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Second Edition

Learning Go

An Idiomatic Approach to Real-World Go Programming

Jon Bodner

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Learning Go

Go has rapidly become the preferred language for building web services. Plenty of tutorials are available to teach Go's syntax to developers with experience in other programming languages, but tutorials aren't enough. They don't teach Go's idioms, so developers end up recreating patterns that don't make sense in a Go context. This practical guide provides the essential background you need to write clear and idiomatic Go.

No matter your level of experience, you'll learn how to think like a Go developer. Author Jon Bodner introduces the design patterns experienced Go developers have adopted and explores the rationale for using them. This updated edition also includes a new chapter on Go tooling.

This book helps you:

- **Write idiomatic code in Go and design a Go project**
- **Understand the reasons behind Go's design decisions**
- **Set up a Go development environment for solo developers or teams**
- **Learn how and when to use reflection, unsafe, and cgo**
- **Discover how Go's features allow the language to run efficiently**
- **Know which features you should use sparingly or not at all**
- **Improve performance, optimize memory usage, and reduce garbage collection**
- **Learn how to use Go's advanced development tools**

"Go is unique and even experienced programmers have to unlearn a few things and think differently about software. *Learning Go* does a good job of working through the big features of the language while pointing out idiomatic code, pitfalls, and design patterns along the way."

—Aaron Schlesinger
Senior Engineer, Microsoft

Jon Bodner is a staff engineer at Datadog, where he leads the effort to simplify onboarding to the company's APM products. He's also the creator of the Proteus data access library. He's been a software engineer, lead developer, and architect for over 25 years.

GO / PROGRAMMING LANGUAGES

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Praise for *Learning Go*, Second Edition

“The first edition of *Learning Go* was an excellent starting point for any developer interested in learning Go, and the second edition is even better. This book is thorough without being monotonous, which is perfect for introducing newcomers to the Go ecosystem.”

—Jonathan Hall, Go Developer and Content Creator

"*Learning Go* does more than teach Go, it teaches good idiomatic Go. It is the perfect book for programmers familiar with other languages who want to learn Go.”

—Chris Hines, Senior Principal Software Engineer, Comcast

Praise for *Learning Go*, First Edition

"Go is unique and even experienced programmers have to unlearn a few things and think differently about software. *Learning Go* does a good job of working through the big features of the language while pointing out idiomatic code, pitfalls, and design patterns along the way."

—Aaron Schlesinger, Senior Engineer, Microsoft

"Jon has been a critical voice in the Go community for many years and we have been strongly benefitted from his talks and articles. With *Learning Go*, Jon has written the programmers' guide to learning Go. It strikes just the right balance of giving a good overview of what you need to know without rehashing well understood concepts from other languages."

—Steve Francia, Go language product lead, Google, and author of Hugo, Cobra, and Viper

"Bodner gets Go. In clear, lively prose, he teaches the language from its basics to advanced topics like reflection and C interop. He demonstrates through numerous examples how to write *idiomatic* Go, with its emphasis on clarity and simplicity. He also takes the time to explain the underlying concepts that can affect your program's behavior, like the effects of pointers on memory layout and garbage collection. Beginners who read this book will come up to speed quickly, and even experienced Go programmers are likely to learn something."

—Jonathan Amsterdam, Software Engineer on the Go team at Google

“*Learning Go* is the essential introduction to what makes the Go programming language unique as well as the design patterns and idioms that make it so powerful. Jon Bodner manages to connect the fundamentals of the language to Go’s philosophy, guiding readers to write Go the way it was meant to be written.”

—Robert Liebowitz, Software Engineer at Morning Consult

“Jon wrote a book that does more than just reference Go; it provides an idiomatic and practical understanding of the language. Jon’s industry experience is what drives this book, and it will help those looking to be immediately productive in the language.”

—William Kennedy, Managing Partner at Ardan Labs

SECOND EDITION

Learning Go

An Idiomatic Approach to Real-World Go Programming

Jon Bodner

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Learning Go
by Jon Bodner

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Preface

In the preface of the first edition, I wrote:

> My first choice for a book title was *Boring Go* because, properly written, Go is boring….
>
> Boring does not mean trivial. Using Go correctly requires an understanding of how its features are intended to fit together. While you can write Go code that looks like Java or Python, you're going to be unhappy with the result and wonder what all the fuss is about. That's where this book comes in. It walks through the features of Go, explaining how to best use them to write idiomatic code that can grow.

Go remains a small language with a small feature set. It still lacks inheritance, aspect-oriented programming, function overloading, operator overloading, pattern matching, named parameters, exceptions, and many additional features that complicate other languages. So why does a book on a boring language need an update?

There are a few reasons for this edition. First, just as boring doesn't mean *trivial*, it also does not mean *unchanging*. Over the past three years, new features, tools, and libraries have arrived. Improvements like structured logging, fuzzing, workspaces, and vulnerability checking help Go developers create reliable, lasting, maintainable code. Now that Go developers have several years of experience with generics, the standard library has started to include type constraints and generic functions to reduce repetitive code. Even the unsafe package has been updated to make it a little safer. Go developers need a resource that explains how to best use these new features.

Secondly, some aspects of Go weren't done justice by the first edition. The introductory chapter didn't flow as well as I'd like. The rich Go tool ecosystem wasn't explored. And first-edition readers asked for exercises and additional sample code. This edition attempts to address those limitations.

Finally, the Go team has introduced something new, and, dare I say, *exciting*. There's now a strategy that allows Go to keep the backward compatibility required for long-term software engineering projects while providing the ability to introduce backward-breaking changes to address long-standing design flaws. The new `for` loop variable scoping rules introduced in Go 1.22 are the first feature to take advantage of this approach.

Go is still boring, it's still fantastic, and it's better than ever. I hope you enjoy this second edition.

Who Should Read This Book

This book is targeted at developers who are looking to pick up a second (or fifth) language. The focus is on people who are new to Go. This ranges from those who don't know anything about Go other than it has a cute mascot, to those who have already worked through a Go tutorial or even written some Go code. The focus for *Learning Go* isn't just how to write programs in Go; it's how to write Go *idiomatically*. More experienced Go developers can find advice on how to best use the newer features of the language. The most important thing is that the reader wants to learn how to write Go code that looks like Go.

Experience is assumed with the tools of the developer trade, such as version control (preferably Git) and IDEs. Readers should be familiar with basic computer science concepts like concurrency and abstraction, as the book explains how they work in Go. Some of the code examples are downloadable from GitHub, and dozens more can be tried out online on The Go Playground. While an internet connection isn't required, it is helpful when reviewing executable examples. Since Go is often used to build and call HTTP servers, some examples assume familiarity with basic HTTP concepts.

While most of Go's features are found in other languages, Go makes different trade-offs, so programs written in it have a different structure. *Learning Go* starts by looking at how to set up a Go development environment, and then covers variables, types, control structures, and functions. If you are tempted to skip over this material, resist the urge and take a look. It is often the details that make your Go code idiomatic. Some of what seems obvious at first glance might actually be subtly surprising when you think about it in depth.

Conventions Used in This Book

The following typographical conventions are used in this book:

Italic
: 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.

`Constant width italic`
: Shows text that should be replaced with user-supplied values or by values determined by context.

This element signifies a tip or suggestion.

This element signifies a general note.

This element indicates a warning or caution.

Using Code Examples

Supplemental material (code examples, exercises, etc.) is available for download at *https://github.com/learning-go-book-2e*.

If you have a technical question or a problem using the code examples, please send email to *bookquestions@oreilly.com*.

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Acknowledgments for the 2nd Edition

I've been humbled and flattered by the response to the first edition of *Learning Go*. It was started in late 2019, completed in late 2020, and released in early 2021. It was, unintentionally, my own pandemic project. Some people baked bread; I explained pointers.

After I finished, people asked me what my next book would be. I told them that I was going to take a well-deserved break and then get to work on a romance novel. But before I could start writing about pirates and princesses, something amazing happened: *Learning Go* was a huge success. It spent the better part of a year as one of the five most popular books on O'Reilly Learning. As sales continued, I saw things in the first edition that I wanted to fix and received letters from readers pointing out errors and omissions. Some were fixed as errata in later printings, but I contacted O'Reilly to see if they would like a new edition, and they were interested.

Returning to *Learning Go* and O'Reilly for the second edition was a pleasant experience. Rita Fernando provided guidance, feedback, and editing. This edition has been made immeasurably better by feedback from Jonathan Amsterdam, Leam Hall, Katie Hockman, Thomas Hunter, Max Horstmann, and Natalie Pistunovich. Chris Hines did an incredibly thorough job finding my mistakes and suggesting better examples. The comments and feedback from Abby Deng and the members of the Go Book Club at Datadog allowed me to makes changes based on feedback from developers new to Go. The (hopefully few) remaining errors are all mine.

My wife and children were kind enough to not mind me skipping out on family movie nights while I figured out the best way to describe new Go features.

I also want to thank the readers of the first edition who reached out to me with their kind words. I thank you all for your support and encouragement.

Acknowledgments for the 1st Edition

Writing a book seems like a solitary task, but it doesn't happen without the help of a great number of people. I mentioned to Carmen Andoh that I wanted to write a book on Go and at GopherCon 2019, and she introduced me to Zan McQuade at O'Reilly. Zan guided me through the acquisition process and continued to provide me advice while I was writing *Learning Go*. Michele Cronin edited the text, gave feedback, and listened during the inevitable rough patches. Tonya Trybula's copyediting and Beth Kelly's production editing made my draft production-quality.

While writing, I received critical feedback (and encouragement) from many people including Jonathan Altman, Jonathan Amsterdam, Johnny Ray Austin, Chris Fauerbach, Chris Hines, Bill Kennedy, Tony Nelson, Phil Pearl, Liz Rice, Aaron Schlesinger, Chris Stout, Kapil Thangavelu, Claire Trivisonno, Volker Uhrig, Jeff Wendling, and

Kris Zaragoza. I'd especially like to recognize Rob Liebowitz, whose detailed notes and rapid responses made this book far better than it would have been without his efforts.

My family put up with me spending nights and weekends at the computer instead of with them. In particular, my wife, Laura, graciously pretended that I didn't wake her up when I'd come to bed at 1 A.M. or later.

Finally, I want to remember the two people who started me on this path four decades ago. The first is Paul Goldstein, the father of a childhood friend. In 1982, Paul showed us a Commodore PET, typed PRINT 2 + 2, and hit the Enter key. I was amazed when the screen said 4 and was instantly hooked. He later taught me how to program and even let me borrow the PET for a few weeks. Second, I'd like to thank my mother for encouraging my interest in programming and computers, despite having no idea what any of it was for. She bought me the BASIC programming cartridge for the Atari 2600, a VIC-20, and then a Commodore 64, along with the programming books that inspired me to want to write my own someday.

Thank you all for helping make this dream of mine come true.

CHAPTER 1

Setting Up Your Go Environment

Every programming language needs a development environment, and Go is no exception. If you've already built a Go program or two, then you have a working environment, but you might have missed out on some of the newer techniques and tools. If this is your first time setting up Go on your computer, don't worry; it's easy to install Go and its supporting tools. After setting up the environment and verifying it, you will build a simple program, learn about the different ways to build and run Go code, and then explore some tools and techniques that make Go development easier.

Installing the Go Tools

To build Go code, you need to download and install the Go development tools. You can find the latest version of the tools at the downloads page on the Go website. Choose the download for your platform and install it. The *.pkg* installer for Mac and the *.msi* installer for Windows automatically install Go in the correct location, remove any old installations, and put the Go binary in the default executable path.

> If you are a Mac developer, you can install Go using Homebrew with the command `brew install go`. Windows developers who use Chocolatey can install Go with the command `choco install golang`.

The various Linux and BSD installers are gzipped TAR files and expand to a directory named *go*. Copy this directory to */usr/local* and add */usr/local/go/bin* to your `$PATH` so that the `go` command is accessible:

```
$ tar -C /usr/local -xzf go1.20.5.linux-amd64.tar.gz
$ echo 'export PATH=$PATH:/usr/local/go/bin' >> $HOME/.bash_profile
$ source $HOME/.bash_profile
```

You might need root permissions to write to */usr/local*. If the `tar` command fails, rerun it with `sudo tar -C /usr/local -xzf go1.20.5.linux-amd64.tar.gz`.

Go programs compile to a single native binary and do not require any additional software to be installed in order to run them. This is in contrast to languages like Java, Python, and JavaScript, which require you to install a virtual machine to run your program. Using a single native binary makes it a lot easier to distribute programs written in Go. This book doesn't cover containers, but developers who use Docker or Kubernetes can often package a Go app inside a scratch or distroless image. You can find details in Geert Baeke's blog post "Distroless or Scratch for Go Apps".

You can validate that your environment is set up correctly by opening up a terminal or command prompt and typing:

```
$ go version
```

If everything is set up correctly, you should see something like this printed:

```
go version go1.20.5 darwin/arm64
```

This tells you that this is Go version 1.20.5 on macOS. (Darwin is the operating system at the heart of macOS, and arm64 is the name for the 64-bit chips based on ARM's designs.) On x64 Linux, you would see:

```
go version go1.20.5 linux/amd64
```

Troubleshooting Your Go Installation

If you get an error instead of the version message, it's likely that you don't have `go` in your executable path, or you have another program named `go` in your path. On macOS and other Unix-like systems, use `which go` to see the `go` command being executed, if any. If nothing is returned, you need to fix your executable path.

If you're on Linux or BSD, it's possible you installed the 64-bit Go development tools on a 32-bit system or the development tools for the wrong chip architecture.

Go Tooling

All of the Go development tools are accessed via the `go` command. In addition to `go version`, there's a compiler (`go build`), code formatter (`go fmt`), dependency manager (`go mod`), test runner (`go test`), a tool that scans for common coding mistakes (`go vet`), and more. They are covered in detail in Chapters 10, 11, and

15. For now, let's take a quick look at the most commonly used tools by writing everyone's favorite first application: "Hello, World!""

Since the introduction of Go in 2009, several changes have occurred in the way Go developers organize their code and their dependencies. Because of this churn, there's lots of conflicting advice, and most of it is obsolete (for example, you can safely ignore discussions about `GOROOT` and `GOPATH`).

For modern Go development, the rule is simple: you are free to organize your projects as you see fit and store them anywhere you want.

Your First Go Program

Let's go over the basics of writing a Go program. Along the way, you will see the parts that make up a simple Go program. You might not understand everything just yet, and that's OK; that's what the rest of the book is for!

Making a Go Module

The first thing you need to do is create a directory to hold your program. Call it *ch1*. On the command line, enter the new directory. If your computer's terminal uses bash or zsh, this looks like the following:

```
$ mkdir ch1
$ cd ch1
```

Inside the directory, run the `go mod init` command to mark this directory as a Go module:

```
$ go mod init hello_world
go: creating new go.mod: module hello_world
```

You will learn more about what a module is in Chapter 10, but for now, all you need to know is that a Go project is called a *module*. A module is not just source code. It is also an exact specification of the dependencies of the code within the module. Every module has a *go.mod* file in its root directory. Running `go mod init` creates this file for you. The contents of a basic *go.mod* file look like this:

```
module hello_world

go 1.20
```

The *go.mod* file declares the name of the module, the minimum supported version of Go for the module, and any other modules that your module depends on. You can think of it as being similar to the *requirements.txt* file used by Python or the *Gemfile* used by Ruby.

You shouldn't edit the *go.mod* file directly. Instead, use the `go get` and `go mod tidy` commands to manage changes to the file. Again, all things related to modules are covered in Chapter 10.

go build

Now let's write some code! Open up a text editor, enter the following text, and save it inside *ch1* with the filename *hello.go*:

```go
package main

import "fmt"

func main() {
fmt.Println("Hello, world!")
}
```

(Yes, the indentation in this code example looks sloppy: I meant to do that! You will see why in just a bit.)

Let's quickly go over the parts of the Go file you created. The first line is a package declaration. Within a Go module, code is organized into one or more packages. The `main` package in a Go module contains the code that starts a Go program.

