns" the memory
char *q = p;
p = NULL;                       now q "owns" it
```

MPFR and GMP objects are indeed allocated on the stack or dynamically, but the MPFR and GMP libraries treat these objects as values, the same way that you would pass an `int` or a `double` by value. There is no way to "transfer ownership" of MPFR and GMP objects.

The final results of an MPFR or GMP calculation should be passed back to `gawk`, by value, as you would a string or a `double`. `gawk` will take care of freeing the storage.

Thus, code in an extension should look like this:

```
mpz_t part1, part2, answer;             declare local values

mpz_set_si(part1, 21);                  do some computations
mpz_set_si(part2, 21);
```

```
mpz_add(answer, part1, part2);
...
/* assume that result is a parameter of type (awk_value_t *). */
make_number_mpz(answer, & result);      set it with final GMP value

mpz_clear(part1);                       release intermediate values
mpz_clear(part2);

return result;                          value in answer managed by gawk
```

17.4.6 Registration Functions

This section describes the API functions for registering parts of your extension with `gawk`.

17.4.6.1 Registering An Extension Function

Extension functions are described by the following record:

```
typedef struct awk_ext_func {
    const char *name;
    awk_value_t *(*const function)(int num_actual_args,
                                   awk_value_t *result,
                                   struct awk_ext_func *finfo);
    const size_t max_expected_args;
    const size_t min_required_args;
    awk_bool_t suppress_lint;
    void *data;        /* opaque pointer to any extra state */
} awk_ext_func_t;
```

The fields are:

`const char *name;`

The name of the new function. `awk`-level code calls the function by this name. This is a regular C string.

Function names must obey the rules for `awk` identifiers. That is, they must begin with either an English letter or an underscore, which may be followed by any number of letters, digits, and underscores. Letter case in function names is significant.

```
awk_value_t *(*const function)(int num_actual_args,
                               awk_value_t *result,
                               struct awk_ext_func *finfo);
```

This is a pointer to the C function that provides the extension's functionality. The function must fill in `*result` with either a number, a string, or a regexp. `gawk` takes ownership of any string memory. As mentioned earlier, string memory *must* come from one of `gawk_malloc()`, `gawk_calloc()`, or `gawk_realloc()`.

The `num_actual_args` argument tells the C function how many actual parameters were passed from the calling `awk` code.

The `finfo` parameter is a pointer to the `awk_ext_func_t` for this function. The called function may access data within it as desired, or not.

The function must return the value of `result`. This is for the convenience of the calling code inside `gawk`.

`const size_t max_expected_args;`
: This is the maximum number of arguments the function expects to receive. If called with more arguments than this, and if lint checking has been enabled, then `gawk` prints a warning message. For more information, see the entry for `suppress_lint`, later in this list.

`const size_t min_required_args;`
: This is the minimum number of arguments the function expects to receive. If called with fewer arguments, `gawk` prints a fatal error message and exits.

`awk_bool_t suppress_lint;`
: This flag tells `gawk` not to print a lint message if lint checking has been enabled and if more arguments were supplied in the call than expected. An extension function can tell if `gawk` already printed at least one such message by checking if '`num_actual_args > finfo->max_expected_args`'. If so, and the function does not want more lint messages to be printed, it should set `finfo->suppress_lint` to `awk_true`.

`void *data;`
: This is an opaque pointer to any data that an extension function may wish to have available when called. Passing the `awk_ext_func_t` structure to the extension function, and having this pointer available in it enable writing a single C or C++ function that implements multiple `awk`-level extension functions.

Once you have a record representing your extension function, you register it with `gawk` using this API function:

`awk_bool_t add_ext_func(const char *name_space, awk_ext_func_t *func);`
: This function returns true upon success, false otherwise. The `name_space` parameter is the namespace in which to place the function (see Chapter 15 [Namespaces in gawk], page 391). Use an empty string (`""`) or `"awk"` to place the function in the default `awk` namespace. The `func` pointer is the address of a `struct` representing your function, as just described.

  `gawk` does not modify what `func` points to, but the extension function itself receives this pointer and can modify what it points to, thus it is purposely not declared to be `const`.

The combination of `min_required_args`, `max_expected_args`, and `suppress_lint` may be confusing. Here is how you should set things up.

Any number of arguments is valid
: Set `min_required_args` and `max_expected_args` to zero and set `suppress_lint` to `awk_true`.

A minimum number of arguments is required, no limit on maximum number of arguments
: Set `min_required_args` to the minimum required. Set `max_expected_args` to zero and set `suppress_lint` to `awk_true`.

A minimum number of arguments is required, a maximum number is expected
: Set `min_required_args` to the minimum required. Set `max_expected_args` to the maximum expected. Set `suppress_lint` to `awk_false`.

A minimum number of arguments is required, and no more than a maximum is allowed
: Set `min_required_args` to the minimum required. Set `max_expected_args` to the maximum expected. Set `suppress_lint` to `awk_false`. In your extension function, check that `num_actual_args` does not exceed `f->max_expected_args`. If it does, issue a fatal error message.

17.4.6.2 Registering An Exit Callback Function

An *exit callback* function is a function that `gawk` calls before it exits. Such functions are useful if you have general "cleanup" tasks that should be performed in your extension (such as closing database connections or other resource deallocations). You can register such a function with `gawk` using the following function:

```
void awk_atexit(void (*funcp)(void *data, int exit_status),
                void *arg0);
```

The parameters are:

`funcp`
: A pointer to the function to be called before `gawk` exits. The `data` parameter will be the original value of `arg0`. The `exit_status` parameter is the exit status value that `gawk` intends to pass to the `exit()` system call.

`arg0`
: A pointer to private data that `gawk` saves in order to pass to the function pointed to by `funcp`.

Exit callback functions are called in last-in, first-out (LIFO) order—that is, in the reverse order in which they are registered with `gawk`.

17.4.6.3 Registering An Extension Version String

You can register a version string that indicates the name and version of your extension with `gawk`, as follows:

```
void register_ext_version(const char *version);
```

Register the string pointed to by `version` with `gawk`. Note that `gawk` does *not* copy the `version` string, so it should not be changed.

`gawk` prints all registered extension version strings when it is invoked with the `--version` option.

17.4.6.4 Customized Input Parsers

By default, `gawk` reads text files as its input. It uses the value of `RS` to find the end of an input record, and then uses `FS` (or `FIELDWIDTHS` or `FPAT`) to split it into fields (see Chapter 4 [Reading Input Files], page 69). Additionally, it sets the value of `RT` (see Section 7.5 [Predefined Variables], page 167).

If you want, you can provide your own custom input parser. An input parser's job is to return a record to the `gawk` record-processing code, along with indicators for the value and length of the data to be used for `RT`, if any.

To provide an input parser, you must first provide two functions (where *XXX* is a prefix name for your extension):

`awk_bool_t` *`XXX`*`_can_take_file(const awk_input_buf_t *iobuf);`
: This function examines the information available in `iobuf` (which we discuss shortly). Based on the information there, it decides if the input parser should be used for this file. If so, it should return true. Otherwise, it should return false. It should not change any state (variable values, etc.) within `gawk`.

`awk_bool_t` *`XXX`*`_take_control_of(awk_input_buf_t *iobuf);`
: When `gawk` decides to hand control of the file over to the input parser, it calls this function. This function in turn must fill in certain fields in the `awk_input_buf_t` structure and ensure that certain conditions are true. It should then return true. If an error of some kind occurs, it should not fill in any fields and should return false; then `gawk` will not use the input parser. The details are presented shortly.

Your extension should package these functions inside an `awk_input_parser_t`, which looks like this:

```
typedef struct awk_input_parser {
    const char *name;   /* name of parser */
    awk_bool_t (*can_take_file)(const awk_input_buf_t *iobuf);
    awk_bool_t (*take_control_of)(awk_input_buf_t *iobuf);
    awk_const struct awk_input_parser *awk_const next;   /* for gawk */
} awk_input_parser_t;
```

The fields are:

`const char *name;`
: The name of the input parser. This is a regular C string.

`awk_bool_t (*can_take_file)(const awk_input_buf_t *iobuf);`
: A pointer to your *`XXX`*`_can_take_file()` function.

`awk_bool_t (*take_control_of)(awk_input_buf_t *iobuf);`
: A pointer to your *`XXX`*`_take_control_of()` function.

`awk_const struct input_parser *awk_const next;`
: This is for use by `gawk`; therefore it is marked `awk_const` so that the extension cannot modify it.

The steps are as follows:

1. Create a `static awk_input_parser_t` variable and initialize it appropriately.
2. When your extension is loaded, register your input parser with `gawk` using the `register_input_parser()` API function (described next).

An `awk_input_buf_t` looks like this:

```
typedef struct awk_input {
    const char *name;       /* filename */
    int fd;                 /* file descriptor */
#define INVALID_HANDLE (-1)
    void *opaque;           /* private data for input parsers */
```

```
        int (*get_record)(char **out, struct awk_input *iobuf,
                          int *errcode, char **rt_start, size_t *rt_len,
                          const awk_fieldwidth_info_t **field_width);
        ssize_t (*read_func)();
        void (*close_func)(struct awk_input *iobuf);
        struct stat sbuf;       /* stat buf */
    } awk_input_buf_t;
```

The fields can be divided into two categories: those for use (initially, at least) by *XXX*`_can_take_file()`, and those for use by *XXX*`_take_control_of()`. The first group of fields and their uses are as follows:

`const char *name;`
: The name of the file.

`int fd;`
: A file descriptor for the file. `gawk` attempts to open the file for reading using the `open()` system call. If it was able to open the file, then `fd` will *not* be equal to `INVALID_HANDLE`. Otherwise, it will.

  An extension can decide that it doesn't want to use the open file descriptor provided by `gawk`. In such a case it can close the file and set `fd` to `INVALID_HANDLE`, or it can leave it alone and keep it's own file descriptor in private data pointed to by the `opaque` pointer (see further in this list). In any case, if the file descriptor is valid, it should *not* just overwrite the value with something else; doing so would cause a resource leak.

`struct stat sbuf;`
: If the file descriptor is valid, then `gawk` will have filled in this structure via a call to the `fstat()` system call. Otherwise, if the `lstat()` system call is available, it will use that. If `lstat()` is not available, then it uses `stat()`.

  Getting the file's information allows extensions to check the type of the file even if it could not be opened. This occurs, for example, on Windows systems when trying to use `open()` on a directory.

  If `gawk` was not able to get the file information, then `sbuf` will be zeroed out. In particular, extension code can check if '`sbuf.st_mode == 0`'. If that's true, then there is no information in `sbuf`.[3]

The *XXX*`_can_take_file()` function should examine these fields and decide if the input parser should be used for the file. The decision can be made based upon `gawk` state (the value of a variable defined previously by the extension and set by `awk` code), the name of the file, whether or not the file descriptor is valid, the information in the `struct stat`, or any combination of these factors.

Once *XXX*`_can_take_file()` has returned true, and `gawk` has decided to use your input parser, it calls *XXX*`_take_control_of()`. That function then fills either the `get_record` field or the `read_func` field in the `awk_input_buf_t`. It must also ensure that `fd` is *not* set

[3] The `st_mode` field indicates both the type of the file and the permissions on the file. Even if the permissions are all zero (such as with '`chmod 000 file`'), the file type information is still there and will be nonzero. So, if '`sbuf.st_mode == 0`' is true, then you know that it really wasn't possible to get the file's information.

to `INVALID_HANDLE`. The following list describes the fields that may be filled by *`XXX`*`_take_control_of()`:

`void *opaque;`
: This is used to hold any state information needed by the input parser for this file. It is "opaque" to `gawk`. The input parser is not required to use this pointer.

```
int (*get_record)(char **out,
                  struct awk_input *iobuf,
                  int *errcode,
                  char **rt_start,
                  size_t *rt_len,
                  const awk_fieldwidth_info_t **field_width);
```
: This function pointer should point to a function that creates the input records. Said function is the core of the input parser. Its behavior is described in the text following this list.

`ssize_t (*read_func)(int, void *, size_t);`
: This function pointer should point to a function that has the same behavior as the standard POSIX `read()` system call. It is an alternative to the `get_record` pointer. Its behavior is also described in the text following this list.

`void (*close_func)(struct awk_input *iobuf);`
: This function pointer should point to a function that does the "teardown." It should release any resources allocated by *`XXX`*`_take_control_of()`. It may also close the file. If it does so, it should set the `fd` field to `INVALID_HANDLE`.

  If `fd` is still not `INVALID_HANDLE` after the call to this function, `gawk` calls the regular `close()` system call.

  Having a "teardown" function is optional. If your input parser does not need it, do not set this field. Then, `gawk` calls the regular `close()` system call on the file descriptor, so it should be valid.

The *`XXX`*`_get_record()` function does the work of creating input records. The parameters are as follows:

`char **out`
: This is a pointer to a `char *` variable that is set to point to the record. `gawk` makes its own copy of the data, so your extension must manage this storage.

`struct awk_input *iobuf`
: This is the `awk_input_buf_t` for the file. Two of its fields should be used by your extension: `fd` for reading data, and `opaque` for managing any private state.

`int *errcode`
: If an error occurs, `*errcode` should be set to an appropriate code from `<errno.h>`.

`char **rt_start`
`size_t *rt_len`
: If the concept of a "record terminator" makes sense, then `*rt_start` should be set to point to the data to be used for `RT`, and `*rt_len` should be set to the

length of the data. Otherwise, *rt_len should be set to zero. Here too, gawk makes its own copy of this data, so your extension must manage this storage.

const awk_fieldwidth_info_t **field_width
: If field_width is not NULL, then *field_width will be initialized to NULL, and the function may set it to point to a structure supplying field width information to override the default field parsing mechanism. Note that this structure will not be copied by gawk; it must persist at least until the next call to get_record or close_func. Note also that field_width is NULL when getline is assigning the results to a variable, thus field parsing is not needed.

  If the parser sets *field_width, then gawk uses this layout to parse the input record, and the PROCINFO["FS"] value will be "API" while this record is active in $0. The awk_fieldwidth_info_t data structure is described below.

The return value is the length of the buffer pointed to by *out, or EOF if end-of-file was reached or an error occurred.

It is guaranteed that errcode is a valid pointer, so there is no need to test for a NULL value. gawk sets *errcode to zero, so there is no need to set it unless an error occurs.

If an error does occur, the function should return EOF and set *errcode to a value greater than zero. In that case, if *errcode does not equal zero, gawk automatically updates the ERRNO variable based on the value of *errcode. (In general, setting '*errcode = errno' should do the right thing.)

As an alternative to supplying a function that returns an input record, you may instead supply a function that simply reads bytes, and let gawk parse the data into records. If you do so, the data should be returned in the multibyte encoding of the current locale. Such a function should follow the same behavior as the read() system call, and you fill in the read_func pointer with its address in the awk_input_buf_t structure.

By default, gawk sets the read_func pointer to point to the read() system call. So your extension need not set this field explicitly.

> **NOTE:** You must choose one method or the other: either a function that returns a record, or one that returns raw data. In particular, if you supply a function to get a record, gawk will call it, and will never call the raw read function.

gawk ships with a sample extension that reads directories, returning records for each entry in a directory (see Section 17.7.6 [Reading Directories], page 474). You may wish to use that code as a guide for writing your own input parser.

When writing an input parser, you should think about (and document) how it is expected to interact with awk code. You may want it to always be called, and to take effect as appropriate (as the readdir extension does). Or you may want it to take effect based upon the value of an awk variable, as the XML extension from the gawkextlib project does (see Section 17.8 [The gawkextlib Project], page 478). In the latter case, code in a BEGINFILE rule can look at FILENAME and ERRNO to decide whether or not to activate your input parser (see Section 7.1.5 [The BEGINFILE and ENDFILE Special Patterns], page 155).

If you would like to override the default field parsing mechanism for a given record, then you must populate an awk_fieldwidth_info_t structure, which looks like this:

```
typedef struct {
        awk_bool_t     use_chars; /* false ==> use bytes */
```

```
        size_t         nf;        /* number of fields in record (NF) */
        struct awk_field_info {
                size_t skip;      /* amount to skip before field starts */
                size_t len;       /* length of field */
        } fields[1];              /* actual dimension should be nf */
} awk_fieldwidth_info_t;
```

The fields are:

`awk_bool_t use_chars;`
: Set this to `awk_true` if the field lengths are specified in terms of potentially multi-byte characters, and set it to `awk_false` if the lengths are in terms of bytes. Performance will be better if the values are supplied in terms of bytes.

`size_t nf;`
: Set this to the number of fields in the input record, i.e. `NF`.

`struct awk_field_info fields[nf];`
: This is a variable-length array whose actual dimension should be `nf`. For each field, the `skip` element should be set to the number of characters or bytes, as controlled by the `use_chars` flag, to skip before the start of this field. The `len` element provides the length of the field. The values in `fields[0]` provide the information for `$1`, and so on through the `fields[nf-1]` element containing the information for `$NF`.

A convenience macro `awk_fieldwidth_info_size(numfields)` is provided to calculate the appropriate size of a variable-length `awk_fieldwidth_info_t` structure containing `numfields` fields. This can be used as an argument to `malloc()` or in a union to allocate space statically. Please refer to the `readdir_test` sample extension for an example.

You register your input parser with the following function:

`void register_input_parser(awk_input_parser_t *input_parser);`
: Register the input parser pointed to by `input_parser` with `gawk`.

17.4.6.5 Customized Output Wrappers

An *output wrapper* is the mirror image of an input parser. It allows an extension to take over the output to a file opened with the '`>`' or '`>>`' I/O redirection operators (see Section 5.6 [Redirecting Output of `print` and `printf`], page 112).

The output wrapper is very similar to the input parser structure:

```
typedef struct awk_output_wrapper {
    const char *name;   /* name of the wrapper */
    awk_bool_t (*can_take_file)(const awk_output_buf_t *outbuf);
    awk_bool_t (*take_control_of)(awk_output_buf_t *outbuf);
    awk_const struct awk_output_wrapper *awk_const next;  /* for gawk */
} awk_output_wrapper_t;
```

The members are as follows:

`const char *name;`
: This is the name of the output wrapper.

`awk_bool_t (*can_take_file)(const awk_output_buf_t *outbuf);`
: This points to a function that examines the information in the `awk_output_buf_t` structure pointed to by `outbuf`. It should return true if the output wrapper wants to take over the file, and false otherwise. It should not change any state (variable values, etc.) within `gawk`.

`awk_bool_t (*take_control_of)(awk_output_buf_t *outbuf);`
: The function pointed to by this field is called when `gawk` decides to let the output wrapper take control of the file. It should fill in appropriate members of the `awk_output_buf_t` structure, as described next, and return true if successful, false otherwise.

`awk_const struct output_wrapper *awk_const next;`
: This is for use by `gawk`; therefore it is marked `awk_const` so that the extension cannot modify it.

The `awk_output_buf_t` structure looks like this:

```
typedef struct awk_output_buf {
    const char *name;   /* name of output file */
    const char *mode;   /* mode argument to fopen */
    FILE *fp;           /* stdio file pointer */
    awk_bool_t redirected;  /* true if a wrapper is active */
    void *opaque;       /* for use by output wrapper */
    size_t (*gawk_fwrite)(const void *buf, size_t size, size_t count,
                FILE *fp, void *opaque);
    int (*gawk_fflush)(FILE *fp, void *opaque);
    int (*gawk_ferror)(FILE *fp, void *opaque);
    int (*gawk_fclose)(FILE *fp, void *opaque);
} awk_output_buf_t;
```

Here too, your extension will define *`XXX`*`_can_take_file()` and *`XXX`*`_take_control_of()` functions that examine and update data members in the `awk_output_buf_t`. The data members are as follows:

`const char *name;`
: The name of the output file.

`const char *mode;`
: The mode string (as would be used in the second argument to `fopen()`) with which the file was opened.

`FILE *fp;` The `FILE` pointer from `<stdio.h>`. `gawk` opens the file before attempting to find an output wrapper.

`awk_bool_t redirected;`
: This field must be set to true by the *`XXX`*`_take_control_of()` function.

`void *opaque;`
: This pointer is opaque to `gawk`. The extension should use it to store a pointer to any private data associated with the file.

```
size_t (*gawk_fwrite)(const void *buf, size_t size, size_t count,
                      FILE *fp, void *opaque);
int (*gawk_fflush)(FILE *fp, void *opaque);
int (*gawk_ferror)(FILE *fp, void *opaque);
int (*gawk_fclose)(FILE *fp, void *opaque);
```

These pointers should be set to point to functions that perform the equivalent function as the `<stdio.h>` functions do, if appropriate. `gawk` uses these function pointers for all output. `gawk` initializes the pointers to point to internal "pass-through" functions that just call the regular `<stdio.h>` functions, so an extension only needs to redefine those functions that are appropriate for what it does.

The *`XXX`*`_can_take_file()` function should make a decision based upon the `name` and `mode` fields, and any additional state (such as `awk` variable values) that is appropriate. `gawk` attempts to open the named file for writing. The `fp` member will be `NULL` only if it fails.

When `gawk` calls *`XXX`*`_take_control_of()`, that function should fill in the other fields as appropriate, except for `fp`, which it should just use normally if it's not `NULL`.

You register your output wrapper with the following function:

```
void register_output_wrapper(awk_output_wrapper_t *output_wrapper);
```

Register the output wrapper pointed to by `output_wrapper` with `gawk`.

17.4.6.6 Customized Two-way Processors

A *two-way processor* combines an input parser and an output wrapper for two-way I/O with the '`|&`' operator (see Section 5.6 [Redirecting Output of `print` and `printf`], page 112). It makes identical use of the `awk_input_parser_t` and `awk_output_buf_t` structures as described earlier.

A two-way processor is represented by the following structure:

```
typedef struct awk_two_way_processor {
    const char *name;   /* name of the two-way processor */
    awk_bool_t (*can_take_two_way)(const char *name);
    awk_bool_t (*take_control_of)(const char *name,
                                  awk_input_buf_t *inbuf,
                                  awk_output_buf_t *outbuf);
    awk_const struct awk_two_way_processor *awk_const next;  /* for gawk */
} awk_two_way_processor_t;
```

The fields are as follows:

```
const char *name;
```

The name of the two-way processor.

```
awk_bool_t (*can_take_two_way)(const char *name);
```

The function pointed to by this field should return true if it wants to take over two-way I/O for this file name. It should not change any state (variable values, etc.) within `gawk`.

```
awk_bool_t (*take_control_of)(const char *name,
                              awk_input_buf_t *inbuf,
                              awk_output_buf_t *outbuf);
```

The function pointed to by this field should fill in the `awk_input_buf_t` and `awk_output_buf_t` structures pointed to by `inbuf` and `outbuf`, respectively. These structures were described earlier.

```
awk_const struct two_way_processor *awk_const next;
```

This is for use by `gawk`; therefore it is marked `awk_const` so that the extension cannot modify it.

As with the input parser and output processor, you provide "yes I can take this" and "take over for this" functions, *`XXX`*`_can_take_two_way()` and *`XXX`*`_take_control_of()`.

You register your two-way processor with the following function:

```
void register_two_way_processor(awk_two_way_processor_t *two_way_processor);
```

Register the two-way processor pointed to by `two_way_processor` with `gawk`.

17.4.7 Printing Messages

You can print different kinds of warning messages from your extension, as described here. Note that for these functions, you must pass in the extension ID received from `gawk` when the extension was loaded:[4]

```
void fatal(awk_ext_id_t id, const char *format, ...);
```

Print a message and then cause `gawk` to exit immediately.

```
void nonfatal(awk_ext_id_t id, const char *format, ...);
```

Print a nonfatal error message.

```
void warning(awk_ext_id_t id, const char *format, ...);
```

Print a warning message.

```
void lintwarn(awk_ext_id_t id, const char *format, ...);
```

Print a "lint warning." Normally this is the same as printing a warning message, but if `gawk` was invoked with '`--lint=fatal`', then lint warnings become fatal error messages.

All of these functions are otherwise like the C `printf()` family of functions, where the `format` parameter is a string with literal characters and formatting codes intermixed.

17.4.8 Updating `ERRNO`

The following functions allow you to update the `ERRNO` variable:

```
void update_ERRNO_int(int errno_val);
```

Set `ERRNO` to the string equivalent of the error code in `errno_val`. The value should be one of the defined error codes in `<errno.h>`, and `gawk` turns it into a (possibly translated) string using the C `strerror()` function.

[4] Because the API uses only ISO C 90 features, it cannot make use of the ISO C 99 variadic macro feature to hide that parameter. More's the pity.

`void update_ERRNO_string(const char *string);`
: Set `ERRNO` directly to the string value of `ERRNO`. `gawk` makes a copy of the value of `string`.

`void unset_ERRNO(void);`
: Unset `ERRNO`.

17.4.9 Requesting Values

All of the functions that return values from `gawk` work in the same way. You pass in an `awk_valtype_t` value to indicate what kind of value you expect. If the actual value matches what you requested, the function returns true and fills in the `awk_value_t` result. Otherwise, the function returns false, and the `val_type` member indicates the type of the actual value. You may then print an error message or reissue the request for the actual value type, as appropriate. This behavior is summarized in Table 17.2.

		Type of Actual Value						
		String	**Strnum**	**Number**	**Regex**	**Bool**	**Array**	**Undefined**
Type Requested	**String**	String	String	String	String	String	false	false
	Strnum	false	Strnum	Strnum	false	false	false	false
	Number	Number	Number	Number	false	Number	false	false
	Regex	false	false	false	Regex	false	false	false
	Bool	false	false	false	false	Bool	false	false
	Array	false	false	false	false	false	Array	false
	Scalar	Scalar	Scalar	Scalar	Scalar	Scalar	false	false
	Undefined	String	Strnum	Number	Regex	Bool	Array	Undefined
	Value cookie	false	false	false	false	false	false	false

Table 17.2: API value types returned

There are a number of points of note:

- A request for `AWK_UNDEFINED` always returns true, filling in the actual type of the particular value. You can think of this as a sort of "wildcard" request.
- Requesting an `AWK_STRING` causes `gawk` to convert any scalar value to a string result, and that is what is returned.
- Requesting an `AWK_NUMBER` causes `gawk` to convert any scalar value, except for a regexp, to a numeric result, and that is what is returned.

  Conversion between string and number in the API thus parallels how `gawk` behaves in running code.
- The API functions do *not* distinguish between `"untyped"` and `"unassigned"` as returned by `typeof()` (see Section 9.3.2 [Dynamic Typing In gawk], page 235). `AWK_UNDEFINED` serves for both. This is unlikely to change, as the documentation and code are already complicated enough.

17.4.10 Accessing and Updating Parameters

Two functions give you access to the arguments (parameters) passed to your extension function. They are:

```
awk_bool_t get_argument(size_t count,
                        awk_valtype_t wanted,
                        awk_value_t *result);
```

Fill in the `awk_value_t` structure pointed to by `result` with the `count`th argument. Return true if the actual type matches `wanted`, and false otherwise. In the latter case, `result->val_type` indicates the actual type (see Table 17.2). Counts are zero-based—the first argument is numbered zero, the second one, and so on. `wanted` indicates the type of value expected.

```
awk_bool_t set_argument(size_t count, awk_array_t array);
```

Convert a parameter that was undefined into an array; this provides call by reference for arrays. Return false if `count` is too big, or if the argument's type is not undefined. See Section 17.4.12 [Array Manipulation], page 444, for more information on creating arrays.

17.4.11 Symbol Table Access

Two sets of routines provide access to global variables, and one set allows you to create and release cached values.

17.4.11.1 Variable Access and Update by Name

The following routines provide the ability to access and update global `awk`-level variables by name. In compiler terminology, identifiers of different kinds are termed *symbols*, thus the "sym" in the routines' names. The data structure that stores information about symbols is termed a *symbol table*. The functions are as follows:

```
awk_bool_t sym_lookup(const char *name,
                      awk_valtype_t wanted,
                      awk_value_t *result);
```

Fill in the `awk_value_t` structure pointed to by `result` with the value of the variable named by the string `name`, which is a regular C string. `wanted` indicates the type of value expected. Return true if the actual type matches `wanted`, and false otherwise. In the latter case, `result->val_type` indicates the actual type (see Table 17.2).

```
awk_bool_t sym_lookup_ns(const char *name,
                         const char *name_space,
                         awk_valtype_t wanted,
                         awk_value_t *result);
```

This is like `sym_lookup()`, but the `name_space` parameter allows you to specify which namespace `name` is part of. `name_space` cannot be `NULL`. If it is `""` or `"awk"`, then `name` is searched for in the default `awk` namespace.

Note that `namespace` is a C++ keyword. For interoperability with C++, you should avoid using that identifier in C code.

```
awk_bool_t sym_update(const char *name, awk_value_t *value);
```

Update the variable named by the string `name`, which is a regular C string. The variable is added to `gawk`'s symbol table if it is not there. Return true if everything worked, and false otherwise.

Changing types (scalar to array or vice versa) of an existing variable is *not* allowed, nor may this routine be used to update an array. This routine cannot be used to update any of the predefined variables (such as `ARGC` or `NF`).

```
awk_bool_t sym_update_ns(const char *name_space, const char *name,
awk_value_t *value);
```

This is like `sym_update()`, but the `name_space` parameter allows you to specify which namespace `name` is part of. `name_space` cannot be `NULL`. If it is `""` or `"awk"`, then `name` is searched for in the default `awk` namespace.

An extension can look up the value of `gawk`'s special variables. However, with the exception of the `PROCINFO` array, an extension cannot change any of those variables.

When searching for or updating variables outside the `awk` namespace (see Chapter 15 [Namespaces in gawk], page 391), function and variable names must be simple identifiers.[5] In addition, namespace names and variable and function names must follow the rules given in Section 15.5 [Namespace and Component Naming Rules], page 392.

17.4.11.2 Variable Access and Update by Cookie

A *scalar cookie* is an opaque handle that provides access to a global variable or array. It is an optimization that avoids looking up variables in `gawk`'s symbol table every time access is needed. This was discussed earlier, in Section 17.4.2 [General-Purpose Data Types], page 420.

The following functions let you work with scalar cookies:

```
awk_bool_t sym_lookup_scalar(awk_scalar_t cookie,
                             awk_valtype_t wanted,
                             awk_value_t *result);
```

Retrieve the current value of a scalar cookie. Once you have obtained a scalar cookie using `sym_lookup()`, you can use this function to get its value more efficiently. Return false if the value cannot be retrieved.

```
awk_bool_t sym_update_scalar(awk_scalar_t cookie, awk_value_t *value);
```

Update the value associated with a scalar cookie. Return false if the new value is not of type `AWK_STRING`, `AWK_STRNUM`, `AWK_REGEX`, or `AWK_NUMBER`. Here too, the predefined variables may not be updated.

It is not obvious at first glance how to work with scalar cookies or what their *raison d'être* really is. In theory, the `sym_lookup()` and `sym_update()` routines are all you really need to work with variables. For example, you might have code that looks up the value of a variable, evaluates a condition, and then possibly changes the value of the variable based on the result of that evaluation, like so:

```
/*  do_magic --- do something really great */

static awk_value_t *
do_magic(int nargs, awk_value_t *result)
{
```

[5] Allowing both namespace plus identifier and `foo::bar` would have been too confusing to document, and to code and test.

```
    awk_value_t value;

    if (   sym_lookup("MAGIC_VAR", AWK_NUMBER, & value)
        && some_condition(value.num_value)) {
            value.num_value += 42;
            sym_update("MAGIC_VAR", & value);
    }

    return make_number(0.0, result);
}
```

This code looks (and is) simple and straightforward. So what's the problem?

Well, consider what happens if `awk`-level code associated with your extension calls the `magic()` function (implemented in C by `do_magic()`), once per record, while processing hundreds of thousands or millions of records. The `MAGIC_VAR` variable is looked up in the symbol table once or twice per function call!

The symbol table lookup is really pure overhead; it is considerably more efficient to get a cookie that represents the variable, and use that to get the variable's value and update it as needed.[6]

Thus, the way to use cookies is as follows. First, install your extension's variable in `gawk`'s symbol table using `sym_update()`, as usual. Then get a scalar cookie for the variable using `sym_lookup()`:

```
static awk_scalar_t magic_var_cookie;    /* cookie for MAGIC_VAR */

static void
my_extension_init()
{
    awk_value_t value;

    /* install initial value */
    sym_update("MAGIC_VAR", make_number(42.0, & value));

    /* get the cookie */
    sym_lookup("MAGIC_VAR", AWK_SCALAR, & value);

    /* save the cookie */
    magic_var_cookie = value.scalar_cookie;
    ...
}
```

Next, use the routines in this section for retrieving and updating the value through the cookie. Thus, `do_magic()` now becomes something like this:

```
/*  do_magic --- do something really great */

static awk_value_t *
```

[6] The difference is measurable and quite real. Trust us.