Next there is an import declaration. The `import` statement lists the packages referenced in this file. You're using a function in the `fmt` (usually pronounced "fumpt") package from the standard library, so you list the package here. Unlike other languages, Go imports only whole packages. You can't limit the import to specific types, functions, constants, or variables within a package.

All Go programs start from the `main` function in the `main` package. You declare this function with `func main()` and a left brace. Like Java, JavaScript, and C, Go uses braces to mark the start and end of code blocks.

The body of the function consists of a single line. It says that you are calling the `Println` function in the `fmt` package with the argument `"Hello, world!"`. As an experienced developer, you can likely guess what this function call does.

After the file is saved, go back to your terminal or command prompt and type:

```
$ go build
```

This creates an executable called `hello_world` (or *hello_world.exe* on Windows) in the current directory. Run it and you will unsurprisingly see `Hello, world!` printed on the screen:

```
$ ./hello_world
Hello, world!
```

The name of the binary matches the name in the module declaration. If you want a different name for your application, or if you want to store it in a different location, use the `-o` flag. For example, if you wanted to compile the code to a binary called "hello," you would use the following:

```
$ go build -o hello
```

In "Using go run to Try Out Small Programs" on page 263, I will cover another way to execute a Go program.

go fmt

One of the chief design goals for Go was to create a language that allowed you to write code efficiently. This meant having simple syntax and a fast compiler. It also led Go's authors to reconsider code formatting. Most languages allow a great deal of flexibility in the way code is formatted. Go does not. Enforcing a standard format makes it a great deal easier to write tools that manipulate source code. This simplifies the compiler and allows the creation of some clever tools for generating code.

There is a secondary benefit as well. Developers have historically wasted extraordinary amounts of time on format wars. Since Go defines a standard way of formatting code, Go developers avoid arguments over brace style and tabs versus spaces. For example, Go programs use tabs to indent, and it is a syntax error if the opening brace is not on the same line as the declaration or command that begins the block.

Many Go developers think the Go team defined a standard format as a way to avoid developer arguments and discovered the tooling advantages later. However, Russ Cox, the development lead for Go, has publicly stated that better tooling was his original motivation.

The Go development tools include a command, `go fmt`, which automatically fixes the whitespace in your code to match the standard format. However, it can't fix braces on the wrong line. Run it with the following:

```
$ go fmt ./...
hello.go
```

Using `./...` tells a Go tool to apply the command to all the files in the current directory and all subdirectories. You will see it again as you learn about more Go tools.

If you open up *hello.go*, you'll see that the line with `fmt.Println` is now properly indented with a single tab.

Remember to run `go fmt` before you compile your code, and, at the very least, before you commit source code changes to your repository! If you forget, make a separate commit that does *only* **`go fmt ./...`** so you don't hide logic changes in an avalanche of formatting changes.

The Semicolon Insertion Rule

The `go fmt` command won't fix braces on the wrong line because of the *semicolon insertion rule*. Like C or Java, Go requires a semicolon at the end of every statement. However, Go developers should never put the semicolons in themselves. The Go compiler adds them automatically, following a simple rule described in Effective Go. If the last token before a newline is any of the following, the lexer inserts a semicolon after the token:

- An identifier (which includes words like `int` and `float64`)
- A basic literal such as a number or string constant
- One of the tokens: `break`, `continue`, `fallthrough`, `return`, `++`, `--`, `)`, or `}`

With this simple rule in place, you can see why putting a brace in the wrong place breaks. If you write your code like this:

```
func main()
{
    fmt.Println("Hello, world!")
}
```

the semicolon insertion rule sees the `)` at the end of the `func main()` line and turns that into:

```
func main();
{
    fmt.Println("Hello, world!");
};
```

And that's not valid Go.

The semicolon insertion rule and the resulting restriction on brace placement is one of the things that makes the Go compiler simpler and faster, while at the same time enforcing a coding style. That's clever.

go vet

In one class of bugs, the code is syntactically valid but quite likely incorrect. The `go` tool includes a command called `go vet` to detect these kinds of errors. Add one to the program and watch it get detected. Change the `fmt.Println` line in *hello.go* to the following:

```
fmt.Printf("Hello, %s!\n")
```

`fmt.Printf` is similar to `printf` in C, Java, Ruby, and many other languages. If you haven't seen `fmt.Printf` before, it is a function with a template for its first parameter, and values for the placeholders in the template in the remaining parameters.

In this example, you have a template (`"Hello, %s!\n"`) with a `%s` placeholder, but no value was specified for the placeholder. This code will compile and run, but it's not correct. One of the things that `go vet` detects is whether a value exists for every placeholder in a formatting template. Run `go vet` on the modified code, and it finds an error:

```
$ go vet ./...
# hello_world
./hello.go:6:2: fmt.Printf format %s reads arg #1, but call has 0 args
```

Now that `go vet` found the bug, you can easily fix it. Change line 6 in *hello.go* to:

```
fmt.Printf("Hello, %s!\n", "world")
```

While `go vet` catches several common programming errors, there are things that it cannot detect. Luckily, third-party Go code-quality tools can close the gap. Some of the most popular code-quality tools are covered in "Using Code-Quality Scanners" on page 267.

Just as you should run `go fmt` to make sure your code is formatted properly, run `go vet` to scan for possible bugs in valid code. These commands are just the first step in ensuring that your code is of high quality. In addition to the advice in this book, all Go developers should read through Effective Go and the Code Review Comments page on Go's wiki to understand what idiomatic Go code looks like.

Choose Your Tools

While you wrote a small Go program using nothing more than a text editor and the `go` command, you'll probably want more advanced tools when working on larger projects. Go IDEs provide many advantages over text editors, including automatic formatting on save, code completion, type checking, error reporting, and integrated debugging. Excellent Go development tools are available for most text editors and IDEs. If you don't already have a favorite tool, two of the most popular Go development environments are Visual Studio Code and GoLand.

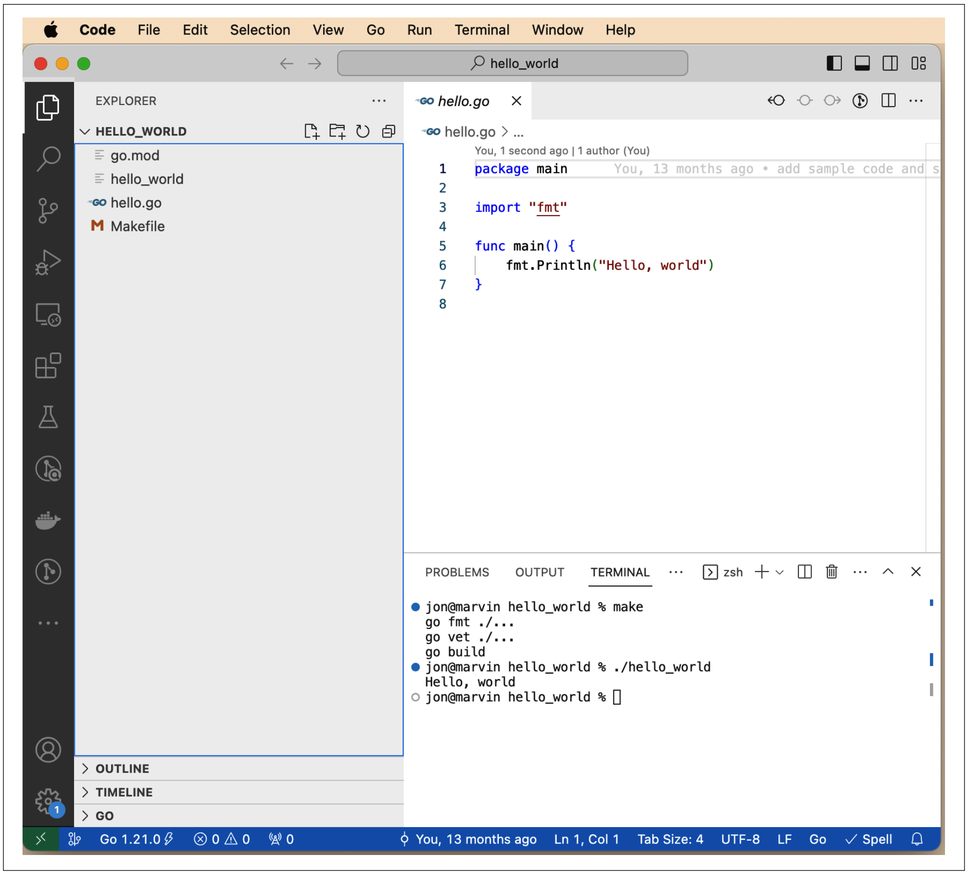
Visual Studio Code

If you are looking for a free development environment, Visual Studio Code from Microsoft is your best option. Since it was released in 2015, VS Code has become the most popular source code editor for developers. It does not ship with Go support, but you can make it a Go development environment by downloading the Go extension from the extensions gallery.

VS Code's Go support relies on third-party extensions that are accessed via its built-in Marketplace. This includes the Go Development tools, the Delve debugger, and gopls, a Go language server developed by the Go team. While you need to install the Go compiler yourself, the Go extension will install Delve and gopls for you.

What is a language server? It's a standard specification for an API that enables editors to implement intelligent editing behavior, like code completion, quality checks, or finding all the places a variable or function is used in your code. You can learn more about language servers and their capabilities by checking out the Language Server Protocol website.

Once your tools are set up, you can open your project and work with it. Figure 1-1 shows you what your project window should look like. "Getting Started with VS Code Go" is a walkthrough that demonstrates the VS Code Go extension.



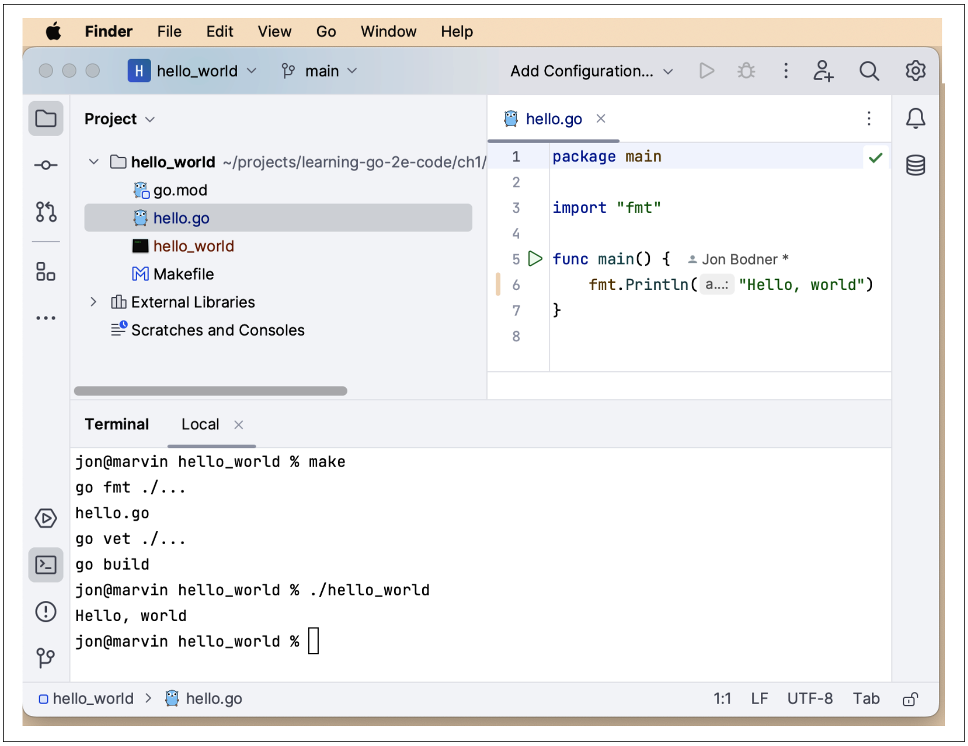
```go
package main

import "fmt"

func main() {
	fmt.Println("Hello, world")
}
```

```
jon@marvin hello_world % make
go fmt ./...
go vet ./...
go build
jon@marvin hello_world % ./hello_world
Hello, world
jon@marvin hello_world %
```

Figure 1-1. Visual Studio Code

GoLand

GoLand is the Go-specific IDE from JetBrains. While JetBrains is best known for Java-centric tools, GoLand is an excellent Go development environment. As you can see in Figure 1-2, GoLand's user interface looks similar to IntelliJ, PyCharm, RubyMine, WebStorm, Android Studio, or any of the other JetBrains IDEs. Its Go support includes refactoring, syntax highlighting, code completion and navigation, documentation pop-ups, a debugger, code coverage, and more. In addition to Go support, GoLand includes JavaScript/HTML/CSS and SQL database tools. Unlike VS Code, GoLand doesn't require you to install a plug-in to get it to work.



```go
package main

import "fmt"

func main() {
    fmt.Println( a...: "Hello, world")
}
```

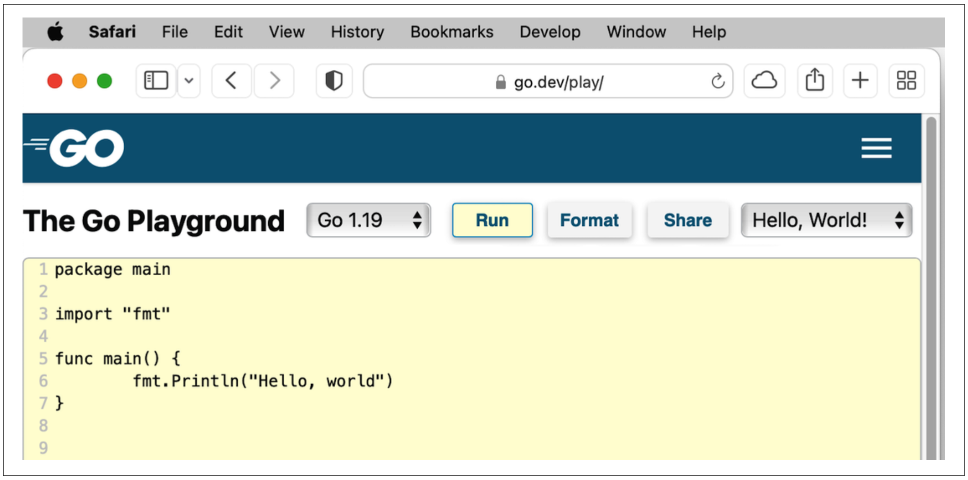
```
jon@marvin hello_world % make
go fmt ./...
hello.go
go vet ./...
go build
jon@marvin hello_world % ./hello_world
Hello, world
jon@marvin hello_world %
```

Figure 1-2. GoLand

If you have already subscribed to IntelliJ Ultimate, you can add Go support via a plug-in. While GoLand is commercial software, JetBrains has a Free License Program for students and core open source contributors. If you don't qualify for a free license, a 30-day free trial is available. After that, you have to pay for GoLand.

The Go Playground

There's one more important tool for Go development, but this is one that you don't install. Visit The Go Playground and you'll see a window that resembles Figure 1-3. If you have used a command-line environment like `irb`, `node`, or `python`, you'll find The Go Playground has a similar feel. It gives you a place to try out and share small programs. Enter your program into the window and click the Run button to execute the code. The Format button runs `go fmt` on your program and updates your imports. The Share button creates a unique URL that you can send to someone else to take a look at your program or to come back to your code at a future date (the URLs have proven to be persistent for a long time, but I wouldn't rely on the playground as your source code repository).



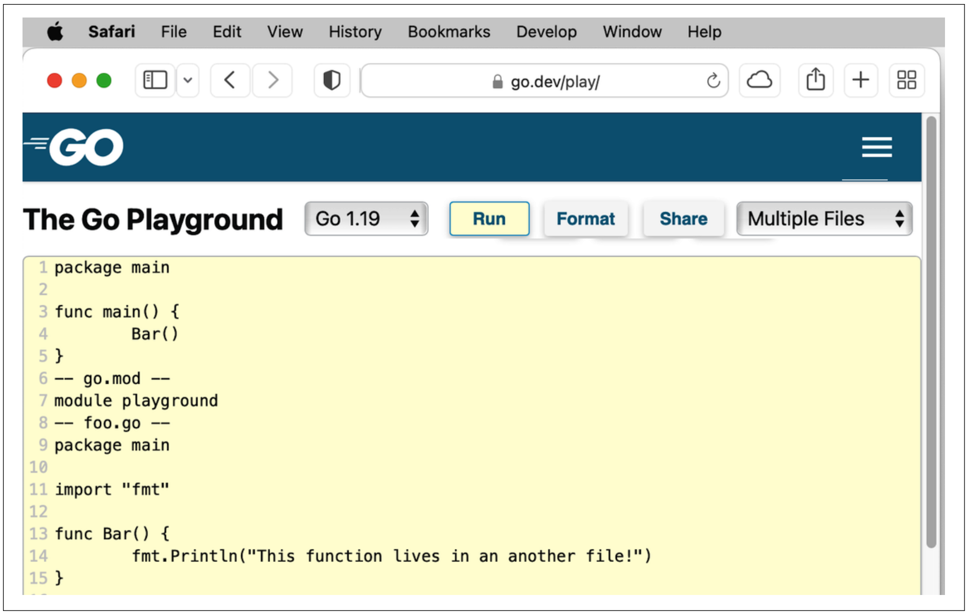
```go
package main

import "fmt"

func main() {
	fmt.Println("Hello, world")
}
```

Figure 1-3. The Go Playground

As you can see in Figure 1-4, you can simulate multiple files by separating each file with a line that looks like `-- filename.go --`. You can even create simulated subdirectories by including a `/` in the filename, such as `-- subdir/my_code.go --`.

Be aware that The Go Playground is on someone else's computer (in particular, Google's computer), so you don't have completely free rein. It gives you a choice of a few versions of Go (usually the current release, the previous release, and the latest development version). You can make network connections only to `localhost`, and processes that run for too long or use too much memory are stopped. If your program depends on time, you need to take into account that the clock is set to November 10, 2009, 23:00:00 UTC (the date of the initial announcement of Go). Even with these limitations, The Go Playground is a useful way to try out new ideas without creating a new project locally. Throughout this book, you'll find links to The Go Playground so you can run code examples without copying them onto your computer.

Do not put sensitive information (such as personally identifiable information, passwords, or private keys) into your playground! If you click the Share button, the information is saved on Google's servers and is accessible to anyone who has the associated Share URL. If you do this by accident, contact Google at *security@golang.org* with the URL and the reason the content needs to be removed.



```
package main

func main() {
	Bar()
}
-- go.mod --
module playground
-- foo.go --
package main

import "fmt"

func Bar() {
	fmt.Println("This function lives in an another file!")
}
```

Figure 1-4. The Go Playground supports multiple files

Makefiles

An IDE is nice to use, but it's hard to automate. Modern software development relies on repeatable, automatable builds that can be run by anyone, anywhere, at any time. Requiring this kind of tooling is good software engineering practice. It avoids the age-old situation where a developer absolves themselves of any build problems with a shrug and the statement, "It works on my machine!" The way to do this is to use some kind of script to specify your build steps. Go developers have adopted `make` as their solution. It lets developers specify a set of operations that are necessary to build a program and the order in which the steps must be performed. You may not be familiar with `make`, but it's been used to build programs on Unix systems since 1976.

Create a file called *Makefile* in the *ch1* directory with the following contents:

```
.DEFAULT_GOAL := build

.PHONY:fmt vet build
fmt:
	go fmt ./...

vet: fmt
	go vet ./...

build: vet
	go build
```

Even if you haven't seen a Makefile before, figuring out what's going on is not too difficult. Each possible operation is called a *target*. The `.DEFAULT_GOAL` defines which target is run when no target is specified. In this case, the default is the `build` target. Next you have the target definitions. The word before the colon (`:`) is the name of the target. Any words after the target (like `vet` in the line `build: vet`) are the other targets that must be run before the specified target runs. The tasks that are performed by the target are on the indented lines after the target. The `.PHONY` line keeps `make` from getting confused if a directory or file in your project has the same name as one of the listed targets.

Run `make` and you should see the following output:

```
$ make
go fmt ./...
go vet ./...
go build
```

Entering a single command formats the code correctly, checks it for nonobvious errors, and compiles it. You can also vet the code with `make vet`, or just run the formatter with `make fmt`. This might not seem like a big improvement, but ensuring that formatting and vetting always happen before a developer (or a script running on a continuous integration build server) triggers a build means you won't miss any steps.

One drawback to Makefiles is that they are exceedingly picky. You *must* indent the steps in a target with a tab. They are also not supported out-of-the-box on Windows. If you are doing your Go development on a Windows computer, you need to install `make` first. The easiest way to do so is to first install a package manager like Chocolatey and then use it to install `make` (for Chocolatey, the command is `choco install make`).

If you want to learn more about writing Makefiles, there's a good tutorial by Chase Lambert, but it does use a tiny bit of C to explain the concepts.

You can find the code from this chapter in the Chapter 1 repository for this book.

The Go Compatibility Promise

As with all programming languages, the Go development tools are periodically updated. Since Go 1.2, a new release has occurred roughly every six months. Patch releases with bug and security fixes are also released as needed. Given the rapid development cycles and the Go team's commitment to backward compatibility, Go releases tend to be incremental rather than expansive. The Go Compatibility Promise is a detailed description of how the Go team plans to avoid breaking Go code. It says that there won't be backward-breaking changes to the language or the standard library for any Go version that starts with 1, unless the change is required for a bug or security fix. In his GopherCon 2022 keynote talk "Compatibility: How Go Programs Keep Working", Russ Cox discusses all the ways that the Go Team works to keep Go code from breaking. He says, "I believe that prioritizing compatibility was the most important design decision that we made in Go 1."

This guarantee doesn't apply to the `go` commands. There have been backward-incompatible changes to the flags and functionality of the `go` commands, and it's entirely possible that it will happen again.

Staying Up-to-Date

Go programs compile to a standalone native binary, so you don't need to worry that updating your development environment could cause your currently deployed programs to fail. You can have programs compiled with different versions of Go running simultaneously on the same computer or virtual machine.

When you are ready to update the Go development tools installed on your computer, Mac and Windows users have the easiest path. Those who installed with `brew` or `chocolatey` can use those tools to update. Those who used the installers on *https://golang.org/dl* can download the latest installer, which removes the old version when it installs the new one.

Linux and BSD users need to download the latest version, move the old version to a backup directory, unpack the new version, and then delete the old version:

```
$ mv /usr/local/go /usr/local/old-go
$ tar -C /usr/local -xzf go1.20.6.linux-amd64.tar.gz
$ rm -rf /usr/local/old-go
```

Technically, you don't need to move the existing installation to a new location; you could just delete it and install the new version. However, this falls in the "better safe than sorry" category. If something goes wrong while installing the new version, it's good to have the previous one around.

Exercises

Each chapter has exercises at the end to let you try out the ideas that I cover. You can find answers to these exercises in the Chapter 1 repository.

1. Take the "Hello, world!" program and run it on The Go Playground. Share a link to the code in the playground with a coworker who would love to learn about Go.
2. Add a target to the Makefile called `clean` that removes the `hello_world` binary and any other temporary files created by `go build`. Take a look at the Go command documentation to find a `go` command to help implement this.

3. Experiment with modifying the formatting in the “Hello, world!” program. Add blank lines, spaces, change indentation, insert newlines. After making a modification, run `go fmt` to see if the formatting change is undone. Also, run `go build` to see if the code still compiles. You can also add additional `fmt.Println` calls so you can see what happens if you put blank lines in the middle of a function.

Wrapping Up

In this chapter, you learned how to install and configure your Go development environment. You also learned about tools for building Go programs and ensuring code quality. Now that your environment is ready, you’re on to the next chapter, where you’ll explore the built-in types in Go and how to declare variables.

CHAPTER 2

Predeclared Types and Declarations

Now that you have your development environment set up, it's time to start looking at Go's language features and how to best use them. When trying to figure out what "best" means, there is one overriding principle: write your programs in a way that makes your intentions clear. As I go through features and discuss the options, I'll explain why I find that a particular approach produces clearer code.

I'll start by looking at the types that are built into Go and how to declare variables of those types. While every programmer has experience with these concepts, Go does some things differently, and subtle differences exist between Go and other languages.

The Predeclared Types

Go has many types built into the language. These are called *predeclared* types. They are similar to types that are found in other languages: booleans, integers, floats, and strings. Using these types idiomatically is sometimes a challenge for developers who are transitioning from another language. You'll look at these types and see how they work best in Go. Before I review the types, let's cover some of the concepts that apply to all types.

The Zero Value

Go, like most modern languages, assigns a default *zero value* to any variable that is declared but not assigned a value. Having an explicit zero value makes code clearer and removes a source of bugs found in C and C++ programs. As I talk about each type, I will also cover the zero value for the type. You can find details on the zero value in The Go Programming Language Specification.

Literals

A Go *literal* is an explicitly specified number, character, or string. Go programs have four common kinds of literals. (I'll cover a rare fifth kind of literal when discussing complex numbers.)

An *integer literal* is a sequence of numbers. Integer literals are base 10 by default, but different prefixes are used to indicate other bases: 0b for binary (base 2), 0o for octal (base 8), or 0x for hexadecimal (base 16). You can use either upper- or lowercase letters for the prefix. A leading 0 with no letter after it is another way to represent an octal literal. Do not use it, as it is very confusing.

To make it easier to read longer integer literals, Go allows you to put underscores in the middle of your literal. This allows you to, for example, group by thousands in base 10 (1_234). These underscores have no effect on the value of the number. The only limitations on underscores are that they can't be at the beginning or end of numbers, and you can't have them next to each other. You could put an underscore between every digit in your literal (1_2_3_4), but don't. Use them to improve readability by breaking up base 10 numbers at the thousands place or to break up binary, octal, or hexadecimal numbers at 1-, 2-, or 4-byte boundaries.

A *floating-point literal* has a decimal point to indicate the fractional portion of the value. They can also have an exponent specified with the letter `e` and a positive or negative number (such as 6.03e23). You also have the option to write them in hexadecimal by using the 0x prefix and the letter `p` for indicating any exponent (0x12.34p5, which is equal to 582.5 in base 10). As integer literals, you can use underscores to format your floating-point literals.

A *rune literal* represents a character and is surrounded by single quotes. Unlike many other languages, in Go single quotes and double quotes are *not* interchangeable. Rune literals can be written as single Unicode characters (`'a'`), 8-bit octal numbers (`'\141'`), 8-bit hexadecimal numbers (`'\x61'`), 16-bit hexadecimal numbers (`'\u0061'`), or 32-bit Unicode numbers (`'\U00000061'`). There are also several backslash-escaped rune literals, with the most useful ones being newline (`'\n'`), tab (`'\t'`), single quote (`'\''`), and backslash (`'\\'`).

Practically speaking, use base 10 to represent your integer and floating-point literals. Octal representations are rare, mostly used to represent POSIX permission flag values (such as 0o777 for rwxrwxrwx). Hexadecimal and binary are sometimes used for bit filters or networking and infrastructure applications. Avoid using any of the numeric escapes for rune literals, unless the context makes your code clearer.

There are two ways to indicate *string literals*. Most of the time, you should use double quotes to create an *interpreted string literal* (e.g., type **`"Greetings and Salutations"`**). These contain zero or more rune literals. They are called "interpreted" because they interpret rune literals (both numeric and backslash escaped) into single characters.

> One rune literal backslash escape is not legal in a string literal: the single quote escape. It is replaced by a backslash escape for double quotes.

The only characters that cannot appear in an interpreted string literal are unescaped backslashes, unescaped newlines, and unescaped double quotes. If you use an interpreted string literal and want your greetings on a different line from your salutations and want "Salutations" to appear in quotes, you need to type **`"Greetings and\n\"Salutations\""`**.

If you need to include backslashes, double quotes, or newlines in your string, using a *raw string literal* is easier. These are delimited with backquotes (`` ` ``) and can contain any character except a backquote. There's no escape character in a raw string literal; all characters are included as is. When using a raw string literal, you write a multiline greeting like so:

```
`Greetings and
"Salutations"`
```

Literals are considered *untyped*. I'll explore this concept more in "Literals Are Untyped" on page 27. As you will see in "var Versus :=" on page 28, there are situations in Go where the type isn't explicitly declared. In those cases, Go uses the *default type* for a literal; if there's nothing in the expression that makes clear what the type of the literal is, the literal defaults to a type. I will mention the default type for literals when discussing the different predeclared types.

Booleans

The `bool` type represents Boolean variables. Variables of `bool` type can have one of two values: `true` or `false`. The zero value for a `bool` is `false`:

```
var flag bool // no value assigned, set to false
var isAwesome = true
```

It's hard to talk about variable types without showing a variable declaration, and vice versa. I'll use variable declarations first and describe them in "var Versus :=" on page 28.

Numeric Types

Go has a large number of numeric types: 12 types (and a few special names) that are grouped into three categories. If you are coming from a language like JavaScript that gets along with only a single numeric type, this might seem like a lot. And in fact, some types are used frequently while others are more esoteric. I'll start by looking at integer types before moving on to floating-point types and the very unusual complex type.

Integer types

Go provides both signed and unsigned integers in a variety of sizes, from one to eight bytes. They are shown in Table 2-1.

Table 2-1. The integer types in Go

Type name	Value range
`int8`	–128 to 127
`int16`	–32768 to 32767
`int32`	–2147483648 to 2147483647
`int64`	–9223372036854775808 to 9223372036854775807
`uint8`	0 to 255
`uint16`	0 to 65535
`uint32`	0 to 4294967295
`uint64`	0 to 18446744073709551615

It might be obvious from the name, but the zero value for all of the integer types is `0`.

The special integer types

Go does have some special names for integer types. A `byte` is an alias for `uint8`; it is legal to assign, compare, or perform mathematical operations between a `byte` and a `uint8`. However, you rarely see `uint8` used in Go code; just call it a `byte`.

The second special name is `int`. On a 32-bit CPU, `int` is a 32-bit signed integer like an `int32`. On most 64-bit CPUs, `int` is a 64-bit signed integer, just like an `int64`. Because `int` isn't consistent from platform to platform, it is a compile-time error to assign, compare, or perform mathematical operations between an `int` and an `int32` or `int64` without a type conversion (see "Explicit Type Conversion" on page 26 for more details). Integer literals default to being of `int` type.

Some uncommon 64-bit CPU architectures use a 32-bit signed integer for the `int` type. Go supports three of them: `amd64p32`, `mips64p32`, and `mips64p32le`.

The third special name is `uint`. It follows the same rules as `int`, only it is unsigned (the values are always 0 or positive).

There are two other special names for integer types, `rune` and `uintptr`. You looked at rune literals earlier and I'll discuss the `rune` type in "A Taste of Strings and Runes" on page 25 and `uintptr` in Chapter 16.

Choosing which integer to use

Go provides more integer types than some other languages. Given all these choices, you might wonder when you should use each of them. You should follow three simple rules:

- If you are working with a binary file format or network protocol that has an integer of a specific size or sign, use the corresponding integer type.
- If you are writing a library function that should work with any integer type, take advantage of Go's generics support and use a generic type parameter to represent any integer type (I talk more about functions and their parameters in Chapter 5 and more about generics in Chapter 8.)
- In all other cases, just use `int`.

You'll likely find legacy code where there's a pair of functions that do the same thing, but one has `int64` for the parameters and variables and the other has `uint64`. The reason is that the API was created before generics were added to Go. Without generics, you needed to write functions with slightly different names to implement the same algorithm with different types. Using `int64` and `uint64` meant that you could write the code once and let callers use type conversions to pass values in and convert data that's returned.

You can see this pattern in the Go standard library within the functions `FormatInt` and `FormatUint` in the `strconv` package.

Integer operators

Go integers support the usual arithmetic operators: +, `-`, `*`, `/`, with `%` for modulus. The result of an integer division is an integer; if you want to get a floating-point result, you need to use a type conversion to make your integers into floating-point numbers.

Also, be careful not to divide an integer by 0; this causes a panic (I talk more about panics in "panic and recover" on page 218).