```
do_magic(int nargs, awk_value_t *result)
{
    awk_value_t value;

    if (   sym_lookup_scalar(magic_var_cookie, AWK_NUMBER, & value)
        && some_condition(value.num_value)) {
            value.num_value += 42;
            sym_update_scalar(magic_var_cookie, & value);
    }
    ...

    return make_number(0.0, result);
}
```

NOTE: The previous code omitted error checking for presentation purposes. Your extension code should be more robust and carefully check the return values from the API functions.

17.4.11.3 Creating and Using Cached Values

The routines in this section allow you to create and release cached values. Like scalar cookies, in theory, cached values are not necessary. You can create numbers and strings using the functions in Section 17.4.4 [Constructor Functions], page 425. You can then assign those values to variables using `sym_update()` or `sym_update_scalar()`, as you like.

However, you can understand the point of cached values if you remember that *every* string value's storage *must* come from `gawk_malloc()`, `gawk_calloc()`, or `gawk_realloc()`. If you have 20 variables, all of which have the same string value, you must create 20 identical copies of the string.[7]

It is clearly more efficient, if possible, to create a value once, and then tell `gawk` to reuse the value for multiple variables. That is what the routines in this section let you do. The functions are as follows:

`awk_bool_t create_value(awk_value_t *value, awk_value_cookie_t *result);`
: Create a cached string or numeric value from `value` for efficient later assignment. Only values of type `AWK_NUMBER`, `AWK_REGEX`, `AWK_STRNUM`, and `AWK_STRING` are allowed. Any other type is rejected. `AWK_UNDEFINED` could be allowed, but doing so would result in inferior performance.

`awk_bool_t release_value(awk_value_cookie_t vc);`
: Release the memory associated with a value cookie obtained from `create_value()`.

You use value cookies in a fashion similar to the way you use scalar cookies. In the extension initialization routine, you create the value cookie:

```
static awk_value_cookie_t answer_cookie;  /* static value cookie */

static void
```

[7] Numeric values are clearly less problematic, requiring only a C `double` to store. But of course, GMP and MPFR values *do* take up more memory.

```
my_extension_init()
{
    awk_value_t value;
    char *long_string;
    size_t long_string_len;

    /* code from earlier */
    ...
    /* ... fill in long_string and long_string_len ... */
    make_malloced_string(long_string, long_string_len, & value);
    create_value(& value, & answer_cookie);    /* create cookie */
    ...
}
```

Once the value is created, you can use it as the value of any number of variables:

```
static awk_value_t *
do_magic(int nargs, awk_value_t *result)
{
    awk_value_t new_value;

    ...    /* as earlier */

    value.val_type = AWK_VALUE_COOKIE;
    value.value_cookie = answer_cookie;
    sym_update("VAR1", & value);
    sym_update("VAR2", & value);
    ...
    sym_update("VAR100", & value);
    ...
}
```

Using value cookies in this way saves considerable storage, as all of `VAR1` through `VAR100` share the same value.

You might be wondering, "Is this sharing problematic? What happens if `awk` code assigns a new value to `VAR1`; are all the others changed too?"

That's a great question. The answer is that no, it's not a problem. Internally, `gawk` uses *reference-counted strings*. This means that many variables can share the same string value, and `gawk` keeps track of the usage. When a variable's value changes, `gawk` simply decrements the reference count on the old value and updates the variable to use the new value.

Finally, as part of your cleanup action (see Section 17.4.6.2 [Registering An Exit Callback Function], page 429) you should release any cached values that you created, using `release_value()`.

17.4.12 Array Manipulation

The primary data structure[8] in `awk` is the associative array (see Chapter 8 [Arrays in `awk`], page 181). Extensions need to be able to manipulate `awk` arrays. The API provides a number of data structures for working with arrays, functions for working with individual elements, and functions for working with arrays as a whole. This includes the ability to "flatten" an array so that it is easy for C code to traverse every element in an array. The array data structures integrate nicely with the data structures for values to make it easy to both work with and create true arrays of arrays (see Section 17.4.2 [General-Purpose Data Types], page 420).

17.4.12.1 Array Data Types

The data types associated with arrays are as follows:

`typedef void *awk_array_t;`

If you request the value of an array variable, you get back an `awk_array_t` value. This value is opaque[9] to the extension; it uniquely identifies the array but can only be used by passing it into API functions or receiving it from API functions. This is very similar to way '`FILE *`' values are used with the `<stdio.h>` library routines.

```
typedef struct awk_element {
    /* convenience linked list pointer, not used by gawk */
    struct awk_element *next;
    enum {
        AWK_ELEMENT_DEFAULT = 0,   /* set by gawk */
        AWK_ELEMENT_DELETE = 1     /* set by extension */
    } flags;
    awk_value_t index;
    awk_value_t value;
} awk_element_t;
```

The `awk_element_t` is a "flattened" array element. `awk` produces an array of these inside the `awk_flat_array_t` (see the next item). Individual elements may be marked for deletion. New elements must be added individually, one at a time, using the separate API for that purpose. The fields are as follows:

`struct awk_element *next;`

This pointer is for the convenience of extension writers. It allows an extension to create a linked list of new elements that can then be added to an array in a loop that traverses the list.

`enum { ... } flags;`

A set of flag values that convey information between the extension and `gawk`. Currently there is only one: `AWK_ELEMENT_DELETE`. Setting it causes `gawk` to delete the element from the original array upon release of the flattened array.

[8] OK, the only data structure.

[9] It is also a "cookie," but the `gawk` developers did not wish to overuse this term.

`index`
`value` The index and value of the element, respectively. *All* memory pointed to by `index` and `value` belongs to `gawk`.

```
typedef struct awk_flat_array {
    awk_const void *awk_const opaque1;     /* for use by gawk */
    awk_const void *awk_const opaque2;     /* for use by gawk */
    awk_const size_t count;      /* how many elements */
    awk_element_t elements[1];   /* will be extended */
} awk_flat_array_t;
```

This is a flattened array. When an extension gets one of these from `gawk`, the `elements` array is of actual size `count`. The `opaque1` and `opaque2` pointers are for use by `gawk`; therefore they are marked `awk_const` so that the extension cannot modify them.

17.4.12.2 Array Functions

The following functions relate to individual array elements:

```
awk_bool_t get_element_count(awk_array_t a_cookie, size_t *count);
```

For the array represented by `a_cookie`, place in `*count` the number of elements it contains. A subarray counts as a single element. Return false if there is an error.

```
awk_bool_t get_array_element(awk_array_t a_cookie,
                             const awk_value_t *const index,
                             awk_valtype_t wanted,
                             awk_value_t *result);
```

For the array represented by `a_cookie`, return in `*result` the value of the element whose index is `index`. `wanted` specifies the type of value you wish to retrieve. Return false if `wanted` does not match the actual type or if `index` is not in the array (see Table 17.2).

The value for `index` can be numeric, in which case `gawk` converts it to a string. Using nonintegral values is possible, but requires that you understand how such values are converted to strings (see Section 6.1.4 [Conversion of Strings and Numbers], page 130); thus, using integral values is safest.

As with *all* strings passed into `gawk` from an extension, the string value of `index` must come from `gawk_malloc()`, `gawk_calloc()`, or `gawk_realloc()`, and `gawk` releases the storage.

```
awk_bool_t set_array_element(awk_array_t a_cookie,
                             const awk_value_t *const index,
                             const awk_value_t *const value);
```

In the array represented by `a_cookie`, create or modify the element whose index is given by `index`. The `ARGV` and `ENVIRON` arrays may not be changed, although the `PROCINFO` array can be. Note that `index` should be string value. However, `gawk` will force a conversion to string if necessary.

```
awk_bool_t set_array_element_by_elem(awk_array_t a_cookie,
                                     awk_element_t element);
```

Like `set_array_element()`, but take the `index` and `value` from `element`. This is a convenience macro.

```
awk_bool_t del_array_element(awk_array_t a_cookie,
                             const awk_value_t* const index);
```

Remove the element with the given index from the array represented by `a_cookie`. Return true if the element was removed, or false if the element did not exist in the array.

The following functions relate to arrays as a whole:

```
awk_array_t create_array(void);
```

Create a new array to which elements may be added. See Section 17.4.12.4 [How To Create and Populate Arrays], page 450, for a discussion of how to create a new array and add elements to it.

```
awk_bool_t clear_array(awk_array_t a_cookie);
```

Clear the array represented by `a_cookie`. Return false if there was some kind of problem, true otherwise. The array remains an array, but after calling this function, it has no elements. This is equivalent to using the `delete` statement (see Section 8.4 [The `delete` Statement], page 190).

```
awk_bool_t destroy_array(awk_array_t a_cookie);
```

Clear the array represented by `a_cookie` and release the array allocated by `create_array`. Return false if there was some kind of problem, true otherwise. The array will no longer exist and cannot be used again.

```
awk_bool_t flatten_array_typed(awk_array_t a_cookie,
                               awk_flat_array_t **data,
                               awk_valtype_t index_type,
                               awk_valtype_t value_type);
```

For the array represented by `a_cookie`, create an `awk_flat_array_t` structure and fill it in with indices and values of the requested types. Set the pointer whose address is passed as `data` to point to this structure. Return true upon success, or false otherwise. See Section 17.4.12.3 [Working With All The Elements of an Array], page 447, for a discussion of how to flatten an array and work with it.

```
awk_bool_t flatten_array(awk_array_t a_cookie, awk_flat_array_t **data);
```

For the array represented by `a_cookie`, create an `awk_flat_array_t` structure and fill it in with `AWK_STRING` indices and `AWK_UNDEFINED` values. This is superseded by `flatten_array_typed()`. It is provided as a macro, and remains for convenience and for source code compatibility with the previous version of the API.

```
awk_bool_t release_flattened_array(awk_array_t a_cookie,
                                   awk_flat_array_t *data);
```

When done with a flattened array, release the storage using this function. You must pass in both the original array cookie and the address of the created

awk_flat_array_t structure. The function returns true upon success, false otherwise.

17.4.12.3 Working With All The Elements of an Array

To *flatten* an array is to create a structure that represents the full array in a fashion that makes it easy for C code to traverse the entire array. Some of the code in extension/testext.c does this, and also serves as a nice example showing how to use the APIs.

We walk through that part of the code one step at a time. First, the gawk script that drives the test extension:

```
@load "testext"
BEGIN {
    n = split("blacky rusty sophie raincloud lucky", pets)
    printf("pets has %d elements\n", length(pets))
    ret = dump_array_and_delete("pets", "3")
    printf("dump_array_and_delete(pets) returned %d\n", ret)
    if ("3" in pets)
        printf("dump_array_and_delete() did NOT remove index \"3\"!\n")
    else
        printf("dump_array_and_delete() did remove index \"3\"!\n")
    print ""
}
```

This code creates an array with split() (see Section 9.1.4 [String-Manipulation Functions], page 200) and then calls dump_array_and_delete(). That function looks up the array whose name is passed as the first argument, and deletes the element at the index passed in the second argument. The awk code then prints the return value and checks if the element was indeed deleted. Here is the C code that implements dump_array_and_delete(). It has been edited slightly for presentation.

The first part declares variables, sets up the default return value in result, and checks that the function was called with the correct number of arguments:

```
static awk_value_t *
dump_array_and_delete(int nargs, awk_value_t *result)
{
    awk_value_t value, value2, value3;
    awk_flat_array_t *flat_array;
    size_t count;
    char *name;
    int i;

    assert(result != NULL);
    make_number(0.0, result);

    if (nargs != 2) {
        printf("dump_array_and_delete: nargs not right "
               "(%d should be 2)\n", nargs);
        goto out;
```

```
}
```

The function then proceeds in steps, as follows. First, retrieve the name of the array, passed as the first argument, followed by the array itself. If either operation fails, print an error message and return:

```
/* get argument named array as flat array and print it */
if (get_argument(0, AWK_STRING, & value)) {
    name = value.str_value.str;
    if (sym_lookup(name, AWK_ARRAY, & value2))
        printf("dump_array_and_delete: sym_lookup of %s passed\n",
               name);
    else {
        printf("dump_array_and_delete: sym_lookup of %s failed\n",
               name);
        goto out;
    }
} else {
    printf("dump_array_and_delete: get_argument(0) failed\n");
    goto out;
}
```

For testing purposes and to make sure that the C code sees the same number of elements as the `awk` code, the second step is to get the count of elements in the array and print it:

```
if (! get_element_count(value2.array_cookie, & count)) {
    printf("dump_array_and_delete: get_element_count failed\n");
    goto out;
}

printf("dump_array_and_delete: incoming size is %lu\n",
       (unsigned long) count);
```

The third step is to actually flatten the array, and then to double-check that the count in the `awk_flat_array_t` is the same as the count just retrieved:

```
if (! flatten_array_typed(value2.array_cookie, & flat_array,
                          AWK_STRING, AWK_UNDEFINED)) {
    printf("dump_array_and_delete: could not flatten array\n");
    goto out;
}

if (flat_array->count != count) {
    printf("dump_array_and_delete: flat_array->count (%lu)"
           " != count (%lu)\n",
            (unsigned long) flat_array->count,
            (unsigned long) count);
    goto out;
}
```

The fourth step is to retrieve the index of the element to be deleted, which was passed as the second argument. Remember that argument counts passed to `get_argument()` are zero-based, and thus the second argument is numbered one:

```
if (! get_argument(1, AWK_STRING, & value3)) {
    printf("dump_array_and_delete: get_argument(1) failed\n");
    goto out;
}
```

The fifth step is where the "real work" is done. The function loops over every element in the array, printing the index and element values. In addition, upon finding the element with the index that is supposed to be deleted, the function sets the `AWK_ELEMENT_DELETE` bit in the `flags` field of the element. When the array is released, `gawk` traverses the flattened array, and deletes any elements that have this flag bit set:

```
for (i = 0; i < flat_array->count; i++) {
    printf("\t%s[\"%.*s\"] = %s\n",
        name,
        (int) flat_array->elements[i].index.str_value.len,
        flat_array->elements[i].index.str_value.str,
        valrep2str(& flat_array->elements[i].value));

    if (strcmp(value3.str_value.str,
               flat_array->elements[i].index.str_value.str) == 0) {
        flat_array->elements[i].flags |= AWK_ELEMENT_DELETE;
        printf("dump_array_and_delete: marking element \"%s\" "
               "for deletion\n",
            flat_array->elements[i].index.str_value.str);
    }
}
```

The sixth step is to release the flattened array. This tells `gawk` that the extension is no longer using the array, and that it should delete any elements marked for deletion. `gawk` also frees any storage that was allocated, so you should not use the pointer (`flat_array` in this code) once you have called `release_flattened_array()`:

```
if (! release_flattened_array(value2.array_cookie, flat_array)) {
    printf("dump_array_and_delete: could not release flattened array\n");
    goto out;
}
```

Finally, because everything was successful, the function sets the return value to success, and returns:

```
    make_number(1.0, result);
out:
    return result;
}
```

Here is the output from running this part of the test:

```
pets has 5 elements
dump_array_and_delete: sym_lookup of pets passed
dump_array_and_delete: incoming size is 5
```

```
        pets["1"] = "blacky"
        pets["2"] = "rusty"
        pets["3"] = "sophie"
dump_array_and_delete: marking element "3" for deletion
        pets["4"] = "raincloud"
        pets["5"] = "lucky"
dump_array_and_delete(pets) returned 1
dump_array_and_delete() did remove index "3"!
```

17.4.12.4 How To Create and Populate Arrays

Besides working with arrays created by `awk` code, you can create arrays and populate them as you see fit, and then `awk` code can access them and manipulate them.

There are two important points about creating arrays from extension code:

- You must install a new array into `gawk`'s symbol table immediately upon creating it. Once you have done so, you can then populate the array.

  Similarly, if installing a new array as a subarray of an existing array, you must add the new array to its parent before adding any elements to it.

  Thus, the correct way to build an array is to work "top down." Create the array, and immediately install it in `gawk`'s symbol table using `sym_update()`, or install it as an element in a previously existing array using `set_array_element()`. We show example code shortly.

- Due to `gawk` internals, after using `sym_update()` to install an array into `gawk`, you have to retrieve the array cookie from the value passed in to `sym_update()` before doing anything else with it, like so:

  ```
  awk_value_t val;
  awk_array_t new_array;

  new_array = create_array();
  val.val_type = AWK_ARRAY;
  val.array_cookie = new_array;

  /* install array in the symbol table */
  sym_update("array", & val);

  new_array = val.array_cookie;    /* YOU MUST DO THIS */
  ```

  If installing an array as a subarray, you must also retrieve the value of the array cookie after the call to `set_element()`.

The following C code is a simple test extension to create an array with two regular elements and with a subarray. The leading `#include` directives and boilerplate variable declarations (see Section 17.4.15 [Boilerplate Code], page 455) are omitted for brevity. The first step is to create a new array and then install it in the symbol table:

```
/* create_new_array --- create a named array */

static void
```

```
create_new_array()
{
    awk_array_t a_cookie;
    awk_array_t subarray;
    awk_value_t index, value;

    a_cookie = create_array();
    value.val_type = AWK_ARRAY;
    value.array_cookie = a_cookie;

    if (! sym_update("new_array", & value))
        printf("create_new_array: sym_update(\"new_array\") failed!\n");
    a_cookie = value.array_cookie;
```

Note how `a_cookie` is reset from the `array_cookie` field in the `value` structure.

The second step is to install two regular values into `new_array`:

```
(void) make_const_string("hello", 5, & index);
(void) make_const_string("world", 5, & value);
if (! set_array_element(a_cookie, & index, & value)) {
    printf("fill_in_array: set_array_element failed\n");
    return;
}

(void) make_const_string("answer", 6, & index);
(void) make_number(42.0, & value);
if (! set_array_element(a_cookie, & index, & value)) {
    printf("fill_in_array: set_array_element failed\n");
    return;
}
```

The third step is to create the subarray and install it:

```
(void) make_const_string("subarray", 8, & index);
subarray = create_array();
value.val_type = AWK_ARRAY;
value.array_cookie = subarray;
if (! set_array_element(a_cookie, & index, & value)) {
    printf("fill_in_array: set_array_element failed\n");
    return;
}
subarray = value.array_cookie;
```

The final step is to populate the subarray with its own element:

```
(void) make_const_string("foo", 3, & index);
(void) make_const_string("bar", 3, & value);
if (! set_array_element(subarray, & index, & value)) {
    printf("fill_in_array: set_array_element failed\n");
    return;
}
```

```
}
```

Here is a sample script that loads the extension and then dumps the array:

```
@load "subarray"

function dumparray(name, array,     i)
{
    for (i in array)
        if (isarray(array[i]))
            dumparray(name "[\"" i "\"]", array[i])
        else
            printf("%s[\"%s\"] = %s\n", name, i, array[i])
}

BEGIN {
    dumparray("new_array", new_array);
}
```

Here is the result of running the script:

```
$ AWKLIBPATH=$PWD gawk -f subarray.awk
⊣ new_array["subarray"]["foo"] = bar
⊣ new_array["hello"] = world
⊣ new_array["answer"] = 42
```

(See Section 17.5 [How gawk Finds Extensions], page 457, for more information on the AWKLIBPATH environment variable.)

17.4.13 Accessing and Manipulating Redirections

The following function allows extensions to access and manipulate redirections.

```
awk_bool_t get_file(const char *name,
                    size_t name_len,
                    const char *filetype,
                    int fd,
                    const awk_input_buf_t **ibufp,
                    const awk_output_buf_t **obufp);
```

Look up file `name` in `gawk`'s internal redirection table. If `name` is `NULL` or `name_len` is zero, return data for the currently open input file corresponding to `FILENAME`. (This does not access the `filetype` argument, so that may be undefined). If the file is not already open, attempt to open it. The `filetype` argument must be zero-terminated and should be one of:

`">"`	A file opened for output.
`">>"`	A file opened for append.
`"<"`	A file opened for input.
`"|>"`	A pipe opened for output.
`"|<"`	A pipe opened for input.
`"|&"`	A two-way coprocess.

On error, return `awk_false`. Otherwise, return `awk_true`, and return additional information about the redirection in the `ibufp` and `obufp` pointers.

For input redirections, the `*ibufp` value should be non-`NULL`, and `*obufp` should be `NULL`. For output redirections, the `*obufp` value should be non-`NULL`, and `*ibufp` should be `NULL`. For two-way coprocesses, both values should be non-`NULL`.

In the usual case, the extension is interested in `(*ibufp)->fd` and/or `fileno((*obufp)->fp)`. If the file is not already open, and the `fd` argument is nonnegative, `gawk` will use that file descriptor instead of opening the file in the usual way. If `fd` is nonnegative, but the file exists already, `gawk` ignores `fd` and returns the existing file. It is the caller's responsibility to notice that neither the `fd` in the returned `awk_input_buf_t` nor the `fd` in the returned `awk_output_buf_t` matches the requested value.

Note that supplying a file descriptor is currently *not* supported for pipes. However, supplying a file descriptor should work for input, output, append, and two-way (coprocess) sockets. If `filetype` is two-way, `gawk` assumes that it is a socket! Note that in the two-way case, the input and output file descriptors may differ. To check for success, you must check whether either matches.

It is anticipated that this API function will be used to implement I/O multiplexing and a socket library.

17.4.14 API Variables

The API provides two sets of variables. The first provides information about the version of the API (both with which the extension was compiled, and with which `gawk` was compiled). The second provides information about how `gawk` was invoked.

17.4.14.1 API Version Constants and Variables

The API provides both a "major" and a "minor" version number. The API versions are available at compile time as C preprocessor defines to support conditional compilation, and as enum constants to facilitate debugging:

API Version	C Preprocessor Define	enum constant
Major	`gawk_api_major_version`	`GAWK_API_MAJOR_VERSION`
Minor	`gawk_api_minor_version`	`GAWK_API_MINOR_VERSION`

Table 17.3: gawk API version constants

The minor version increases when new functions are added to the API. Such new functions are always added to the end of the API `struct`.

The major version increases (and the minor version is reset to zero) if any of the data types change size or member order, or if any of the existing functions change signature.

It could happen that an extension may be compiled against one version of the API but loaded by a version of `gawk` using a different version. For this reason, the major and minor API versions of the running `gawk` are included in the API `struct` as read-only constant integers:

`api->major_version`
: The major version of the running `gawk`.

`api->minor_version`
: The minor version of the running `gawk`.

It is up to the extension to decide if there are API incompatibilities. Typically, a check like this is enough:

```
if (   api->major_version != GAWK_API_MAJOR_VERSION
    || api->minor_version < GAWK_API_MINOR_VERSION) {
        fprintf(stderr, "foo_extension: version mismatch with gawk!\n");
        fprintf(stderr, "\tmy version (%d, %d), gawk version (%d, %d)\n",
                GAWK_API_MAJOR_VERSION, GAWK_API_MINOR_VERSION,
                api->major_version, api->minor_version);
        exit(1);
}
```

Such code is included in the boilerplate `dl_load_func()` macro provided in `gawkapi.h` (discussed in Section 17.4.15 [Boilerplate Code], page 455).

17.4.14.2 GMP and MPFR Version Information

The API also includes information about the versions of GMP and MPFR with which the running `gawk` was compiled (if any). They are included in the API `struct` as read-only constant integers:

`api->gmp_major_version`
: The major version of the GMP library used to compile `gawk`.

`api->gmp_minor_version`
: The minor version of the GMP library used to compile `gawk`.

`api->mpfr_major_version`
: The major version of the MPFR library used to compile `gawk`.

`api->mpfr_minor_version`
: The minor version of the MPFR library used to compile `gawk`.

These fields are set to zero if `gawk` was compiled without MPFR support.

You can check if the versions of MPFR and GMP that you are using match those of `gawk` with the following macro:

`check_mpfr_version(extension)`
: The `extension` is the extension id passed to all the other macros and functions defined in `gawkapi.h`. If you have not included the `<mpfr.h>` header file, then this macro will be defined to do nothing.

  If you have included that file, then this macro compares the MPFR and GMP major and minor versions against those of the library you are compiling against. If your libraries are newer than `gawk`'s, it produces a fatal error message.

  The `dl_load_func()` macro (see Section 17.4.15 [Boilerplate Code], page 455) calls `check_mpfr_version()`.

17.4.14.3 Informational Variables

The API provides access to several variables that describe whether the corresponding command-line options were enabled when `gawk` was invoked. The variables are:

`do_csv` This variable is true if `gawk` was invoked with `--csv` option.

`do_debug` This variable is true if `gawk` was invoked with `--debug` option.

`do_lint` This variable is true if `gawk` was invoked with `--lint` option.

`do_mpfr` This variable is true if `gawk` was invoked with `--bignum` option.

`do_profile`
: This variable is true if `gawk` was invoked with `--profile` option.

`do_sandbox`
: This variable is true if `gawk` was invoked with `--sandbox` option.

`do_traditional`
: This variable is true if `gawk` was invoked with `--traditional` option.

The value of `do_lint` can change if `awk` code modifies the `LINT` predefined variable (see Section 7.5 [Predefined Variables], page 167). The others should not change during execution.

17.4.15 Boilerplate Code

As mentioned earlier (see Section 17.3 [How It Works at a High Level], page 415), the function definitions as presented are really macros. To use these macros, your extension must provide a small amount of boilerplate code (variables and functions) toward the top of your source file, using predefined names as described here. The boilerplate needed is also provided in comments in the `gawkapi.h` header file:

```
/* Boilerplate code: */
int plugin_is_GPL_compatible;

static gawk_api_t *const api;
static awk_ext_id_t ext_id;
static const char *ext_version = NULL; /* or ... = "some string" */

static awk_ext_func_t func_table[] = {
    { "name", do_name, 1, 0, awk_false, NULL },
    /* ... */
};

/* EITHER: */

static awk_bool_t (*init_func)(void) = NULL;

/* OR: */

static awk_bool_t
init_my_extension(void)
```

```
{
    ...
}

static awk_bool_t (*init_func)(void) = init_my_extension;

dl_load_func(func_table, some_name, "name_space_in_quotes")
```

These variables and functions are as follows:

`int plugin_is_GPL_compatible;`
: This asserts that the extension is compatible with the GNU GPL (see [GNU General Public License], page 557). If your extension does not have this, `gawk` will not load it (see Section 17.2 [Extension Licensing], page 415).

`static gawk_api_t *const api;`
: This global `static` variable should be set to point to the `gawk_api_t` pointer that `gawk` passes to your `dl_load()` function. This variable is used by all of the macros.

`static awk_ext_id_t ext_id;`
: This global static variable should be set to the `awk_ext_id_t` value that `gawk` passes to your `dl_load()` function. This variable is used by all of the macros.

`static const char *ext_version = NULL; /* or ... = "some string" */`
: This global `static` variable should be set either to `NULL`, or to point to a string giving the name and version of your extension.

`static awk_ext_func_t func_table[] = { ... };`
: This is an array of one or more `awk_ext_func_t` structures, as described earlier (see Section 17.4.6.1 [Registering An Extension Function], page 427). It can then be looped over for multiple calls to `add_ext_func()`.

`static awk_bool_t (*init_func)(void) = NULL;`
OR
`static awk_bool_t init_my_extension(void) { ... }`
`static awk_bool_t (*init_func)(void) = init_my_extension;`
: If you need to do some initialization work, you should define a function that does it (creates variables, opens files, etc.) and then define the `init_func` pointer to point to your function. The function should return `awk_false` upon failure, or `awk_true` if everything goes well.

  If you don't need to do any initialization, define the pointer and initialize it to `NULL`.

`dl_load_func(func_table, some_name, "name_space_in_quotes")`
: This macro expands to a `dl_load()` function that performs all the necessary initializations.

The point of all the variables and arrays is to let the `dl_load()` function (from the `dl_load_func()` macro) do all the standard work. It does the following:

1. Check the API versions. If the extension major version does not match `gawk`'s, or if the extension minor version is greater than `gawk`'s, it prints a fatal error message and exits.

2. Check the MPFR and GMP versions. If there is a mismatch, it prints a fatal error message and exits.
3. Load the functions defined in `func_table`. If any of them fails to load, it prints a warning message but continues on.
4. If the `init_func` pointer is not `NULL`, call the function it points to. If it returns `awk_false`, print a warning message.
5. If `ext_version` is not `NULL`, register the version string with `gawk`.

17.4.16 Changes From Version 1 of the API

The current API is *not* binary compatible with version 1 of the API. You will have to recompile your extensions in order to use them with the current version of `gawk`.

Fortunately, at the possible expense of some compile-time warnings, the API remains source-code–compatible with the previous API. The major differences are the additional members in the `awk_ext_func_t` structure, and the addition of the third argument to the C implementation function (see Section 17.4.6.1 [Registering An Extension Function], page 427).

Here is a list of individual features that changed from version 1 to version 2 of the API:

- Numeric values can now have MPFR/MPZ variants (see Section 17.4.2 [General-Purpose Data Types], page 420).
- There are new string types: `AWK_REGEX` and `AWK_STRNUM` (see Section 17.4.2 [General-Purpose Data Types], page 420).
- The `ezalloc()` macro is new (see Section 17.4.3 [Memory Allocation Functions and Convenience Macros], page 423).
- The `awk_ext_func_t` structure changed. Instead of `num_expected_args`, it now has `max_expected` and `min_required` (see Section 17.4.6.1 [Registering An Extension Function], page 427).
- For `get_record()`, an input parser can now specify field widths (see Section 17.4.6.4 [Customized Input Parsers], page 429).
- Extensions can now produce nonfatal error messages (see Section 17.4.7 [Printing Messages], page 437).
- When flattening an array, you can now specify the index and value types (see Section 17.4.12.2 [Array Functions], page 445).
- The `get_file()` API is new (see Section 17.4.13 [Accessing and Manipulating Redirections], page 452).

17.5 How gawk Finds Extensions

Compiled extensions have to be installed in a directory where `gawk` can find them. If `gawk` is configured and built in the default fashion, the directory in which to find extensions is `/usr/local/lib/gawk`. You can also specify a search path with a list of directories to search for compiled extensions. See Section 2.5.2 [The AWKLIBPATH Environment Variable], page 43, for more information.

17.6 Example: Some File Functions

No matter where you go, there you are.
—Buckaroo Banzai

Two useful functions that are not in `awk` are `chdir()` (so that an `awk` program can change its directory) and `stat()` (so that an `awk` program can gather information about a file). In order to illustrate the API in action, this section implements these functions for `gawk` in an extension.

17.6.1 Using `chdir()` and `stat()`

This section shows how to use the new functions at the `awk` level once they've been integrated into the running `gawk` interpreter. Using `chdir()` is very straightforward. It takes one argument, the new directory to change to:

```
@load "filefuncs"
...
newdir = "/home/arnold/funstuff"
ret = chdir(newdir)
if (ret < 0) {
    printf("could not change to %s: %s\n", newdir, ERRNO) > "/dev/stderr"
    exit 1
}
...
```

The return value is negative if the `chdir()` failed, and `ERRNO` (see Section 7.5 [Predefined Variables], page 167) is set to a string indicating the error.

Using `stat()` is a bit more complicated. The C `stat()` function fills in a structure that has a fair amount of information. The right way to model this in `awk` is to fill in an associative array with the appropriate information:

```
file = "/home/arnold/.profile"
ret = stat(file, fdata)
if (ret < 0) {
    printf("could not stat %s: %s\n",
               file, ERRNO) > "/dev/stderr"
    exit 1
}
printf("size of %s is %d bytes\n", file, fdata["size"])
```

The `stat()` function always clears the data array, even if the `stat()` fails. It fills in the following elements:

`"name"` The name of the file that was `stat()`ed.

`"dev"`
`"ino"` The file's device and inode numbers, respectively.

`"mode"` The file's mode, as a numeric value. This includes both the file's type and its permissions.

`"nlink"` The number of hard links (directory entries) the file has.

"uid"
"gid" The numeric user and group ID numbers of the file's owner.

"size" The size in bytes of the file.

"blocks" The number of disk blocks the file actually occupies. This may not be a function of the file's size if the file has holes.

"atime"
"mtime"
"ctime" The file's last access, modification, and inode update times, respectively. These are numeric timestamps, suitable for formatting with `strftime()` (see Section 9.1.6 [Time Functions], page 215).

"pmode" The file's "printable mode." This is a string representation of the file's type and permissions, such as is produced by '`ls -l`'—for example, `"drwxr-xr-x"`.

"type" A printable string representation of the file's type. The value is one of the following:

"blockdev"
"chardev"
The file is a block or character device ("special file").

"directory"
The file is a directory.

"fifo" The file is a named pipe (also known as a FIFO).

"file" The file is just a regular file.

"socket" The file is an `AF_UNIX` ("Unix domain") socket in the filesystem.

"symlink"
The file is a symbolic link.

"devbsize"
The size of a block for the element indexed by `"blocks"`. This information is derived from either the `DEV_BSIZE` constant defined in `<sys/param.h>` on most systems, or the `S_BLKSIZE` constant in `<sys/stat.h>` on BSD systems. For some other systems, *a priori* knowledge is used to provide a value. Where no value can be determined, it defaults to 512.

Several additional elements may be present, depending upon the operating system and the type of the file. You can test for them in your `awk` program by using the `in` operator (see Section 8.1.2 [Referring to an Array Element], page 183):

"blksize"
The preferred block size for I/O to the file. This field is not present on all POSIX-like systems in the C `stat` structure.

"linkval"
If the file is a symbolic link, this element is the name of the file the link points to (i.e., the value of the link).

"rdev"
"major"
"minor" If the file is a block or character device file, then these values represent the numeric device number and the major and minor components of that number, respectively.

17.6.2 C Code for `chdir()` and `stat()`

Here is the C code for these extensions.[10]

The file includes a number of standard header files, and then includes the `gawkapi.h` header file, which provides the API definitions. Those are followed by the necessary variable declarations to make use of the API macros and boilerplate code (see Section 17.4.15 [Boilerplate Code], page 455):

```
#ifdef HAVE_CONFIG_H
#include <config.h>
#endif

#include <stdio.h>
#include <assert.h>
#include <errno.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>

#include <sys/types.h>
#include <sys/stat.h>

#include "gawkapi.h"

#include "gettext.h"
#define _(msgid)  gettext(msgid)
#define N_(msgid) msgid

#include "gawkfts.h"
#include "stack.h"

static const gawk_api_t *api;    /* for convenience macros to work */
static awk_ext_id_t ext_id;
static awk_bool_t init_filefuncs(void);
static awk_bool_t (*init_func)(void) = init_filefuncs;
static const char *ext_version = "filefuncs extension: version 1.0";

int plugin_is_GPL_compatible;
```

By convention, for an `awk` function `foo()`, the C function that implements it is called `do_foo()`. The function should have two arguments. The first is an `int`, usually called

[10] This version is edited slightly for presentation. See `extension/filefuncs.c` in the `gawk` distribution for the complete version.

nargs, that represents the number of actual arguments for the function. The second is a pointer to an awk_value_t structure, usually named result:

```
/*  do_chdir --- provide dynamically loaded chdir() function for gawk */

static awk_value_t *
do_chdir(int nargs, awk_value_t *result, struct awk_ext_func *unused)
{
    awk_value_t newdir;
    int ret = -1;

    assert(result != NULL);
```

The newdir variable represents the new directory to change to, which is retrieved with get_argument(). Note that the first argument is numbered zero.

If the argument is retrieved successfully, the function calls the chdir() system call. Otherwise, if the chdir() fails, it updates ERRNO:

```
    if (get_argument(0, AWK_STRING, & newdir)) {
        ret = chdir(newdir.str_value.str);
        if (ret < 0)
            update_ERRNO_int(errno);
    }
```

Finally, the function returns the return value to the awk level:

```
    return make_number(ret, result);
}
```

The stat() extension is more involved. First comes a function that turns a numeric mode into a printable representation (e.g., octal 0644 becomes '-rw-r--r--'). This is omitted here for brevity:

```
/* format_mode --- turn a stat mode field into something readable */

static char *
format_mode(unsigned long fmode)
{
    ...
}
```

Next comes a function for reading symbolic links, which is also omitted here for brevity:

```
/* read_symlink --- read a symbolic link into an allocated buffer.
   ... */

static char *
read_symlink(const char *fname, size_t bufsize, ssize_t *linksize)
{
    ...
}
```

Two helper functions simplify entering values in the array that will contain the result of the stat():

```
/* array_set --- set an array element */
```

```
static void
array_set(awk_array_t array, const char *sub, awk_value_t *value)
{
    awk_value_t index;

    set_array_element(array,
                      make_const_string(sub, strlen(sub), & index),
                      value);

}

/* array_set_numeric --- set an array element with a number */

static void
array_set_numeric(awk_array_t array, const char *sub, double num)
{
    awk_value_t tmp;

    array_set(array, sub, make_number(num, & tmp));
}
```

The following function does most of the work to fill in the `awk_array_t` result array with values obtained from a valid `struct stat`. This work is done in a separate function to support the `stat()` function for `gawk` and also to support the `fts()` extension, which is included in the same file but whose code is not shown here (see Section 17.7.1 [File-Related Functions], page 468).

The first part of the function is variable declarations, including a table to map file types to strings:

```
/* fill_stat_array --- do the work to fill an array with stat info */

static int
fill_stat_array(const char *name, awk_array_t array, struct stat *sbuf)
{
    char *pmode;    /* printable mode */
    const char *type = "unknown";
    awk_value_t tmp;
    static struct ftype_map {
        unsigned int mask;
        const char *type;
    } ftype_map[] = {
        { S_IFREG, "file" },
        { S_IFBLK, "blockdev" },
        { S_IFCHR, "chardev" },
        { S_IFDIR, "directory" },
#ifdef S_IFSOCK
        { S_IFSOCK, "socket" },
```

```
#endif
#ifdef S_IFIFO
        { S_IFIFO, "fifo" },
#endif
#ifdef S_IFLNK
        { S_IFLNK, "symlink" },
#endif
#ifdef S_IFDOOR /* Solaris weirdness */
        { S_IFDOOR, "door" },
#endif
    };
    int j, k;
```

The destination array is cleared, and then code fills in various elements based on values in the `struct stat`:

```
    /* empty out the array */
    clear_array(array);

    /* fill in the array */
    array_set(array, "name", make_const_string(name, strlen(name),
                                               & tmp));
    array_set_numeric(array, "dev", sbuf->st_dev);
    array_set_numeric(array, "ino", sbuf->st_ino);
    array_set_numeric(array, "mode", sbuf->st_mode);
    array_set_numeric(array, "nlink", sbuf->st_nlink);
    array_set_numeric(array, "uid", sbuf->st_uid);
    array_set_numeric(array, "gid", sbuf->st_gid);
    array_set_numeric(array, "size", sbuf->st_size);
    array_set_numeric(array, "blocks", sbuf->st_blocks);
    array_set_numeric(array, "atime", sbuf->st_atime);
    array_set_numeric(array, "mtime", sbuf->st_mtime);
    array_set_numeric(array, "ctime", sbuf->st_ctime);

    /* for block and character devices, add rdev,
       major and minor numbers */
    if (S_ISBLK(sbuf->st_mode) || S_ISCHR(sbuf->st_mode)) {
        array_set_numeric(array, "rdev", sbuf->st_rdev);
        array_set_numeric(array, "major", major(sbuf->st_rdev));
        array_set_numeric(array, "minor", minor(sbuf->st_rdev));
    }
```

The latter part of the function makes selective additions to the destination array, depending upon the availability of certain members and/or the type of the file. It then returns zero, for success:

```
#ifdef HAVE_STRUCT_STAT_ST_BLKSIZE
    array_set_numeric(array, "blksize", sbuf->st_blksize);
#endif
```

```
    pmode = format_mode(sbuf->st_mode);
    array_set(array, "pmode", make_const_string(pmode, strlen(pmode),
                                                & tmp));

    /* for symbolic links, add a linkval field */
    if (S_ISLNK(sbuf->st_mode)) {
        char *buf;
        ssize_t linksize;

        if ((buf = read_symlink(name, sbuf->st_size,
                    & linksize)) != NULL)
            array_set(array, "linkval",
                      make_malloced_string(buf, linksize, & tmp));
        else
            warning(ext_id, _("stat: unable to read symbolic link `%s'"),
                    name);
    }

    /* add a type field */
    type = "unknown";   /* shouldn't happen */
    for (j = 0, k = sizeof(ftype_map)/sizeof(ftype_map[0]); j < k; j++) {
        if ((sbuf->st_mode & S_IFMT) == ftype_map[j].mask) {
            type = ftype_map[j].type;
            break;
        }
    }

    array_set(array, "type", make_const_string(type, strlen(type), & tmp));

    return 0;
}
```

The third argument to `stat()` was not discussed previously. This argument is optional. If present, it causes `do_stat()` to use the `stat()` system call instead of the `lstat()` system call. This is done by using a function pointer: `statfunc`. `statfunc` is initialized to point to `lstat()` (instead of `stat()`) to get the file information, in case the file is a symbolic link. However, if the third argument is included, `statfunc` is set to point to `stat()`, instead.

Here is the `do_stat()` function, which starts with variable declarations and argument checking:

```
/* do_stat --- provide a stat() function for gawk */

static awk_value_t *
do_stat(int nargs, awk_value_t *result, struct awk_ext_func *unused)
{
    awk_value_t file_param, array_param;
    char *name;
    awk_array_t array;
```

```
    int ret;
    struct stat sbuf;
    /* default is lstat() */
    int (*statfunc)(const char *path, struct stat *sbuf) = lstat;

    assert(result != NULL);
```

Then comes the actual work. First, the function gets the arguments. Next, it gets the information for the file. If the called function (`lstat()` or `stat()`) returns an error, the code sets `ERRNO` and returns:

```
    /* file is first arg, array to hold results is second */
    if (   ! get_argument(0, AWK_STRING, & file_param)
        || ! get_argument(1, AWK_ARRAY, & array_param)) {
        warning(ext_id, _("stat: bad parameters"));
        return make_number(-1, result);
    }

    if (nargs == 3) {
        statfunc = stat;
    }

    name = file_param.str_value.str;
    array = array_param.array_cookie;

    /* always empty out the array */
    clear_array(array);

    /* stat the file; if error, set ERRNO and return */
    ret = statfunc(name, & sbuf);
    if (ret < 0) {
        update_ERRNO_int(errno);
        return make_number(ret, result);
    }
```

The tedious work is done by `fill_stat_array()`, shown earlier. When done, the function returns the result from `fill_stat_array()`:

```
    ret = fill_stat_array(name, array, & sbuf);

    return make_number(ret, result);
}
```

Finally, it's necessary to provide the "glue" that loads the new function(s) into `gawk`.

The `filefuncs` extension also provides an `fts()` function, which we omit here (see Section 17.7.1 [File-Related Functions], page 468). For its sake, there is an initialization function:

```
/* init_filefuncs --- initialization routine */

static awk_bool_t
```

```
init_filefuncs(void)
{
    ...
}
```

We are almost done. We need an array of `awk_ext_func_t` structures for loading each function into `gawk`:

```
static awk_ext_func_t func_table[] = {
    { "chdir", do_chdir, 1, 1, awk_false, NULL },
    { "stat",  do_stat, 3, 2, awk_false, NULL },
    ...
};
```

Each extension must have a routine named `dl_load()` to load everything that needs to be loaded. It is simplest to use the `dl_load_func()` macro in `gawkapi.h`:

```
/* define the dl_load() function using the boilerplate macro */

dl_load_func(func_table, filefuncs, "")
```

And that's it!

17.6.3 Integrating the Extensions

Now that the code is written, it must be possible to add it at runtime to the running `gawk` interpreter. First, the code must be compiled. Assuming that the functions are in a file named `filefuncs.c`, and *idir* is the location of the `gawkapi.h` header file, the following steps[11] create a GNU/Linux shared library:

```
$ gcc -fPIC -shared -DHAVE_CONFIG_H -c -O -g -Iidir filefuncs.c
$ gcc -o filefuncs.so -shared filefuncs.o
```

Once the library exists, it is loaded by using the `@load` directive:

```
# file testff.awk
@load "filefuncs"

BEGIN {
    "pwd" | getline curdir  # save current directory
    close("pwd")

    chdir("/tmp")
    system("pwd")   # test it
    chdir(curdir)   # go back

    print "Info for testff.awk"
    ret = stat("testff.awk", data)
    print "ret =", ret
    for (i in data)
```

[11] In practice, you would probably want to use the GNU Autotools (Automake, Autoconf, Libtool, and `gettext`) to configure and build your libraries. Instructions for doing so are beyond the scope of this book. See Section 17.8 [The gawkextlib Project], page 478, for Internet links to the tools.

```
        printf "data[\"%s\"] = %s\n", i, data[i]
    print "testff.awk modified:",
        strftime("%m %d %Y %H:%M:%S", data["mtime"])

    print "\nInfo for JUNK"
    ret = stat("JUNK", data)
    print "ret =", ret
    for (i in data)
        printf "data[\"%s\"] = %s\n", i, data[i]
    print "JUNK modified:", strftime("%m %d %Y %H:%M:%S", data["mtime"])
}
```

The `AWKLIBPATH` environment variable tells `gawk` where to find extensions (see Section 17.5 [How gawk Finds Extensions], page 457). We set it to the current directory and run the program:

```
$ AWKLIBPATH=$PWD gawk -f testff.awk
⊣ /tmp
⊣ Info for testff.awk
⊣ ret = 0
⊣ data["blksize"] = 4096
⊣ data["devbsize"] = 512
⊣ data["mtime"] = 1412004710
⊣ data["mode"] = 33204
⊣ data["type"] = file
⊣ data["dev"] = 2053
⊣ data["gid"] = 1000
⊣ data["ino"] = 10358899
⊣ data["ctime"] = 1412004710
⊣ data["blocks"] = 8
⊣ data["nlink"] = 1
⊣ data["name"] = testff.awk
⊣ data["atime"] = 1412004716
⊣ data["pmode"] = -rw-rw-r--
⊣ data["size"] = 666
⊣ data["uid"] = 1000
⊣ testff.awk modified: 09 29 2014 18:31:50
⊣
⊣ Info for JUNK
⊣ ret = -1
⊣ JUNK modified: 01 01 1970 02:00:00
```

17.7 The Sample Extensions in the gawk Distribution

This section provides a brief overview of the sample extensions that come in the `gawk` distribution. Some of them are intended for production use (e.g., the `filefuncs`, `readdir`, and `inplace` extensions). Others mainly provide example code that shows how to use the extension API.

17.7.1 File-Related Functions

The `filefuncs` extension provides three different functions, as follows. The usage is:

`@load "filefuncs"`
: This is how you load the extension.

`result = chdir("/some/directory")`
: The `chdir()` function is a direct hook to the `chdir()` system call to change the current directory. It returns zero upon success or a value less than zero upon error. In the latter case, it updates `ERRNO`.

`result = stat("/some/path", statdata [, follow])`
: The `stat()` function provides a hook into the `stat()` system call. It returns zero upon success or a value less than zero upon error. In the latter case, it updates `ERRNO`.

  By default, it uses the `lstat()` system call. However, if passed a third argument, it uses `stat()` instead.

  In all cases, it clears the `statdata` array. When the call is successful, `stat()` fills the `statdata` array with information retrieved from the filesystem, as follows:

Subscript	**Field in `struct stat`**	**File type**
`"name"`	The file name	All
`"dev"`	`st_dev`	All
`"ino"`	`st_ino`	All
`"mode"`	`st_mode`	All
`"nlink"`	`st_nlink`	All
`"uid"`	`st_uid`	All
`"gid"`	`st_gid`	All
`"size"`	`st_size`	All
`"atime"`	`st_atime`	All
`"mtime"`	`st_mtime`	All
`"ctime"`	`st_ctime`	All
`"rdev"`	`st_rdev`	Device files
`"major"`	`st_major`	Device files
`"minor"`	`st_minor`	Device files
`"blksize"`	`st_blksize`	All
`"pmode"`	A human-readable version of the mode value, like that printed by `ls` (for example, `"-rwxr-xr-x"`)	All
`"linkval"`	The value of the symbolic link	Symbolic links
`"type"`	The type of the file as a string—one of `"file"`, `"blockdev"`, `"chardev"`, `"directory"`, `"socket"`, `"fifo"`, `"symlink"`, `"door"`, or `"unknown"` (not all systems support all file types)	All

`flags = or(FTS_PHYSICAL, ...)`
`result = fts(pathlist, flags, filedata)`

Walk the file trees provided in `pathlist` and fill in the `filedata` array, as described next. `flags` is the bitwise OR of several predefined values, also described in a moment. Return zero if there were no errors, otherwise return −1.

The `fts()` function provides a hook to the C library `fts()` routines for traversing file hierarchies. Instead of returning data about one file at a time in a stream, it fills in a multidimensional array with data about each file and directory encountered in the requested hierarchies.

The arguments are as follows:

`pathlist` An array of file names. The element values are used; the index values are ignored.

`flags` This should be the bitwise OR of one or more of the following predefined constant flag values. At least one of `FTS_LOGICAL` or `FTS_PHYSICAL` must be provided; otherwise `fts()` returns an error value and sets `ERRNO`. The flags are:

`FTS_LOGICAL`
: Do a "logical" file traversal, where the information returned for a symbolic link refers to the linked-to file, and not to the symbolic link itself. This flag is mutually exclusive with `FTS_PHYSICAL`.

`FTS_PHYSICAL`
: Do a "physical" file traversal, where the information returned for a symbolic link refers to the symbolic link itself. This flag is mutually exclusive with `FTS_LOGICAL`.

`FTS_NOCHDIR`
: As a performance optimization, the C library `fts()` routines change directory as they traverse a file hierarchy. This flag disables that optimization.

`FTS_COMFOLLOW`
: Immediately follow a symbolic link named in `pathlist`, whether or not `FTS_LOGICAL` is set.

`FTS_SEEDOT`
: By default, the C library `fts()` routines do not return entries for `.` (dot) and `..` (dot-dot). This option causes entries for dot-dot to also be included. (The extension always includes an entry for dot; more on this in a moment.)

`FTS_XDEV` During a traversal, do not cross onto a different mounted filesystem.

`filedata` The `filedata` array holds the results. `fts()` first clears it. Then it creates an element in `filedata` for every element in `pathlist`. The index is the name of the directory or file given in `pathlist`. The element for this index is itself an array. There are two cases:

The path is a file
: In this case, the array contains two or three elements:

  `"path"`
  : The full path to this file, starting from the "root" that was given in the `pathlist` array.

  `"stat"`
  : This element is itself an array, containing the same information as provided by the `stat()` function described earlier for its `statdata` argument. The element may not be present if the `stat()` system call for the file failed.

  `"error"`
  : If some kind of error was encountered, the array will also contain an element named `"error"`, which is a string describing the error.

The path is a directory
: In this case, the array contains one element for each entry in the directory. If an entry is a file, that element is the same as for files, just described. If the entry is a directory, that element is (recursively) an array describing the subdirectory. If `FTS_SEEDOT` was provided in the flags, then there will also be an element named `".."`. This element will be an array containing the data as provided by `stat()`.

  In addition, there will be an element whose index is `"."`. This element is an array containing the same two or three elements as for a file: `"path"`, `"stat"`, and `"error"`.

The `fts()` function returns zero if there were no errors. Otherwise, it returns -1.

> **NOTE:** The `fts()` extension does not exactly mimic the interface of the C library `fts()` routines, choosing instead to provide an interface that is based on associative arrays, which is more comfortable to use from an `awk` program. This includes the lack of a comparison function, because `gawk` already provides powerful array sorting facilities. Although an `fts_read()`-like interface could have been provided, this felt less natural than simply creating a multidimensional array to represent the file hierarchy and its information.

See `test/fts.awk` in the `gawk` distribution for an example use of the `fts()` extension function.

17.7.2 Interface to `fnmatch()`

This extension provides an interface to the C library `fnmatch()` function. The usage is:

`@load "fnmatch"`
: This is how you load the extension.

`result = fnmatch(pattern, string, flags)`
: The return value is zero on success, `FNM_NOMATCH` if the string did not match the pattern, or a different nonzero value if an error occurred.

In addition to the `fnmatch()` function, the `fnmatch` extension adds one constant (`FNM_NOMATCH`), and an array of flag values named `FNM`.

The arguments to `fnmatch()` are:

`pattern` The file name wildcard to match

`string` The file name string

`flag` Either zero, or the bitwise OR of one or more of the flags in the `FNM` array

The flags are as follows:

Array element	**Corresponding flag defined by `fnmatch()`**
`FNM["CASEFOLD"]`	`FNM_CASEFOLD`
`FNM["FILE_NAME"]`	`FNM_FILE_NAME`
`FNM["LEADING_DIR"]`	`FNM_LEADING_DIR`
`FNM["NOESCAPE"]`	`FNM_NOESCAPE`
`FNM["PATHNAME"]`	`FNM_PATHNAME`
`FNM["PERIOD"]`	`FNM_PERIOD`

Here is an example:

```
@load "fnmatch"
...
flags = or(FNM["PERIOD"], FNM["NOESCAPE"])
if (fnmatch("*.a", "foo.c", flags) == FNM_NOMATCH)
    print "no match"
```

17.7.3 Interface to `fork()`, `wait()`, and `waitpid()`

The `fork` extension adds three functions, as follows:

`@load "fork"`
: This is how you load the extension.

`pid = fork()`
: This function creates a new process. The return value is zero in the child and the process ID number of the child in the parent, or -1 upon error. In the latter case, `ERRNO` indicates the problem. In the child, `PROCINFO["pid"]` and `PROCINFO["ppid"]` are updated to reflect the correct values.

`ret = waitpid(pid)`
: This function takes a numeric argument, which is the process ID to wait for. The return value is that of the `waitpid()` system call.

`ret = wait()`
: This function waits for the first child to die. The return value is that of the `wait()` system call.

There is no corresponding `exec()` function.

Here is an example:

```
@load "fork"
...
if ((pid = fork()) == 0)
    print "hello from the child"
else
    print "hello from the parent"
```

17.7.4 Enabling In-Place File Editing

The `inplace` extension emulates GNU `sed`'s `-i` option, which performs "in-place" editing of each input file. Like GNU `sed`, the `inplace` extension replaces links (both hard and symbolic) with new files. If you wish to affect the target, you must dereference it first, for example using `realpath` from GNU Coreutils. It uses the bundled `inplace.awk` include file to invoke the extension properly. This extension makes use of the namespace facility to place all the variables and functions in the `inplace` namespace (see Chapter 15 [Namespaces in gawk], page 391):

```
# inplace --- load and invoke the inplace extension.

@load "inplace"

# Please set inplace::suffix to make a backup copy.  For example, you may
# want to set inplace::suffix to .bak on the command line or in a BEGIN rule.

# Before there were namespaces in gawk, this extension used
# INPLACE_SUFFIX as the variable for making backup copies. We allow this
# too, so that any code that used the previous version continues to work.

# By default, each filename on the command line will be edited inplace.
# But you can selectively disable this by adding an inplace::enable=0 argument
# prior to files that you do not want to process this way.  You can then
# reenable it later on the commandline by putting inplace::enable=1 before files
# that you wish to be subject to inplace editing.

# N.B. We call inplace::end() in the BEGINFILE and END rules so that any
# actions in an ENDFILE rule will be redirected as expected.

@namespace "inplace"

BEGIN {
    enable = 1          # enabled by default
}

BEGINFILE {
    sfx = (suffix ? suffix : awk::INPLACE_SUFFIX)
    if (filename != "")
        end(filename, sfx)
    if (enable)
        begin(filename = FILENAME, sfx)
    else
        filename = ""
}
```

```
END {
    if (filename != "")
        end(filename, (suffix ? suffix : awk::INPLACE_SUFFIX))
}
```

For each regular file that is processed, the extension redirects standard output to a temporary file configured to have the same owner and permissions as the original. After the file has been processed, the extension restores standard output to its original destination. (Due to this implementation, it helps to redirect `gawk`'s standard output to `/dev/null`, instead of leaving it set to your terminal, so that output will be block-buffered instead of line-buffered.)

If `inplace::suffix` is not an empty string, the original file is linked to a backup file name created by appending that suffix. Finally, the temporary file is renamed to the original file name.

Note that the use of this feature can be controlled by placing '`inplace::enable=0`' on the command-line prior to listing files that should not be processed this way. You can reenable inplace editing by adding an '`inplace::enable=1`' argument prior to files that should be subject to inplace editing.

The `inplace::filename` variable serves to keep track of the current file name so as to not invoke `inplace::end()` before processing the first file.

If any error occurs, the extension issues a fatal error to terminate processing immediately without damaging the original file.

Here are some simple examples:

```
$ gawk -i inplace '{ gsub(/foo/, "bar") }; { print }' file1 file2 file3
```

To keep a backup copy of the original files, try this:

```
$ gawk -i inplace -v inplace::suffix=.bak '{ gsub(/foo/, "bar") }
> { print }' file1 file2 file3
```

Please note that, while the extension does attempt to preserve ownership and permissions, it makes no attempt to copy the ACLs from the original file.

If the program dies prematurely, as might happen if an unhandled signal is received, a temporary file may be left behind.

17.7.5 Character and Numeric values: `ord()` and `chr()`

The `ordchr` extension adds two functions, named `ord()` and `chr()`, as follows:

`@load "ordchr"`
: This is how you load the extension.

`number = ord(string)`
: Return the numeric value of the first character in `string`.

`char = chr(number)`
: Return a string whose first character is that represented by `number`.

These functions are inspired by the Pascal language functions of the same name. Here is an example:

```
@load "ordchr"
```

```
...
printf("The numeric value of 'A' is %d\n", ord("A"))
printf("The string value of 65 is %s\n", chr(65))
```

As of release 5.4 of `gawk`, the extension can handle multibyte / wide character sets. If given an invalid multibyte string, in a UTF-8 locale, `ord()` returns the Unicode "invalid character" value, `0xFFFD`. Otherwise, it returns the numeric value of the first byte in the string. In a single-byte locale, `ord()` always returns the numeric value of the first byte in the string.

17.7.6 Reading Directories

The `readdir` extension adds an input parser for directories. The usage is as follows:

```
@load "readdir"
```

When this extension is in use, instead of skipping directories named on the command line (or with `getline`), they are read, with each entry returned as a record.

The record consists of three fields separated by forward slash characters. The first two are the inode number and the file name, and the third field is a single letter indicating the type of the file. The letters and their corresponding file types are shown in Table 17.4.

Letter	File type
`b`	Block device
`c`	Character device
`d`	Directory
`f`	Regular file
`l`	Symbolic link
`p`	Named pipe (FIFO)
`s`	Socket

Table 17.4: File types returned by the `readdir` extension

On systems where the directory entry contains the file type, the third field is filled in from that information. On systems without the file type information, the extension falls back to calling the `stat()` system call in order to provide the information. Thus the third field should never be '`u`' (for "unknown").

Normally, when reading directories, you should set `FS` equal to `"/"`. However, you may instead chose to create `PROCINFO["readdir_override"]` (with any value). If this element exists when the directory is opened, then the extension automatically sets the fields in each record for you.

By default, if a directory cannot be opened (due to permission problems, for example), `gawk` will exit. As with regular files, this situation can be handled using a `BEGINFILE` rule that checks `ERRNO` and prints an error or otherwise handles the problem.

Here is an example:

```
@load "readdir"
...
BEGIN { FS = "/" }
{ print "file name is", $2 }
```

17.7.7 Reversing Output

The `revoutput` extension adds a simple output wrapper that reverses the characters in each output line. Its main purpose is to show how to write an output wrapper, although it may be mildly amusing for the unwary. Here is an example:

```
@load "revoutput"

BEGIN {
    REVOUT = 1
    print "don't panic" > "/dev/stdout"
}
```

The output from this program is '`cinap t'nod`'.

17.7.8 Two-Way I/O Example

The `revtwoway` extension adds a simple two-way processor that reverses the characters in each line sent to it for reading back by the `awk` program. Its main purpose is to show how to write a two-way processor, although it may also be mildly amusing. The following example shows how to use it:

```
@load "revtwoway"

BEGIN {
    cmd = "/magic/mirror"
    print "don't panic" |& cmd
    cmd |& getline result
    print result
    close(cmd)
}
```

The output from this program also is: '`cinap t'nod`'.

17.7.9 Dumping and Restoring an Array

The `rwarray` extension adds four functions, named `writea()`, `reada()`, `writeall()` and `readall()`, as follows:

`@load "rwarray"`
: This is how you load the extension.

`ret = writea(file, array)`
: This function takes a string argument, which is the name of the file to which to dump the array, and the array itself as the second argument. `writea()` understands arrays of arrays. It returns one on success, or zero upon failure.

`ret = reada(file, array)`
: `reada()` is the inverse of `writea()`; it reads the file named as its first argument, filling in the array named as the second argument. It clears the array first. Here too, the return value is one on success, or zero upon failure.

`ret = writeall(file)`
: This function takes a string argument, which is the name of the file to which to dump the state of all variables. Calling this function is completely equivalent to calling `writea(file, SYMTAB)`. It returns one on success, or zero upon failure

`ret = readall(file)`
: This function takes a string argument, which is the name of the file from which to read the contents of various global variables. For each variable in the file, the data is loaded unless the variable has already been assigned a value or used as an array. In that case, the data for that variable in the file is ignored. It returns one on success, or zero upon failure.

The array created by `reada()` is identical to that written by `writea()` in the sense that the contents are the same. However, due to implementation issues, the array traversal order of the re-created array is likely to be different from that of the original array. As array traversal order in `awk` is by default undefined, this is (technically) not a problem. If you need to guarantee a particular traversal order, use the array sorting features in `gawk` to do so (see Section 12.3 [Controlling Array Traversal and Array Sorting], page 344).

The file contains binary data. All integral values are written in network byte order. However, double-precision floating-point values are written as native binary data. Thus, arrays containing only string data can theoretically be dumped on systems with one byte order and restored on systems with a different one, but this has not been tried.

Note that the `writeall()` and `readall()` functions provide a mechanism for maintaining persistent state across repeated invocations of a program. If, for example, a program calculates some statistics based on the data in a series of files, it could save state using `writeall()` after processing N files, and then reload the state using `readall()` when the N+1st file arrives to update the results.

Here is an example:

```
@load "rwarray"
...
ret = writea("arraydump.bin", array)
...
ret = reada("arraydump.bin", array)
...
ret = writeall("globalstate.bin")
...
ret = readall("globalstate.bin")
```

17.7.10 Reading an Entire File

The `readfile` extension adds a single function named `readfile()`, and an input parser:

`@load "readfile"`
: This is how you load the extension.

`result = readfile("/some/path")`
: The argument is the name of the file to read. The return value is a string containing the entire contents of the requested file. Upon error, the function returns the empty string and sets `ERRNO`.

`BEGIN { PROCINFO["readfile"] = 1 }`
: In addition, the extension adds an input parser that is activated if `PROCINFO["readfile"]` exists. When activated, each input file is returned in its entirety as `$0`. `RT` is set to the null string.

Here is an example:

```
@load "readfile"
...
contents = readfile("/path/to/file");
if (contents == "" && ERRNO != "") {
    print("problem reading file", ERRNO) > "/dev/stderr"
    ...
}
```

17.7.11 Extension Time Functions

The `time` extension adds three functions, named `gettimeofday()` `sleep()`, and `strptime()`, as follows:

`@load "time"`
: This is how you load the extension.

`the_time = gettimeofday()`
: Return the time in seconds that has elapsed since 1970-01-01 UTC as a floating-point value. If the time is unavailable on this platform, return −1 and set `ERRNO`. The returned time should have sub-second precision, but the actual precision may vary based on the platform. If the standard C `gettimeofday()` system call is available on this platform, then it simply returns the value. Otherwise, if on MS-Windows, it tries to use `GetSystemTimeAsFileTime()`.

`result = sleep(`*`seconds`*`)`
: Attempt to sleep for *seconds* seconds. If *seconds* is negative, or the attempt to sleep fails, return −1 and set `ERRNO`. Otherwise, return zero after sleeping for the indicated amount of time. Note that *seconds* may be a floating-point (non-integral) value. Implementation details: depending on platform availability, this function tries to use `nanosleep()` or `select()` to implement the delay.

`timeval = strptime(`*`string`*`,` *`format`*`)`
: This function takes two arguments, a string representing a date and time, and a format string describing the data in the string. It calls the C library `strptime()` function with the given values. If the parsing succeeds, the results are passed to the C library `mktime()` function, and its result is returned, expressing the time in seconds since the epoch in the current local timezone, regardless of any timezone specified in the string arguments. Otherwise it returns −1 upon error.

17.7.12 API Tests

The `testext` extension exercises parts of the extension API that are not tested by the other samples. The `extension/testext.c` file contains both the C code for the extension and `awk` test code inside C comments that run the tests. The testing framework extracts the `awk` code and runs the tests. See the source file for more information.

17.8 The gawkextlib Project

The gawkextlib project provides a number of gawk extensions, including one for processing XML files. This is the evolution of the original xgawk (XML gawk) project.

There are a number of extensions. The list of available extensions as well as their on-line full documentation can be seen in the gawkextlib web pages.

Some of the more interesting extensions are:

- abort extension. It allows you to exit immediately from your awk program without running the END rules.
- json extension. This serializes a multidimensional array into a JSON string, and can deserialize a JSON string into a gawk array. This extension is interesting since it is written in C++ instead of C.
- MPFR library extension. This provides access to a number of MPFR functions that gawk's native MPFR support does not.
- Select extension. It provides functionality based on the select() system call.
- XML parser extension, using the Expat XML parsing library

You can check out the code for the gawkextlib project using the Git distributed source code control system. The command is as follows:

```
git clone git://git.code.sf.net/p/gawkextlib/code gawkextlib-code
```

You will need to have the RapidJson JSON parser library installed in order to build and use the json extension.

You will need to have the Expat XML parser library installed in order to build and use the XML extension.

In addition, you must have the GNU Autotools installed (Autoconf, Automake, Libtool, and GNU gettext).

The simple recipe for building and testing gawkextlib is as follows. First, build and install gawk:

```
cd .../path/to/gawk/code
./configure --prefix=/tmp/newgawk       Install in /tmp/newgawk for now
make && make check                      Build and check that all is OK
make install                            Install gawk
```

Next, go to https://sourceforge.net/projects/gawkextlib/files to download gawkextlib and any extensions that you would like to build. The README file at that site explains how to build the code. If you installed gawk in a non-standard location, you will need to specify '`./configure --with-gawk=`*`/path/to/gawk`*' to find it. You may need to use the sudo utility to install both gawk and gawkextlib, depending upon how your system works.

If you write an extension that you wish to share with other gawk users, consider doing so through the gawkextlib project. See the project's website for more information.

17.9 Summary

- You can write extensions (sometimes called plug-ins) for gawk in C or C++ using the application programming interface (API) defined by the gawk developers.

- Extensions must have a license compatible with the GNU General Public License (GPL), and they must assert that fact by declaring a variable named `plugin_is_GPL_compatible`.
- Communication between `gawk` and an extension is two-way. `gawk` passes a `struct` to the extension that contains various data fields and function pointers. The extension can then call into `gawk` via the supplied function pointers to accomplish certain tasks.
- One of these tasks is to "register" the name and implementation of new `awk`-level functions with `gawk`. The implementation takes the form of a C function pointer with a defined signature. By convention, implementation functions are named `do_`*`XXXX`*`()` for some `awk`-level function *`XXXX`*`()`.
- The API is defined in a header file named `gawkapi.h`. You must include a number of standard header files *before* including it in your source file.
- API function pointers are provided for the following kinds of operations:
  - Allocating, reallocating, and releasing memory
  - Registration functions (you may register extension functions, exit callbacks, a version string, input parsers, output wrappers, and two-way processors)
  - Printing fatal, nonfatal, warning, and "lint" warning messages
  - Updating `ERRNO`, or unsetting it
  - Accessing parameters, including converting an undefined parameter into an array
  - Symbol table access (retrieving a global variable, creating one, or changing one)
  - Creating and releasing cached values; this provides an efficient way to use values for multiple variables and can be a big performance win
  - Manipulating arrays (retrieving, adding, deleting, and modifying elements; getting the count of elements in an array; creating a new array; clearing an array; and flattening an array for easy C-style looping over all its indices and elements)
- The API defines a number of standard data types for representing `awk` values, array elements, and arrays.
- The API provides convenience functions for constructing values. It also provides memory management functions to ensure compatibility between memory allocated by `gawk` and memory allocated by an extension.
- *All* memory passed from `gawk` to an extension must be treated as read-only by the extension.
- *All* memory passed from an extension to `gawk` must come from the API's memory allocation functions. `gawk` takes responsibility for the memory and releases it when appropriate.
- The API provides information about the running version of `gawk` so that an extension can make sure it is compatible with the `gawk` that loaded it.
- It is easiest to start a new extension by copying the boilerplate code described in this chapter. Macros in the `gawkapi.h` header file make this easier to do.
- The `gawk` distribution includes a number of small but useful sample extensions. The `gawkextlib` project includes several more (larger) extensions. If you wish to write an extension and contribute it to the community of `gawk` users, the `gawkextlib` project is the place to do so.

17.10 Exercises

1. Add functions to implement system calls such as `chown()`, `chmod()`, and `umask()` to the file operations extension presented in Section 17.6.2 [C Code for `chdir()` and `stat()`], page 460.
2. Write an input parser that prints a prompt if the input is a from a "terminal" device. You can use the `isatty()` function to tell if the input file is a terminal. (Hint: this function is usually expensive to call; try to call it just once.) The content of the prompt should come from a variable settable by `awk`-level code. You can write the prompt to standard error. However, for best results, open a new file descriptor (or file pointer) on `/dev/tty` and print the prompt there, in case standard error has been redirected.

   Why is standard error a better choice than standard output for writing the prompt? Which reading mechanism should you replace, the one to get a record, or the one to read raw bytes?
3. Write a wrapper script that provides an interface similar to '`sed -i`' for the "inplace" extension presented in Section 17.7.4 [Enabling In-Place File Editing], page 472.

Part IV:
Appendices

Appendix A The Evolution of the awk Language

This book describes the GNU implementation of awk, which follows the POSIX specification. Many longtime awk users learned awk programming with the original awk implementation in Version 7 Unix. (This implementation was the basis for awk in Berkeley Unix, through 4.3-Reno. Subsequent versions of Berkeley Unix, and, for a while, some systems derived from 4.4BSD-Lite, used various versions of gawk for their awk.) This chapter briefly describes the evolution of the awk language, with cross-references to other parts of the book where you can find more information.

A.1 Major Changes Between V7 and SVR3.1

The awk language evolved considerably between the release of Version 7 Unix (1978) and the new version that was first made generally available in System V Release 3.1 (1987). This section summarizes the changes, with cross-references to further details:

- The requirement for ';' to separate rules on a line (see Section 1.6 [awk Statements Versus Lines], page 28)
- User-defined functions and the return statement (see Section 9.2 [User-Defined Functions], page 225)
- The delete statement (see Section 8.4 [The delete Statement], page 190)
- The do-while statement (see Section 7.4.3 [The do-while Statement], page 160)
- The built-in functions atan2(), cos(), sin(), rand(), and srand() (see Section 9.1.3 [Numeric Functions], page 198)
- The built-in functions gsub(), sub(), and match() (see Section 9.1.4 [String-Manipulation Functions], page 200)
- The built-in functions close() and system() (see Section 9.1.5 [Input/Output Functions], page 211)
- The ARGC, ARGV, FNR, RLENGTH, RSTART, and SUBSEP predefined variables (see Section 7.5 [Predefined Variables], page 167)
- Assignable $0 (see Section 4.4 [Changing the Contents of a Field], page 75)
- The conditional expression using the ternary operator '?:' (see Section 6.3.4 [Conditional Expressions], page 145)
- The expression '*indx* in *array*' outside of for statements (see Section 8.1.2 [Referring to an Array Element], page 183)
- The exponentiation operator '^' (see Section 6.2.1 [Arithmetic Operators], page 132) and its assignment operator form '^=' (see Section 6.2.3 [Assignment Expressions], page 135)
- C-compatible operator precedence, which breaks some old awk programs (see Section 6.5 [Operator Precedence (How Operators Nest)], page 148)
- Regexps as the value of FS (see Section 4.5 [Specifying How Fields Are Separated], page 77) and as the third argument to the split() function (see Section 9.1.4 [String-Manipulation Functions], page 200), rather than using only the first character of FS
- Dynamic regexps as operands of the '~' and '!~' operators (see Section 3.6 [Using Dynamic Regexps], page 63)

- The escape sequences '`\b`', '`\f`', and '`\r`' (see Section 3.2 [Escape Sequences], page 52)
- Redirection of input for the `getline` function (see Section 4.10 [Explicit Input with `getline`], page 92)
- Multiple `BEGIN` and `END` rules (see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154)
- Multidimensional arrays (see Section 8.5 [Multidimensional Arrays], page 192)

A.2 Changes Between SVR3.1 and SVR4

The System V Release 4 (1989) version of Unix `awk` added these features (some of which originated in `gawk`):

- The `ENVIRON` array (see Section 7.5 [Predefined Variables], page 167)
- Multiple `-f` options on the command line (see Section 2.2 [Command-Line Options], page 33)
- The `-v` option for assigning variables before program execution begins (see Section 2.2 [Command-Line Options], page 33)
- The `--` signal for terminating command-line options
- The '`\a`', '`\v`', and '`\x`' escape sequences (see Section 3.2 [Escape Sequences], page 52)
- A defined return value for the `srand()` built-in function (see Section 9.1.3 [Numeric Functions], page 198)
- The `toupper()` and `tolower()` built-in string functions for case translation (see Section 9.1.4 [String-Manipulation Functions], page 200)
- A cleaner specification for the '`%c`' format-control letter in the `printf` function (see Section 5.5.2 [Format-Control Letters], page 107)
- The ability to dynamically pass the field width and precision (`"%*.*d"`) in the argument list of `printf` and `sprintf()` (see Section 5.5.2 [Format-Control Letters], page 107)
- The use of regexp constants, such as `/foo/`, as expressions, where they are equivalent to using the matching operator, as in '`$0 ~ /foo/`' (see Section 6.1.2 [Using Regular Expression Constants], page 126)
- Processing of escape sequences inside command-line variable assignments (see Section 6.1.3.2 [Assigning Variables on the Command Line], page 129)

A.3 Changes Between SVR4 and POSIX `awk`

The POSIX Command Language and Utilities standard for `awk` (1992) introduced the following changes into the language:

- The use of `-W` for implementation-specific options (see Section 2.2 [Command-Line Options], page 33)
- The use of `CONVFMT` for controlling the conversion of numbers to strings (see Section 6.1.4 [Conversion of Strings and Numbers], page 130)
- The concept of a numeric string and tighter comparison rules to go with it (see Section 6.3.2 [Variable Typing and Comparison Expressions], page 139)
- The use of predefined variables as function parameter names is forbidden (see Section 9.2.1 [Function Definition Syntax], page 225)

- More complete documentation of many of the previously undocumented features of the language

In 2012, a number of extensions that had been commonly available for many years were finally added to POSIX. They are:

- The `fflush()` built-in function for flushing buffered output (see Section 9.1.5 [Input/Output Functions], page 211)
- The `nextfile` statement (see Section 7.4.9 [The `nextfile` Statement], page 165)
- The ability to delete all of an array at once with '`delete array`' (see Section 8.4 [The `delete` Statement], page 190)

See Section A.7 [Common Extensions Summary], page 496, for a list of common extensions not permitted by the POSIX standard.

The 2018 POSIX standard can be found online at `https://pubs.opengroup.org/onlinepubs/9699919799/`.

A.4 Extensions in Brian Kernighan's `awk`

Brian Kernighan has made his version available via his home page (see Section B.5 [Other Freely Available `awk` Implementations], page 523).

This section describes common extensions that originally appeared in his version of `awk`:

- The '`**`' and '`**=`' operators (see Section 6.2.1 [Arithmetic Operators], page 132, and Section 6.2.3 [Assignment Expressions], page 135)
- The use of `func` as an abbreviation for `function` (see Section 9.2.1 [Function Definition Syntax], page 225)
- The `fflush()` built-in function for flushing buffered output (see Section 9.1.5 [Input/Output Functions], page 211)

See Section A.7 [Common Extensions Summary], page 496, for a full list of the extensions available in his `awk`.

A.5 Extensions in `gawk` Not in POSIX `awk`

The GNU implementation, `gawk`, adds a large number of features. They can all be disabled with either the `--traditional` or `--posix` options (see Section 2.2 [Command-Line Options], page 33).

A number of features have come and gone over the years. This section summarizes the additional features over POSIX `awk` that are in the current version of `gawk`.

- Additional predefined variables:
  - The `ARGIND`, `BINMODE`, `ERRNO`, `FIELDWIDTHS`, `FPAT`, `IGNORECASE`, `LINT`, `PROCINFO`, `RT`, and `TEXTDOMAIN` variables (see Section 7.5 [Predefined Variables], page 167)
- Special files in I/O redirections:
  - The `/dev/stdin`, `/dev/stdout`, `/dev/stderr`, and `/dev/fd/N` special file names (see Section 5.8 [Special File names in `gawk`], page 116)
  - The `/inet`, `/inet4`, and `/inet6` special files for TCP/IP networking using '`|&`' to specify which version of the IP protocol to use (see Section 12.5 [Using `gawk` for Network Programming], page 354)

- Changes and/or additions to the language:
  - The '`\x`' escape sequence (see Section 3.2 [Escape Sequences], page 52)
  - Full support for both POSIX and GNU regexps (see Chapter 3 [Regular Expressions], page 51)
  - The ability for `FS` and for the third argument to `split()` to be null strings (see Section 4.5.3 [Making Each Character a Separate Field], page 79)
  - The ability for `RS` to be a regexp (see Section 4.1 [How Input Is Split into Records], page 69)
  - The ability to use octal and hexadecimal constants in `awk` program source code (see Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124)
  - The '`|&`' operator for two-way I/O to a coprocess (see Section 12.4 [Two-Way Communications with Another Process], page 351)
  - Indirect function calls (see Section 9.5 [Indirect Function Calls], page 238)
  - Directories on the command line produce a warning and are skipped (see Section 4.13 [Directories on the Command Line], page 101)
  - Output with `print` and `printf` need not be fatal (see Section 5.11 [Enabling Nonfatal Output], page 120)
  - Namespaces and the use of `::` to designate an identifier within a namespace (see Chapter 15 [Namespaces in `gawk`], page 391).
- New keywords:
  - The `BEGINFILE` and `ENDFILE` special patterns (see Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155)
  - The `switch` statement (see Section 7.4.5 [The `switch` Statement], page 161)
- Changes to standard `awk` functions:
  - The optional second argument to `close()` that allows closing one end of a two-way pipe to a coprocess (see Section 12.4 [Two-Way Communications with Another Process], page 351)
  - POSIX compliance for `gsub()` and `sub()` with `--posix`
  - The `length()` function accepts an array argument and returns the number of elements in the array (see Section 9.1.4 [String-Manipulation Functions], page 200)
  - The optional third argument to the `match()` function for capturing text-matching subexpressions within a regexp (see Section 9.1.4 [String-Manipulation Functions], page 200)
  - Positional specifiers in `printf` formats for making translations easier (see Section 13.4.2 [Rearranging `printf` Arguments], page 370)
  - The `split()` function's additional optional fourth argument, which is an array to hold the text of the field separators (see Section 9.1.4 [String-Manipulation Functions], page 200)
- Additional functions only in `gawk`:
  - The `gensub()`, `patsplit()`, and `strtonum()` functions for more powerful text manipulation (see Section 9.1.4 [String-Manipulation Functions], page 200)

  - The `asort()` and `asorti()` functions for sorting arrays (see Section 12.3 [Controlling Array Traversal and Array Sorting], page 344)
  - The `mktime()`, `systime()`, and `strftime()` functions for working with timestamps (see Section 9.1.6 [Time Functions], page 215)
  - The `and()`, `compl()`, `lshift()`, `or()`, `rshift()`, and `xor()` functions for bit manipulation (see Section 9.1.7 [Bit-Manipulation Functions], page 220)
  - The `isarray()` function to check whether a variable is an array, and the more general `typeof()` function (see Section 9.1.8 [Getting Type Information], page 223)
  - The `mkbool()` function to create a Boolean value (see Section 9.1.2 [Generating Boolean Values], page 198)
  - The `bindtextdomain()`, `dcgettext()`, and `dcngettext()` functions for internationalization (see Section 13.3 [Internationalizing `awk` Programs], page 367)
- Changes and/or additions in the command-line options:
  - The `AWKPATH` environment variable for specifying a path search for the `-f` command-line option (see Section 2.2 [Command-Line Options], page 33)
  - The `AWKLIBPATH` environment variable for specifying a path search for the `-l` command-line option (see Section 2.2 [Command-Line Options], page 33)
  - The `-b`, `-c`, `-C`, `-d`, `-D`, `-e`, `-E`, `-g`, `-h`, `-i`, `-l`, `-L`, `-M`, `-n`, `-N`, `-o`, `-O`, `-p`, `-P`, `-r`, `-s`, `-S`, `-t`, and `-V` short options. Also, the ability to use GNU-style long-named options that start with `--`, and the `--assign`, `--bignum`, `--characters-as-bytes`, `--copyright`, `--debug`, `--dump-variables`, `--exec`, `--field-separator`, `--file`, `--gen-pot`, `--help`, `--include`, `--lint`, `--lint-old`, `--load`, `--non-decimal-data`, `--optimize`, `--no-optimize`, `--posix`, `--pretty-print`, `--profile`, `--re-interval`, `--sandbox`, `--source`, `--traditional`, `--use-lc-numeric`, and `--version` long options (see Section 2.2 [Command-Line Options], page 33).
- Support for the following obsolete systems was removed from the code and the documentation for `gawk` version 4.0:
  - Amiga
  - Atari
  - BeOS
  - Cray
  - MIPS RiscOS
  - MS-DOS with the Microsoft Compiler
  - MS-Windows with the Microsoft Compiler
  - NeXT
  - SunOS 3.x, Sun 386 (Road Runner)
  - Tandem (non-POSIX)
  - Prestandard VAX C compiler for VAX/VMS
  - GCC for Alpha has not been tested for a while.
- Support for the following obsolete system was removed from the code for `gawk` version 4.1:
  - Ultrix

- Support for the following systems was removed from the code for `gawk` version 4.2:
  - MirBSD
  - GNU/Linux on Alpha
- Support for the following systems was removed from the code for `gawk` version 5.2:
  - OS/2
  - DJGPP
  - VAX/VMS

A.6 History of `gawk` Features

This section describes the features in `gawk` over and above those in POSIX `awk`, in the order they were added to `gawk`.

Version 2.10 of `gawk` introduced the following features:

- The `AWKPATH` environment variable for specifying a path search for the `-f` command-line option (see Section 2.2 [Command-Line Options], page 33).
- The `IGNORECASE` variable and its effects (see Section 3.8 [Case Sensitivity in Matching], page 66).
- The `/dev/stdin`, `/dev/stdout`, `/dev/stderr` and `/dev/fd/N` special file names (see Section 5.8 [Special File names in `gawk`], page 116).

Version 2.13 of `gawk` introduced the following features:

- The `FIELDWIDTHS` variable and its effects (see Section 4.6 [Reading Fixed-Width Data], page 84).
- The `systime()` and `strftime()` built-in functions for obtaining and printing timestamps (see Section 9.1.6 [Time Functions], page 215).
- Additional command-line options (see Section 2.2 [Command-Line Options], page 33):
  - The `-W lint` option to provide error and portability checking for both the source code and at runtime.
  - The `-W compat` option to turn off the GNU extensions.
  - The `-W posix` option for full POSIX compliance.

Version 2.14 of `gawk` introduced the following feature:

- The `next file` statement for skipping to the next data file (see Section 7.4.9 [The `nextfile` Statement], page 165).

Version 2.15 of `gawk` introduced the following features:

- New variables (see Section 7.5 [Predefined Variables], page 167):
  - `ARGIND`, which tracks the movement of `FILENAME` through `ARGV`.
  - `ERRNO`, which contains the system error message when `getline` returns −1 or `close()` fails.
- The `/dev/pid`, `/dev/ppid`, `/dev/pgrpid`, and `/dev/user` special file names. These have since been removed.
- The ability to delete all of an array at once with '`delete array`' (see Section 8.4 [The `delete` Statement], page 190).

- Command-line option changes (see Section 2.2 [Command-Line Options], page 33):
  - The ability to use GNU-style long-named options that start with `--`.
  - The `--source` option for mixing command-line and library-file source code.

Version 3.0 of `gawk` introduced the following features:

- New or changed variables:
  - `IGNORECASE` changed, now applying to string comparison as well as regexp operations (see Section 3.8 [Case Sensitivity in Matching], page 66).
  - `RT`, which contains the input text that matched `RS` (see Section 4.1 [How Input Is Split into Records], page 69).
- Full support for both POSIX and GNU regexps (see Chapter 3 [Regular Expressions], page 51).
- The `gensub()` function for more powerful text manipulation (see Section 9.1.4 [String-Manipulation Functions], page 200).
- The `strftime()` function acquired a default time format, allowing it to be called with no arguments (see Section 9.1.6 [Time Functions], page 215).
- The ability for `FS` and for the third argument to `split()` to be null strings (see Section 4.5.3 [Making Each Character a Separate Field], page 79).
- The ability for `RS` to be a regexp (see Section 4.1 [How Input Is Split into Records], page 69).
- The `next file` statement became `nextfile` (see Section 7.4.9 [The `nextfile` Statement], page 165).
- The `fflush()` function from BWK `awk` (then at Bell Laboratories; see Section 9.1.5 [Input/Output Functions], page 211).
- New command-line options:
  - The `--lint-old` option to warn about constructs that are not available in the original Version 7 Unix version of `awk` (see Section A.1 [Major Changes Between V7 and SVR3.1], page 483).
  - The `-m` option from BWK `awk`. (Brian was still at Bell Laboratories at the time.) This was later removed from both his `awk` and from `gawk`.
  - The `--re-interval` option to provide interval expressions in regexps (see Section 3.3 [Regular Expression Operators], page 54).
  - The `--traditional` option was added as a better name for `--compat` (see Section 2.2 [Command-Line Options], page 33).
- The use of GNU Autoconf to control the configuration process (see Section B.2.1 [Compiling `gawk` for Unix-Like Systems], page 507).
- Amiga support. This has since been removed.

Version 3.1 of `gawk` introduced the following features:

- New variables (see Section 7.5 [Predefined Variables], page 167):
  - `BINMODE`, for non-POSIX systems, which allows binary I/O for input and/or output files (see Section B.3.1.3 [Using `gawk` on PC Operating Systems], page 511).
  - `LINT`, which dynamically controls lint warnings.

  - `PROCINFO`, an array for providing process-related information.
  - `TEXTDOMAIN`, for setting an application's internationalization text domain (see Chapter 13 [Internationalization with `gawk`], page 365).
- The ability to use octal and hexadecimal constants in `awk` program source code (see Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124).
- The '`|&`' operator for two-way I/O to a coprocess (see Section 12.4 [Two-Way Communications with Another Process], page 351).
- The `/inet` special files for TCP/IP networking using '`|&`' (see Section 12.5 [Using `gawk` for Network Programming], page 354).
- The optional second argument to `close()` that allows closing one end of a two-way pipe to a coprocess (see Section 12.4 [Two-Way Communications with Another Process], page 351).
- The optional third argument to the `match()` function for capturing text-matching subexpressions within a regexp (see Section 9.1.4 [String-Manipulation Functions], page 200).
- Positional specifiers in `printf` formats for making translations easier (see Section 13.4.2 [Rearranging `printf` Arguments], page 370).
- A number of new built-in functions:
  - The `asort()` and `asorti()` functions for sorting arrays (see Section 12.3 [Controlling Array Traversal and Array Sorting], page 344).
  - The `bindtextdomain()`, `dcgettext()` and `dcngettext()` functions for internationalization (see Section 13.3 [Internationalizing `awk` Programs], page 367).
  - The `extension()` function and the ability to add new built-in functions dynamically. This has seen removed. It was replaced by the new extension mechanism. See Chapter 17 [Writing Extensions for `gawk`], page 415.
  - The `mktime()` function for creating timestamps (see Section 9.1.6 [Time Functions], page 215).
  - The `and()`, `or()`, `xor()`, `compl()`, `lshift()`, `rshift()`, and `strtonum()` functions (see Section 9.1.7 [Bit-Manipulation Functions], page 220).
- The support for '`next file`' as two words was removed completely (see Section 7.4.9 [The `nextfile` Statement], page 165).
- Additional command-line options (see Section 2.2 [Command-Line Options], page 33):
  - The `--dump-variables` option to print a list of all global variables.
  - The `--exec` option, for use in CGI scripts.
  - The `--gen-po` command-line option and the use of a leading underscore to mark strings that should be translated (see Section 13.4.1 [Extracting Marked Strings], page 369).
  - The `--non-decimal-data` option to allow non-decimal input data (see Section 12.1 [Allowing Nondecimal Input Data], page 343).
  - The `--profile` option and `pgawk`, the profiling version of `gawk`, for producing execution profiles of `awk` programs (see Section 12.6 [Profiling Your `awk` Programs], page 356).

  - The `--use-lc-numeric` option to force `gawk` to use the locale's decimal point for parsing input data (see Section 6.1.4 [Conversion of Strings and Numbers], page 130).

- The use of GNU Automake to help in standardizing the configuration process (see Section B.2.1 [Compiling `gawk` for Unix-Like Systems], page 507).
- The use of GNU `gettext` for `gawk`'s own message output (see Section 13.6 [`gawk` Can Speak Your Language], page 374).
- BeOS support. This was later removed.
- Tandem support. This was later removed.
- The Atari port became officially unsupported and was later removed entirely.
- The source code changed to use ISO C standard-style function definitions.
- POSIX compliance for `sub()` and `gsub()` (see Section 9.1.4.1 [More about '\' and '&' with `sub()`, `gsub()`, and `gensub()`], page 209).
- The `length()` function was extended to accept an array argument and return the number of elements in the array (see Section 9.1.4 [String-Manipulation Functions], page 200).
- The `strftime()` function acquired a third argument to enable printing times as UTC (see Section 9.1.6 [Time Functions], page 215).

Version 4.0 of `gawk` introduced the following features:

- Variable additions:
  - `FPAT`, which allows you to specify a regexp that matches the fields, instead of matching the field separator (see Section 4.7 [Defining Fields by Content], page 87).
  - If `PROCINFO["sorted_in"]` exists, '`for (iggy in foo)`' loops sort the indices before looping over them. The value of this element provides control over how the indices are sorted before the loop traversal starts (see Section 8.1.6 [Using Predefined Array Scanning Orders with `gawk`], page 186).
  - `PROCINFO["strftime"]`, which holds the default format for `strftime()` (see Section 9.1.6 [Time Functions], page 215).
- The special files `/dev/pid`, `/dev/ppid`, `/dev/pgrpid` and `/dev/user` were removed.
- Support for IPv6 was added via the `/inet6` special file. `/inet4` forces IPv4 and `/inet` chooses the system default, which is probably IPv4 (see Section 12.5 [Using `gawk` for Network Programming], page 354).
- The use of '`\s`' and '`\S`' escape sequences in regular expressions (see Section 3.7 [`gawk`-Specific Regexp Operators], page 64).
- Interval expressions became part of default regular expressions (see Section 3.3 [Regular Expression Operators], page 54).
- POSIX character classes work even with `--traditional` (see Section 3.3 [Regular Expression Operators], page 54).
- `break` and `continue` became invalid outside a loop, even with `--traditional` (see Section 7.4.6 [The `break` Statement], page 163, and also see Section 7.4.7 [The `continue` Statement], page 164).
- `fflush()`, `nextfile`, and '`delete` *array*' are allowed if `--posix` or `--traditional`, since they are all now part of POSIX.

- An optional third argument to `asort()` and `asorti()`, specifying how to sort (see Section 9.1.4 [String-Manipulation Functions], page 200).
- The behavior of `fflush()` changed to match BWK `awk` and for POSIX; now both '`fflush()`' and '`fflush("")`' flush all open output redirections (see Section 9.1.5 [Input/Output Functions], page 211).
- The `isarray()` function which distinguishes if an item is an array or not, to make it possible to traverse arrays of arrays (see Section 9.1.8 [Getting Type Information], page 223).
- The `patsplit()` function which gives the same capability as `FPAT`, for splitting (see Section 9.1.4 [String-Manipulation Functions], page 200).
- An optional fourth argument to the `split()` function, which is an array to hold the values of the separators (see Section 9.1.4 [String-Manipulation Functions], page 200).
- Arrays of arrays (see Section 8.6 [Arrays of Arrays], page 193).
- The `BEGINFILE` and `ENDFILE` special patterns (see Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155).
- Indirect function calls (see Section 9.5 [Indirect Function Calls], page 238).
- `switch` / `case` are enabled by default (see Section 7.4.5 [The `switch` Statement], page 161).
- Command-line option changes (see Section 2.2 [Command-Line Options], page 33):
  - The `-b` and `--characters-as-bytes` options which prevent `gawk` from treating input as a multibyte string.
  - The redundant `--compat`, `--copyleft`, and `--usage` long options were removed.
  - The `--gen-po` option was finally renamed to the correct `--gen-pot`.
  - The `--sandbox` option which disables certain features.
  - All long options acquired corresponding short options, for use in '`#!`' scripts.
- Directories named on the command line now produce a warning, not a fatal error, unless `--posix` or `--traditional` are used (see Section 4.13 [Directories on the Command Line], page 101).
- The `gawk` internals were rewritten, bringing the `dgawk` debugger and possibly improved performance (see Chapter 14 [Debugging `awk` Programs], page 375).
- Per the GNU Coding Standards, dynamic extensions must now define a global symbol indicating that they are GPL-compatible (see Section 17.2 [Extension Licensing], page 415).
- In POSIX mode, string comparisons use `strcoll()` / `wcscoll()` (see Section 6.3.2.3 [String Comparison Based on Locale Collating Order], page 143).
- The option for raw sockets was removed, since it was never implemented (see Section 12.5 [Using `gawk` for Network Programming], page 354).
- Ranges of the form '`[d-h]`' are treated as if they were in the C locale, no matter what kind of regexp is being used, and even if `--posix` (see Section A.8 [Regexp Ranges and Locales: A Long Sad Story], page 497).
- Support was removed for the following systems:
  - Atari

- Amiga
- BeOS
- Cray
- MIPS RiscOS
- MS-DOS with the Microsoft Compiler
- MS-Windows with the Microsoft Compiler
- NeXT
- SunOS 3.x, Sun 386 (Road Runner)
- Tandem (non-POSIX)
- Prestandard VAX C compiler for VAX/VMS

Version 4.1 of `gawk` introduced the following features:

- Three new arrays: `SYMTAB`, `FUNCTAB`, and `PROCINFO["identifiers"]` (see Section 7.5.2 [Built-in Variables That Convey Information], page 169).
- The three executables `gawk`, `pgawk`, and `dgawk`, were merged into one, named just `gawk`. As a result the command-line options changed.
- Command-line option changes (see Section 2.2 [Command-Line Options], page 33):
  - The `-D` option invokes the debugger.
  - The `-i` and `--include` options load `awk` library files.
  - The `-l` and `--load` options load compiled dynamic extensions.
  - The `-M` and `--bignum` options enable MPFR.
  - The `-o` option only does pretty-printing.
  - The `-p` option is used for profiling.
  - The `-R` option was removed.
- Support for high precision arithmetic with MPFR (see Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399).
- The `and()`, `or()` and `xor()` functions changed to allow any number of arguments, with a minimum of two (see Section 9.1.7 [Bit-Manipulation Functions], page 220).
- The dynamic extension interface was completely redone (see Chapter 17 [Writing Extensions for gawk], page 415).
- Redirected `getline` became allowed inside `BEGINFILE` and `ENDFILE` (see Section 7.1.5 [The BEGINFILE and ENDFILE Special Patterns], page 155).
- Support for nonfatal I/O (see Section 5.11 [Enabling Nonfatal Output], page 120).
- The `where` command was added to the debugger (see Section 14.3.4 [Working with the Stack], page 385).
- Support for Ultrix was removed.

Version 4.2 of `gawk` introduced the following changes:

- Changes to `ENVIRON` are reflected into `gawk`'s environment and that of programs that it runs. See Section 7.5.2 [Built-in Variables That Convey Information], page 169.
- `FIELDWIDTHS` was enhanced to allow skipping characters before assigning a value to a field (see Section 4.7 [Defining Fields by Content], page 87).

- The `PROCINFO["argv"]` array. See Section 7.5.2 [Built-in Variables That Convey Information], page 169.
- The maximum number of hexadecimal digits in '`\x`' escapes is now two. See Section 3.2 [Escape Sequences], page 52.
- Strongly typed regexp constants of the form '`@/.../`' (see Section 6.1.2.2 [Strongly Typed Regexp Constants], page 127).
- The bitwise functions changed, making negative arguments into a fatal error (see Section 9.1.7 [Bit-Manipulation Functions], page 220).
- The `mktime()` function now accepts an optional second argument (see Section 9.1.6 [Time Functions], page 215).
- The `typeof()` function (see Section 9.1.8 [Getting Type Information], page 223).
- Optimizations are enabled by default. Use `-s` / `--no-optimize` to disable optimizations.
- For many years, POSIX specified that default field splitting only allowed spaces and tabs to separate fields, and this was how `gawk` behaved with `--posix`. As of 2013, the standard restored historical behavior, and now default field splitting with `--posix` also allows newlines to separate fields.
- Nonfatal output with `print` and `printf`. See Section 5.11 [Enabling Nonfatal Output], page 120.
- Retryable I/O via `PROCINFO[`*`input-file`*`, "RETRY"]`; (see Section 4.12 [Retrying Reads After Certain Input Errors], page 101).
- Changes to the pretty-printer (see Section 12.6 [Profiling Your `awk` Programs], page 356):
  - The `--pretty-print` option no longer runs the `awk` program too.
  - Comments in the source program are preserved and placed into the output file.
  - Explicit parentheses for expressions in the input are preserved in the generated output.
- Improvements to the extension API (see Chapter 17 [Writing Extensions for `gawk`], page 415):
  - The `get_file()` function to access open redirections.
  - The `nonfatal()` function for generating nonfatal error messages.
  - Support for GMP and MPFR values.
  - Input parsers can now override the default field parsing mechanism by specifying explicit locations.
- Shell startup files are supplied with the distribution and installed by '`make install`' (see Section B.2.2 [Shell Startup Files], page 508).
- The `igawk` program and its manual page are no longer installed when `gawk` is built. See Section 11.3.9 [An Easy Way to Use Library Functions], page 328.
- Support for MirBSD was removed.
- Support for GNU/Linux on Alpha was removed.

Version 5.0 added the following features:

- The `PROCINFO["platform"]` array element, which allows you to write code that takes the operating system / platform into account.

Version 5.1 was created to release gawk with a correct major version number for the API. This was overlooked for version 5.0, unfortunately. It added the following features:

- The index for this manual was completely reworked.
- Support was added for MSYS2.
- asort() and asorti() were changed to allow FUNCTAB and SYMTAB as the first argument if a second destination array is supplied (see Section 9.1.4 [String-Manipulation Functions], page 200).
- The -I/--trace options were added to print a trace of the byte codes as they execute (see Section 2.2 [Command-Line Options], page 33).
- $0 and the fields are now cleared before starting a BEGINFILE rule (see Section 7.1.5 [The BEGINFILE and ENDFILE Special Patterns], page 155).
- Several example programs in the manual were updated to their modern POSIX equivalents.
- The "no effect" lint warnings from --lint were fixed up and now behave more sanely (see Section 2.2 [Command-Line Options], page 33).
- Handling of Infinity and NaN values were improved. See Section 16.2 [Other Stuff to Know], page 400, and also see Section 16.7 [Standards Versus Existing Practice], page 411.

Version 5.2 added the following features:

- The mkbool() built-in function (see Section 9.1.2 [Generating Boolean Values], page 198).
- Interval expressions in regular expressions are enabled by default (see Section 3.3.2 [Some Notes On Interval Expressions], page 57).
- Support for the FNV1-A hash algorithm for its hash function (see Section 2.5.3 [Other Environment Variables], page 44).
- The gawkbug script for reporting bugs (see Section B.4.2 [Submitting Bug Reports], page 519).
- Terence Kelly's persistent memory allocator (PMA) was added, allowing the use of persistent data on certain systems (see Section 12.7 [Preserving Data Between Runs], page 360).
- PROCINFO["pma"] exists if the PMA allocator is compiled in (see Section 7.5.2 [Built-in Variables That Convey Information], page 169).

Version 5.3 added the following features:

- Comma separated value (CSV) field splitting and the --csv command-line option (see Section 4.5.4 [Working With Comma Separated Value Files], page 80).
- PROCINFO["CSV"] exists if gawk was invoked with --csv (see Section 7.5.2 [Built-in Variables That Convey Information], page 169).
- The do_csv API information variable (see Section 17.4.14.3 [Informational Variables], page 455).
- The ability to make gawk buffer output to pipes (see Section 5.10 [Speeding Up Pipe Output], page 120).
- The '\u' escape sequence (see Section 3.2 [Escape Sequences], page 52).

- Support for OpenVMS 9.2-2 x86_64 (at version 5.3.1).
- The need for GNU `libsigsegv` was removed from `gawk`. The value-add was never very much and it caused problems in some environments.
- Support for OSF/1 was removed.

Version 5.4 added the following features:

- The `--enable-O3` option to `configure` was added (see Section B.2.3 [Additional Configuration Options], page 508).
- Use of the new MinRX regular expression matcher as the default matching engine (see Section 3.9 [Selecting the Regexp Matching Engine], page 67). This brings full POSIX compliance to `gawk`'s regular expression matching.
- The `@nsinclude` directive for including files without resetting the namespace to '`awk`' (see Section 15.8 [Including A File Without Changing The Namespace], page 395).
- The ability to call `length()` on an array is no longer an extension, as it became part of POSIX in 2004 (see Section 9.1.4 [String-Manipulation Functions], page 200).
- Persistent memory was enabled on FreeBSD, MidnightBSD, NetBSD and OpenBSD (see Section 12.7 [Preserving Data Between Runs], page 360).
- Hexadecimal floating-point values may be used in program source code, with the `strtonum()` function, and with the `--non-decimal-data` option (see Section 12.1 [Allowing Nondecimal Input Data], page 343).
- Support for UDP in `gawk`'s networking was marked as obsolete (see Section 12.5 [Using `gawk` for Network Programming], page 354).
- The MinGW port of `gawk` for MS-Windows gained support for UTF-8 encoding of non-ASCII text when codepage 65001 is used by the Windows terminal (see Section B.3.1.3 [Using `gawk` on PC Operating Systems], page 511).
- Support was added for OpenVMS 9 on x86_64 hardware, and support for OpenVMS 8 on Alpha and Itanium was updated.

A.7 Common Extensions Summary

The following table summarizes the common extensions supported by `gawk`, Brian Kernighan's `awk`, and `mawk`, the three most widely used freely available versions of `awk` (see Section B.5 [Other Freely Available `awk` Implementations], page 523).

Feature	BWK `awk`	`mawk`	`gawk`	Now standard
`**` and `**=` operators	X		X	
'`\x`' escape sequence	X	X	X	
'`\u`' escape sequence	X		X	
`/dev/stdin` special file	X	X	X	
`/dev/stdout` special file	X	X	X	
`/dev/stderr` special file	X	X	X	
`BINMODE` variable		X	X	
CSV support	X		X	
`FS` as null string	X	X	X	
`delete` without subscript	X	X	X	X
`fflush()` function	X	X	X	X

`func` keyword	X		X	
`nextfile` statement	X	X	X	X
`RS` as regexp	X	X	X	
Time-related functions		X	X	

A.8 Regexp Ranges and Locales: A Long Sad Story

This section describes the confusing history of ranges within regular expressions and their interactions with locales, and how this affected different versions of `gawk`.

The original Unix tools that worked with regular expressions defined character ranges (such as '`[a-z]`') to match any character between the first character in the range and the last character in the range, inclusive. Ordering was based on the numeric value of each character in the machine's native character set. Thus, on ASCII-based systems, '`[a-z]`' matched all the lowercase letters, and only the lowercase letters, as the numeric values for the letters from '`a`' through '`z`' were contiguous. (On an EBCDIC system, the range '`[a-z]`' includes additional nonalphabetic characters as well.)

Almost all introductory Unix literature explained range expressions as working in this fashion, and in particular, would teach that the "correct" way to match lowercase letters was with '`[a-z]`', and that '`[A-Z]`' was the "correct" way to match uppercase letters. And indeed, this was true.[1]

The 1992 POSIX standard introduced the idea of locales (see Section 6.6 [Where You Are Makes a Difference], page 149). Because many locales include other letters besides the plain 26 letters of the English alphabet, the POSIX standard added character classes (see Section 3.4 [Using Bracket Expressions], page 60) as a way to match different kinds of characters besides the traditional ones in the ASCII character set.

However, the standard *changed* the interpretation of range expressions. In the `"C"` and `"POSIX"` locales, a range expression like '`[a-dx-z]`' is still equivalent to '`[abcdxyz]`', as in ASCII. But outside those locales, the ordering was defined to be based on *collation order*.

What does that mean? In many locales, '`A`' and '`a`' are both less than '`B`'. In other words, these locales sort characters in dictionary order, and '`[a-dx-z]`' is typically not equivalent to '`[abcdxyz]`'; instead, it might be equivalent to '`[ABCXYabcdxyz]`', for example.

This point needs to be emphasized: much literature teaches that you should use '`[a-z]`' to match a lowercase character. But on systems with non-ASCII locales, this also matches all of the uppercase characters except '`A`' or '`Z`'! This was a continuous cause of confusion, even well into the twenty-first century.

To demonstrate these issues, the following example uses the `sub()` function, which does text replacement (see Section 9.1.4 [String-Manipulation Functions], page 200). Here, the intent is to remove trailing uppercase characters:

```
$ echo something1234abc | gawk-3.1.8 '{ sub("[A-Z]*$", ""); print }'
⊣ something1234a
```

This output is unexpected, as the '`bc`' at the end of '`something1234abc`' should not normally match '`[A-Z]*`'. This result is due to the locale setting (and thus you may not see it on your system).

[1] And Life was good.

Similar considerations apply to other ranges. For example, '`["-/]`' is perfectly valid in ASCII, but is not valid in many Unicode locales, such as `en_US.UTF-8`.

Early versions of `gawk` used regexp matching code that was not locale-aware, so ranges had their traditional interpretation.

When `gawk` switched to using locale-aware regexp matchers, the problems began; especially as both GNU/Linux and commercial Unix vendors started implementing non-ASCII locales, *and making them the default*. Perhaps the most frequently asked question became something like, "Why does '`[A-Z]`' match lowercase letters?!?"

This situation existed for close to 10 years, if not more, and the `gawk` maintainer grew weary of trying to explain that `gawk` was being nicely standards-compliant, and that the issue was in the user's locale. During the development of version 4.0, he modified `gawk` to always treat ranges in the original, pre-POSIX fashion, unless `--posix` was used (see Section 2.2 [Command-Line Options], page 33).[2]

Fortunately, shortly before the final release of `gawk` 4.0, the maintainer learned that the 2008 standard had changed the definition of ranges, such that outside the `"C"` and `"POSIX"` locales, the meaning of range expressions was *undefined*.[3]

By using this lovely technical term, the standard gives license to implementers to implement ranges in whatever way they choose. The `gawk` maintainer chose to apply the pre-POSIX meaning both with the default regexp matching and when `--traditional` or `--posix` are used. In all cases `gawk` remains POSIX-compliant.

A.9 Major Contributors to `gawk`

> *Always give credit where credit is due.*
> —*Anonymous*

This section names the major contributors to `gawk` and/or this book, in approximate chronological order:

- Dr. Alfred V. Aho, Dr. Peter J. Weinberger, and Dr. Brian W. Kernighan, all of Bell Laboratories, designed and implemented Unix `awk`, from which `gawk` gets the majority of its feature set.
- Paul Rubin did the initial design and implementation in 1986, and wrote the first draft (around 40 pages) of this book.
- Jay Fenlason finished the initial implementation.
- Diane Close revised the first draft of this book, bringing it to around 90 pages.
- Richard Stallman helped finish the implementation and the initial draft of this book. He is also the founder of the FSF and the GNU Project.
- John Woods contributed parts of the code (mostly fixes) in the initial version of `gawk`.
- In 1988, David Trueman took over primary maintenance of `gawk`, making it compatible with "new" `awk`, and greatly improving its performance.

[2] And thus was born the Campaign for Rational Range Interpretation (or RRI). A number of GNU tools have already implemented this change, or will soon. Thanks to Karl Berry for coining the phrase "Rational Range Interpretation."

[3] See the standard and its rationale.

- Conrad Kwok, Scott Garfinkle, and Kent Williams did the initial ports to MS-DOS with various versions of MSC.
- Pat Rankin provided the VMS port and its documentation.
- Hal Peterson provided help in porting `gawk` to Cray systems. (This is no longer supported.)
- Kai Uwe Rommel provided the initial port to OS/2 and its documentation.
- Michal Jaegermann provided the port to Atari systems and its documentation. (This port is no longer supported.) He continues to provide portability checking, and has done a lot of work to make sure `gawk` works on non-32-bit systems.
- Fred Fish provided the port to Amiga systems and its documentation. (With Fred's sad passing, this is no longer supported.)
- Scott Deifik formerly maintained the MS-DOS port using DJGPP.
- Eli Zaretskii currently maintains the MS-Windows port using MinGW.
- Juan Grigera provided a port to Windows32 systems. (This is no longer supported.)
- For many years, Dr. Darrel Hankerson acted as coordinator for the various ports to different PC platforms and created binary distributions for various PC operating systems. He was also instrumental in keeping the documentation up to date for the various PC platforms.
- Christos Zoulas provided the `extension()` built-in function for dynamically adding new functions. (This was obsoleted at `gawk` 4.1.)
- Jürgen Kahrs contributed the initial version of the TCP/IP networking code and documentation, and motivated the inclusion of the '`|&`' operator.
- Stephen Davies provided the initial port to Tandem systems and its documentation. (However, this is no longer supported.) He was also instrumental in the initial work to integrate the byte-code internals into the `gawk` code base. Additionally, he did most of the work enabling the pretty-printer to preserve and output comments.
- Matthew Woehlke provided improvements for Tandem's POSIX-compliant systems.
- Martin Brown provided the port to BeOS and its documentation. (This is no longer supported.)
- Arno Peters did the initial work to convert `gawk` to use GNU Automake and GNU `gettext`.
- Alan J. Broder provided the initial version of the `asort()` function as well as the code for the optional third argument to the `match()` function.
- Andreas Buening updated the `gawk` port for OS/2.
- Isamu Hasegawa, of IBM in Japan, contributed support for multibyte characters.
- Michael Benzinger contributed the initial code for `switch` statements.
- Patrick T.J. McPhee contributed the code for dynamic loading in Windows32 environments. (This is no longer supported.)
- Anders Wallin helped keep the VMS port going for several years.
- Assaf Gordon contributed the initial code to implement the `--sandbox` option.
- John Haque made the following contributions:
  - The modifications to convert `gawk` into a byte-code interpreter, including the debugger

  - The addition of true arrays of arrays
  - The additional modifications for support of arbitrary-precision arithmetic
  - The initial text of Chapter 16 [Arithmetic and Arbitrary-Precision Arithmetic with gawk], page 399,
  - The work to merge the three versions of gawk into one, for the 4.1 release
  - Improved array internals for arrays indexed by integers
  - The improved array sorting features were also driven by John, together with Pat Rankin
- Panos Papadopoulos contributed the original text for Section 2.7 [Including Other Files into Your Program], page 46.
- Efraim Yawitz contributed the original text for Chapter 14 [Debugging awk Programs], page 375.
- John Naman contributed the original text for Section 9.4 [A Note On Shadowed Variables], page 237.
- Stuart Ferguson reworked the text in Section 4.7 [Defining Fields by Content], page 87.
- The development of the extension API first released with gawk 4.1 was driven primarily by Arnold Robbins and Andrew Schorr, with notable contributions from the rest of the development team.
- John Malmberg contributed significant improvements to the OpenVMS port and the related documentation.
- Antonio Giovanni Colombo rewrote a number of examples in the early chapters that were severely dated, for which I am incredibly grateful. He also provided and maintains the Italian translation.
- Marco Curreli, together with Antonio Colombo, translated this book into Italian. It is included in the gawk distribution.
- Juan Manuel Guerrero took over maintenance of the DJGPP port.
- "Jannick" provided support for MSYS2.
- Arnold Robbins has been working on gawk since 1988, at first helping David Trueman, and as the primary maintainer since around 1994.

A.10 Summary

- The awk language has evolved over time. The first release was with V7 Unix, circa 1978. In 1987, for System V Release 3.1, major additions, including user-defined functions, were made to the language. Additional changes were made for System V Release 4, in 1989. Since then, further minor changes have happened under the auspices of the POSIX standard.
- Brian Kernighan's awk provides a small number of extensions that are implemented in common with other versions of awk.
- gawk provides a large number of extensions over POSIX awk. They can be disabled with either the --traditional or --posix options.
- The interaction of POSIX locales and regexp matching in gawk has been confusing over the years. Today, gawk implements Rational Range Interpretation, where ranges

of the form '`[a-z]`' match *only* the characters numerically between '`a`' through '`z`' in the machine's native character set. Usually this is ASCII, but it can be EBCDIC on IBM S/390 systems.

- Many people have contributed to `gawk` development over the years. We hope that the list provided in this chapter is complete and gives the appropriate credit where credit is due.

Appendix B Installing gawk

This appendix provides instructions for installing gawk on the various platforms that are supported by the developers. The primary developer supports GNU/Linux (and Unix), whereas the other ports are contributed. See Section B.4 [Reporting Problems and Bugs], page 518, for the email addresses of the people who maintain the respective ports.

B.1 The gawk Distribution

This section describes how to get the gawk distribution, how to extract it, and then what is in the various files and subdirectories.

B.1.1 Getting the gawk Distribution

There are two ways to get GNU software:

- Copy it from someone else who already has it.
- Retrieve gawk from the Internet host ftp.gnu.org, in the directory /gnu/gawk. Both anonymous ftp and http access are supported. If you have the wget program, you can use a command like the following:

```
wget https://ftp.gnu.org/gnu/gawk/gawk-5.4.0.tar.gz
```

The GNU software archive is mirrored around the world. The up-to-date list of mirror sites is available from the main FSF website. Try to use one of the mirrors; they will be less busy, and you can usually find one closer to your site.

You may also retrieve the gawk source code from the official Git repository; for more information see Section C.2.1 [Accessing The gawk Git Repository], page 529.

B.1.2 Extracting the Distribution

gawk is distributed as several tar files compressed with different compression programs: gzip, bzip2, and xz. For simplicity, the rest of these instructions assume you are using the one compressed with the GNU Gzip program (gzip).

Once you have the distribution (e.g., gawk-5.4.0.tar.gz), use gzip to expand the file and then use tar to extract it. You can use the following pipeline to produce the gawk distribution:

```
gzip -d -c gawk-5.4.0.tar.gz | tar -xvpf -
```

On a system with GNU tar, you can let tar do the decompression for you:

```
tar -xvpzf gawk-5.4.0.tar.gz
```

Extracting the archive creates a directory named gawk-5.4.0 in the current directory.

The distribution file name is of the form gawk-*V.R.P*.tar.gz. The *V* represents the major version of gawk, the *R* represents the current release of version *V*, and the *P* represents a *patch level*, meaning that minor bugs have been fixed in the release. The current patch level is 0, but when retrieving distributions, you should get the version with the highest version, release, and patch level. (Note, however, that patch levels greater than or equal to 60 denote "beta" or nonproduction software; you might not want to retrieve such a version unless you don't mind experimenting.) If you are not on a Unix or GNU/Linux system, you need to make other arrangements for getting and extracting the gawk distribution. You should consult a local expert.

B.1.3 Contents of the gawk Distribution

The gawk distribution has a number of C source files, documentation files, subdirectories, and files related to the configuration process (see Section B.2 [Compiling and Installing gawk on Unix-Like Systems], page 507), as well as several subdirectories related to different non-Unix operating systems:

Various '.c', '.y', and '.h' files
: These files contain the actual gawk source code.

support/*
: C header and source files for routines that gawk uses, but that are not part of its core functionality. For example, argument parsing, regular expression matching, and random number generating routines are all kept here.

ABOUT-NLS
: A file containing information about GNU gettext and translations.

AUTHORS
: A file with some information about the authorship of gawk. It exists only to satisfy the pedants at the Free Software Foundation.

README
README_d/README.*
: Descriptive files: README for gawk under Unix and the rest for the various hardware and software combinations.

INSTALL
: A file providing an overview of the configuration and installation process.

ChangeLog
: A detailed list of source code changes as bugs are fixed or improvements made. There are similar files in all of the subdirectories.

ChangeLog.0
ChangeLog.1
: Older lists of source code changes. There are similar files in all of the subdirectories.

NEWS
: A list of changes to gawk since the last release or patch. There may be similar files in other subdirectories.

NEWS.0
NEWS.1
: Older lists of changes to gawk. There may be similar files in other subdirectories.

COPYING
: The GNU General Public License.

POSIX.STD
: A description of behaviors in the POSIX standard for awk that are left undefined, or where gawk may not comply fully, as well as a list of things that the POSIX standard should describe but does not.

doc/awkforai.txt
: Pointers to the original draft of a short article describing why gawk is a good language for artificial intelligence (AI) programming.

doc/bc_notes
: A brief description of gawk's "byte code" internals.

`doc/README.card`
`doc/ad.block`
`doc/awkcard.in`
`doc/cardfonts`
`doc/colors`
`doc/macros`
`doc/no.colors`
`doc/setter.outline`
: The `troff` source for a five-color `awk` reference card. A modern version of `troff` such as GNU `troff` (`groff`) is needed to produce the color version. See the file `README.card` for instructions if you have an older `troff`.

`doc/gawk.1`
: The `troff` source for a manual page describing `gawk`. This is distributed for the convenience of Unix users.

`doc/gawk.texi`
: The Texinfo source file for this book. It should be processed by `texi2dvi` or `texi2pdf` to produce a printed document, and by `makeinfo` to produce an Info or HTML file. The `Makefile` takes care of this processing and produces printable output via `texi2dvi` or `texi2pdf`.

`doc/gawk.info`
: The generated Info file for this book.

`doc/gawkinet.texi`
: The Texinfo source file for *TCP/IP Internetworking with* `gawk`. It should be processed with TEX (via `texi2dvi` or `texi2pdf`) to produce a printed document and with `makeinfo` to produce an Info or HTML file.

`doc/gawkinet.info`
: The generated Info file for *TCP/IP Internetworking with* `gawk`.

`doc/gawkworkflow.texi`
: The Texinfo source file for *Participating in* `gawk` *Development*. It should be processed with TEX (via `texi2dvi` or `texi2pdf`) to produce a printed document and with `makeinfo` to produce an Info or HTML file.

`doc/gawkworkflow.info`
: The generated Info file for *Participating in* `gawk` *Development*.

`doc/pm-gawk.texi`
: The Texinfo source file for *Persistent-Memory* `gawk` *User Manual*. It should be processed with TEX (via `texi2dvi` or `texi2pdf`) to produce a printed document and with `makeinfo` to produce an Info or HTML file.

`doc/pm-gawk.info`
: The generated Info file for *Persistent-Memory* `gawk` *User Manual*.

`doc/pm-gawk.1`
: The `troff` source for a manual page describing the persistent memory features presented in Section 12.7 [Preserving Data Between Runs], page 360.

`doc/igawk.1`
: The `troff` source for a manual page describing the `igawk` program presented in Section 11.3.9 [An Easy Way to Use Library Functions], page 328. (Since `gawk` can do its own `@include` processing, neither `igawk` nor `igawk.1` are installed.)

`doc/it/*` Files for the Italian translation of this book, produced and contributed by Antonio Colombo and Marco Curreli.

`doc/Makefile.in`
: The input file used during the configuration process to generate the actual `Makefile` for creating the documentation.

`Makefile.am`
`*/Makefile.am`
: Files used by the GNU Automake software for generating the `Makefile.in` files used by Autoconf and `configure`.

`Makefile.in`
`aclocal.m4`
`build-aux/*`
`configh.in`
`configure.ac`
`configure`
`custom.h`
`missing_d/*`
`m4/*` These files and subdirectories are used when configuring and compiling `gawk` for various Unix systems. Most of them are explained in Section B.2 [Compiling and Installing gawk on Unix-Like Systems], page 507. The rest are there to support the main infrastructure.

`po/*` The `po` library contains message translations.

`awklib/extract.awk`
`awklib/Makefile.am`
`awklib/Makefile.in`
`awklib/eg/*`
: The `awklib` directory contains a copy of `extract.awk` (see Section 11.3.7 [Extracting Programs from Texinfo Source Files], page 323), which can be used to extract the sample programs from the Texinfo source file for this book. It also contains a `Makefile.in` file, which `configure` uses to generate a `Makefile`. `Makefile.am` is used by GNU Automake to create `Makefile.in`. The library functions from Chapter 10 [A Library of awk Functions], page 247, are included as ready-to-use files in the `gawk` distribution. They are installed as part of the installation process. The rest of the programs in this book are available in appropriate subdirectories of `awklib/eg`.

`extension/*`
: The source code, manual pages, and infrastructure files for the sample extensions included with `gawk`. See Chapter 17 [Writing Extensions for gawk], page 415, for more information.

`extras/*` Additional non-essential files. Currently, this directory contains some shell startup files to be installed in `/etc/profile.d` to aid in manipulating the `AWKPATH` and `AWKLIBPATH` environment variables. See Section B.2.2 [Shell Startup Files], page 508, for more information.

`posix/*` Files needed for building `gawk` on POSIX-compliant systems.

`pc/*` Files needed for building `gawk` under MS-Windows (see Section B.3.1 [Installation on MS-Windows], page 511, for details).

`vms/*` Files needed for building `gawk` under OpenVMS (see Section B.3.2 [Compiling and Installing gawk on OpenVMS], page 514, for details).

`test/*` A test suite for `gawk`. You can use '`make check`' from the top-level `gawk` directory to run your version of `gawk` against the test suite. If `gawk` successfully passes '`make check`', then you can be confident of a successful port.

B.2 Compiling and Installing gawk on Unix-Like Systems

Usually, you can compile and install `gawk` by typing only two commands. However, if you use an unusual system, you may need to configure `gawk` for your system yourself.

B.2.1 Compiling gawk for Unix-Like Systems

The normal installation steps should work on all modern commercial Unix-derived systems, GNU/Linux, BSD-based systems, and the Cygwin environment for MS-Windows.

After you have extracted the `gawk` distribution, `cd` to `gawk-5.4.0`. As with most GNU software, you configure `gawk` for your system by running the `configure` program. This program is a Bourne shell script that is generated automatically using GNU Autoconf. (The Autoconf software is described fully in *Autoconf—Generating Automatic Configuration Scripts*, which can be found online at the Free Software Foundation's website.)

To configure `gawk`, simply run `configure`:

```
sh ./configure
```

This produces a `Makefile` and `config.h` tailored to your system. The `config.h` file describes various facts about your system. You might want to edit the `Makefile` to change the `CFLAGS` variable, which controls the command-line options that are passed to the C compiler (such as optimization levels or compiling for debugging).

Alternatively, you can add your own values for most `make` variables on the command line, such as `CC` and `CFLAGS`, when running `configure`:

```
CC=cc CFLAGS=-g sh ./configure
```

See the file `INSTALL` in the `gawk` distribution for all the details.

After you have run `configure` and possibly edited the `Makefile`, type:

```
make
```

Shortly thereafter, you should have an executable version of `gawk`. That's all there is to it! To verify that `gawk` is working properly, run '`make check`'. All of the tests should succeed. If these steps do not work, or if any of the tests fail, check the files in the `README_d` directory to see if you've found a known problem. If the failure is not described there, send in a bug report (see Section B.4 [Reporting Problems and Bugs], page 518).

Of course, once you've built `gawk`, it is likely that you will wish to install it. To do so, you need to run the command '`make install`', as a user with the appropriate permissions. How to do this varies by system, but on many systems you can use the `sudo` command to do so. The command then becomes '`sudo make install`'. It is likely that you will be asked for your password, and you will have to have been set up previously as a user who is allowed to run the `sudo` command.

B.2.1.1 Building With MPFR

Use of the MPFR library with `gawk` is an optional feature: if you have the MPFR and GMP libraries already installed when you configure and build `gawk`, `gawk` automatically will be able to use them.

You can install these libraries from source code by fetching them from the GNU distribution site at `ftp.gnu.org`.

Most modern systems provide package managers which save you the trouble of building from source. They fetch and install the library header files and binaries for you. You will need to research how to do this for your particular system.

B.2.2 Shell Startup Files

The distribution contains shell startup files `gawk.sh` and `gawk.csh`, containing functions to aid in manipulating the `AWKPATH` and `AWKLIBPATH` environment variables. On a Fedora GNU/Linux system, these files should be installed in `/etc/profile.d`; on other platforms, the appropriate location may be different.

`gawkpath_default`
: Reset the `AWKPATH` environment variable to its default value.

`gawkpath_prepend`
: Add the argument to the front of the `AWKPATH` environment variable.

`gawkpath_append`
: Add the argument to the end of the `AWKPATH` environment variable.

`gawklibpath_default`
: Reset the `AWKLIBPATH` environment variable to its default value.

`gawklibpath_prepend`
: Add the argument to the front of the `AWKLIBPATH` environment variable.

`gawklibpath_append`
: Add the argument to the end of the `AWKLIBPATH` environment variable.

B.2.3 Additional Configuration Options

There are several additional options you may use on the `configure` command line when compiling `gawk` from scratch, including:

`--disable-extensions`
: Disable the extension mechanism within `gawk`. With this option, it is not possible to use dynamic extensions. This also disables configuring and building the sample extensions in the `extension` directory.

  This option may be useful for cross-compiling. The default action is to dynamically check if the extensions can be configured and compiled.

`--disable-lint`
: Disable all lint checking within `gawk`. The `--lint` and `--lint-old` options (see Section 2.2 [Command-Line Options], page 33) are accepted, but silently do nothing. Similarly, setting the `LINT` variable (see Section 7.5.1 [Built-in Variables That Control `awk`], page 167) has no effect on the running `awk` program.

  When used with the GNU Compiler Collection's (GCC's) automatic dead-code-elimination, this option cuts almost 23K bytes off the size of the `gawk` executable on GNU/Linux x86_64 systems. Results on other systems and with other compilers are likely to vary. Using this option may bring you some slight performance improvement.

  > **CAUTION:** Using this option will cause some of the tests in the test suite to fail. This option may be removed at a later date.

`--disable-mpfr`
: Skip checking for the MPFR and GMP libraries. This is useful mainly for the developers, to make sure nothing breaks if MPFR support is not available.

`--disable-nls`
: Disable all message-translation facilities. This is usually not desirable, but it may bring you some slight performance improvement.

`--enable-builtin-intdiv0`
: Add a new built-in function, `intdiv0()`, which generates integer division and remainder results at the same time. This is discussed more in Section 16.5 [Arbitrary-Precision Integer Arithmetic with `gawk`], page 409.

`--enable-O3`
: Use the GCC option `-O3` when compiling `gawk` instead of the standard `-O2`. The additional optimizations may improve `gawk`'s performance. However, in other projects, `-O3` has been known to cause bugs, thus its use is not the default.

`--enable-versioned-extension-dir`
: Use a versioned directory for extensions. The directory name will include the major and minor API versions in it. This makes it possible to keep extensions for different API versions on the same system without their conflicting with one another.

Use the command '`./configure --help`' to see the full list of options supplied by `configure`.

B.2.4 The Configuration Process

This section is of interest only if you know something about using the C language and Unix-like operating systems.

The source code for `gawk` generally attempts to adhere to formal standards wherever possible. This means that `gawk` uses library routines that are specified by the ISO C standard and by the POSIX operating system interface standard. The `gawk` source code requires using an ISO C compiler (the 1999 standard).

Many Unix systems do not support all of either the ISO or the POSIX standards. The `missing_d` subdirectory in the `gawk` distribution contains replacement versions of those functions that are most likely to be missing.

The `config.h` file that `configure` creates contains definitions that describe features of the particular operating system where you are attempting to compile `gawk`. The three things described by this file are: what header files are available, so that they can be correctly included, what (supposedly) standard functions are actually available in your C libraries, and various miscellaneous facts about your operating system. For example, there may not be an `st_blksize` element in the `stat` structure. In this case, '`HAVE_STRUCT_STAT_ST_BLKSIZE`' is undefined.

It is possible for your C compiler to lie to `configure`. It may do so by not exiting with an error when a library function is not available. To get around this, edit the `custom.h` file. Use an '`#ifdef`' that is appropriate for your system, and either `#define` any constants that `configure` should have defined but didn't, or `#undef` any constants that `configure` defined and should not have. The `custom.h` file is automatically included by the `config.h` file.

It is also possible that the `configure` program generated by Autoconf will not work on your system in some other fashion. If you do have a problem, the `configure.ac` file is the input for Autoconf. You may be able to change this file and generate a new version of `configure` that works on your system (see Section B.4 [Reporting Problems and Bugs], page 518, for information on how to report problems in configuring `gawk`). The same mechanism may be used to send in updates to `configure.ac` and/or `custom.h`.

B.2.5 Compiling from Git

Building `gawk` directly from the development source control repository is possible, but not recommended for everyday users, as the code may not be as stable as released versions are. If you really do want to do that, here are the steps:

```
git clone https://git.savannah.gnu.org/git/gawk.git
cd gawk
./bootstrap.sh && ./configure && make && make check
```

B.2.6 Building the Documentation

The generated Info documentation is included in the distribution `tar` files; you should not need to rebuild it. However, if it needs to be done, simply running `make` will do it, assuming that you have a recent enough version of `makeinfo` installed.

If you wish to build the PDF version of the manuals, you will need to have TEX installed, and possibly additional packages that provide the necessary fonts and tools, such as `dvi2pdf` and `ps2pdf`. You will also need GNU Troff (`groff`) installed in order to format the reference card and the manual page (see Section B.1.3 [Contents of the gawk Distribution], page 504). Managing this process is beyond the scope of this book.

Assuming you have all you need, then the following commands produce the PDF versions of the documentation:

```
cd doc
make pdf
```

This creates PDF versions of all three Texinfo documents included in the distribution, as well as of the manual page and the reference card.

Similarly, if you have a recent enough version of `makeinfo`, you can make the HTML version of the manuals with:

```
cd doc
make html
```

This creates HTML versions of all three Texinfo documents included in the distribution.

B.3 Installation on Other Operating Systems

This section describes how to install `gawk` on various non-Unix systems.

B.3.1 Installation on MS-Windows

This section covers installation and usage of `gawk` on Intel architecture machines running any version of MS-Windows. In this section, the term "Windows32" refers to any of Microsoft Windows 95/98/ME/NT/2000/XP/Vista/7/8/10/11.

See also the `README_d/README.pc` file in the distribution.

B.3.1.1 Installing a Prepared Distribution for MS-Windows Systems

The only supported binary distribution for MS-Windows systems is that provided by Eli Zaretskii's "ezwinports" project. Install the compiled `gawk` from there. Note that to run that port, you need to have the `libgcc_s_dw2-1.dll` file installed on your system. This file is part of the GCC distribution, and should reside either in the same directory where you install `gawk.exe` or somewhere on your system's `Path`. You can download this file from the MinGW site; look under the "MinGW.org Compiler Collection (GCC)" for the `LibGCC-1.DLL` download.

B.3.1.2 Compiling `gawk` for PC Operating Systems

`gawk` can be compiled for Windows32 using MinGW (Windows32). The file `README_d/README.pc` in the `gawk` distribution contains additional notes, and `pc/Makefile` contains important information on compilation options.

To build `gawk` for Windows32, copy the files in the `pc` directory (*except* for `ChangeLog`) to the directory with the rest of the `gawk` sources, then invoke `make` with the appropriate target name as an argument to build `gawk`. The `Makefile` copied from the `pc` directory contains a configuration section with comments and may need to be edited in order to work with your `make` utility.

The `Makefile` supports a number of targets for building various Windows32 versions. A list of targets is printed if the `make` command is given without a target. As an example, to build a native MS-Windows binary of `gawk` using the MinGW tools, type '`make mingw32`'.

If you are building with MinGW using anything other than `pc/Makefile`, be sure to pass the `-D__USE_MINGW_ANSI_STDIO` command-line option to GCC. This is necessary for correct operation of Gawk on Windows, in particular for displaying translated messages.

B.3.1.3 Using `gawk` on PC Operating Systems

Information in this section applies to the MinGW port of `gawk` for MS-Windows. See Section B.3.1.4 [Using gawk In The Cygwin Environment], page 514, for information about the Cygwin port.

The MS-Windows version of `gawk` searches for program files as described in Section 2.5.1 [The AWKPATH Environment Variable], page 42. However, semicolons (rather than colons)

separate elements in the `AWKPATH` variable. If `AWKPATH` is not set or is empty, then the default search path is '`.;d:/usr/lib/awk;c:/lib/awk;c:/gnu/lib/awk`'.

Similarly, the `AWKLIBPATH` environment variable, which tells `gawk` where to look for dynamic extensions (see Chapter 17 [Writing Extensions for `gawk`], page 415), also uses semicolons to separate directories. If not set in the environment, the default value hard-coded into `gawk` is '`d:/usr/lib/gawk/ext-`*`api-version`*', where *api-version* is the version of gawk API version for which `gawk` was compiled (see Section 17.4.14.1 [API Version Constants and Variables], page 453).

MS-Windows traditionally supported internationalization and localization via *codepages*. Each Windows locale specifies a system-wide codepage, which defines both the non-ASCII characters supported by Windows and their encoding into small integer values. Most Windows locales use a single-byte encoding; the notable exceptions are CJK (Chinese, Japanese, and Korean) codepages which use one or two bytes for each non-ASCII character. Recent versions of MS-Windows also support Unicode and the UTF-8 encoding, but introduction of this support is slow: as of this writing, setting UTF-8 as the system-wide codepage on Windows is still considered an experimental feature, which by default is turned off. The Windows designation of the UTF-8 encoding is known as *codepage 65001*.

The MinGW build of `gawk` for MS-Windows supports multibyte characters according to the codepage defined by the current system locale, and it also includes (starting with version 5.4) reasonable support for text encoded in UTF-8. When the system's codepage is anything other than 65001, `gawk` uses the functions from the MS-Windows C runtime library to convert between multibyte and wide-character representation of text, and for character classification and collation; this is in most cases limited to characters inside the Unicode Basic Multilingual Plane (BMP), due to the limitations of the Windows runtime. By contrast, if the system's codepage is set to 65001, `gawk` attempts to support the full range of Unicode codepoints, including the BMP and all the 16 Supplementary Planes defined by Unicode, by using its own conversion and classification routines instead of those in the Windows C runtime. (This might still fail to work as well as it does on modern POSIX systems, because these routines rely on the character database data included with your Windows installation.)

When codepage 65001 is used, `gawk` uses UTF-8 to encode multibyte text, and converts between UTF-8 and 32-bit Unicode codepoints internally. Thus on Windows, to make sure `awk` programs written for POSIX systems which handle multibyte non-ASCII text work correctly on MS-Windows, you should use codepage 65001.

As a special feature, `gawk` version 5.4 and later will use UTF-8 internally even when the system-wide codepage is something other than 65001, if `gawk` detects that the Windows terminal window in which it runs uses codepage 65001 for console output. (Unlike on POSIX systems, Windows users can change the console encoding independently of the system-wide locale's encoding.) To switch the Windows terminal to using UTF-8 encoding, type '`chcp 65001`' at the Windows shell's prompt. This causes `gawk` on Windows to support the full range of Unicode characters even without changing the system-wide locale's codepage. We recommend that you use codepage 65001 on Windows 11 and later systems, where the Windows terminal supports UTF-8 quite well.

Note that `gawk` on Windows will still treat all input data as single-byte characters when invoked with the `-b` command-line option (see Section 2.2 [Command-Line Options],

page 33), or when running under the `"C"` locale (i.e., when the `LC_ALL` environment variable is set to the value '`C`' by typing '`set LC_ALL=C`' at the shell prompt before invoking `gawk`). This overrides the codepage-defined encoding of text.

Under MS-Windows, `gawk` (and many other text programs) silently translates end-of-line '`\r\n`' to '`\n`' on input and '`\n`' to '`\r\n`' on output. A special `BINMODE` variable (c.e.) allows control over these translations and is interpreted as follows:

- If `BINMODE` is `"r"` or one, then binary mode is set on read (i.e., no translations on reads).
- If `BINMODE` is `"w"` or two, then binary mode is set on write (i.e., no translations on writes).
- If `BINMODE` is `"rw"` or `"wr"` or three, binary mode is set for both read and write.
- `BINMODE=`*`non-null-string`* is the same as '`BINMODE=3`' (i.e., no translations on reads or writes). However, `gawk` issues a warning message if the string is not one of `"rw"` or `"wr"`.

The modes for standard input and standard output are set one time only (after the command line is read, but before processing any of the `awk` program). Setting `BINMODE` for standard input or standard output is accomplished by using an appropriate '`-v BINMODE=`*N*' option on the command line. `BINMODE` is set at the time a file or pipe is opened and cannot be changed midstream.

On POSIX-compatible systems, this variable's value has no effect. Thus, if you think your program will run on multiple different systems and that you may need to use `BINMODE`, you should simply set it (in the program or on the command line) unconditionally, and not worry about the operating system on which your program is running.

The name `BINMODE` was chosen to match `mawk` (see Section B.5 [Other Freely Available `awk` Implementations], page 523). `mawk` and `gawk` handle `BINMODE` similarly; however, `mawk` adds a '`-W BINMODE=`*N*' option and an environment variable that can set `BINMODE`, `RS`, and `ORS`. The files `binmode[1-3].awk` (under `gnu/lib/awk` in some of the prepared binary distributions) have been chosen to match `mawk`'s '`-W BINMODE=`*N*' option. These can be changed or discarded; in particular, the setting of `RS` giving the fewest "surprises" is open to debate. `mawk` uses '`RS = "\r\n"`' if binary mode is set on read, which is appropriate for files with the MS-DOS-style end-of-line.

To illustrate, the following examples set binary mode on writes for standard output and other files, and set `ORS` as the "usual" MS-DOS-style end-of-line:

```
gawk -v BINMODE=2 -v ORS="\r\n" ...
```

or:

```
gawk -v BINMODE=w -f binmode2.awk ...
```

These give the same result as the '`-W BINMODE=2`' option in `mawk`. The following changes the record separator to `"\r\n"` and sets binary mode on reads, but does not affect the mode on standard input:

```
gawk -v RS="\r\n" -e "BEGIN { BINMODE = 1 }" ...
```

or:

```
gawk -f binmode1.awk ...
```

With proper quoting, in the first example the setting of `RS` can be moved into the `BEGIN` rule.

Under MS-Windows, the MinGW port of `gawk` supports both the '`|&`' operator and TCP/IP networking (see Section 12.5 [Using gawk for Network Programming], page 354).

B.3.1.4 Using gawk In The Cygwin Environment

`gawk` can be built and used "out of the box" under MS-Windows if you are using the Cygwin environment. This environment provides an excellent simulation of GNU/Linux, using Bash, GCC, GNU Make, and other GNU programs. Compilation and installation for Cygwin is the same as for a Unix system:

```
tar -xvpzf gawk-5.4.0.tar.gz
cd gawk-5.4.0
./configure
make && make check
```

When compared to GNU/Linux on the same system, the '`configure`' step on Cygwin takes considerably longer. However, it does finish, and then the '`make`' proceeds as usual.

You may also install `gawk` using the regular Cygwin installer. In general Cygwin supplies the latest released version.

Recent versions of Cygwin open all files in binary mode. This means that you should use '`RS = "\r?\n"`' in order to be able to handle standard MS-Windows text files with carriage-return plus line-feed line endings.

The Cygwin environment supports both the '`|&`' operator and TCP/IP networking (see Section 12.5 [Using gawk for Network Programming], page 354).

B.3.1.5 Using gawk In The MSYS Environment

In the MSYS environment under MS-Windows, `gawk` automatically uses binary mode for reading and writing files. Thus, there is no need to use the `BINMODE` variable.

This can cause problems with other Unix-like components that have been ported to MS-Windows that expect `gawk` to do automatic translation of `"\r\n"`, because it won't.

Under MSYS2, compilation using the standard '`./configure && make`' recipe works "out of the box."

B.3.2 Compiling and Installing gawk on OpenVMS

This subsection describes how to compile and install `gawk` under OpenVMS.

B.3.2.1 Compiling gawk on OpenVMS

To compile `gawk` under OpenVMS, there is a `descrip.mms` for use with `MMK` or `MMS` as the equivalent of a `makefile`. `MMS` requires a DCL symbol for the hardware type such '`"__x86_64__ = "TRUE"`' to properly build.

```
$ __x86_64__ == "TRUE"
$ MMS/DESCRIPTION=[.vms]descrip.mms gawk
```

or:

```
$ MMK/DESCRIPTION=[.vms]descrip.mms gawk
```

MMK is an open source, free, near-clone of MMS and can better handle ODS-5 volumes with upper- and lowercase file names. MMK is available from https://github.com/endlesssoftware/mmk.

With ODS-5 volumes and extended parsing enabled, the case of the target parameter may need to be exact.

gawk has been tested using these VMS Software, Inc. Community editions:

- VSI C x86-64 V7.6-001 (GEM 50YAN) on OpenVMS x86_64 V9.2-3
- HP C V7.3-010 on OpenVMS Alpha V8.4-2L1.
- HP C V7.3-020 on OpenVMS IA64 V8.4-2L3.[1]

Due to HPE cancelling the Hobbyist licensing program, no more testing is being done on older releases of OpenVMS.

See Section B.3.2.5 [The OpenVMS GNV Project], page 518, for information on building gawk as a PCSI kit that is compatible with the GNV product.

B.3.2.2 Compiling gawk Dynamic Extensions on OpenVMS

The extensions that have been ported to OpenVMS can be built using one of the following commands:

```
$ __x86_64__ == "TRUE"
$ MMS/DESCRIPTION=[.vms]descrip.mms extensions
```

or:

```
$ MMK/DESCRIPTION=[.vms]descrip.mms extensions
```

gawk uses AWKLIBPATH as either an environment variable or a logical name to find the dynamic extensions.

Dynamic extensions need to be compiled with the same compiler options for floating-point, pointer size, and symbol name handling as were used to compile gawk itself. X86_64, Alpha, and Itanium should use IEEE floating point. The pointer size is 32 bits, and the symbol name handling should be exact case with CRC shortening for symbols longer than 32 bits.

```
/name=(as_is,short)
/float=ieee/ieee_mode=denorm_results
```

Compile-time macros need to be defined before the first OpenVMS-supplied header file is included, as follows:

```
#if (__CRTL_VER >= 70200000)
#define _LARGEFILE 1
#endif

#ifdef __CRTL_VER
#if __CRTL_VER >= 80200000
#define _USE_STD_STAT 1
#endif
#endif
```

[1] The IA64 architecture is also known as "Itanium."

If you are writing your own extensions to run on OpenVMS, you must supply these definitions yourself. The `config.h` file created when building `gawk` on OpenVMS does this for you; if instead you use that file or a similar one, then you must remember to include it before any OpenVMS-supplied header files.

B.3.2.3 Installing `gawk` on OpenVMS

To use `gawk`, all you need is a "foreign" command, which is a `DCL` symbol whose value begins with a dollar sign. For example:

```
$ GAWK :== $disk1:[gnubin]gawk
```

Substitute the actual location of `gawk.exe` for '`$disk1:[gnubin]`'. The symbol should be placed in the `login.com` of any user who wants to run `gawk`, so that it is defined every time the user logs on. Alternatively, the symbol may be placed in the system-wide `sylogin.com` procedure, which allows all users to run `gawk`.

If your `gawk` was installed by a PCSI kit into the `GNV$GNU:` directory tree, the program will be known as `GNV$GNU:[bin]gnv$gawk.exe` and the help file will be `GNV$GNU:[vms_help]gawk.hlp`.

The PCSI kit also installs a `GNV$GNU:[vms_bin]gawk_verb.cld` file that can be used to add `gawk` and `awk` as DCL commands.

For just the current process you can use:

```
$ set command gnv$gnu:[vms_bin]gawk_verb.cld
```

Or the system manager can use `GNV$GNU:[vms_bin]gawk_verb.cld` to add the `gawk` and `awk` commands to the system-wide '`DCLTABLES`'.

The DCL syntax is documented in the `gawk.hlp` file.

Optionally, the `gawk.hlp` entry can be loaded into an OpenVMS help library:

```
$ LIBRARY/HELP sys$help:helplib [.vms]gawk.hlp
```

(You may want to substitute a site-specific help library rather than the standard OpenVMS library '`HELPLIB`'.) After loading the help text, the command:

```
$ HELP GAWK
```

provides information about both the `gawk` implementation and the `awk` programming language.

The logical name '`AWK_LIBRARY`' can designate a default location for `awk` program files. For the `-f` option, if the specified file name has no device or directory path information in it, `gawk` looks in the current directory first, then in the directory specified by the translation of '`AWK_LIBRARY`' if the file is not found. If, after searching in both directories, the file still is not found, `gawk` appends the suffix '`.awk`' to the file name and retries the file search. If '`AWK_LIBRARY`' has no definition, a default value of '`SYS$LIBRARY:`' is used for it.

B.3.2.4 Running `gawk` on OpenVMS

Command-line parsing and quoting conventions are significantly different on OpenVMS, so examples in this book or from other sources often need minor changes. They *are* minor though, and all `awk` programs should run correctly.

Here are a couple of trivial tests:

```
$ gawk -- "BEGIN {print ""Hello, World!""}"
```

```
$ gawk -"W" version
! could also be -"W version" or "-W version"
```

Note that uppercase and mixed-case text must be quoted.

The OpenVMS port of `gawk` includes a `DCL`-style interface in addition to the original shell-style interface (see the help entry for details). One side effect of dual command-line parsing is that if there is only a single parameter (as in the quoted program string), the command becomes ambiguous. To work around this, the normally optional `--` flag is required to force Unix-style parsing rather than `DCL` parsing. If any other dash-type options (or multiple parameters such as data files to process) are present, there is no ambiguity and `--` can be omitted.

The `exit` value is a Unix-style value and is encoded into an OpenVMS exit status value when the program exits.

The OpenVMS severity bits will be set based on the `exit` value. A failure is indicated by 1, and OpenVMS sets the `ERROR` status. A fatal error is indicated by 2, and OpenVMS sets the `FATAL` status. All other values will have the `SUCCESS` status. The exit value is encoded to comply with OpenVMS coding standards and will have the `C_FACILITY_NO` of `0x350000` with the constant `0xA000` added to the number shifted over by 3 bits to make room for the severity codes.

To extract the actual `gawk` exit code from the OpenVMS status, use:

```
unix_status = (vms_status .and. %x7f8) / 8
```

A C program that uses `exec()` to call `gawk` will get the original Unix-style exit value.

OpenVMS reports time values in GMT unless one of the `SYS$TIMEZONE_RULE` or `TZ` logical names is set.

The default search path, when looking for `awk` program files specified by the `-f` option, is `"SYS$DISK:[],AWK_LIBRARY:"`. The logical name `AWKPATH` can be used to override this default. The format of `AWKPATH` is a comma-separated list of directory specifications. When defining it, the value should be quoted so that it retains a single translation and not a multitranslation `RMS` searchlist.

This restriction also applies to running `gawk` under GNV, as redirection is always to a DCL command.

If you are redirecting data to an OpenVMS command or utility, the current implementation requires setting up an OpenVMS foreign command that runs a command file before invoking `gawk`. (This restriction may be removed in a future release of `gawk` on OpenVMS.)

Without this command file, the input data will also appear prepended to the output data.

This also allows simulating POSIX commands that are not found on OpenVMS or the use of GNV utilities.

The example below is for `gawk` redirecting data to the OpenVMS `sort` command.

```
$ sort = "@device:[dir]vms_gawk_sort.com"
```

The command file needs to be of the format in the example below.

The first line inhibits the passed input data from also showing up in the output. It must be in the format in the example.

The next line creates a foreign command that overrides the outer foreign command which prevents an infinite recursion of command files.

The next to the last command redirects `sys$input` to be `sys$command`, in order to pick up the data that is being redirected to the command.

The last line runs the actual command. It must be the last command as the data redirected from `gawk` will be read when the command file ends.

```
$!'f$verify(0,0)'
$ sort := sort
$ define/user sys$input sys$command:
$ sort sys$input: sys$output:
```

B.3.2.5 The OpenVMS GNV Project

The OpenVMS GNV package provides a build environment similar to POSIX with ports of a collection of open source tools. The `gawk` found in the GNV base kit is an older port. Currently, the GNV project is being reorganized to supply individual PCSI packages for each component. See https://sourceforge.net/p/gnv/wiki/InstallingGNVPackages/.

The normal build procedure for `gawk` produces a program that is suitable for use with GNV.

To be compatible and share common code with GNV projects, all OpenVMS-specific defines and prototypes for `gawk` are in the process of being moved to `vms/config_vms.h`. The `vms` directory will have missing or updated system header files and any replacement routines that will hide most of the differences between OpenVMS and Linux. This is intended to make `gawk` easier to maintain.

The file `vms/gawk_build_steps.txt` in the distribution documents the procedure for building an OpenVMS PCSI kit that is compatible with GNV.

B.4 Reporting Problems and Bugs

There is nothing more dangerous than a bored archaeologist.
—Douglas Adams, The Hitchhiker's Guide to the Galaxy

If you have problems with `gawk` or think that you have found a bug, report it to the developers; we cannot promise to do anything, but we might well want to fix it.

B.4.1 Defining What Is and What Is Not A Bug

Before talking about reporting bugs, let's define what is a bug, and what is not.

A bug is:

- When `gawk` behaves differently from what's described in the POSIX standard, and that difference is not mentioned in this book as being done on purpose.
- When `gawk` behaves differently from what's described in this book.
- When `gawk` behaves differently from other `awk` implementations in particular circumstances, and that behavior cannot be attributed to an additional feature in `gawk`.
- Something that is obviously wrong, such as a core dump.
- When this book is unclear or ambiguous about a particular feature's behavior.

The following things are *not* bugs, and should not be reported to the bug mailing list. You can ask about them on the "help" mailing list (see Section B.4.5 [Where To Send Non-bug Questions], page 522), but don't be surprised if you get an answer of the form "that's how `gawk` behaves and it isn't going to change." Here's the list:

- Missing features, for any definition of *feature*. For example, additional built-in arithmetic functions, or additional ways to split fields or records, or anything else.

  The number of features that `gawk` does *not* have is by definition infinite. It cannot be all things to all people. In short, just because `gawk` doesn't do what *you* think it should, it's not necessarily a bug.
- Behaviors that are defined by the POSIX standard and/or for historical compatibility with Unix `awk`. Even if you happen to dislike those behaviors, they're not going to change: changing them would break millions of existing `awk` programs.
- Behaviors that differ from how it's done in other languages. `awk` and `gawk` stand on their own and do not have to follow the crowd. This is particularly true when the requested behavior change would break backwards compatibility.

  This applies also to differences in behavior between `gawk` and other language compilers and interpreters, such as wishes for more detailed descriptions of what the problem is when a syntax error is encountered.
- Documentation issues of the form "the manual doesn't tell me how to do XYZ." The manual is not a cookbook to solve every little problem you may have. Its purpose is to teach you how to solve your problems on your own.
- General questions and discussion about `awk` programming or why `gawk` behaves the way it does. For that use the "help" mailing list: see Section B.4.5 [Where To Send Non-bug Questions], page 522.

For more information, see *Fork My Code, Please!—An Open Letter To Those of You Who Are Unhappy*, by Arnold Robbins and Chet Ramey.

A Note About Fuzzers

In recent years, people have been running "fuzzers" to generate invalid `awk` programs in order to find and report (so-called) bugs in `gawk`.

In general, such reports are not of much practical use. The programs they create are not realistic and the bugs found are generally from some kind of memory corruption that is fatal anyway.

So, if you want to run a fuzzer against `gawk` and report the results, you may do so, but be aware that such reports don't carry the same weight as reports of real bugs do.

B.4.2 Submitting Bug Reports

Before reporting a bug, make sure you have really found a genuine bug.

Here are the steps for submitting a bug report. Following them will make both your life and the lives of the maintainers much easier.

1. Make sure that what you want to report is appropriate. See Section B.4.1 [Defining What Is and What Is Not A Bug], page 518. If it's not, you are wasting your time and ours.

2. Verify that you have the latest version of `gawk`. Many bugs (usually subtle ones) are fixed at each release, and if yours is out-of-date, the problem may already have been solved.
3. Please see if setting the environment variable `LC_ALL` to `LC_ALL=C` causes things to behave as you expect. If so, it's a locale issue, and may or may not really be a bug.
4. Carefully reread the documentation and see if it says you can do what you're trying to do. If it's not clear whether you should be able to do something or not, report that too; it's a bug in the documentation!
5. Before reporting a bug or trying to fix it yourself, try to isolate it to the smallest possible `awk` program and input data file that reproduce the problem.
6. Use the `gawkbug` program to submit the bug report. This program sets up a bug report template and opens it in your editor. You then need to edit it appropriately to include:
   - The program and data file.
   - The exact results `gawk` gave you. Also say what you expected to occur; this helps us decide whether the problem is really in the documentation.
   - A fix if you have one.
7. Do *not* send screenshots. Instead, use copy/paste to send text, or send files.
8. Please be sure to send all mail in *plain text*, not (or not exclusively) in HTML.
9. *All email must be in English. This is the only language understood in common by all the maintainers.*

The `gawkbug` program sends email to `bug-gawk@gnu.org`.

The `gawk` maintainers subscribe to this address, and thus they will receive your bug report. Do *not* send mail to the maintainers directly; the bug reporting address is preferred because the email list is archived at the GNU Project.

If you are using OpenVMS or the MinGW build of `gawk`, the `gawkbug` script won't be available. Please send the previously listed information directly in an email to the bug list. Please send any test program or data files as attachments, instead of inline in the email, to avoid their being mangled by various mail systems.

> **NOTE:** Many distributions of GNU/Linux and the various BSD-based operating systems have their own bug reporting systems. If you report a bug using your distribution's bug reporting system, you should also send a copy to `bug-gawk@gnu.org`.
>
> This is for two reasons. First, although some distributions forward bug reports "upstream" to the GNU mailing list, many don't, so there is a good chance that the `gawk` maintainers won't even see the bug report! Second, mail to the GNU list is archived, and having everything at the GNU Project keeps things self-contained and not dependent on other organizations.

Please note: We ask that you follow the GNU Kind Communication Guidelines in your correspondence on the list (as well as off of it).

Additionally, just to be clear, on the list:

- Personal attacks (so called *ad hominem attacks*) are always inappropriate. If you make such attacks, you will be banned from the list.

- Discussion of proprietary software is strongly discouraged on GNU mailing lists. If you continue to discuss such software after being asked not to, you will also be banned.

B.4.3 Please Don't Post Bug Reports to USENET

> I gave up on Usenet a couple of years ago and haven't really looked back. It's like sports talk radio—you feel smarter for not having read it.
>
> —*Chet Ramey*

Please do *not* try to report bugs in `gawk` by posting to the Usenet/Internet newsgroup `comp.lang.awk`. Although some of the `gawk` developers occasionally read this news group, the primary `gawk` maintainer no longer does. Thus it's virtually guaranteed that he will *not* see your posting.

If you really don't care about the previous paragraph and continue to post bug reports in `comp.lang.awk`, then understand that you're not reporting bugs, you're just whining.

Similarly, posting bug reports or questions in web forums (such as Stack Overflow) may get you an answer, but it won't be from the `gawk` maintainers, who do not spend their time in web forums. The steps described here are the only officially recognized way for reporting bugs. Really.

B.4.4 What To Do If You Think There Is A Performance Issue

If you think that `gawk` is too slow at doing a particular task, you should investigate before sending in a bug report. Here are the steps to follow:

1. Run `gawk` with the `--profile` option (see Section 2.2 [Command-Line Options], page 33) to see what your program is doing. It may be that you have written it in an inefficient manner. For example, you may be doing something for every record that could be done just once, for every file. (Use a `BEGINFILE` rule; see Section 7.1.5 [The `BEGINFILE` and `ENDFILE` Special Patterns], page 155.) Or you may be doing something for every file that only needs to be done once per run of the program. (Use a `BEGIN` rule; see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154.)
2. If profiling at the `awk` level doesn't help, then you will need to compile `gawk` itself for profiling at the C language level.

   To do that, start with the latest released version of `gawk`. Unpack the source code in a new directory, and configure it:

   ```
   $ tar -xpzvf gawk-X.Y.Z.tar.gz
   ...                                   Output omitted
   $ cd gawk-X.Y.Z
   $ ./configure
   ...                                   Output omitted
   ```
3. Edit the files `Makefile` and `support/Makefile`. Change every instance of `-O2` or `-O` to `-pg`. This causes `gawk` to be compiled for profiling.
4. Compile the program by running the `make` command:

   ```
   $ make
   ...                                   Output omitted
   ```
5. Run the freshly compiled `gawk` on a *real* program, using *real* data. Using an artificial program to try to time one particular feature of `gawk` is useless; real `awk` programs

generally spend most of their time doing I/O, not computing. If you want to prove that something is slow, it *must* be done using a real program and real data.

Use a data file that is large enough for the statistical profiling to measure where `gawk` spends its time. It should be at least 100 megabytes in size.