Integer division in Go follows truncation toward zero; see the Go spec's section on arithmetic operators for the full details.

You can combine any of the arithmetic operators with = to modify a variable: +=, -=, *=, /=, and %=. For example, the following code results in x having the value 20:

```go
var x int = 10
x *= 2
```

You compare integers with ==, !=, >, >=, <, and <=.

Go also has bit-manipulation operators for integers. You can bit shift left and right with << and >>, or do bit masks with & (bitwise AND), | (bitwise OR), ^ (bitwise XOR), and &^ (bitwise AND NOT). As with the arithmetic operators, you can also combine all the bitwise operators with = to modify a variable: &=, |=, ^=, &^=, <<=, and >>=.

Floating-point types

Go has two floating-point types, as shown in Table 2-2.

Table 2-2. The floating-point types in Go

Type name	Largest absolute value	Smallest (nonzero) absolute value
`float32`	3.40282346638528859811704183484516925440e+38	1.401298464324817070923729583289916131280e-45
`float64`	1.797693134862315708145274237317043567981e+308	4.940656458412465441765687928682213723651e-324

Like the integer types, the zero value for the floating-point types is 0.

Floating point in Go is similar to floating-point math in other languages. Go uses the IEEE 754 specification, giving a large range and limited precision. Picking which floating-point type to use is straightforward: unless you have to be compatible with an existing format, use `float64`. Floating-point literals have a default type of `float64`, so always using `float64` is the simplest option. It also helps mitigate floating-point accuracy issues since a `float32` has only six- or seven-decimal digits of precision. Don't worry about the difference in memory size unless you have used the profiler to determine that it is a significant source of problems. (Testing and profiling are covered in Chapter 15.)

The bigger question is whether you should be using a floating-point number at all. In many cases, the answer is no. Just like other languages, Go floating-point numbers have a huge range, but they cannot store every value in that range; they store the nearest approximation. Because floats aren't exact, they can be used only in situations where inexact values are acceptable or the rules of floating point are well understood. That limits them to things like graphics, statistics, and scientific operations.

A floating-point number cannot represent a decimal value exactly. Do not use them to represent money or any other value that must have an exact decimal representation! You'll look at a third-party module for handling exact decimal values in "Importing Third-Party Code" on page 240.

IEEE 754

As mentioned earlier, Go (and most other programming languages) stores floating-point numbers using a specification called IEEE 754.

The actual rules are outside the scope of this book, and they aren't straightforward. You can learn more about IEEE 754 from The Floating Point Guide.

You can use all the standard mathematical and comparison operators with floats, except `%`. Floating-point division has a couple of interesting properties. Dividing a nonzero floating-point variable by 0 returns `+Inf` or `-Inf` (positive or negative infinity), depending on the sign of the number. Dividing a floating-point variable set to 0 by 0 returns `NaN` (Not a Number).

While Go lets you use `==` and `!=` to compare floats, don't do it. Because of the inexact nature of floats, two floating-point values might not be equal when you think they should be. Instead, define a maximum allowed variance and see if the difference between two floats is less than that. This value (sometimes called *epsilon*) depends on your accuracy needs; I can't give you a simple rule. If you aren't sure, consult your friendly local mathematician for advice. If you can't find one, The Floating Point Guide has a "Comparison" page that can help you out (or possibly convince you to avoid floating-point numbers unless absolutely necessary).

Complex types (you're probably not going to use these)

There is one more numeric type and it is pretty unusual. Go has first-class support for complex numbers. If you don't know what complex numbers are, you are not the target audience for this feature; feel free to skip ahead.

There isn't a lot to the complex number support in Go. Go defines two complex number types. `complex64` uses `float32` values to represent the real and imaginary part, and `complex128` uses `float64` values. Both are declared with the `complex` built-in function:

```
var complexNum = complex(20.3, 10.2)
```

Go uses a few rules to determine the type of the value returned by `complex`:

- If you use untyped constants or literals for both function parameters, you'll create an untyped complex literal, which has a default type of `complex128`.
- If both values passed into `complex` are of `float32` type, you'll create a `complex64`.
- If one value is a `float32` and the other value is an untyped constant or literal that can fit within a `float32`, you'll create a `complex64`.
- Otherwise, you'll create a `complex128`.

All the standard floating-point arithmetic operators work on complex numbers. Just as with floats, you can use `==` or `!=` to compare them, but they have the same precision limitations, so it's best to use the epsilon technique. You can extract the real and imaginary portions of a complex number with the `real` and `imag` built-in functions, respectively. The `math/cmplx` package has additional functions for manipulating `complex128` values.

The zero value for both types of complex numbers has 0 assigned to both the real and imaginary portions of the number.

Example 2-1 shows a simple program that demonstrates how complex numbers work. You can run it for yourself on The Go Playground or in the *sample_code/complex_numbers* directory in the Chapter 2 repository.

Example 2-1. Complex numbers

```
func main() {
    x := complex(2.5, 3.1)
    y := complex(10.2, 2)
    fmt.Println(x + y)
    fmt.Println(x - y)
    fmt.Println(x * y)
    fmt.Println(x / y)
    fmt.Println(real(x))
    fmt.Println(imag(x))
    fmt.Println(cmplx.Abs(x))
}
```

Running this code gives you the following:

```
(12.7+5.1i)
(-7.699999999999999+1.1i)
(19.3+36.62i)
(0.2934098482043688+0.24639022584228065i)
2.5
3.1
3.982461550347975
```

You can see floating-point imprecision on display here too.

In case you were wondering what the fifth kind of primitive literal was, Go supports imaginary literals to represent the imaginary portion of a complex number. They look just like floating-point literals, but they have an `i` for a suffix.

Despite having complex numbers as a predeclared type, Go is not a popular language for numerical computing. Adoption has been limited because other features (like matrix support) are not part of the language and libraries have to use inefficient replacements, like slices of slices. (You'll look at slices in Chapter 3 and how they are implemented in Chapter 6.) But if you need to calculate a Mandelbrot set as part of a larger program, or implement a quadratic equation solver, complex number support is there for you.

You might be wondering why Go includes complex numbers. The answer is simple: Ken Thompson, one of the creators of Go (and Unix), thought they would be interesting. There has been discussion about removing complex numbers from a future version of Go, but it's easier to just ignore the feature.

If you do want to write numerical computing applications in Go, you can use the third-party Gonum package. It takes advantage of complex numbers and provides useful libraries for things like linear algebra, matrices, integration, and statistics. But you should consider other languages first.

A Taste of Strings and Runes

This brings us to strings. Like most modern languages, Go includes strings as a built-in type. The zero value for a string is the empty string. Go supports Unicode; as I showed "Literals" on page 18, you can put any Unicode character into a string. Like integers and floats, strings are compared for equality using `==`, difference with `!=`, or ordering with `>`, `>=`, `<`, or `<=`. They are concatenated by using the `+` operator.

Strings in Go are immutable; you can reassign the value of a string variable, but you cannot change the value of the string that is assigned to it.

Go also has a type that represents a single code point. The *rune* type is an alias for the `int32` type, just as `byte` is an alias for `uint8`. As you could probably guess, a rune literal's default type is a rune, and a string literal's default type is a string.

If you are referring to a character, use the rune type, not the `int32` type. They might be the same to the compiler, but you want to use the type that clarifies the intent of your code:

```
var myFirstInitial rune = 'J' // good - the type name matches the usage
var myLastInitial int32 = 'B' // bad - legal but confusing
```

I am going to talk a lot more about strings in the next chapter, covering some implementation details, relationships with bytes and runes, as well as advanced features and pitfalls.

Explicit Type Conversion

Most languages that have multiple numeric types automatically convert from one to another when needed. This is called *automatic type promotion*, and while it seems very convenient, it turns out that the rules to properly convert one type to another can get complicated and produce unexpected results. As a language that values clarity of intent and readability, Go doesn't allow automatic type promotion between variables. You must use a *type conversion* when variable types do not match. Even different-sized integers and floats must be converted to the same type to interact. This makes it clear exactly what type you want without having to memorize any type conversion rules (see Example 2-2).

Example 2-2. Type conversions

```
var x int = 10
var y float64 = 30.2
var sum1 float64 = float64(x) + y
var sum2 int = x + int(y)
fmt.Println(sum1, sum2)
```

In this sample code, you define four variables. `x` is an `int` with the value 10, and `y` is a `float64` with the value 30.2. Since these are not identical types, you need to convert them to add them together. For `sum1`, you convert `x` to a `float64` using a `float64` type conversion, and for `sum2`, you convert `y` to an `int` using an `int` type conversion. When you run this code, it prints out 40.2 40.

The same behavior applies with different-sized integer types (see Example 2-3).

Example 2-3. Integer type conversions

```go
var x int = 10
var b byte = 100
var sum3 int = x + int(b)
var sum4 byte = byte(x) + b
fmt.Println(sum3, sum4)
```

You can run these examples on The Go Playground or in the *sample_code/type_conversion* directory in the Chapter 2 repository.

This strictness around types has other implications. Since all type conversions in Go are explicit, you cannot treat another Go type as a boolean. In many languages, a nonzero number or a nonempty string can be interpreted as a boolean `true`. Just like automatic type promotion, the rules for "truthy" values vary from language to language and can be confusing. Unsurprisingly, Go doesn't allow truthiness. In fact, *no other type can be converted to a bool, implicitly or explicitly*. If you want to convert from another data type to boolean, you must use one of the comparison operators (`==`, `!=`, `>`, `<`, `<=`, or `>=`). For example, to check if variable `x` is equal to 0, the code would be `x == 0`. If you want to check if string `s` is empty, use `s == ""`.

Type conversions are one of the places where Go chooses to add a little verbosity in exchange for a great deal of simplicity and clarity. You'll see this trade-off multiple times. Idiomatic Go values comprehensibility over conciseness.

Literals Are Untyped

While you can't add two integer variables together if they are declared to be of different types of integers, Go lets you use an integer literal in floating-point expressions or even assign an integer literal to a floating-point variable:

```go
var x float64 = 10
var y float64 = 200.3 * 5
```

This is because, as I mentioned earlier, literals in Go are untyped. Go is a practical language, and it makes sense to avoid forcing a type until the developer specifies one. This means they can be used with any variable whose type is compatible with the literal. When you look at user-defined types in Chapter 7, you'll see that you can even use literals with user-defined types based on predefined types. Being untyped goes only so far; you can't assign a literal string to a variable with a numeric type or a literal number to a string variable, nor can you assign a float literal to an `int`. These are all flagged by the compiler as errors. Size limitations also exist; while you can write numeric literals that are larger than any integer can hold, it is a compile-time error to try to assign a literal whose value overflows the specified variable, such as trying to assign the literal 1000 to a variable of type `byte`.

var Versus :=

For a small language, Go has a lot of ways to declare variables. There's a reason for this: each declaration style communicates something about how the variable is used. Let's go through the ways you can declare a variable in Go and see when each is appropriate.

The most verbose way to declare a variable in Go uses the `var` keyword, an explicit type, and an assignment. It looks like this:

```go
var x int = 10
```

If the type on the righthand side of the = is the expected type of your variable, you can leave off the type from the left side of the =. Since the default type of an integer literal is `int`, the following declares `x` to be a variable of type `int`:

```go
var x = 10
```

Conversely, if you want to declare a variable and assign it the zero value, you can keep the type and drop the = on the righthand side:

```go
var x int
```

You can declare multiple variables at once with `var`, and they can be of the same type:

```go
var x, y int = 10, 20
```

You can declare all zero values of the same type:

```go
var x, y int
```

or of different types:

```go
var x, y = 10, "hello"
```

There's one more way to use `var`. If you are declaring multiple variables at once, you can wrap them in a *declaration list*:

```go
var (
    x    int
    y        = 20
    z    int = 30
    d, e     = 40, "hello"
    f, g string
)
```

Go also supports a short declaration and assignment format. When you are within a function, you can use the `:=` operator to replace a `var` declaration that uses type inference. The following two statements do exactly the same thing—they declare x to be an int with the value of 10:

```
var x = 10
x := 10
```

As with var, you can declare multiple variables at once using :=. These two lines both assign 10 to x and "hello" to y:

```
var x, y = 10, "hello"
x, y := 10, "hello"
```

The := operator can do one trick that you cannot do with var: it allows you to assign values to existing variables too. As long as at least one new variable is on the lefthand side of the :=, any of the other variables can already exist:

```
x := 10
x, y := 30, "hello"
```

Using := has one limitation. If you are declaring a variable at the package level, you must use var because := is not legal outside of functions.

How do you know which style to use? As always, choose what makes your intent clearest. The most common declaration style within functions is :=. Outside of a function, use declaration lists on the rare occasions when you are declaring multiple package-level variables.

In some situations within functions, you should avoid :=:

- When initializing a variable to its zero value, use `var x int`. This makes it clear that the zero value is intended.
- When assigning an untyped constant or a literal to a variable and the default type for the constant or literal isn't the type you want for the variable, use the long var form with the type specified. While it is legal to use a type conversion to specify the type of the value and use := to write `x := byte(20)`, it is idiomatic to write `var x byte = 20`.
- Because := allows you to assign to both new and existing variables, it sometimes creates new variables when you think you are reusing existing ones (see "Shadowing Variables" on page 68 for details). In those situations, explicitly declare all your new variables with var to make it clear which variables are new, and then use the assignment operator (=) to assign values to both new and old variables.

While var and := allow you to declare multiple variables on the same line, use this style only when assigning multiple values returned from a function or the comma ok idiom (see Chapter 5 and "The comma ok Idiom" on page 58).

You should rarely declare variables outside of functions, in what's called the *package block* (see "Blocks" on page 67). Package-level variables whose values change are a bad idea. When you have a variable outside of a function, it can be difficult to track the changes made to it, which makes it hard to understand how data is flowing through your program. This can lead to subtle bugs. As a general rule, you should only declare variables in the package block that are effectively immutable.

Avoid declaring variables outside of functions because they complicate data flow analysis.

You might be wondering: does Go provide a way to *ensure* that a value is immutable? It does, but it is a bit different from what you may have seen in other programming languages. It's time to learn about `const`.

Using const

Many languages have a way to declare a value as immutable. In Go, this is done with the `const` keyword. At first glance, it seems to work exactly as it would in other languages. Try out the code in Example 2-4 on The Go Playground or in the *sample_code/const_declaration* directory in the Chapter 2 repository.

Example 2-4. `const` declarations

```
package main

import "fmt"

const x int64 = 10

const (
    idKey   = "id"
    nameKey = "name"
)

const z = 20 * 10

func main() {
    const y = "hello"

    fmt.Println(x)
    fmt.Println(y)

    x = x + 1 // this will not compile!
    y = "bye" // this will not compile!
    fmt.Println(x)
    fmt.Println(y)
}
```

When you run this code, compilation fails with the following error messages:

```
./prog.go:20:2: cannot assign to x (constant 10 of type int64)
./prog.go:21:2: cannot assign to y (untyped string constant "hello")
```

As you see, you declare a constant at the package level or within a function. Just as with `var`, you can (and should) declare a group of related constants within a set of parentheses.

Be aware that `const` in Go is very limited. Constants in Go are a way to give names to literals. They can only hold values that the compiler can figure out at compile time. This means that they can be assigned:

- Numeric literals
- `true` and `false`
- Strings
- Runes
- The values returned by the built-in functions `complex`, `real`, `imag`, `len`, and `cap`
- Expressions that consist of operators and the preceding values

I'll cover the `len` and `cap` functions in the next chapter. Another value that can be used with `const` is called `iota`. I'll talk about `iota` when I discuss creating your own types in Chapter 7.

Go doesn't provide a way to specify that a value calculated at runtime is immutable. For example, the following code will fail to compile with the error `x + y (value of type int) is not constant`:

```
x := 5
y := 10
const z = x + y // this won't compile!
```

As you'll see in the next chapter, there are no immutable arrays, slices, maps, or structs, and there's no way to declare that a field in a struct is immutable. This is less limiting than it sounds. Within a function, it is clear if a variable is being modified, so immutability is less important. In "Go Is Call by Value" on page 114, you'll see how Go prevents modifications to variables that are passed as parameters to functions.

Constants in Go are a way to give names to literals. There is *no* way in Go to declare that a variable is immutable.

Typed and Untyped Constants

Constants can be typed or untyped. An untyped constant works exactly like a literal; it has no type of its own but does have a default type that is used when no other type can be inferred. A typed constant can be directly assigned only to a variable of that type.

Whether to make a constant typed depends on why the constant was declared. If you are giving a name to a mathematical constant that could be used with multiple numeric types, keep the constant untyped. In general, leaving a constant untyped gives you more flexibility. In certain situations, you'll want a constant to enforce a type. You'll see a use for typed constants when I cover enumerations with `iota` in "iota Is for Enumerations—Sometimes" on page 152.

Here's what an untyped constant declaration looks like:

```go
const x = 10
```

All of the following assignments are legal:

```go
var y int = x
var z float64 = x
var d byte = x
```

Here's what a typed constant declaration looks like:

```go
const typedX int = 10
```

This constant can be assigned directly only to an `int`. Assigning it to any other type produces a compile-time error like this:

```
cannot use typedX (type int) as type float64 in assignment
```

Unused Variables

One of the goals for Go is to make it easier for large teams to collaborate on programs. To do so, Go has some rules that are unique among programming languages. In Chapter 1, you saw that Go programs need to be formatted in a specific way with `go fmt` to make it easier to write code-manipulation tools and to provide coding standards. Another Go requirement is that *every declared local variable must be read*. It is a *compile-time error* to declare a local variable and to not read its value.

The compiler's unused variable check is not exhaustive. As long as a variable is read once, the compiler won't complain, even if there are writes to the variable that are never read. The following is a valid Go program that you can run on The Go Playground or in the *sample_code/assignments_not_read* directory in the Chapter 2 repository:

```
func main() {
    x := 10 // this assignment isn't read!
    x = 20
    fmt.Println(x)
    x = 30 // this assignment isn't read!
}
```

While the compiler and `go vet` do not catch the unused assignments of 10 and 30 to `x`, third-party tools can detect them. I'll talk about these tools in "Using Code-Quality Scanners" on page 267.

The Go compiler won't stop you from creating unread package-level variables. This is one more reason you should avoid creating package-level variables.

Unused Constants

Perhaps surprisingly, the Go compiler allows you to create unread constants with `const`. This is because constants in Go are calculated at compile time and cannot have any side effects. This makes them easy to eliminate: if a constant isn't used, it is simply not included in the compiled binary.

Naming Variables and Constants

There is a difference between Go's rules for naming variables and the patterns that Go developers follow when naming their variables and constants. Like most languages, Go requires identifier names to start with a letter or underscore, and the name can contain numbers, underscores, and letters. Go's definition of "letter" and "number" is a bit broader than many languages. Any Unicode character considered a letter or digit is allowed. This makes all the variable definitions in Example 2-5 perfectly valid Go.

Example 2-5. Variable names you should never use

```
_0 := 0_0
_𝟙 := 20
π := 3
ａ := "hello" // Unicode U+FF41
```

```
__ := "double underscore" // two underscores
fmt.Println(_0)
fmt.Println(_𝟙)
fmt.Println(π)
fmt.Println(ａ)
fmt.Println(__)
```

You can test out this awful code on The Go Playground. While it works, *do not* use variable names like this. These names are considered nonidiomatic because they break the fundamental rule of making sure that your code communicates what it is doing. These names are confusing or difficult to type on many keyboards. Look-alike Unicode code points are the most insidious, because even if they appear to be the same character, they represent entirely different variables. You can run the code shown in Example 2-6 on The Go Playground or in the *sample_code/look_alike_code_points* directory in the Chapter 2 repository.

Example 2-6. Using look-alike code points for variable names

```
func main() {
    ａ := "hello"   // Unicode U+FF41
    a := "goodbye" // standard lowercase a (Unicode U+0061)
    fmt.Println(ａ)
    fmt.Println(a)
}
```

When you run this program, you get:

```
hello
goodbye
```

Even though the underscore is a valid character in a variable name, it is rarely used, because idiomatic Go doesn't use snake case (names like `index_counter` or `number_tries`). Instead, idiomatic Go uses camel case (names like `indexCounter` or `numberTries`) when an identifier name consists of multiple words.

An underscore by itself (_) is a special identifier name in Go; I'll talk more about it when I cover functions in Chapter 5.

In many languages, constants are always written in all uppercase letters, with words separated by underscores (names like `INDEX_COUNTER` or `NUMBER_TRIES`). Go does not follow this pattern. This is because Go uses the case of the first letter in the name of a package-level declaration to determine if the item is accessible outside the package. I will revisit this when I talk about packages in Chapter 10.

Within a function, favor short variable names. *The smaller the scope for a variable, the shorter the name that's used for it*. It is common in Go to see single-letter variable names used with `for` loops. For example, the names `k` and `v` (short for *key* and *value*) are used as the variable names in a `for-range` loop. If you are using a standard `for` loop, `i` and `j` are common names for the index variable. There are other idiomatic ways to name variables of common types; I will mention them as I cover more parts of the standard library.

Some languages with weaker type systems encourage developers to include the expected type of the variable in the variable's name. Since Go is strongly typed, you don't need to do this to keep track of the underlying type. However, you may see Go code where the first letter of a type is used as the variable name (for example, `i` for integers or `f` for floats). When you define your own types, similar patterns apply, especially when naming receiver variables (which are covered in "Methods" on page 144).

These short names serve two purposes. The first is that they eliminate repetitive typing, keeping your code shorter. Second, they serve as a check on how complicated your code is. If you find it hard to keep track of your short-named variables, your block of code is likely doing too much.

When naming variables and constants in the package block, use more descriptive names. The type should still be excluded from the name, but since the scope is wider, you need a more complete name to clarify what the value represents.

For more discussion of Go naming recommendations, read the Naming section of Google's Go Style Decisions.

Exercises

These exercises demonstrate the concepts discussed in the chapter. Solutions to these exercises, along with the programs in this chapter, are in the Chapter 2 repository.

1. Write a program that declares an integer variable called `i` with the value 20. Assign `i` to a floating-point variable named `f`. Print out `i` and `f`.
2. Write a program that declares a constant called `value` that can be assigned to both an integer and a floating-point variable. Assign it to an integer called `i` and a floating-point variable called `f`. Print out `i` and `f`.
3. Write a program with three variables, one named `b` of type `byte`, one named `smallI` of type `int32`, and one named `bigI` of type `uint64`. Assign each variable the maximum legal value for its type; then add `1` to each variable. Print out their values.

Wrapping Up

You've covered a lot of ground here, understanding how to use the predeclared types, declare variables, and work with assignments and operators. In the next chapter, we will look at the composite types in Go: arrays, slices, maps, and structs. We will also take another look at strings and runes and how they interact with character encodings.

CHAPTER 3

Composite Types

In the previous chapter, you looked at literals and predeclared variable types: numbers, booleans, and strings. In this chapter, you'll learn about the composite types in Go, the built-in functions that support them, and the best practices for working with them.

Arrays—Too Rigid to Use Directly

Like most programming languages, Go has arrays. However, arrays are rarely used directly in Go. You'll learn why in a bit, but first let's quickly cover array declaration syntax and use.

All elements in the array must be of the type that's specified. There are a few declaration styles. In the first, you specify the size of the array and the type of the elements in the array:

```
var x [3]int
```

This creates an array of three `int`s. Since no values were specified, all of the elements (`x[0]`, `x[1]`, and `x[2]`) are initialized to the zero value for an `int`, which is (of course) 0. If you have initial values for the array, you specify them with an *array literal*:

```
var x = [3]int{10, 20, 30}
```

If you have a *sparse array* (an array where most elements are set to their zero value), you can specify only the indices with nonzero values in the array literal:

```
var x = [12]int{1, 5: 4, 6, 10: 100, 15}
```

This creates an array of 12 `int`s with the following values: [1, 0, 0, 0, 0, 4, 6, 0, 0, 0, 100, 15].

When using an array literal to initialize an array, you can replace the number that specifies the number of elements in the array with `...`:

```
var x = [...]int{10, 20, 30}
```

You can use `==` and `!=` to compare two arrays. Arrays are equal if they are the same length and contain equal values:

```
var x = [...]int{1, 2, 3}
var y = [3]int{1, 2, 3}
fmt.Println(x == y) // prints true
```

Go has only one-dimensional arrays, but you can simulate multidimensional arrays:

```
var x [2][3]int
```

This declares `x` to be an array of length 2 whose type is an array of `int`s of length 3. This sounds pedantic, but some languages have true matrix support, like Fortran or Julia; Go isn't one of them.

Like most languages, arrays in Go are read and written using bracket syntax:

```
x[0] = 10
fmt.Println(x[2])
```

You cannot read or write past the end of an array or use a negative index. If you do this with a constant or literal index, it is a compile-time error. An out-of-bounds read or write with a variable index compiles but fails at runtime with a *panic* (you'll learn more about panics in "panic and recover" on page 218).

Finally, the built-in function `len` takes in an array and returns its length:

```
fmt.Println(len(x))
```

Earlier I said that arrays in Go are rarely used explicitly. This is because they come with an unusual limitation: Go considers the *size* of the array to be part of the *type* of the array. This makes an array that's declared to be `[3]int` a different type from an array that's declared to be `[4]int`. This also means that you cannot use a variable to specify the size of an array, because types must be resolved at compile time, not at runtime.

What's more, *you can't use a type conversion to directly convert arrays of different sizes to identical types*. Because you can't convert arrays of different sizes into each other, you can't write a function that works with arrays of any size and you can't assign arrays of different sizes to the same variable.

You'll learn how arrays work behind the scenes when I discuss memory layout in Chapter 6.

Because of these restrictions, don't use arrays unless you know the exact length you need ahead of time. For example, some of the cryptographic functions in the standard library return arrays because the sizes of checksums are defined as part of the algorithm. This is the exception, not the rule.

This raises the question: why is such a limited feature in the language? The main reason arrays exist in Go is to provide the backing store for *slices*, which are one of the most useful features of Go.

Slices

Most of the time, when you want a data structure that holds a sequence of values, a slice is what you should use. What makes slices so useful is that you can grow slices as needed. This is because the length of a slice is *not* part of its type. This removes the biggest limitations of arrays and allows you to write a single function that processes slices of any size (I'll cover function writing in Chapter 5). After going over the basics of using slices in Go, I'll cover the best ways to use them.

Working with slices looks a lot like working with arrays, but subtle differences exist. The first thing to notice is that you don't specify the size of the slice when you declare it:

```
var x = []int{10, 20, 30}
```

Using `[...]` makes an array. Using `[]` makes a slice.

This creates a slice of three `int`s using a *slice literal*. Just as with arrays, you can also specify only the indices with nonzero values in the slice literal:

```
var x = []int{1, 5: 4, 6, 10: 100, 15}
```

This creates a slice of 12 `int`s with the following values: [1, 0, 0, 0, 0, 4, 6, 0, 0, 0, 100, 15].

You can simulate multidimensional slices and make a slice of slices:

```
var x [][]int
```

You read and write slices using bracket syntax, and, just as with arrays, you can't read or write past the end or use a negative index:

```
x[0] = 10
fmt.Println(x[2])
```

So far, slices have seemed identical to arrays. You start to see the differences between arrays and slices when you look at declaring slices without using a literal:

```
var x []int
```

This creates a slice of `int`s. Since no value is assigned, `x` is assigned the zero value for a slice, which is something you haven't seen before: `nil`. I'll talk more about `nil` in Chapter 6, but it is slightly different from the `null` that's found in other languages. In Go, `nil` is an identifier that represents the lack of a value for some types. Like the untyped numeric constants you saw in the previous chapter, `nil` has no type, so it can be assigned or compared against values of different types. A `nil` slice contains nothing.

A slice is the first type you've seen that isn't *comparable*. It is a compile-time error to use `==` to see if two slices are identical or `!=` to see if they are different. The only thing you can compare a slice with using `==` is `nil`:

```
fmt.Println(x == nil) // prints true
```

Since Go 1.21, the `slices` package in the standard library includes two functions to compare slices. The `slices.Equal` function takes in two slices and returns `true` if the slices are the same length, and all of the elements are equal. It requires the elements of the slice to be comparable. The other function, `slices.EqualFunc`, lets you pass in a function to determine equality and does not require the slice elements to be comparable. You'll learn about passing functions into functions in "Passing Functions as Parameters" on page 107. The other functions in the `slices` package are covered in "Adding Generics to the Standard Library" on page 201.

```
x := []int{1, 2, 3, 4, 5}
y := []int{1, 2, 3, 4, 5}
z := []int{1, 2, 3, 4, 5, 6}
s := []string{"a", "b", "c"}
fmt.Println(slices.Equal(x, y)) // prints true
fmt.Println(slices.Equal(x, z)) // prints false
fmt.Println(slices.Equal(x, s)) // does not compile
```

The `reflect` package contains a function called `DeepEqual` that can compare almost anything, including slices. It's a legacy function, primarily intended for testing. Before the inclusion of `slices.Equal` and `slices.EqualFunc`, `reflect.DeepEqual` was often used to compare slices. Don't use it in new code, as it is slower and less safe than using the functions in the `slices` package.

len

Go provides several built-in functions to work with slices. You've already seen the built-in `len` function when looking at arrays. It works for slices too. Passing a `nil` slice to `len` returns 0.

> Functions like `len` are built into Go because they can do things that can't be done by the functions that you can write. You've already seen that `len`'s parameter can be any type of array or any type of slice. You'll soon see that it also works for strings and maps. In "Channels" on page 291, you'll see it working with channels. Trying to pass a variable of any other type to `len` is a compile-time error. As you'll see in Chapter 5, Go doesn't let developers write a function that accepts any string, array, slice, channel, or map, but rejects other types.

append

The built-in `append` function is used to grow slices:

```go
var x []int
x = append(x, 10) // assign result to the variable that's passed in
```

The `append` function takes at least two parameters, a slice of any type and a value of that type. It returns a slice of the same type, which is assigned to the variable that was passed to `append`. In this example, you are appending to a `nil` slice, but you can append to a slice that already has elements:

```go
var x = []int{1, 2, 3}
x = append(x, 4)
```

You can append more than one value at a time:

```go
x = append(x, 5, 6, 7)
```

One slice is appended onto another by using the `...` operator to expand the source slice into individual values (you'll learn more about the `...` operator in "Variadic Input Parameters and Slices" on page 95):

```go
y := []int{20, 30, 40}
x = append(x, y...)
```

It is a compile-time error if you forget to assign the value returned from `append`. You might be wondering why as it seems a bit repetitive. I will talk about this in greater detail in Chapter 5, but Go is a *call-by-value* language. Every time you pass a parameter to a function, Go makes a copy of the value that's passed in. Passing a slice to the `append` function actually passes a copy of the slice to the function. The function adds the values to the copy of the slice and returns the copy. You then assign the returned slice back to the variable in the calling function.

Capacity

As you've seen, a slice is a sequence of values. Each element in a slice is assigned to consecutive memory locations, which makes it quick to read or write these values. The length of a slice is the number of consecutive memory locations that have been assigned a value. Every slice also has a *capacity*, which is the number of consecutive memory locations reserved. This can be larger than the length. Each time you append to a slice, one or more values is added to the end of the slice. Each value added increases the length by one. When the length reaches the capacity, there's no more room to put values. If you try to add additional values when the length equals the capacity, the `append` function uses the Go runtime to allocate a new backing array for the slice with a larger capacity. The values in the original backing array are copied to the new one, the new values are added to the end of the new backing array, and the slice is updated to refer to the new backing array. Finally, the updated slice is returned.

The Go Runtime

Every high-level language relies on a set of libraries to enable programs written in that language to run, and Go is no exception. The Go runtime provides services like memory allocation and garbage collection, concurrency support, networking, and implementations of built-in types and functions.