```
$ ./gawk -f realprogram.awk realdata > /dev/null
```

6. When done, you should have a file in the current directory named `gmon.out`. Run the command '`gprof gawk gmon.out > gprof.out`'.
7. Submit a bug report explaining what you think is slow. Include the `gprof.out` file with it.

   Preferably, you should also submit the program and the data, or else indicate where to get the data if the file is large.
8. If you have not submitted your program and data, be prepared to apply patches and rerun the profiling in order to see if the patches were effective.

If you are incapable or unwilling to do the steps listed above, then you will just have to live with `gawk` as it is.

B.4.5 Where To Send Non-bug Questions

If you have questions related to `awk` programming, or why `gawk` behaves a certain way, or any other `awk`- or `gawk`-related issue, please *do not* send it to the bug reporting address.

As of July, 2021, there is a separate mailing list for this purpose: `help-gawk@gnu.org`. Anything that is not a bug report should be sent to that list.

> **NOTE:** If you disregard these directions and send non-bug mails to the bug list, you will be told to use the help list. After two such requests you will be silently *blacklisted* from the bug list.

Please note: As with the bug list, we ask that you follow the GNU Kind Communication Guidelines in your correspondence on the help list (as well as off of it).

If you wish to the subscribe to the list, in order to help out others, or to learn from others, here are instructions, courtesy of Bob Proulx:

Subscribe by email
: Send an email message to `help-gawk-request@gnu.org` with "subscribe" in the body of the message. The subject does not matter and is not used.

Subscribe by web form
: To use the web interface visit the list information page. Use the subscribe form to fill out your email address and submit using the `Subscribe` button.

Reply to the confirmation message
: In both cases then reply to the confirmation message that is sent to your address in reply.

Bob mentions that you may also use email for subscribing and unsubscribing. For example:

```
$ echo help | mailx -s request help-gawk-request@gnu.org
$ echo subscribe | mailx -s request help-gawk-request@gnu.org
$ echo unsubscribe | mailx -s request help-gawk-request@gnu.org
```

B.4.6 Reporting Problems with Non-Unix Ports

If you find bugs in one of the non-Unix ports of `gawk`, send an email to the bug list, with a copy to the person who maintains that port. The maintainers are named in the following list, as well as in the `README` file in the `gawk` distribution. Information in the `README` file should be considered authoritative if it conflicts with this book.

The people maintaining the various `gawk` ports are:

Unix and POSIX systems	Arnold Robbins, arnold@skeeve.com
MS-Windows with MinGW	Eli Zaretskii, eliz@gnu.org
OpenVMS	John Malmberg, wb8tyw@qsl.net
z/OS (OS/390)	Daniel Richard G. skunk@iSKUNK.ORG

If your bug is also reproducible under Unix, send a copy of your report to the bug-gawk@gnu.org email list as well.

B.5 Other Freely Available `awk` Implementations

> *Implementation is the sincerest form of flattery.*
> —*L. Peter Deutsch*

> *It's kind of fun to put comments like this in your awk code:*
> `// Do C++ comments work? answer: yes! of course`
> —*Michael Brennan*

There are a number of other freely available `awk` implementations. This section briefly describes where to get them.

The following programs are all written in C:

Unix `awk` Brian Kernighan, one of the original designers of Unix `awk`, has made his implementation of `awk` freely available. You can retrieve it from GitHub:

```
git clone https://github.com/onetrueawk/awk bwkawk
```

This command creates a copy of the Git repository in a directory named `bwkawk`. If you omit the last argument from the `git` command line, the repository copy is created in a directory named `awk`.

To build it, review the settings in the `makefile`, and then just run `make`. Note that the result of compilation is named `a.out`; you will have to rename it to something reasonable.

See Section A.7 [Common Extensions Summary], page 496, for a list of extensions in this `awk` that are not in POSIX `awk`.

In 2023, Brian Kernighan, along with Al Aho and Peter Weinberger, published a second edition of their book on `awk`. Professor Kernighan also maintains a companion web site for the book. A copy of all the book's programs are available there for download.

As a side note, Dan Bornstein has created a Git repository tracking all the versions of BWK `awk` that he could find. It's available at https://github.com/danfuzz/one-true-awk.

`mawk` Michael Brennan wrote an independent implementation of `awk`, called `mawk`. It is available under the GPL (see [GNU General Public License], page 557), just as `gawk` is.

The original distribution site for the `mawk` source code no longer has it. A copy is available at `https://www.skeeve.com/gawk/mawk1.3.3.tar.gz`.

In 2009, Thomas Dickey took on `mawk` maintenance. Basic information is available on the project's web page. The download URL is `https://invisible-island.net/datafiles/release/mawk.tar.gz`.

Once you have it, `gunzip` may be used to decompress this file. Installation is similar to `gawk`'s (see Section B.2 [Compiling and Installing `gawk` on Unix-Like Systems], page 507).

See Section A.7 [Common Extensions Summary], page 496, for a list of extensions in `mawk` that are not in POSIX `awk`.

`mawk` 2.0 In 2016, Michael Brennan resumed `mawk` development. His development snapshots are available via Git from the project's GitHub page.

`awka` Written by Andrew Sumner, `awka` translates `awk` programs into C, compiles them, and links them with a library of functions that provide the core `awk` functionality. It also has a number of extensions.

Both the `awk` translator and the library are released under the GPL.

To get `awka`, go to `https://sourceforge.net/projects/awka`.

The project is frozen; no new code changes have been made since approximately 2001.

Revive Awka
This project, available at `https://github.com/noyesno/awka`, intends to fix bugs in `awka` and add more features.

This project also seems to be frozen; no new code changes have been made since approximately 2021.

`pawk` Nelson H.F. Beebe at the University of Utah has modified BWK `awk` to provide timing and profiling information. It is different from `gawk` with the `--profile` option (see Section 12.6 [Profiling Your `awk` Programs], page 356) in that it uses CPU-based profiling, not line-count profiling. You may find it at either `ftp://ftp.math.utah.edu/pub/pawk/pawk-20030606.tar.gz` or `https://www.math.utah.edu/pub/pawk/pawk-20030606.tar.gz`.

BusyBox `awk`
BusyBox is a GPL-licensed program providing small versions of many applications within a single executable. It is aimed at embedded systems. It includes a full implementation of POSIX `awk`. When building it, be careful not to do '`make install`' as it will overwrite copies of other applications in your `/usr/local/bin`. For more information, see the project's home page.

The OpenSolaris POSIX `awk`
The versions of `awk` in `/usr/xpg4/bin` and `/usr/xpg6/bin` on Solaris are more or less POSIX-compliant. They are based on the `awk` from Mortice Kern

Systems for PCs. We were able to make this code compile and work under GNU/Linux with 1–2 hours of work. Making it more generally portable (using GNU Autoconf and/or Automake) would take more work, and this has not been done, at least to our knowledge.

The source code used to be available from the OpenSolaris website. However, that project was ended and the website shut down. Fortunately, the Illumos project makes this implementation available. You can view the files one at a time from `https://github.com/joyent/illumos-joyent/blob/master/usr/src/cmd/awk_xpg4`.

Libmawk
: This is an embeddable `awk` interpreter derived from `mawk`. For more information, see `http://repo.hu/projects/libmawk/`.

Mircea Neacsu's Embeddable `awk`
: Mircea Neacsu has created an embeddable `awk` interpreter, based on BWK awk. It's available at `https://github.com/neacsum/awk`. A short overview of how to use it may be found at `https://www.codeproject.com/Articles/5264205/Embedding-AWK-in-a-C-program`.

`awkcc`
: This is an early adaptation of Unix `awk` that translates `awk` into C code. It was done by J. Christopher Ramming at Bell Labs, circa 1988. It's available at `https://github.com/nokia/awkcc`. Bringing this up to date would be an interesting software engineering exercise.

QSE `awk`
: This is an embeddable `awk` interpreter. For more information, see `https://code.google.com/p/qse/`. The source can be found at `https://code.google.com/archive/p/qse/source/default/source`.

`wak`
: `wak` (a permutation of the letters in `awk`) is a small, mostly POSIX compatible version of `awk` written in C by Ray Gardner. The source code is available from its Github repository. Some nice articles about its development may be found in the author's weblog.

The following implementations are written in Go:

`goawk`
: This is an `awk` interpreter written in the Go programming language. It implements POSIX `awk`, with a few minor extensions. Source code is available from `https://github.com/benhoyt/goawk`. The author wrote a nice article describing the implementation.

`AWKgo`
: This is an `awk` to Go translator. It was written by the author of `goawk`. (See the previous entry in this list.) Source code is available from `https://github.com/benhoyt/goawk/tree/master/awkgo`. The author's article about it is at `https://benhoyt.com/writings/awkgo/`.

The following implementations are written in Java:

`jawk`
: This is an interpreter for `awk` written in Java. It claims to be a full interpreter, although because it uses Java facilities for I/O and for regexp matching, the language it supports is different from POSIX `awk`. More information is available on the project's home page.

Hoijui's `jawk`
: This project, available at https://github.com/hoijui/Jawk, is another `awk` interpreter written in Java. It uses modern Java build tools.

This version is written in Python:

`pawk`
: This is a Python module that claims to bring `awk`-like features to Python. See https://github.com/alecthomas/pawk for more information. (This is not related to Nelson Beebe's modified version of BWK `awk`, described earlier.)

There are several versions written in Rust:

`rust-awk`
: This program implements a small subset of `awk` in Rust. Many features are missing. The code is available at https://github.com/wenley/rust-awk.

`frawk`
: This is a language for writing short programs. "To a first approximation, it is an implementation of the AWK language; many common `awk` programs produce equivalent output when passed to `frawk`." However, it has a number of important additional features. The code is available at https://github.com/ezrosent/frawk.

`zawk`
: This program is based off of `frawk`. The code is available at https://crates.io/crates/zawk.

`awk-rs`
: This program simply claims to be "`awk` written in rust." It seems to be frozen, with no updates since 2020. The code is available at https://github.com/conradludgate/awk-rs.

`awk-rs`
: This program seems to be the most complete and actively maintained of the versions written in Rust. It used to be named `rawk` but is now called `awk-rs`. It seems to be different from the other version with the same name. The code is available at https://github.com/pegasusheavy/rawk.

This version is written in Zig:

`dawk`
: An implementation of `awk` in the Zig programming language. See https://codeberg.org/triallax/dawk.

And finally, this tool is written in shell:

`cppawk`
: Quoting from the web page, "`cppawk` is a tiny shell script that is used like `awk`. It invokes the C preprocessor (GNU `cpp`) on the Awk code and calls Awk on the result." This program may be of use if the way `gawk`'s `@include` facility works doesn't suit your needs. For more information, see https://www.kylheku.com/cgit/cppawk/.

See also the "Versions and implementations" section of the Wikipedia article on `awk` for information on additional versions.

An interesting collection of library functions is available at https://github.com/e36freak/awk-libs.

An interesting collection of `gawk` extensions is available https://github.com/su8/gawk-extensions.

B.6 Summary

- The gawk distribution is available from the GNU Project's main distribution site, ftp.gnu.org. The canonical build recipe is:

  ```
  wget https://ftp.gnu.org/gnu/gawk/gawk-5.4.0.tar.gz
  tar -xvpzf gawk-5.4.0.tar.gz
  cd gawk-5.4.0
  ./configure && make && make check
  ```

  NOTE: Because of the 'https://' URL, you may have to supply the --no-check-certificate option to wget to download the file.
- gawk may be built on non-POSIX systems as well. The currently supported systems are MS-Windows using MSYS, MSYS2, MinGW, and Cygwin, and OpenVMS. Instructions for each system are included in this appendix.
- Bug reports should be sent via email to bug-gawk@gnu.org. Bug reports should be in English and should include the version of gawk, how it was compiled, and a short program and data file that demonstrate the problem.
- Non-bug emails should be sent to help-gawk@gnu.org. Repeatedly sending non-bug emails to the bug list will get you blacklisted from it.
- There are a number of other freely available awk implementations. Many are POSIX-compliant; others are less so.

Appendix C Implementation Notes

This appendix contains information mainly of interest to implementers and maintainers of `gawk`. Everything in it applies specifically to `gawk` and not to other implementations.

C.1 Downward Compatibility and Debugging

See Section A.5 [Extensions in `gawk` Not in POSIX `awk`], page 485, for a summary of the GNU extensions to the `awk` language and program. All of these features can be turned off by invoking `gawk` with the `--traditional` option or with the `--posix` option.

If `gawk` is compiled for debugging with '`-DDEBUG`', then there is one more option available on the command line:

`-Y`
`--parsedebug`
: Print out the parse stack information as the program is being parsed.

This option is intended only for serious `gawk` developers and not for the casual user. It probably has not even been compiled into your version of `gawk`, since it slows down execution.

C.2 Making Additions to `gawk`

If you find that you want to enhance `gawk` in a significant fashion, you are perfectly free to do so. That is the point of having free software; the source code is available and you are free to change it as you want (see [GNU General Public License], page 557).

This section discusses the ways you might want to change `gawk` as well as any considerations you should bear in mind.

C.2.1 Accessing The `gawk` Git Repository

As `gawk` is Free Software, the source code is always available. Section B.1 [The `gawk` Distribution], page 503, describes how to get and build the formal, released versions of `gawk`.

However, if you want to modify `gawk` and contribute back your changes, you will probably wish to work with the development version. To do so, you will need to access the `gawk` source code repository. The code is maintained using the Git distributed version control system. You will need to install it if your system doesn't have it. Once you have done so, use the command:

```
git clone git://git.savannah.gnu.org/gawk.git
```

This clones the `gawk` repository. If you are behind a firewall that does not allow you to use the Git native protocol, you can still access the repository using:

```
git clone https://git.savannah.gnu.org/git/gawk.git
```

(Using the `https` URL is considered to be more secure.)

Once you have made changes, you can use '`git diff`' to produce a patch, and send that to the `gawk` maintainer; see Section B.4 [Reporting Problems and Bugs], page 518, for how to do that.

Once upon a time there was Git–CVS gateway for use by people who could not install Git. However, this gateway no longer works, so you may have better luck using a more modern version control system like Bazaar, that has a Git plug-in for working with Git repositories.

C.2.2 Adding New Features

You are free to add any new features you like to `gawk`. However, if you want your changes to be incorporated into the `gawk` distribution, there are several steps that you need to take in order to make it possible to include them:

1. Discuss the proposed new feature with the `gawk` maintainer. The bug list may be used for this. Even if I don't wish to include your feature, be aware that you are still free to add it and distribute your own "fork" of `gawk`.
2. Before building the new feature into `gawk` itself, consider writing it as an extension (see Chapter 17 [Writing Extensions for gawk], page 415). If that's not possible, continue with the rest of the steps in this list.
3. Be prepared to sign the appropriate paperwork. In order for the FSF to distribute your changes, you must either place those changes in the public domain and submit a signed statement to that effect, or assign the copyright in your changes to the FSF. Both of these actions are easy to do and *many* people have done so already. If you have questions, please contact me (see Section B.4 [Reporting Problems and Bugs], page 518), or `assign@gnu.org`.
4. Get the latest version. It is much easier for me to integrate changes if they are relative to the most recent distributed version of `gawk`, or better yet, relative to the latest code in the Git repository. If your version of `gawk` is very old, I may not be able to integrate your changes at all. (See Section B.1.1 [Getting the gawk Distribution], page 503, for information on getting the latest version of `gawk`.)
5. Follow the *GNU Coding Standards*. This document describes how GNU software should be written. If you haven't read it, please do so, preferably *before* starting to modify `gawk`. (The *GNU Coding Standards* are available from the GNU Project's website. Texinfo, Info, and DVI versions are also available.)
6. Use the `gawk` coding style. The C code for `gawk` follows the instructions in the *GNU Coding Standards*, with minor exceptions. The code is formatted using the traditional "K&R" style, particularly as regards to the placement of braces and the use of TABs. In brief, the coding rules for `gawk` are as follows:
   - Use ANSI/ISO style (prototype) function headers when defining functions.
   - Put the name of the function at the beginning of its own line.
   - Use '`#elif`' instead of nesting '`#if`' inside '`#else`'.
   - Put the return type of the function, even if it is `int`, on the line above the line with the name and arguments of the function.
   - Put spaces around parentheses used in control structures (`if`, `while`, `for`, `do`, and `switch`).
   - Do not parenthesize the expression used with `return`.
   - Do not put spaces in front of parentheses used in function calls.
   - Put spaces around all C operators and after commas in function calls.

- Do not use the comma operator to produce multiple side effects, except in `for` loop initialization and increment parts, and in macro bodies.
- Use real TABs for indenting, not spaces.
- Use the "K&R" brace layout style.
- Use comparisons against `NULL` and `'\0'` in the conditions of `if`, `while`, and `for` statements, as well as in the `case`s of `switch` statements, instead of just the plain pointer or character value.
- Do not, *under any circumstances*, use the '`-1 == foo`' or '`0 >= bar`' style of comparison expressions. I have known about it for decades, and I understand why some people like it. Nonetheless, I abhor it with a passion, and code that uses it will never be accepted.
- Use `true` and `false` for `bool` values, the `NULL` symbolic constant for pointer values, and the character constant `'\0'` where appropriate, instead of `1` and `0`.
- Provide one-line descriptive comments for each function.
- Do not use the `alloca()` function for allocating memory off the stack. Its use causes more portability trouble than is worth the minor benefit of not having to free the storage. Instead, use `malloc()` and `free()`.
- Do not use comparisons of the form '`! strcmp(a, b)`' or similar. As Henry Spencer once said, "`strcmp()` is not a boolean!" Instead, use '`strcmp(a, b) == 0`'.
- If adding new bit flag values, use explicit hexadecimal constants (`0x001`, `0x002`, `0x004`, and so on) instead of shifting one left by successive amounts ('`(1<<0)`', '`(1<<1)`', and so on).

  NOTE: If I have to reformat your code to follow the coding style used in `gawk`, I may not bother to integrate your changes at all.

7. Update the documentation. Along with your new code, please supply new sections and/or chapters for this book. If at all possible, please use real Texinfo, instead of just supplying unformatted ASCII text (although even that is better than no documentation at all). Conventions to be followed in *GAWK: Effective AWK Programming* are provided after the '`@bye`' at the end of the Texinfo source file. If possible, please update the `man` page as well.

   You will also have to sign paperwork for your documentation changes.

8. Submit changes as unified diffs. Use '`diff -u -r -N`' to compare the original `gawk` source tree with your version. I recommend using the GNU version of `diff`, or best of all, '`git diff`' or '`git format-patch`'. Send the output produced by `diff` to me when you submit your changes. (See Section B.4 [Reporting Problems and Bugs], page 518, for the electronic mail information.)

   Using this format makes it easy for me to apply your changes to the master version of the `gawk` source code (using `patch`). If I have to apply the changes manually, using a text editor, I may not do so, particularly if there are lots of changes.

9. Include an entry for the `ChangeLog` file with your submission. This helps further minimize the amount of work I have to do, making it easier for me to accept patches. It is simplest if you just make this part of your diff.

Although this sounds like a lot of work, please remember that while you may write the new code, I have to maintain it and support it. If it isn't possible for me to do that with a minimum of extra work, then I probably will not.

C.2.3 Porting `gawk` to a New Operating System

If you want to port `gawk` to a new operating system, there are several steps:

1. Follow the guidelines in the previous section concerning coding style, submission of diffs, and so on.
2. Be prepared to sign the appropriate paperwork. In order for the FSF to distribute your code, you must either place your code in the public domain and submit a signed statement to that effect, or assign the copyright in your code to the FSF. Both of these actions are easy to do and *many* people have done so already. If you have questions, please contact me, or `gnu@gnu.org`.
3. When doing a port, bear in mind that your code must coexist peacefully with the rest of `gawk` and the other ports. Avoid gratuitous changes to the system-independent parts of the code. If at all possible, avoid sprinkling '`#ifdef`'s just for your port throughout the code.

   If the changes needed for a particular system affect too much of the code, I probably will not accept them. In such a case, you can, of course, distribute your changes on your own, as long as you comply with the GPL (see [GNU General Public License], page 557).
4. A number of the files that come with `gawk` are maintained by other people. Thus, you should not change them unless it is for a very good reason; i.e., changes are not out of the question, but changes to these files are scrutinized extra carefully. These are all the files in the `support` directory within the `gawk` distribution. See there.
5. A number of other files are provided by the GNU Autotools (Autoconf, Automake, and GNU `gettext`). You should not change them either, unless it is for a very good reason. The files are `ABOUT-NLS`, `INSTALL`, and all the files in the `build-aux` directory.
6. Be willing to continue to maintain the port. Non-Unix operating systems are supported by volunteers who maintain the code needed to compile and run `gawk` on their systems. If no-one volunteers to maintain a port, it becomes unsupported and it may be necessary to remove it from the distribution.
7. Supply an appropriate `gawkmisc.???` file. Each port has its own `gawkmisc.???` that implements certain operating system specific functions. This is cleaner than a plethora of '`#ifdef`'s scattered throughout the code. The `gawkmisc.c` in the main source directory includes the appropriate `gawkmisc.???` file from each subdirectory. Be sure to update it as well.

   Each port's `gawkmisc.???` file has a suffix reminiscent of the machine or operating system for the port—for example, `pc/gawkmisc.pc` and `vms/gawkmisc.vms`. The use of separate suffixes, instead of plain `gawkmisc.c`, makes it possible to move files from a port's subdirectory into the main subdirectory, without accidentally destroying the real `gawkmisc.c` file. (Currently, this is only an issue for the PC operating system ports.)
8. Supply a `Makefile` as well as any other C source and header files that are necessary for your operating system. All your code should be in a separate subdirectory, with a name

that is the same as, or reminiscent of, either your operating system or the computer system. If possible, try to structure things so that it is not necessary to move files out of the subdirectory into the main source directory. If that is not possible, then be sure to avoid using names for your files that duplicate the names of files in the main source directory.

9. Update the documentation. Please write a section (or sections) for this book describing the installation and compilation steps needed to compile and/or install `gawk` for your system.

Following these steps makes it much easier to integrate your changes into `gawk` and have them coexist happily with other operating systems' code that is already there.

In the code that you supply and maintain, feel free to use a coding style and brace layout that suits your taste.

C.2.4 Why Generated Files Are Kept In Git

If you look at the `gawk` source in the Git repository, you will notice that it includes files that are automatically generated by GNU infrastructure tools, such as `Makefile.in` from Automake and even `configure` from Autoconf.

This is different from many Free Software projects that do not store the derived files, because that keeps the repository less cluttered, and it is easier to see the substantive changes when comparing versions and trying to understand what changed between commits.

However, there are several reasons why the `gawk` maintainer likes to have everything in the repository.

First, because it is then easy to reproduce any given version completely, without relying upon the availability of (older, likely obsolete, and maybe even impossible to find) other tools.

As an extreme example, if you ever even think about trying to compile, oh, say, the V7 `awk`, you will discover that not only do you have to bootstrap the V7 `yacc` to do so, but you also need the V7 `lex`. And the latter is pretty much impossible to bring up on a modern GNU/Linux system.[1]

(Or, let's say `gawk` 1.2 required `bison` whatever-it-was in 1989 and that there was no `awkgram.c` file in the repository. Is there a guarantee that we could find that `bison` version? Or that *it* would build?)

If the repository has all the generated files, then it's easy to just check them out and build. (Or *easier*, depending upon how far back we go.)

And that brings us to the second (and stronger) reason why all the files really need to be in Git. It boils down to who do you cater to—the `gawk` developer(s), or the user who just wants to check out a version and try it out?

The `gawk` maintainer wants it to be possible for any interested `awk` user in the world to just clone the repository, check out the branch of interest and build it, without their having to have the correct version(s) of the autotools.[2] That is the point of the `bootstrap.sh` file. It touches the various other files in the right order such that

[1] We tried. It was painful.

[2] There is one GNU program that is (in our opinion) severely difficult to bootstrap from the Git repository. For example, on the author's old (but still working) PowerPC Macintosh with macOS 10.5, it was

```
# The canonical incantation for building GNU software:
./bootstrap.sh && ./configure && make
```

will *just work*.

This is extremely important for the `master` and `gawk-X.Y-stable` branches.

Further, the `gawk` maintainer would argue that it's also important for the `gawk` developers. When he tried to check out the `xgawk` branch[3] to build it, he couldn't. (No `ltmain.sh` file, and he had no idea how to create it, and that was not the only problem.)

He felt *extremely* frustrated. With respect to that branch, the maintainer is no different than Jane User who wants to try to build `gawk-4.1-stable` or `master` from the repository.

Thus, the maintainer thinks that it's not just important, but critical, that for any given branch, the above incantation *just works*.

A third reason to have all the files is that without them, using '`git bisect`' to try to find the commit that introduced a bug is exceedingly difficult. The maintainer tried to do that on another project that requires running bootstrapping scripts just to create `configure` and so on; it was really painful. When the repository is self-contained, using `git bisect` in it is very easy.

What are some of the consequences and/or actions to take?

1. We don't mind that there are differing files in the different branches as a result of different versions of the autotools.
   A. It's the maintainer's job to merge them and he will deal with it.
   B. He is really good at '`git diff x y > /tmp/diff1 ; gvim /tmp/diff1`' to remove the diffs that aren't of interest in order to review code.
2. It would certainly help if everyone used the same versions of the GNU tools as he does, which in general are the latest released versions of Automake, Autoconf, `bison`, GNU `gettext`, and Libtool.

   Installing from source is quite easy. It's how the maintainer worked for years (and still works). He had `/usr/local/bin` at the front of his `PATH` and just did:

   ```
   wget https://ftp.gnu.org/gnu/package/package-x.y.z.tar.gz
   tar -xpzvf package-x.y.z.tar.gz
   cd package-x.y.z
   ./configure && make && make check
   make install    # as root
   ```

   NOTE: Because of the '`https://`' URL, you may have to supply the `--no-check-certificate` option to `wget` to download the file.

Most of the above was originally written by the maintainer to other `gawk` developers. It raised the objection from one of the developers ". . . that anybody pulling down the source from Git is not an end user."

---

necessary to bootstrap a ton of software, starting with Git itself, in order to try to work with the latest code. It's not pleasant, and especially on older systems, it's a big waste of time.

Starting with the latest tarball was no picnic either. The maintainers had dropped `.gz` and `.bz2` files and only distribute `.tar.xz` files. It was necessary to bootstrap `xz` first!

[3] A branch (since removed) created by one of the other developers that did not include the generated files.

However, this is not true. There are "power `awk` users" who can build `gawk` (using the magic incantation shown previously) but who can't program in C. Thus, the major branches should be kept buildable all the time.

It was then suggested that there be a `cron` job to create nightly tarballs of "the source." Here, the problem is that there are source trees, corresponding to the various branches! So, nightly tarballs aren't the answer, especially as the repository can go for weeks without significant change being introduced.

Fortunately, the Git server can meet this need. For any given branch named *branchname*, use:

```
wget https://git.savannah.gnu.org/cgit/gawk.git/snapshot/gawk-branchname.tar.gz
```

to retrieve a snapshot of the given branch.

C.3 Probable Future Extensions

AWK is a language similar to PERL, only considerably more elegant.
—*Arnold Robbins*

Hey!
—*Larry Wall*

The `TODO` file in the `master` branch of the `gawk` Git repository lists possible future enhancements. Some of these relate to the source code, and others to possible new features. Please see that file for the list. See Section C.2 [Making Additions to gawk], page 529, if you are interested in tackling any of the projects listed there.

C.4 Some Limitations of the Implementation

This following table describes limits of `gawk` on a Unix-like system (although it is variable even then). Other systems may have different limits.

Item	Limit
Characters in a character class	2^(number of bits per byte)
Length of input record in bytes	`ULONG_MAX`
Length of output record	Unlimited
Length of source line	Unlimited
Number of fields in a record	`ULONG_MAX`
Number of file redirections	Unlimited
Number of input records in one file	`MAX_LONG`
Number of input records total	`MAX_LONG`
Number of pipe redirections	min(number of processes per user, number of open files)
Numeric values	Double-precision floating point (if not using MPFR)
Size of a field in bytes	`ULONG_MAX`
Size of a literal string in bytes	`ULONG_MAX`
Size of a printf string in bytes	`ULONG_MAX`

C.5 Extension API Design

This section documents the design of the extension API, including a discussion of some of the history and problems that needed to be solved.

The first version of extensions for gawk was developed in the mid-1990s and released with gawk 3.1 in the late 1990s. The basic mechanisms and design remained unchanged for close to 15 years, until 2012.

The old extension mechanism used data types and functions from gawk itself, with a "clever hack" to install extension functions.

gawk included some sample extensions, of which a few were really useful. However, it was clear from the outset that the extension mechanism was bolted onto the side and was not really well thought out.

C.5.1 Problems With The Old Mechanism

The old extension mechanism had several problems:

- It depended heavily upon gawk internals. Any time the NODE structure[4] changed, an extension would have to be recompiled. Furthermore, to really write extensions required understanding something about gawk's internal functions. There was some documentation in this book, but it was quite minimal.
- Being able to call into gawk from an extension required linker facilities that are common on Unix-derived systems but that did not work on MS-Windows systems; users wanting extensions on MS-Windows had to statically link them into gawk, even though MS-Windows supports dynamic loading of shared objects.
- The API would change occasionally as gawk changed; no compatibility between versions was ever offered or planned for.

Despite the drawbacks, the xgawk project developers forked gawk and developed several significant extensions. They also enhanced gawk's facilities relating to file inclusion and shared object access.

A new API was desired for a long time, but only in 2012 did the gawk maintainer and the xgawk developers finally start working on it together. More information about the xgawk project is provided in Section 17.8 [The gawkextlib Project], page 478.

C.5.2 Goals For A New Mechanism

Some goals for the new API were:

- The API should be independent of gawk internals. Changes in gawk internals should not be visible to the writer of an extension function.
- The API should provide *binary* compatibility across gawk releases as long as the API itself does not change.
- The API should enable extensions written in C or C++ to have roughly the same "appearance" to awk-level code as awk functions do. This means that extensions should have:
  - The ability to access function parameters.
  - The ability to turn an undefined parameter into an array (call by reference).
  - The ability to create, access and update global variables.
  - Easy access to all the elements of an array at once ("array flattening") in order to loop over all the element in an easy fashion for C code.

[4] A critical central data structure inside gawk.

– The ability to create arrays (including gawk's true arrays of arrays).

Some additional important goals were:

- The API should use only features in ISO C 90, so that extensions can be written using the widest range of C and C++ compilers. The header should include the appropriate '`#ifdef __cplusplus`' and '`extern "C"`' magic so that a C++ compiler could be used. (If using C++, the runtime system has to be smart enough to call any constructors and destructors, as gawk is a C program. As of this writing, this has not been tested.)
- The API mechanism should not require access to gawk's symbols[5] by the compile-time or dynamic linker, in order to enable creation of extensions that also work on MS-Windows.

During development, it became clear that there were other features that should be available to extensions, which were also subsequently provided:

- Extensions should have the ability to hook into gawk's I/O redirection mechanism. In particular, the xgawk developers provided a so-called "open hook" to take over reading records. During development, this was generalized to allow extensions to hook into input processing, output processing, and two-way I/O.
- An extension should be able to provide a "call back" function to perform cleanup actions when gawk exits.
- An extension should be able to provide a version string so that gawk's `--version` option can provide information about extensions as well.

The requirement to avoid access to gawk's symbols is, at first glance, a difficult one to meet.

One design, apparently used by Perl and Ruby and maybe others, would be to make the mainline gawk code into a library, with the gawk utility a small C `main()` function linked against the library.

This seemed like the tail wagging the dog, complicating build and installation and making a simple copy of the gawk executable from one system to another (or one place to another on the same system!) into a chancy operation.

Pat Rankin suggested the solution that was adopted. See Section 17.3 [How It Works at a High Level], page 415, for the details.

C.5.3 Other Design Decisions

As an arbitrary design decision, extensions can read the values of predefined variables and arrays (such as ARGV and FS), but cannot change them, with the exception of PROCINFO.

The reason for this is to prevent an extension function from affecting the flow of an awk program outside its control. While a real awk function can do what it likes, that is at the discretion of the programmer. An extension function should provide a service or make a C API available for use within awk, and not mess with FS or ARGC and ARGV.

In addition, it becomes easy to start down a slippery slope. How much access to gawk facilities do extensions need? Do they need getline? What about calling gsub() or

[5] The *symbols* are the variables and functions defined inside gawk. Access to these symbols by code external to gawk loaded dynamically at runtime is problematic on MS-Windows.

compiling regular expressions? What about calling into `awk` functions? (*That* would be messy.)

In order to avoid these issues, the `gawk` developers chose to start with the simplest, most basic features that are still truly useful.

Another decision is that although `gawk` provides nice things like MPFR, and arrays indexed internally by integers, these features are not being brought out to the API in order to keep things simple and close to traditional `awk` semantics. (In fact, arrays indexed internally by integers are so transparent that they aren't even documented!)

Additionally, all functions in the API check that their pointer input parameters are not `NULL`. If they are, they return an error. (It is a good idea for extension code to verify that pointers received from `gawk` are not `NULL`. Such a thing should not happen, but the `gawk` developers are only human, and they have been known to occasionally make mistakes.)

With time, the API will undoubtedly evolve; the `gawk` developers expect this to be driven by user needs. For now, the current API seems to provide a minimal yet powerful set of features for creating extensions.

C.5.4 Room For Future Growth

The API can later be expanded, in at least the following way:

- `gawk` passes an "extension id" into the extension when it first loads the extension. The extension then passes this id back to `gawk` with each function call. This mechanism allows `gawk` to identify the extension calling into it, should it need to know.

Of course, as of this writing, no decisions have been made with respect to the above.

C.6 Summary

- `gawk`'s extensions can be disabled with either the `--traditional` option or with the `--posix` option. The `--parsedebug` option is available if `gawk` is compiled with '`-DDEBUG`'.
- The source code for `gawk` is maintained in a publicly accessible Git repository. Anyone may check it out and view the source.
- Contributions to `gawk` are welcome. Following the steps outlined in this chapter will make it easier to integrate your contributions into the code base. This applies both to new feature contributions and to ports to additional operating systems.
- `gawk` has some limits—generally those that are imposed by the machine architecture.
- The extension API design was intended to solve a number of problems with the previous extension mechanism, enable features needed by the `xgawk` project, and provide binary compatibility going forward.
- The previous extension mechanism is no longer supported and was removed from the code base with the 4.2 release.

Appendix D Basic Programming Concepts

This appendix attempts to define some of the basic concepts and terms that are used throughout the rest of this book. As this book is specifically about `awk`, and not about computer programming in general, the coverage here is by necessity fairly cursory and simplistic. (If you need more background, there are many other introductory texts that you should refer to instead.)

D.1 What a Program Does

At the most basic level, the job of a program is to process some input data and produce results. See Figure D.1.

Figure D.1: General Program Flow

The "program" in the figure can be either a compiled program[1] (such as `ls`), or it may be *interpreted*. In the latter case, a machine-executable program such as `awk` reads your program, and then uses the instructions in your program to process the data.

When you write a program, it usually consists of the following, very basic set of steps, as shown in Figure D.2:

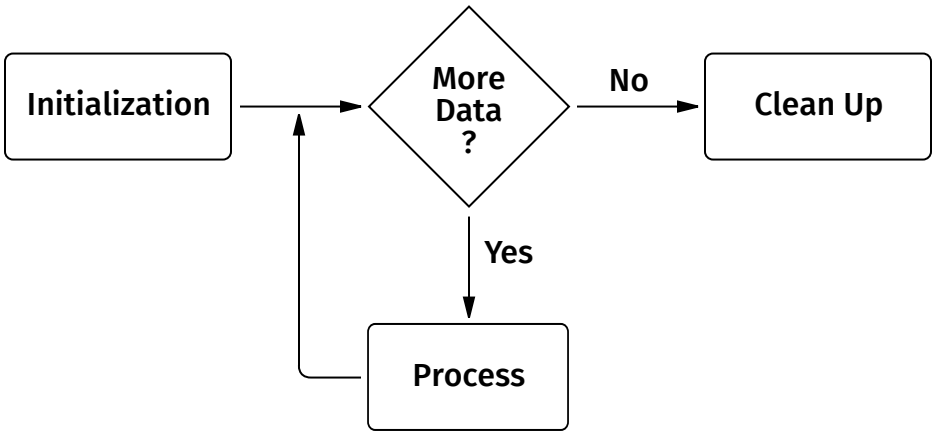

Figure D.2: Basic Program Steps

[1] Compiled programs are typically written in lower-level languages such as C, C++, or Ada, and then translated, or *compiled*, into a form that the computer can execute directly.

Initialization
: These are the things you do before actually starting to process data, such as checking arguments, initializing any data you need to work with, and so on. This step corresponds to `awk`'s `BEGIN` rule (see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154).

  If you were baking a cake, this might consist of laying out all the mixing bowls and the baking pan, and making sure you have all the ingredients that you need.

Processing
: This is where the actual work is done. Your program reads data, one logical chunk at a time, and processes it as appropriate.

  In most programming languages, you have to manually manage the reading of data, checking to see if there is more each time you read a chunk. `awk`'s pattern-action paradigm (see Chapter 1 [Getting Started with `awk`], page 17) handles the mechanics of this for you.

  In baking a cake, the processing corresponds to the actual labor: breaking eggs, mixing the flour, water, and other ingredients, and then putting the cake into the oven.

Clean Up
: Once you've processed all the data, you may have things you need to do before exiting. This step corresponds to `awk`'s `END` rule (see Section 7.1.4 [The `BEGIN` and `END` Special Patterns], page 154).

  After the cake comes out of the oven, you still have to wrap it in plastic wrap to keep anyone from tasting it, as well as wash the mixing bowls and utensils.

An *algorithm* is a detailed set of instructions necessary to accomplish a task, or process data. It is much the same as a recipe for baking a cake. Programs implement algorithms. Often, it is up to you to design the algorithm and implement it, simultaneously.

The "logical chunks" we talked about previously are called *records*, similar to the records a company keeps on employees, a school keeps for students, or a doctor keeps for patients. Each record has many component parts, such as first and last names, date of birth, address, and so on. The component parts are referred to as the *fields* of the record.

The act of reading data is termed *input*, and that of generating results, not too surprisingly, is termed *output*. They are often referred to together as "input/output," and even more often, as "I/O" for short. (You will also see "input" and "output" used as verbs.)

`awk` manages the reading of data for you, as well as the breaking it up into records and fields. Your program's job is to tell `awk` what to do with the data. You do this by describing *patterns* in the data to look for, and *actions* to execute when those patterns are seen. This *data-driven* nature of `awk` programs usually makes them both easier to write and easier to read.

D.2 Data Values in a Computer

In a program, you keep track of information and values in things called *variables*. A variable is just a name for a given value, such as `first_name`, `last_name`, `address`, and so on. `awk` has several predefined variables, and it has special names to refer to the current input record and the fields of the record. You may also group multiple associated values under one name, as an array.

Data, particularly in `awk`, consists of either numeric values, such as 42 or 3.1415927, or string values. String values are essentially anything that's not a number, such as a name. Strings are sometimes referred to as *character data*, since they store the individual characters that comprise them. Individual variables, as well as numeric and string variables, are referred to as *scalar* values. Groups of values, such as arrays, are not scalars.

Section 16.1 [A General Description of Computer Arithmetic], page 399, provided a basic introduction to numeric types (integer and floating-point) and how they are used in a computer. Please review that information, including a number of caveats that were presented.

While you are probably used to the idea of a number without a value (i.e., zero), it takes a bit more getting used to the idea of zero-length character data. Nevertheless, such a thing exists. It is called the *null string*. The null string is character data that has no value. In other words, it is empty. It is written in `awk` programs like this: `""`.

Humans are used to working in decimal; i.e., base 10. In base 10, numbers go from 0 to 9, and then "roll over" into the next column. (Remember grade school? $42 = 4 \times 10 + 2$.)

There are other number bases though. Computers commonly use base 2 or *binary*, base 8 or *octal*, and base 16 or *hexadecimal*. In binary, each column represents two times the value in the column to its right. Each column may contain either a 0 or a 1. Thus, binary 1010 represents $(1 \times 8) + (0 \times 4) + (1 \times 2) + (0 \times 1)$, or decimal 10. Octal and hexadecimal are discussed more in Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124.

At the very lowest level, computers store values as groups of binary digits, or *bits*. Modern computers group bits into groups of eight, called *bytes*. Advanced applications sometimes have to manipulate bits directly, and `gawk` provides functions for doing so.

Programs are written in programming languages. Hundreds, if not thousands, of programming languages exist. One of the most popular is the C programming language. The C language had a very strong influence on the design of the `awk` language.

There have been several versions of C. The first is often referred to as "K&R" C, after the initials of Brian Kernighan and Dennis Ritchie, the authors of the first book on C. (Dennis Ritchie created the language, and Brian Kernighan was one of the creators of `awk`.)

In the mid-1980s, an effort began to produce an international standard for C. This work culminated in 1989, with the production of the ANSI standard for C. This standard became an ISO standard in 1990. In 1999, a revised ISO C standard was approved and released. Where it makes sense, POSIX `awk` is compatible with 1999 ISO C.

Glossary

Action — A series of `awk` statements attached to a rule. If the rule's pattern matches an input record, `awk` executes the rule's action. Actions are always enclosed in braces. (See Section 7.3 [Actions], page 157.)

Ada — A programming language originally defined by the U.S. Department of Defense for embedded programming. It was designed to enforce good Software Engineering practices.

Amazing `awk` Assembler
Henry Spencer at the University of Toronto wrote a retargetable assembler completely as `sed` and `awk` scripts. It is thousands of lines long, including machine descriptions for several eight-bit microcomputers. It is a good example of a program that would have been better written in another language.

Amazingly Workable Formatter (`awf`)
Henry Spencer at the University of Toronto wrote a formatter that accepts a large subset of the '`nroff -ms`' and '`nroff -man`' formatting commands, using `awk` and `sh`.

Anchor — The regexp metacharacters '`^`' and '`$`', which force the match to the beginning or end of the string, respectively.

ANSI — The American National Standards Institute. This organization produces many standards, among them the standards for the C and C++ programming languages. These standards often become international standards as well. See also "ISO."

Argument — An argument can be two different things. It can be an option or a file name passed to a command while invoking it from the command line, or it can be something passed to a *function* inside a program, e.g. inside `awk`.

In the latter case, an argument can be passed to a function in two ways. Either it is given to the called function by value, i.e., a copy of the value of the variable is made available to the called function, but the original variable cannot be modified by the function itself; or it is given by reference, i.e., a pointer to the interested variable is passed to the function, which can then directly modify it. In `awk` scalars are passed by value, and arrays are passed by reference. See "Pass By Value/Reference."

Array — A grouping of multiple values under the same name. Most languages just provide sequential arrays. `awk` provides associative arrays.

Assertion — A statement in a program that a condition is true at this point in the program. Useful for reasoning about how a program is supposed to behave.

Assignment
An `awk` expression that changes the value of some `awk` variable or data object. An object that you can assign to is called an *lvalue*. The assigned values are called *rvalues*. See Section 6.2.3 [Assignment Expressions], page 135.

Associative Array
: Arrays in which the indices may be numbers or strings, not just sequential integers in a fixed range.

`awk` Language
: The language in which `awk` programs are written.

`awk` Program
: An `awk` program consists of a series of *patterns* and *actions*, collectively known as *rules*. For each input record given to the program, the program's rules are all processed in turn. `awk` programs may also contain function definitions.

`awk` Script
: Another name for an `awk` program.

Bash
: The GNU version of the standard shell (the **B**ourne-**A**gain **SH**ell). See also "Bourne Shell."

Binary
: Base-two notation, where the digits are `0`–`1`. Since electronic circuitry works "naturally" in base 2 (just think of Off/On), everything inside a computer is calculated using base 2. Each digit represents the presence (or absence) of a power of 2 and is called a *bit*. So, for example, the base-two number `10101` is the same as decimal 21, $((1 \times 16) + (1 \times 4) + (1 \times 1))$.

  Since base-two numbers quickly become very long to read and write, they are usually grouped by 3 (i.e., they are read as octal numbers), or by 4 (i.e., they are read as hexadecimal numbers). There is no direct way to insert base 2 numbers in a C program. If need arises, such numbers are usually inserted as octal or hexadecimal numbers. The number of base-two digits that fit into registers used for representing integer numbers in computers is a rough indication of the computing power of the computer itself. Most computers nowadays use 64 bits for representing integer numbers in their registers, but 32-bit, 16-bit and 8-bit registers have been widely used in the past. See Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124.

Bit
: Short for "Binary Digit." All values in computer memory ultimately reduce to binary digits: values that are either zero or one. Groups of bits may be interpreted differently—as integers, floating-point numbers, character data, addresses of other memory objects, or other data. `awk` lets you work with floating-point numbers and strings. `gawk` lets you manipulate bit values with the built-in functions described in Section 9.1.7 [Bit-Manipulation Functions], page 220.

  Computers are often defined by how many bits they use to represent integer values. Typical systems are 32-bit systems, but 64-bit systems are becoming increasingly popular, and 16-bit systems have essentially disappeared.

Boolean Expression
: Named after the English mathematician Boole. See also "Logical Expression."

Bourne Shell
: The standard shell (`/bin/sh`) on Unix and Unix-like systems, originally written by Steven R. Bourne at Bell Laboratories. Many shells (Bash, `ksh`, `pdksh`, `zsh`) are generally upwardly compatible with the Bourne shell.

Braces
: The characters '`{`' and '`}`'. Braces are used in `awk` for delimiting actions, compound statements, and function bodies.

Bracket Expression
: Inside a *regular expression*, an expression included in square brackets, meant to designate a single character as belonging to a specified character class. A bracket expression can contain a list of one or more characters, like '`[abc]`', a range of characters, like '`[A-Z]`', or a name, delimited by '`:`', that designates a known set of characters, like '`[:digit:]`'. The form of bracket expression enclosed between '`:`' is independent of the underlying representation of the character themselves, which could utilize the ASCII, EBCDIC, or Unicode codesets, depending on the architecture of the computer system, and on localization. See also "Regular Expression."

Built-in Function
: The `awk` language provides built-in functions that perform various numerical, I/O-related, and string computations. Examples are `sqrt()` (for the square root of a number) and `substr()` (for a substring of a string). `gawk` provides functions for timestamp management, bit manipulation, array sorting, type checking, and runtime string translation. (See Section 9.1 [Built-in Functions], page 197.)

Built-in Variable
: `ARGC`, `ARGV`, `CONVFMT`, `ENVIRON`, `FILENAME`, `FNR`, `FS`, `NF`, `NR`, `OFMT`, `OFS`, `ORS`, `RLENGTH`, `RSTART`, `RS`, and `SUBSEP` are the variables that have special meaning to `awk`. In addition, `ARGIND`, `BINMODE`, `ERRNO`, `FIELDWIDTHS`, `FPAT`, `IGNORECASE`, `LINT`, `PROCINFO`, `RT`, and `TEXTDOMAIN` are the variables that have special meaning to `gawk`. Changing some of them affects `awk`'s running environment. (See Section 7.5 [Predefined Variables], page 167.)

C
: The system programming language that most GNU software is written in. The `awk` programming language has C-like syntax, and this book points out similarities between `awk` and C when appropriate.

  In general, `gawk` attempts to be as similar to the 1990 version of ISO C as makes sense.

c.e.
: See "Common Extension."

C Shell
: The C Shell (`csh` or its improved version, `tcsh`) is a Unix shell that was created by Bill Joy in the late 1970s. The C shell was differentiated from other shells by its interactive features and overall style, which looks more like C. The C Shell is not backward compatible with the Bourne Shell, so special attention is required when converting scripts written for other Unix shells to the C shell, especially with regard to the management of shell variables. See also "Bourne Shell."

C++
: A popular object-oriented programming language derived from C.

Character Class
: See "Bracket Expression."

Character List
: See "Bracket Expression."

Character Set
: The set of numeric codes used by a computer system to represent the characters (letters, numbers, punctuation, etc.) of a particular country or place. The most common character set in use today is ASCII (American Standard Code for Information Interchange). Many European countries use an extension of ASCII known as ISO-8859-1 (ISO Latin-1). The Unicode character set is increasingly popular and standard, and is particularly widely used on GNU/Linux systems.

CHEM
: A preprocessor for `pic` that reads descriptions of molecules and produces `pic` input for drawing them. It was written in `awk` by Brian Kernighan and Jon Bentley, and is available from `https://netlib.org/typesetting/chem`.

Comparison Expression
: A relation that is either true or false, such as '`a < b`'. Comparison expressions are used in `if`, `while`, `do`, and `for` statements, and in patterns to select which input records to process. (See Section 6.3.2 [Variable Typing and Comparison Expressions], page 139.)

Compiler
: A program that translates human-readable source code into machine-executable object code. The object code is then executed directly by the computer. See also "Interpreter."

Common Extension
: An extension to the `awk` language found in two or more `awk` implementations.

Complemented Bracket Expression
: The negation of a *bracket expression*. All that is *not* described by a given bracket expression. The symbol '`^`' precedes the negated bracket expression. E.g.: '`[^[:digit:]]`' designates whatever character is not a digit. '`[^bad]`' designates whatever character is not one of the letters '`b`', '`a`', or '`d`'. See "Bracket Expression."

Compound Statement
: A series of `awk` statements, enclosed in curly braces. Compound statements may be nested. (See Section 7.4 [Control Statements in Actions], page 158.)

Computed Regexps
: See "Dynamic Regular Expressions."

Concatenation
: Concatenating two strings means sticking them together, one after another, producing a new string. For example, the string '`foo`' concatenated with the string '`bar`' gives the string '`foobar`'. (See Section 6.2.2 [String Concatenation], page 134.)

Conditional Expression
: An expression using the '`?:`' ternary operator, such as '*`expr1 ? expr2 : expr3`*'. The expression *expr1* is evaluated; if the result is true, the value of the whole expression is the value of *expr2*; otherwise the value is *expr3*. In either case,

only one of *expr2* and *expr3* is evaluated. (See Section 6.3.4 [Conditional Expressions], page 145.)

Control Statement
: A control statement is an instruction to perform a given operation or a set of operations inside an `awk` program, if a given condition is true. Control statements are: `if`, `for`, `while`, and `do` (see Section 7.4 [Control Statements in Actions], page 158).

Cookie
: A peculiar goodie, token, saying or remembrance produced by or presented to a program. (With thanks to Professor Doug McIlroy.)

Coprocess
: A subordinate program with which two-way communications is possible.

Curly Braces
: See "Braces."

Dark Corner
: An area in the language where specifications often were (or still are) not clear, leading to unexpected or undesirable behavior. Such areas are marked in this book with the picture of a flashlight in the margin and are indexed under the heading "dark corner."

Data Driven
: A description of `awk` programs, where you specify the data you are interested in processing, and what to do when that data is seen.

Data Objects
: These are numbers and strings of characters. Numbers are converted into strings and vice versa, as needed. (See Section 6.1.4 [Conversion of Strings and Numbers], page 130.)

d.c.
: See "Dark Corner."

Deadlock
: The situation in which two communicating processes are each waiting for the other to perform an action.

Debugger
: A program used to help developers remove "bugs" from (de-bug) their programs.

Double Precision
: An internal representation of numbers that can have fractional parts. Double precision numbers keep track of more digits than do single precision numbers, but operations on them are sometimes more expensive. This is the way `awk` stores numeric values. It is the C type `double`.

Dynamic Regular Expression
: A dynamic regular expression is a regular expression written as an ordinary expression. It could be a string constant, such as `"foo"`, but it may also be an expression whose value can vary. (See Section 3.6 [Using Dynamic Regexps], page 63.)

Empty String
: See "Null String."

Environment
: A collection of strings, of the form '*name*=*val*', that each program has available to it. Users generally place values into the environment in order to provide information to various programs. Typical examples are the environment variables `HOME` and `PATH`.

Epoch
: The date used as the "beginning of time" for timestamps. Time values in most systems are represented as seconds since the epoch, with library functions available for converting these values into standard date and time formats.

  The epoch on Unix and POSIX systems is 1970-01-01 00:00:00 UTC. See also "GMT" and "UTC."

Escape Sequences
: A special sequence of characters used for describing nonprinting characters, such as '`\n`' for newline or '`\033`' for the ASCII ESC (Escape) character. (See Section 3.2 [Escape Sequences], page 52.)

Extension
: An additional feature or change to a programming language or utility not defined by that language's or utility's standard. `gawk` has (too) many extensions over POSIX `awk`.

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Field
: When `awk` reads an input record, it splits the record into pieces separated by whitespace (or by a separator regexp that you can change by setting the predefined variable `FS`). Such pieces are called fields. If the pieces are of fixed length, you can use the built-in variable `FIELDWIDTHS` to describe their lengths. If you wish to specify the contents of fields instead of the field separator, you can use the predefined variable `FPAT` to do so. (See Section 4.5 [Specifying How Fields Are Separated], page 77, Section 4.6 [Reading Fixed-Width Data], page 84, and Section 4.7 [Defining Fields by Content], page 87.)

Flag
: A variable whose truth value indicates the existence or nonexistence of some condition.

Floating-Point Number
: Often referred to in mathematical terms as a "rational" or real number, this is just a number that can have a fractional part. See also "Double Precision" and "Single Precision."

Format
: Format strings control the appearance of output in the `strftime()` and `sprintf()` functions, and in the `printf` statement as well. Also, data conversions from numbers to strings are controlled by the format strings contained in the predefined variables `CONVFMT` and `OFMT`. (See Section 5.5.2 [Format-Control Letters], page 107.)

Fortran
: Shorthand for FORmula TRANslator, one of the first programming languages available for scientific calculations. It was created by John Backus, and has been available since 1957. It is still in use today.

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FSF
: See "Free Software Foundation."

Function
: A part of an `awk` program that can be invoked from every point of the program, to perform a task. `awk` has several built-in functions. Users can define their own functions in every part of the program. Function can be recursive, i.e., they may invoke themselves. See Chapter 9 [Functions], page 197. In `gawk` it is also possible to have functions shared among different programs, and included where required using the `@include` directive (see Section 2.7 [Including Other Files into Your Program], page 46). In `gawk` the name of the function that should be invoked can be generated at run time, i.e., dynamically. The `gawk` extension API provides constructor functions (see Section 17.4.4 [Constructor Functions], page 425).

`gawk`
: The GNU implementation of `awk`.

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GMT
: "Greenwich Mean Time." This is the old term for UTC. It is the time of day used internally for Unix and POSIX systems. See also "Epoch" and "UTC."

GNU
: "GNU's not Unix". An on-going project of the Free Software Foundation to create a complete, freely distributable, POSIX-compliant computing environment.

GNU/Linux
: A variant of the GNU system using the Linux kernel, instead of the Free Software Foundation's Hurd kernel. The Linux kernel is a stable, efficient, full-featured clone of Unix that has been ported to a variety of architectures. It is most popular on PC-class systems, but runs well on a variety of other systems too. The Linux kernel source code is available under the terms of the GNU General Public License, which is perhaps its most important aspect.

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Hexadecimal
: Base 16 notation, where the digits are `0`–`9` and `A`–`F`, with '`A`' representing 10, '`B`' representing 11, and so on, up to '`F`' for 15. Hexadecimal numbers are written in C using a leading '`0x`', to indicate their base. Thus, `0x12` is 18 ($(1 \times 16) + 2$). See Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124.

I/O
: Abbreviation for "Input/Output," the act of moving data into and/or out of a running program.

Input Record
: A single chunk of data that is read in by `awk`. Usually, an `awk` input record consists of one line of text. (See Section 4.1 [How Input Is Split into Records], page 69.)

Integer
: A whole number, i.e., a number that does not have a fractional part.

Internationalization
: The process of writing or modifying a program so that it can use multiple languages without requiring further source code changes.

Interpreter
: A program that reads human-readable source code directly, and uses the instructions in it to process data and produce results. `awk` is typically (but not always) implemented as an interpreter. See also "Compiler."

Interval Expression
: A component of a regular expression that lets you specify repeated matches of some part of the regexp. Interval expressions were not originally available in `awk` programs.

ISO
: The International Organization for Standardization. This organization produces international standards for many things, including programming languages, such as C and C++. In the computer arena, important standards like those for C, C++, and POSIX become both American national and ISO international standards simultaneously. This book refers to Standard C as "ISO C" throughout. See the ISO website for more information about the name of the organization and its language-independent three-letter acronym.

Java
: A modern programming language originally developed by Sun Microsystems (now Oracle) supporting Object-Oriented programming. Although usually implemented by compiling to the instructions for a standard virtual machine (the JVM), the language can be compiled to native code.

Keyword
: In the `awk` language, a keyword is a word that has special meaning. Keywords are reserved and may not be used as variable names.

  `gawk`'s keywords are: `BEGIN`, `BEGINFILE`, `END`, `ENDFILE`, `break`, `case`, `continue`, `default`, `delete`, `do...while`, `else`, `exit`, `for...in`, `for`, `function`, `func`, `if`, `next`, `nextfile`, `switch`, and `while`.

Korn Shell
: The Korn Shell (`ksh`) is a Unix shell which was developed by David Korn at Bell Laboratories in the early 1980s. The Korn Shell is backward-compatible with the Bourne shell and includes many features of the C shell. See also "Bourne Shell."

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Linux
: See "GNU/Linux."

Localization
: The process of providing the data necessary for an internationalized program to work in a particular language.

Logical Expression
: An expression using the operators for logic, AND, OR, and NOT, written '`&&`', '`||`', and '`!`' in `awk`. Often called *Boolean expressions*, after the mathematician who pioneered this kind of mathematical logic.

Lvalue
: An expression that can appear on the left side of an assignment operator. In most languages, lvalues can be variables or array elements. In `awk`, a field designator can also be used as an lvalue.

Matching
: The act of testing a string against a regular expression. If the regexp describes the contents of the string, it is said to *match* it.

Metacharacters
: Characters used within a regexp that do not stand for themselves. Instead, they denote regular expression operations, such as repetition, grouping, or alternation.

Nesting
: Nesting is where information is organized in layers, or where objects contain other similar objects. In `gawk` the `@include` directive can be nested. The "natural" nesting of arithmetic and logical operations can be changed using parentheses (see Section 6.5 [Operator Precedence (How Operators Nest)], page 148).

No-op
: An operation that does nothing.

Null String
: A string with no characters in it. It is represented explicitly in `awk` programs by placing two double quote characters next to each other (`""`). It can appear in input data by having two successive occurrences of the field separator appear next to each other.

Number
: A numeric-valued data object. Modern `awk` implementations use double precision floating-point to represent numbers. Ancient `awk` implementations used single precision floating-point.

Octal
: Base-eight notation, where the digits are `0`–`7`. Octal numbers are written in C using a leading '`0`', to indicate their base. Thus, `013` is 11 ($(1 \times 8) + 3$). See Section 6.1.1.2 [Octal and Hexadecimal Numbers], page 124.

Output Record
: A single chunk of data that is written out by `awk`. Usually, an `awk` output record consists of one or more lines of text. See Section 4.1 [How Input Is Split into Records], page 69.

Pattern
: Patterns tell `awk` which input records are interesting to which rules.

  A pattern is an arbitrary conditional expression against which input is tested. If the condition is satisfied, the pattern is said to *match* the input record. A typical pattern might compare the input record against a regular expression. (See Section 7.1 [Pattern Elements], page 151.)

PEBKAC An acronym describing what is possibly the most frequent source of computer usage problems. (Problem Exists Between Keyboard And Chair.)

Plug-in See "Extensions."

POSIX The name for a series of standards that specify a Portable Operating System interface. The "IX" denotes the Unix heritage of these standards. The main standard of interest for `awk` users is *IEEE Standard for Information Technology, Standard 1003.1™-2017 (Revision of IEEE Std 1003.1-2008)*. The 2018 POSIX standard can be found online at `https://pubs.opengroup.org/onlinepubs/9699919799/`.

Precedence
The order in which operations are performed when operators are used without explicit parentheses.

Private Variables and/or functions that are meant for use exclusively by library functions and not for the main `awk` program. Special care must be taken when naming such variables and functions. (See Section 10.1 [Naming Library Function Global Variables], page 248.)

Range (of input lines)
A sequence of consecutive lines from the input file(s). A pattern can specify ranges of input lines for `awk` to process or it can specify single lines. (See Section 7.1 [Pattern Elements], page 151.)

Record See "Input record" and "Output record."

Recursion When a function calls itself, either directly or indirectly. If this is clear, stop, and proceed to the next entry. Otherwise, refer to the entry for "recursion."

Redirection
Redirection means performing input from something other than the standard input stream, or performing output to something other than the standard output stream.

You can redirect input to the `getline` function using the '`<`', '`|`', and '`|&`' operators. You can redirect the output of the `print` and `printf` statements to a file or a system command, using the '`>`', '`>>`', '`|`', and '`|&`' operators. (See Section 4.10 [Explicit Input with `getline`], page 92, and Section 5.6 [Redirecting Output of `print` and `printf`], page 112.)

Reference Counts
An internal mechanism in `gawk` to minimize the amount of memory needed to store the value of string variables. If the value assumed by a variable is used in more than one place, only one copy of the value itself is kept, and the associated reference count is increased when the same value is used by an additional variable, and decreased when the related variable is no longer in use. When the reference count goes to zero, the memory space used to store the value of the variable is freed.

Regexp See "Regular Expression."

Regular Expression
: A regular expression ("regexp" for short) is a pattern that denotes a set of strings, possibly an infinite set. For example, the regular expression '`R.*xp`' matches any string starting with the letter '`R`' and ending with the letters '`xp`'. In `awk`, regular expressions are used in patterns and in conditional expressions. Regular expressions may contain escape sequences. (See Chapter 3 [Regular Expressions], page 51.)

Regular Expression Constant
: A regular expression constant is a regular expression written within slashes, such as `/foo/`. This regular expression is chosen when you write the `awk` program and cannot be changed during its execution. (See Section 3.1 [How to Use Regular Expressions], page 51.)

Regular Expression Operators
: See "Metacharacters."

Rounding
: Rounding the result of an arithmetic operation can be tricky. More than one way of rounding exists, and in `gawk` it is possible to choose which method should be used in a program. See Section 16.4.5 [Setting the Rounding Mode], page 408.

Rule
: A segment of an `awk` program that specifies how to process single input records. A rule consists of a *pattern* and an *action*. `awk` reads an input record; then, for each rule, if the input record satisfies the rule's pattern, `awk` executes the rule's action. Otherwise, the rule does nothing for that input record.

Rvalue
: A value that can appear on the right side of an assignment operator. In `awk`, essentially every expression has a value. These values are rvalues.

Scalar
: A single value, be it a number or a string. Regular variables are scalars; arrays and functions are not.

Search Path
: In `gawk`, a list of directories to search for `awk` program source files. In the shell, a list of directories to search for executable programs.

`sed`
: See "Stream Editor."

Seed
: The initial value, or starting point, for a sequence of random numbers.

Shell
: The command interpreter for Unix and POSIX-compliant systems. The shell works both interactively, and as a programming language for batch files, or shell scripts.

Short-Circuit
: The nature of the `awk` logical operators '`&&`' and '`||`'. If the value of the entire expression is determinable from evaluating just the lefthand side of these operators, the righthand side is not evaluated. (See Section 6.3.3 [Boolean Expressions], page 144.)

Side Effect
: A side effect occurs when an expression has an effect aside from merely producing a value. Assignment expressions, increment and decrement expressions,

and function calls have side effects. (See Section 6.2.3 [Assignment Expressions], page 135.)

Single Precision
: An internal representation of numbers that can have fractional parts. Single precision numbers keep track of fewer digits than do double precision numbers, but operations on them are sometimes less expensive in terms of CPU time. This is the type used by some ancient versions of `awk` to store numeric values. It is the C type `float`.

Space
: The character generated by hitting the space bar on the keyboard.

Special File
: A file name interpreted internally by `gawk`, instead of being handed directly to the underlying operating system—for example, `/dev/stderr`. (See Section 5.8 [Special File names in `gawk`], page 116.)

Statement
: An expression inside an `awk` program in the action part of a pattern–action rule, or inside an `awk` function. A statement can be a variable assignment, an array operation, a loop, etc.

Stream Editor
: A program that reads records from an input stream and processes them one or more at a time. This is in contrast with batch programs, which may expect to read their input files in entirety before starting to do anything, as well as with interactive programs which require input from the user.

String
: A datum consisting of a sequence of characters, such as '`I am a string`'. Constant strings are written with double quotes in the `awk` language and may contain escape sequences. (See Section 3.2 [Escape Sequences], page 52.)

Tab
: The character generated by hitting the *TAB* key on the keyboard. It usually expands to up to eight spaces upon output.

Text Domain
: A unique name that identifies an application. Used for grouping messages that are translated at runtime into the local language.

Timestamp
: A value in the "seconds since the epoch" format used by Unix and POSIX systems. Used for the `gawk` functions `mktime()`, `strftime()`, and `systime()`. See also "Epoch," "GMT," and "UTC."

Unix
: A computer operating system originally developed in the early 1970's at AT&T Bell Laboratories. It initially became popular in universities around the world and later moved into commercial environments as a software development system and network server system. There are many commercial versions of Unix, as well as several work-alike systems whose source code is freely available (such as GNU/Linux, NetBSD, FreeBSD, and OpenBSD).

UTC
: The accepted abbreviation for "Universal Coordinated Time." This is standard time in Greenwich, England, which is used as a reference time for day and date calculations. See also "Epoch" and "GMT."

Variable
: A name for a value. In `awk`, variables may be either scalars or arrays.

Whitespace
: A sequence of space, TAB, or newline characters occurring inside an input record or a string.

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