The Go runtime is compiled into every Go binary. This is different from languages that use a virtual machine, which must be installed separately to allow programs written in those languages to function. Including the runtime in the binary makes it easier to distribute Go programs and avoids worries about compatibility issues between the runtime and the program. The drawback of including the runtime in the binary is that even the simplest Go program produces a binary that's about 2 MB.

When a slice grows via `append`, it takes time for the Go runtime to allocate new memory and copy the existing data from the old memory to the new. The old memory also needs to be garbage collected. For this reason, the Go runtime usually increases a slice by more than one each time it runs out of capacity. The rule as of Go 1.18 is to double the capacity of a slice when the current capacity is less than 256. A bigger slice increases by `(current_capacity + 768)/4`. This slowly converges at 25% growth (a slice with capacity of 512 will grow by 63%, but a slice with capacity 4,096 will grow by only 30%).

Just as the built-in `len` function returns the current length of a slice, the built-in `cap` function returns the current capacity of a slice. It is used far less frequently than `len`. Most of the time, `cap` is used to check if a slice is large enough to hold new data, or if a call to `make` is needed to create a new slice.

You can also pass an array to the `cap` function, but `cap` always returns the same value as `len` for arrays. Don't put it in your code, but save this trick for Go trivia night.

Let's take a look at how adding elements to a slice changes the length and capacity. Run the code in Example 3-1 on The Go Playground or in the *sample_code/len_cap* directory in the Chapter 3 repository.

Example 3-1. Understanding capacity

```
var x []int
fmt.Println(x, len(x), cap(x))
x = append(x, 10)
fmt.Println(x, len(x), cap(x))
x = append(x, 20)
fmt.Println(x, len(x), cap(x))
x = append(x, 30)
fmt.Println(x, len(x), cap(x))
x = append(x, 40)
fmt.Println(x, len(x), cap(x))
x = append(x, 50)
fmt.Println(x, len(x), cap(x))
```

When you build and run the code, you'll see the following output. Notice how and when the capacity increases:

```
[] 0 0
[10] 1 1
[10 20] 2 2
[10 20 30] 3 4
[10 20 30 40] 4 4
[10 20 30 40 50] 5 8
```

While it's nice that slices grow automatically, it's far more efficient to size them once. If you know how many things you plan to put into a slice, create it with the correct initial capacity. You do that with the `make` function.

make

You've already seen two ways to declare a slice, using a slice literal or the `nil` zero value. While useful, neither way allows you to create an empty slice that already has a length or capacity specified. That's the job of the built-in `make` function. It allows you to specify the type, length, and, optionally, the capacity. Let's take a look:

```
x := make([]int, 5)
```

This creates an `int` slice with a length of 5 and a capacity of 5. Since it has a length of 5, `x[0]` through `x[4]` are valid elements, and they are all initialized to 0.

One common beginner mistake is to try to populate those initial elements using `append`:

```
x := make([]int, 5)
x = append(x, 10)
```

The 10 is placed at the end of the slice, *after* the zero values in elements 0–4 because `append` always increases the length of a slice. The value of `x` is now [0 0 0 0 0 10], with a length of 6 and a capacity of 10 (the capacity was doubled as soon as the sixth element was appended).

You can also specify an initial capacity with `make`:

```
x := make([]int, 5, 10)
```

This creates an `int` slice with a length of 5 and a capacity of 10.

You can also create a slice with zero length but a capacity that's greater than zero:

```
x := make([]int, 0, 10)
```

In this case, you have a non-`nil` slice with a length of 0 but a capacity of 10. Since the length is 0, you can't directly index into it, but you can append values to it:

```
x := make([]int, 0, 10)
x = append(x, 5,6,7,8)
```

The value of `x` is now [5 6 7 8], with a length of 4 and a capacity of 10.

Never specify a capacity that's less than the length! It is a compile-time error to do so with a constant or numeric literal. If you use a variable to specify a capacity that's smaller than the length, your program will panic at runtime.

Emptying a Slice

Go 1.21 added a `clear` function that takes in a slice and sets all of the slice's elements to their zero value. The length of the slice remains unchanged. The following code:

```
s := []string{"first", "second", "third"}
fmt.Println(s, len(s))
clear(s)
fmt.Println(s, len(s))
```

prints out:

```
[first second third] 3
[  ] 3
```

(Remember, the zero value for a string is an empty string `""`!)

Declaring Your Slice

Now that you've seen all these ways to create slices, how do you choose which slice declaration style to use? The primary goal is to minimize the number of times the slice needs to grow. If it's possible that the slice won't need to grow at all, use a `var` declaration with no assigned value to create a `nil` slice, as shown in Example 3-2.

Example 3-2. Declaring a slice that might stay `nil`

```go
var data []int
```

You can create a slice using an empty slice literal:

```go
var x = []int{}
```

This creates a slice with zero length and zero capacity. It is confusingly different from a `nil` slice. Because of implementation reasons, comparing a zero-length slice to `nil` returns `false`, while comparing a `nil` slice to `nil` returns `true`. For simplicity, favor `nil` slices. A zero-length slice is useful only when converting a slice to JSON. You'll look at this more in "encoding/json" on page 327.

If you have some starting values, or if a slice's values aren't going to change, then a slice literal is a good choice (see Example 3-3).

Example 3-3. Declaring a slice with default values

```go
data := []int{2, 4, 6, 8} // numbers we appreciate
```

If you have a good idea of how large your slice needs to be, but don't know what those values will be when you are writing the program, use `make`. The question then becomes whether you should specify a nonzero length in the call to `make` or specify a zero length and a nonzero capacity. There are three possibilities:

- If you are using a slice as a buffer (you'll see this in "io and Friends" on page 319), then specify a nonzero length.
- If you are *sure* you know the exact size you want, you can specify the length and index into the slice to set the values. This is often done when transforming values in one slice and storing them in a second. The downside to this approach is that if you have the size wrong, you'll end up with either zero values at the end of the slice or a panic from trying to access elements that don't exist.

- In other situations, use make with a zero length and a specified capacity. This allows you to use append to add items to the slice. If the number of items turns out to be smaller, you won't have an extraneous zero value at the end. If the number of items is larger, your code will not panic.

The Go community is split between the second and third approaches. I personally prefer using append with a slice initialized to a zero length. It might be slower in some situations, but it is less likely to introduce a bug.

append always increases the length of a slice! If you have specified a slice's length using make, be sure that you mean to append to it before you do so, or you might end up with a bunch of surprise zero values at the beginning of your slice.

Slicing Slices

A *slice expression* creates a slice from a slice. It's written inside brackets and consists of a starting offset and an ending offset, separated by a colon (:). The starting offset is the first position in the slice that is included in the new slice, and the ending offset is one past the last position to include. If you leave off the starting offset, 0 is assumed. Likewise, if you leave off the ending offset, the end of the slice is substituted. You can see how this works by running the code in Example 3-4 on The Go Playground or in the *sample_code/slicing_slices* directory in the Chapter 3 repository.

Example 3-4. Slicing slices

```go
x := []string{"a", "b", "c", "d"}
y := x[:2]
z := x[1:]
d := x[1:3]
e := x[:]
fmt.Println("x:", x)
fmt.Println("y:", y)
fmt.Println("z:", z)
fmt.Println("d:", d)
fmt.Println("e:", e)
```

It gives the following output:

```
x: [a b c d]
y: [a b]
z: [b c d]
d: [b c]
e: [a b c d]
```

When you take a slice from a slice, you are *not* making a copy of the data. Instead, you now have two variables that are sharing memory. This means that changes to an element in a slice affect all slices that share that element. Let's see what happens when you change values. You can run the code in Example 3-5 on The Go Playground or in the *sample_code/slice_share_storage* directory in the Chapter 3 repository.

Example 3-5. Slices with overlapping storage

```
x := []string{"a", "b", "c", "d"}
y := x[:2]
z := x[1:]
x[1] = "y"
y[0] = "x"
z[1] = "z"
fmt.Println("x:", x)
fmt.Println("y:", y)
fmt.Println("z:", z)
```

You get the following output:

```
x: [x y z d]
y: [x y]
z: [y z d]
```

Changing `x` modified both `y` and `z`, while changes to `y` and `z` modified `x`.

Slicing slices gets extra confusing when combined with `append`. Try out the code in Example 3-6 on The Go Playground or in the *sample_code/slice_append_storage* directory in the Chapter 3 repository.

Example 3-6. `append` makes overlapping slices more confusing

```
x := []string{"a", "b", "c", "d"}
y := x[:2]
fmt.Println(cap(x), cap(y))
y = append(y, "z")
fmt.Println("x:", x)
fmt.Println("y:", y)
```

Running this code gives the following output:

```
4 4
x: [a b z d]
y: [a b z]
```

What's going on? Whenever you take a slice from another slice, the subslice's capacity is set to the capacity of the original slice, minus the starting offset of the subslice within the original slice. This means elements of the original slice beyond the end of the subslice, including unused capacity, are shared by both slices.

When you make the `y` slice from `x`, the length is set to 2, but the capacity is set to 4, the same as `x`. Since the capacity is 4, appending onto the end of `y` puts the value in the third position of `x`.

This behavior creates some odd scenarios, with multiple slices appending and overwriting each other's data. See if you can guess what the code in Example 3-7 prints out, then run it on The Go Playground or in the *sample_code/confusing_slices* directory in the Chapter 3 repository to see if you guessed correctly.

Example 3-7. Even more confusing slices

```
x := make([]string, 0, 5)
x = append(x, "a", "b", "c", "d")
y := x[:2]
z := x[2:]
fmt.Println(cap(x), cap(y), cap(z))
y = append(y, "i", "j", "k")
x = append(x, "x")
z = append(z, "y")
fmt.Println("x:", x)
fmt.Println("y:", y)
fmt.Println("z:", z)
```

To avoid complicated slice situations, you should either never use `append` with a subslice or make sure that `append` doesn't cause an overwrite by using a *full slice expression*. This is a little weird, but it makes clear how much memory is shared between the parent slice and the subslice. The full slice expression includes a third part, which indicates the last position in the parent slice's capacity that's available for the subslice. Subtract the starting offset from this number to get the subslice's capacity. Example 3-8 shows the first four lines from the previous example, modified to use full slice expressions.

Example 3-8. The full slice expression protects against `append`

```
x := make([]string, 0, 5)
x = append(x, "a", "b", "c", "d")
y := x[:2:2]
z := x[2:4:4]
```

Try out this code on The Go Playground or in the *sample_code/full_slice_expression* directory in the Chapter 3 repository. Both `y` and `z` have a capacity of `2`. Because you limited the capacity of the subslices to their lengths, appending additional elements onto `y` and `z` created new slices that didn't interact with the other slices. After this code runs, `x` is set to `[a b c d x]`, `y` is set to `[a b i j k]`, and `z` is set to `[c d y]`.

Be careful when taking a slice of a slice! Both slices share the same memory, and changes to one are reflected in the other. Avoid modifying slices after they have been sliced or if they were produced by slicing. Use a three-part slice expression to prevent `append` from sharing capacity between slices.

copy

If you need to create a slice that's independent of the original, use the built-in `copy` function. Let's take a look at a simple example, which you can run on The Go Playground or in the *sample_code/copy_slice* directory in the Chapter 3 repository:

```
x := []int{1, 2, 3, 4}
y := make([]int, 4)
num := copy(y, x)
fmt.Println(y, num)
```

You get this output:

```
[1 2 3 4] 4
```

The `copy` function takes two parameters. The first is the destination slice, and the second is the source slice. The function copies as many values as it can from source to destination, limited by whichever slice is smaller, and returns the number of elements copied. The *capacity* of `x` and `y` doesn't matter; it's the length that's important.

You can also copy a subset of a slice. The following code copies the first two elements of a four-element slice into a two-element slice:

```
x := []int{1, 2, 3, 4}
y := make([]int, 2)
num := copy(y, x)
```

The variable `y` is set to [1 2], and `num` is set to 2.

You could also copy from the middle of the source slice:

```
x := []int{1, 2, 3, 4}
y := make([]int, 2)
copy(y, x[2:])
```

You are copying the third and fourth elements in `x` by taking a slice of the slice. Also note that *you don't assign the output of* `copy` *to a variable*. If you don't need the number of elements copied, you don't need to assign it.

The `copy` function allows you to copy between two slices that cover overlapping sections of an underlying slice:

```
x := []int{1, 2, 3, 4}
num := copy(x[:3], x[1:])
fmt.Println(x, num)
```

In this case, you are copying the last three values in `x` on top of the first three values of `x`. This prints out [2 3 4 4] 3.

You can use `copy` with arrays by taking a slice of the array. You can make the array either the source or the destination of the copy. You can try out the following code on The Go Playground or in the *sample_code/copy_array* directory in the Chapter 3 repository:

```
x := []int{1, 2, 3, 4}
d := [4]int{5, 6, 7, 8}
y := make([]int, 2)
copy(y, d[:])
fmt.Println(y)
copy(d[:], x)
fmt.Println(d)
```

The first call to `copy` copies the first two values in array `d` into slice `y`. The second copies all of the values in slice `x` into array `d`. This produces the following output:

```
[5 6]
[1 2 3 4]
```

Converting Arrays to Slices

Slices aren't the only thing you can slice. If you have an array, you can take a slice from it using a slice expression. This is a useful way to bridge an array to a function that takes only slices. To convert an entire array into a slice, use the `[:]` syntax:

```
xArray := [4]int{5, 6, 7, 8}
xSlice := xArray[:]
```

You can also convert a subset of an array into a slice:

```
x := [4]int{5, 6, 7, 8}
y := x[:2]
z := x[2:]
```

Be aware that taking a slice from an array has the same memory-sharing properties as taking a slice from a slice. If you run the following code on The Go Playground or in the *sample_code/slice_array_memory* directory in the Chapter 3 repository:

```
x := [4]int{5, 6, 7, 8}
y := x[:2]
z := x[2:]
x[0] = 10
fmt.Println("x:", x)
fmt.Println("y:", y)
fmt.Println("z:", z)
```

you get this output:

```
x: [10 6 7 8]
y: [10 6]
z: [7 8]
```

Converting Slices to Arrays

Use a type conversion to make an array variable from a slice. You can convert an entire slice to an array of the same type, or you can create an array from a subset of the slice.

When you convert a slice to an array, the data in the slice is copied to new memory. That means that changes to the slice won't affect the array, and vice versa.

The following code:

```
xSlice := []int{1, 2, 3, 4}
xArray := [4]int(xSlice)
smallArray := [2]int(xSlice)
xSlice[0] = 10
fmt.Println(xSlice)
fmt.Println(xArray)
fmt.Println(smallArray)
```

prints out:

```
[10 2 3 4]
[1 2 3 4]
[1 2]
```

The size of the array must be specified at compile time. It's a compile-time error to use `[...]` in a slice to array type conversion.

While the size of the array can be smaller than the size of the slice, it cannot be bigger. Unfortunately, the compiler cannot detect this, and your code will panic at runtime if you specify an array size that's bigger than the length (not the capacity) of the slice. The following code:

```
panicArray := [5]int(xSlice)
fmt.Println(panicArray)
```

panics at runtime with the message:

```
panic: runtime error: cannot convert slice with length 4 to array
     or pointer to array with length 5
```

I haven't talked about pointers yet, but you can also use a type conversion to convert a slice into a pointer to an array:

```
xSlice := []int{1,2,3,4}
xArrayPointer := (*[4]int)(xSlice)
```

After converting a slice to an array pointer, the storage between the two is shared. A change to one will change the other:

```
xSlice[0] = 10
xArrayPointer[1] = 20
fmt.Println(xSlice) // prints [10 20 3 4]
fmt.Println(xArrayPointer) // prints &[10 20 3 4]
```

Pointers are covered in Chapter 6.

You can try all of the array type conversions on The Go Playground or in the *sample_code/array_conversion* directory in the Chapter 3 repository.

In "Arrays—Too Rigid to Use Directly" on page 37, I mentioned that you can't use arrays as function parameters when the size of the array being passed in might vary. Technically, you can work around this limitation by converting an array to a slice, converting the slice to an array of a different size, and then passing the second array in to a function. The second array must be shorter than the first array, or your program will panic. While this might be helpful in a pinch, if you find yourself doing this frequently, strongly consider changing your function's API to take a slice instead of an array.

Strings and Runes and Bytes

Now that I've talked about slices, we can look at strings again. You might think that a string in Go is made out of runes, but that's not the case. Under the covers, Go uses a sequence of bytes to represent a string. These bytes don't have to be in any particular character encoding, but several Go library functions (and the `for-range` loop that I discuss in the next chapter) assume that a string is composed of a sequence of UTF-8-encoded code points.

According to the language specification, Go source code is always written in UTF-8. Unless you use hexadecimal escapes in a string literal, your string literals are written in UTF-8.

Just as you can extract a single value from an array or a slice, you can extract a single value from a string by using an *index expression*:

```
var s string = "Hello there"
var b byte = s[6]
```

Like arrays and slices, string indexes are zero-based; in this example, `b` is assigned the numeric value of the seventh position in `s`, which is `116` (the UTF-8 value of a lowercase t).

The slice expression notation that you used with arrays and slices also works with strings:

```
var s string = "Hello there"
var s2 string = s[4:7]
var s3 string = s[:5]
var s4 string = s[6:]
```

This assigns "o t" to `s2`, "Hello" to `s3`, and "there" to `s4`. You can try out this code on The Go Playground or in the *sample_code/string_slicing* directory in the Chapter 3 repository.

While it's handy that Go allows you to use slicing notation to make substrings and use index notation to extract individual entries from a string, you should be careful when doing so. Since strings are immutable, they don't have the modification problems that slices of slices do. There is a different problem, though. A string is composed of a sequence of bytes, while a code point in UTF-8 can be anywhere from one to four bytes long. The previous example was entirely composed of code points that are one byte long in UTF-8, so everything worked out as expected. But when dealing with languages other than English or with emojis, you run into code points that are multiple bytes long in UTF-8:

```
var s string = "Hello 🌞"
var s2 string = s[4:7]
var s3 string = s[:5]
var s4 string = s[6:]
```

In this example, `s3` will still be equal to "Hello." The variable `s4` is set to the sun emoji. But `s2` is not set to "o 🌞." Instead, you get "o �." That's because you copied only the first byte of the sun emoji's code point, which is not a valid code point on its own.

Go allows you to pass a string to the built-in `len` function to find the length of the string. Given that string index and slice expressions count positions in bytes, it's not surprising that the length returned is the length in bytes, not in code points:

```
var s string = "Hello 🌞"
fmt.Println(len(s))
```

This code prints out 10, not 7, because it takes four bytes to represent the sun with smiling face emoji in UTF-8. You can run these sun emoji examples on The Go Playground or in the *sample_code/sun_slicing* directory in the Chapter 3 repository.

Even though Go allows you to use slicing and indexing syntax with strings, you should use it only when you know that your string contains only characters that take up one byte.

Because of this complicated relationship among runes, strings, and bytes, Go has some interesting type conversions between these types. A single rune or byte can be converted to a string:

```
var a rune    = 'x'
var s string  = string(a)
var b byte    = 'y'
var s2 string = string(b)
```

A common bug for new Go developers is to try to make an `int` into a `string` by using a type conversion:

```
var x int = 65
var y = string(x)
fmt.Println(y)
```

This results in `y` having the value "A," not "65." As of Go 1.15, `go vet` blocks a type conversion to string from any integer type other than `rune` or `byte`.

A string can be converted back and forth to a slice of bytes or a slice of runes. Try Example 3-9 on The Go Playground or in the *sample_code/string_to_slice* directory in the Chapter 3 repository.

Example 3-9. Converting strings to slices

```
var s string = "Hello, 🌞"
var bs []byte = []byte(s)
var rs []rune = []rune(s)
fmt.Println(bs)
fmt.Println(rs)
```

When you run this code, you see the following:

```
[72 101 108 108 111 44 32 240 159 140 158]
[72 101 108 108 111 44 32 127774]
```

The first output line has the string converted to UTF-8 bytes. The second has the string converted to runes.

Most data in Go is read and written as a sequence of bytes, so the most common string type conversions are back and forth with a slice of bytes. Slices of runes are uncommon.

UTF-8

UTF-8 is the most commonly used encoding for Unicode. Unicode uses four bytes (32 bits) to represent each *code point*, the technical name for each character and modifier. Given this, the simplest way to represent Unicode code points is to store four bytes for each code point. This is called UTF-32. It is mostly unused because it wastes so much space. Due to Unicode implementation details, 11 of the 32 bits are always zero. Another common encoding is UTF-16, which uses one or two 16-bit (2-byte) sequences to represent each code point. This is also wasteful; much of the content in the world is written using code points that fit into a single byte. And that's where UTF-8 comes in.

UTF-8 is clever. It lets you use a single byte to represent the Unicode characters whose values are below 128 (which includes all of the letters, numbers, and punctuation commonly used in English), but expands to a maximum of four bytes to represent Unicode code points with larger values. The result is that the *worst* case for UTF-8 is the same as using UTF-32. UTF-8 has some other nice properties. Unlike UTF-32 and UTF-16, you don't have to worry about little-endian versus big-endian. It also allows you to look at any byte in a sequence and tell if you are at the start of a UTF-8 sequence or somewhere in the middle. That means you can't accidentally read a character incorrectly.

The only downside is that you cannot randomly access a string encoded with UTF-8. While you can detect if you are in the middle of a character, you can't tell how many characters in you are. You need to start at the beginning of the string and count. Go doesn't require a string to be written in UTF-8 but strongly encourages it. You'll see how to work with UTF-8 strings in upcoming chapters.

Fun fact: UTF-8 was invented in 1992 by Ken Thompson and Rob Pike, two of the creators of Go.

Rather than use the slice and index expressions with strings, you should extract substrings and code points from strings using the functions in the `strings` and `unicode/utf8` packages in the standard library. In the next chapter, you'll see how to use a `for-range` loop to iterate over the code points in a string.

Maps

Slices are useful when you have sequential data. Like most languages, Go provides a built-in data type for situations where you want to associate one value to another. The map type is written as `map[keyType]valueType`. Let's take a look at a few ways to declare maps. First, you can use a `var` declaration to create a map variable that's set to its zero value:

```
var nilMap map[string]int
```

In this case, `nilMap` is declared to be a map with `string` keys and `int` values. The zero value for a map is `nil`. A `nil` map has a length of 0. Attempting to read a `nil` map always returns the zero value for the map's value type. However, *attempting to write to a `nil` map variable causes a panic.*

You can use a `:=` declaration to create a map variable by assigning it a *map literal*:

```
totalWins := map[string]int{}
```

In this case, you are using an empty map literal. This is not the same as a `nil` map. It has a length of 0, but you can read and write to a map assigned an empty map literal. Here's what a nonempty map literal looks like:

```
teams := map[string][]string {
    "Orcas": []string{"Fred", "Ralph", "Bijou"},
    "Lions": []string{"Sarah", "Peter", "Billie"},
    "Kittens": []string{"Waldo", "Raul", "Ze"},
}
```

A map literal's body is written as the key, followed by a colon (:), then the value. A comma separates each key-value pair in the map, even on the last line. In this example, the value is a slice of strings. The type of the value in a map can be anything. There are some restrictions on the types of the keys that I'll discuss in a bit.

If you know how many key-value pairs you intend to put in the map but don't know the exact values, you can use `make` to create a map with a default size:

```
ages := make(map[int][]string, 10)
```

Maps created with `make` still have a length of 0, and they can grow past the initially specified size.

Maps are like slices in several ways:

- Maps automatically grow as you add key-value pairs to them.
- If you know how many key-value pairs you plan to insert into a map, you can use `make` to create a map with a specific initial size.
- Passing a map to the `len` function tells you the number of key-value pairs in a map.

- The zero value for a map is `nil`.
- Maps are not comparable. You can check if they are equal to `nil`, but you cannot check if two maps have identical keys and values using `==` or differ using `!=`.

The key for a map can be any comparable type. This means *you cannot use a slice or a map as the key for a map*.

> When should you use a map, and when should you use a slice? You should use slices for lists of data when the data should be processed sequentially or the order of the elements is important.
>
> Maps are useful when you need to organize values using something other than an increasing integer value, such as a name.

What Is a Hash Map?

In computer science, a *map* is a data structure that associates (or maps) one value to another. Maps can be implemented in several ways, each with its own trade-offs. The map that's built into Go is a *hash map*, or *hash table*. If you aren't familiar with the concept, Chapter 5 in *Grokking Algorithms* by Aditya Bhargava (Manning) describes what a hash table is and why they are so useful.

It's great that Go includes a hash map implementation as part of the runtime, because building your own is hard to get right. If you'd like to learn more about how Go does it, watch "Inside the Map Implementation", a talk from GopherCon 2016 by Keith Randall.

Go doesn't require (or even allow) you to define your own hash algorithm or equality definition. Instead, the Go runtime that's compiled into every Go program has code that implements hash algorithms for all types that are allowed to be keys.

Reading and Writing a Map

Let's look at a short program that declares, writes to, and reads from a map. You can run the program in Example 3-10 on The Go Playground or in the *sample_code/map_read_write* directory in the Chapter 3 repository.

Example 3-10. Using a map

```go
totalWins := map[string]int{}
totalWins["Orcas"] = 1
totalWins["Lions"] = 2
fmt.Println(totalWins["Orcas"])
fmt.Println(totalWins["Kittens"])
totalWins["Kittens"]++
fmt.Println(totalWins["Kittens"])
totalWins["Lions"] = 3
fmt.Println(totalWins["Lions"])
```

When you run this program, you'll see the following output:

```
1
0
1
3
```

You assign a value to a map key by putting the key within brackets and using `=` to specify the value, and you read the value assigned to a map key by putting the key within brackets. Note that you cannot use `:=` to assign a value to a map key.

When you try to read the value assigned to a map key that was never set, the map returns the zero value for the map's value type. In this case, the value type is an `int`, so you get back a 0. You can use the `++` operator to increment the numeric value for a map key. Because a map returns its zero value by default, this works even when there's no existing value associated with the key.

The comma ok Idiom

As you've seen, a map returns the zero value if you ask for the value associated with a key that's not in the map. This is handy when implementing things like the `totalWins` counter you saw earlier. However, you sometimes do need to find out if a key is in a map. Go provides the *comma ok idiom* to tell the difference between a key that's associated with a zero value and a key that's not in the map:

```
m := map[string]int{
    "hello": 5,
    "world": 0,
}
v, ok := m["hello"]
fmt.Println(v, ok)

v, ok = m["world"]
fmt.Println(v, ok)

v, ok = m["goodbye"]
fmt.Println(v, ok)
```

Rather than assign the result of a map read to a single variable, with the comma ok idiom you assign the results of a map read to two variables. The first gets the value associated with the key. The second value returned is a bool. It is usually named `ok`. If `ok` is `true`, the key is present in the map. If `ok` is `false`, the key is not present. In this example, the code prints out `5 true`, `0 true`, and `0 false`.

The comma ok idiom is used in Go when you want to differentiate between reading a value and getting back the zero value. You'll see it again when you read from channels in Chapter 12 and when you use type assertions in Chapter 7.

Deleting from Maps

Key-value pairs are removed from a map via the built-in `delete` function:

```
m := map[string]int{
    "hello": 5,
    "world": 10,
}
delete(m, "hello")
```

The `delete` function takes a map and a key and then removes the key-value pair with the specified key. If the key isn't present in the map or if the map is `nil`, nothing happens. The `delete` function doesn't return a value.

Emptying a Map

The `clear` function that you saw in "Emptying a Slice" on page 44 works on maps also. A cleared map has its length set to zero, unlike a cleared slice. The following code:

```
m := map[string]int{
    "hello": 5,
    "world": 10,
}
fmt.Println(m, len(m))
clear(m)
fmt.Println(m, len(m))
```

prints out:

```
map[hello:5 world:10] 2
map[] 0
```

Comparing Maps

Go 1.21 added a package to the standard library called `maps` that contains helper functions for working with maps. You'll learn more about this package in "Adding Generics to the Standard Library" on page 201. Two functions in the package are useful for comparing if two maps are equal, `maps.Equal` and `maps.EqualFunc`. They are analogous to the `slices.Equal` and `slices.EqualFunc` functions:

```
m := map[string]int{
    "hello": 5,
    "world": 10,
}
n := map[string]int{
    "world": 10,
    "hello": 5,
}
fmt.Println(maps.Equal(m, n)) // prints true
```

Using Maps as Sets

Many languages include a set in their standard library. A *set* is a data type that ensures there is at most one of a value, but doesn't guarantee that the values are in any particular order. Checking to see if an element is in a set is fast, no matter how many elements are in the set. (Checking to see if an element is in a slice takes longer, as you add more elements to the slice.)

Go doesn't include a set, but you can use a map to simulate some of its features. Use the key of the map for the type that you want to put into the set and use a `bool` for the value. The code in Example 3-11 demonstrates the concept. You can run it on The Go Playground or in the *sample_code/map_set* directory in the Chapter 3 repository.

Example 3-11. Using a map as a set

```
intSet := map[int]bool{}
vals := []int{5, 10, 2, 5, 8, 7, 3, 9, 1, 2, 10}
for _, v := range vals {
    intSet[v] = true
}
fmt.Println(len(vals), len(intSet))
fmt.Println(intSet[5])
fmt.Println(intSet[500])
if intSet[100] {
    fmt.Println("100 is in the set")
}
```

You want a set of `int`s, so you create a map where the keys are of `int` type and the values are of `bool` type. You iterate over the values in `vals` using a `for-range` loop (which I discuss in "The for-range Statement" on page 76) to place them into `intSet`, associating each `int` with the boolean value `true`.

We wrote 11 values into `intSet`, but the length of `intSet` is 8, because you cannot have duplicate keys in a map. If you look for 5 in `intSet`, it returns `true`, because there is a key with the value 5. However, if you look for 500 or 100 in `intSet`, it returns `false`. This is because you haven't put either value into `intSet`, which causes the map to return the zero value for the map value, and the zero value for a `bool` is `false`.

If you need sets that provide operations like union, intersection, and subtraction, you can either write one yourself or use one of the many third-party libraries that provide the functionality. (You'll learn more about using third-party libraries in Chapter 10.)

Some people prefer to use `struct{}` for the value when a map is being used to implement a set. (I'll discuss structs in the next section.) The advantage is that an empty struct uses zero bytes, while a boolean uses one byte.

The disadvantage is that using a `struct{}` makes your code clumsier. You have a less obvious assignment, and you need to use the comma ok idiom to check if a value is in the set:

```
intSet := map[int]struct{}{}
vals := []int{5, 10, 2, 5, 8, 7, 3, 9, 1, 2, 10}
for _, v := range vals {
    intSet[v] = struct{}{}
}
if _, ok := intSet[5]; ok {
    fmt.Println("5 is in the set")
}
```

Unless you have very large sets, the difference in memory usage will not likely be significant enough to outweigh the disadvantages.

Structs

Maps are a convenient way to store some kinds of data, but they have limitations. They don't define an API since there's no way to constrain a map to allow only certain keys. Also, all values in a map must be of the same type. For these reasons, maps are not an ideal way to pass data from function to function. When you have related data that you want to group together, you should define a *struct*.

If you already know an object-oriented language, you might be wondering about the difference between classes and structs. The difference is simple: Go doesn't have classes, because it doesn't have inheritance. This doesn't mean that Go doesn't have some of the features of object-oriented languages it just does things a little differently. You'll learn more about the object-oriented features of Go in Chapter 7.

Most languages have a concept that's similar to a struct, and the syntax that Go uses to read and write structs should look familiar:

```
type person struct {
    name string
    age  int
    pet  string
}
```

A struct type is defined with the keyword `type`, the name of the struct type, the keyword `struct`, and a pair of braces (`{}`). Within the braces, you list the fields in the struct. Just as you put the variable name first and the variable type second in a `var` declaration, you put the struct field name first and the struct field type second. Also note that unlike in map literals, no commas separate the fields in a struct declaration. You can define a struct type inside or outside of a function. A struct type that's defined within a function can be used only within that function. (You'll learn more about functions in Chapter 5.)

Technically, you can scope a struct definition to any block level. You'll learn more about blocks in Chapter 4.

Once a struct type is declared, you can define variables of that type:

```
var fred person
```

Here we are using a `var` declaration. Since no value is assigned to `fred`, it gets the zero value for the `person` struct type. A zero value struct has every field set to the field's zero value.

A *struct literal* can be assigned to a variable as well:

```
bob := person{}
```

Unlike maps, there is no difference between assigning an empty struct literal and not assigning a value at all. Both initialize all fields in the struct to their zero values. There are two styles for a nonempty struct literal. First, a struct literal can be specified as a comma-separated list of values for the fields inside of braces:

```
julia := person{
    "Julia",
    40,
    "cat",
}
```

When using this struct literal format, a value for every field in the struct must be specified, and the values are assigned to the fields in the order they were declared in the struct definition.

The second struct literal style looks like the map literal style:

```
beth := person{
    age:  30,
    name: "Beth",
}
```

You use the names of the fields in the struct to specify the values. This style has some advantages. It allows you to specify the fields in any order, and you don't need to provide a value for all fields. Any field not specified is set to its zero value.

You cannot mix the two struct literal styles: either all fields are specified with names, or none of them are. For small structs where all fields are always specified, the simpler struct literal style is fine. In other cases, use the names. It's more verbose, but it makes clear what value is being assigned to what field without having to reference the struct definition. It's also more maintainable. If you initialize a struct without using the field names and a future version of the struct adds additional fields, your code will no longer compile.

A field in a struct is accessed with dot notation:

```
bob.name = "Bob"
fmt.Println(bob.name)
```

Just as you use brackets for both reading and writing to a map, you use dotted notation for reading and writing to struct fields.

Anonymous Structs

You can also declare that a variable implements a struct type without first giving the struct type a name. This is called an *anonymous struct*:

```
var person struct {
    name string
    age  int
    pet  string
}

person.name = "bob"
person.age = 50
person.pet = "dog"

pet := struct {
    name string
    kind string
}{
    name: "Fido",
    kind: "dog",
}
```

In this example, the types of the variables `person` and `pet` are anonymous structs. You assign (and read) fields in an anonymous struct just as you do for a named struct type. Just as you can initialize an instance of a named struct with a struct literal, you can do the same for an anonymous struct as well.

You might wonder when it's useful to have a data type that's associated only with a single instance. Anonymous structs are handy in two common situations. The first is when you translate external data into a struct or a struct into external data (like JSON or Protocol Buffers). This is called *unmarshaling* and *marshaling* data, respectively. You'll learn how to do this in "encoding/json" on page 327.

Writing tests is another place where anonymous structs pop up. You'll use a slice of anonymous structs when writing table-driven tests in Chapter 15.

Comparing and Converting Structs

Whether a struct is comparable depends on the struct's fields. Structs that are entirely composed of comparable types are comparable; those with slice or map fields are not (as you will see in later chapters, function and channel fields also prevent a struct from being comparable).

Unlike in Python or Ruby, in Go there's no magic method that can be overridden to redefine equality and make `==` and `!=` work for incomparable structs. You can, of course, write your own function that you use to compare structs.

Just as Go doesn't allow comparisons between variables of different primitive types, Go doesn't allow comparisons between variables that represent structs of different types. Go does allow you to perform a type conversion from one struct type to another *if the fields of both structs have the same names, order, and types*. Let's see what this means. Given this struct:

```go
type firstPerson struct {
    name string
    age  int
}
```

you can use a type conversion to convert an instance of `firstPerson` to `secondPerson`, but you can't use `==` to compare an instance of `firstPerson` and an instance of `secondPerson`, because they are different types:

```go
type secondPerson struct {
    name string
    age  int
}
```

You can't convert an instance of `firstPerson` to `thirdPerson`, because the fields are in a different order:

```go
type thirdPerson struct {
    age  int
    name string
}
```

You can't convert an instance of firstPerson to fourthPerson because the field names don't match:

```
type fourthPerson struct {
    firstName string
    age       int
}
```

Finally, you can't convert an instance of firstPerson to fifthPerson because there's an additional field:

```
type fifthPerson struct {
    name          string
    age           int
    favoriteColor string
}
```

Anonymous structs add a small twist: if two struct variables are being compared and at least one has a type that's an anonymous struct, you can compare them without a type conversion if the fields of both structs have the same names, order, and types. You can also assign between named and anonymous struct types if the fields of both structs have the same names, order, and types:

```
type firstPerson struct {
    name string
    age  int
}
f := firstPerson{
    name: "Bob",
    age:  50,
}
var g struct {
    name string
    age  int
}

// compiles -- can use = and == between identical named and anonymous structs
g = f
fmt.Println(f == g)
```

Exercises

The following exercises will test what you've learned about Go's composite types. You can find solutions in the *exercise_solutions* directory in the Chapter 3 Repository.

1. Write a program that defines a variable named greetings of type slice of strings with the following values: "Hello", "Hola", "नमस्कार", "こんにちは", and "Привіт". Create a subslice containing the first two values; a second subslice with the second, third, and fourth values; and a third subslice with the fourth and fifth values. Print out all four slices.

2. Write a program that defines a string variable called `message` with the value `"Hi 👧 and 👦"` and prints the fourth rune in it as a character, not a number.
3. Write a program that defines a struct called `Employee` with three fields: `firstName`, `lastName`, and `id`. The first two fields are of type `string`, and the last field (`id`) is of type `int`. Create three instances of this struct using whatever values you'd like. Initialize the first one using the struct literal style without names, the second using the struct literal style with names, and the third with a `var` declaration. Use dot notation to populate the fields in the third struct. Print out all three structs.

Wrapping Up

You've learned a lot about composite types in Go. In addition to learning more about strings, you now know how to use the built-in generic container types: slices and maps. You can also construct your own composite types via structs. In the next chapter, you're going to take a look at Go's control structures: `for`, `if/else`, and `switch`. You will also learn how Go organizes code into blocks and how the different block levels can lead to surprising behavior.

CHAPTER 4

Blocks, Shadows, and Control Structures

Now that I have covered variables, constants, and built-in types, you are ready to look at programming logic and organization. I'll start by explaining blocks and how they control when an identifier is available. Then I'll present Go's control structures: `if`, `for`, and `switch`. Finally, I will talk about `goto` and the one situation when you should use it.

Blocks

Go lets you declare variables in lots of places. You can declare them outside of functions, as the parameters to functions, and as local variables within functions.

So far, you've written only the `main` function, but you'll write functions with parameters in the next chapter.

Each place where a declaration occurs is called a *block*. Variables, constants, types, and functions declared outside of any functions are placed in the *package* block. You've used `import` statements in your programs to gain access to printing and math functions (and I will talk about them in detail in Chapter 10). They define names for other packages that are valid for the file that contains the `import` statement. These names are in the *file* block. All the variables defined at the top level of a function (including the parameters to a function) are in a block. Within a function, every set of braces (`{}`) defines another block, and in a bit you will see that the control structures in Go define blocks of their own.

You can access an identifier defined in any outer block from within any inner block. This raises the question: what happens when you have a declaration with the same name as an identifier in a containing block? If you do that, you *shadow* the identifier created in the outer block.

Shadowing Variables

Before I explain what shadowing is, let's take a look at some code (see Example 4-1). You can run it on The Go Playground or in the *sample_code/shadow_variables* directory in the Chapter 4 repository.

Example 4-1. Shadowing variables

```go
func main() {
    x := 10
    if x > 5 {
        fmt.Println(x)
        x := 5
        fmt.Println(x)
    }
    fmt.Println(x)
}
```

Before you run this code, try to guess what it's going to print out:

- Nothing prints; the code does not compile
- 10 on line one, 5 on line two, 5 on line three
- 10 on line one, 5 on line two, 10 on line three

Here's what happens:

```
10
5
10
```

A *shadowing variable* is a variable that has the same name as a variable in a containing block. For as long as the shadowing variable exists, you cannot access a shadowed variable.

In this case, you almost certainly didn't want to create a brand-new `x` inside the `if` statement. Instead, you probably wanted to assign 5 to the `x` declared at the top level of the function block. At the first `fmt.Println` inside the `if` statement, you are able to access the `x` declared at the top level of the function. On the next line, though, you *shadow* `x` by *declaring a new variable with the same name* inside the block created by the `if` statement's body. At the second `fmt.Println`, when you access the variable named `x`, you get the shadowing variable, which has the value of 5. The closing brace for the `if` statement's body ends the block where the shadowing `x` exists, and at the third `fmt.Println`, when you access the variable named `x`, you get the variable declared at the top level of the function, which has the value of 10. Notice that this `x` didn't disappear or get reassigned; there was just no way to access it once it was shadowed in the inner block.

I mentioned in the previous chapter that in some situations I avoid using `:=` because it can make it unclear what variables are being used. That's because it is very easy to accidentally shadow a variable when using `:=`. Remember, you can use `:=` to create and assign to multiple variables at once. Also, not all variables on the lefthand side have to be new for `:=` to be legal. You can use `:=` as long as there is at least one new variable on the lefthand side. Let's look at another program (see Example 4-2), which you can find on The Go Playground or in the *sample_code/shadow_multiple_assignment* directory in the Chapter 4 repository.

Example 4-2. Shadowing with multiple assignment

```
func main() {
    x := 10
    if x > 5 {
        x, y := 5, 20
        fmt.Println(x, y)
    }
    fmt.Println(x)
}
```

Running this code gives you the following:

```
5 20
10
```

Although there was an existing definition of `x` in an outer block, `x` was still shadowed within the `if` statement. That's because `:=` reuses only variables that are declared in the current block. When using `:=`, make sure that you don't have any variables from an outer scope on the lefthand side unless you intend to shadow them.

You also need to be careful to ensure that you don't shadow a package import. I'll talk more about importing packages in Chapter 10, but you've been importing the `fmt` package to print out results of our programs. Let's see what happens when you declare a variable called `fmt` within your `main` function, as shown in Example 4-3. You can try to run it on The Go Playground or in the *sample_code/shadow_package_names* directory in the Chapter 4 repository.

Example 4-3. Shadowing package names

```
func main() {
    x := 10
    fmt.Println(x)
    fmt := "oops"
    fmt.Println(fmt)
}
```

When you try to run this code, you get an error:

```
fmt.Println undefined (type string has no field or method Println)
```

Notice that the problem isn't that you named your variable `fmt`; it's that you tried to access something that the local variable `fmt` didn't have. Once the local variable `fmt` is declared, it shadows the package named `fmt` in the file block, making it impossible to use the `fmt` package for the rest of the `main` function.

The Universe Block

One more block is a little weird: the universe block. Remember, Go is a small language with only 25 keywords. What's interesting is that the built-in types (like `int` and `string`), constants (like `true` and `false`), and functions (like `make` or `close`) aren't included in that list. Neither is `nil`. So, where are they?

Rather than make them keywords, Go considers these *predeclared identifiers* and defines them in the universe block, which is the block that contains all other blocks.

Because these names are declared in the universe block, they can be shadowed in other scopes. You can see this happen by running the code in Example 4-4 on The Go Playground or in the *sample_code/shadow_true* directory in the Chapter 4 repository.

Example 4-4. Shadowing `true`

```
fmt.Println(true)
true := 10
fmt.Println(true)
```

When you run it, you'll see:

```
true
10
```

You must be very careful to never redefine any identifiers in the universe block. If you accidentally do so, you will get some strange behavior. If you are lucky, you'll get compilation failures. If you are not, you'll have a harder time tracking down the source of your problems.

Since shadowing is useful in a few instances (later chapters will point them out), `go vet` does not report it as a likely error. In "Using Code-Quality Scanners" on page 267, you'll learn about third-party tools that can detect accidental shadowing in your code.

if

The `if` statement in Go is much like the `if` statement in most programming languages. Because it is such a familiar construct, I've used it in previous sample code without worrying that it'd be confusing. Example 4-5 shows a more complete sample.

Example 4-5. `if` and `else`

```go
n := rand.Intn(10)
if n == 0 {
    fmt.Println("That's too low")
} else if n > 5 {
    fmt.Println("That's too big:", n)
} else {
    fmt.Println("That's a good number:", n)
}
```

The most visible difference between `if` statements in Go and other languages is that you don't put parentheses around the condition. But Go adds another feature to `if` statements that helps you better manage your variables.

As I discussed in "Shadowing Variables" on page 68, any variable declared within the braces of an `if` or `else` statement exists only within that block. This isn't that uncommon; it is true in most languages. What Go adds is the ability to declare variables that are scoped to the condition and to both the `if` and `else` blocks. Take a look at Example 4-6, which rewrites our previous example to use this scope.

Example 4-6. Scoping a variable to an `if` statement

```go
if n := rand.Intn(10); n == 0 {
    fmt.Println("That's too low")
} else if n > 5 {
    fmt.Println("That's too big:", n)
} else {
    fmt.Println("That's a good number:", n)
}
```

Having this special scope is handy. It lets you create variables that are available only where they are needed. Once the series of `if/else` statements ends, `n` is undefined. You can test this by trying to run the code in Example 4-7 on The Go Playground or in the *sample_code/if_bad_scope* directory in the Chapter 4 repository.

Example 4-7. Out of scope...

```
if n := rand.Intn(10); n == 0 {
    fmt.Println("That's too low")
} else if n > 5 {
    fmt.Println("That's too big:", n)
} else {
    fmt.Println("That's a good number:", n)
}
fmt.Println(n)
```

Attempting to run this code produces a compilation error:

```
undefined: n
```

Technically, you can put any *simple statement* before the comparison in an `if` statement—including a function call that doesn't return a value or an assignment of a new value to an existing variable. But don't do this. Use this feature only to define new variables that are scoped to the `if/else` statements; anything else would be confusing.

Also be aware that just like any other block, a variable declared as part of an `if` statement will shadow variables with the same name that are declared in containing blocks.

for, Four Ways

As in other languages in the C family, Go uses a `for` statement to loop. What makes Go different from other languages is that `for` is the *only* looping keyword in the language. Go accomplishes this by using the `for` keyword in four formats:

- A complete, C-style `for`
- A condition-only `for`
- An infinite `for`
- `for-range`

The Complete for Statement

The first `for` loop style is the complete `for` declaration you might be familiar with from C, Java, or JavaScript, as shown in Example 4-8.

Example 4-8. A complete `for` statement

```
for i := 0; i < 10; i++ {
    fmt.Println(i)
}
```

You might be unsurprised to find that this program prints out the numbers from 0 to 9, inclusive.

Just like the `if` statement, the `for` statement does not use parentheses around its parts. Otherwise, it should look familiar. The `if` statement has three parts, separated by semicolons. The first part is an initialization that sets one or more variables before the loop begins. You should remember two important details about the initialization section. First, you *must* use `:=` to initialize the variables; `var` is *not* legal here. Second, just as variable declarations in `if` statements, you can shadow a variable here.

The second part is the comparison. This must be an expression that evaluates to a `bool`. It is checked immediately *before* each iteration of the loop. If the expression evaluates to `true`, the loop body is executed.

The last part of a standard `for` statement is the increment. You usually see something like `i{plus}{plus}` here, but any assignment is valid. It runs immediately after each iteration of the loop, before the condition is evaluated.

Go allows you to leave out one or more of the three parts of the `for` statement. Most commonly, you'll either leave off the initialization if it is based on a value calculated before the loop:

```
i := 0
for ; i < 10; i++ {
    fmt.Println(i)
}
```

or you'll leave off the increment because you have a more complicated increment rule inside the loop:

```
for i := 0; i < 10; {
    fmt.Println(i)
    if i % 2 == 0 {
        i++
    } else {
        i+=2
    }
}
```

The Condition-Only for Statement

When you leave off both the initialization and the increment in a `for` statement, do not include the semicolons. (If you do, `go fmt` will remove them.) That leaves a `for` statement that functions like the `while` statement found in C, Java, JavaScript, Python, Ruby, and many other languages. It looks like Example 4-9.

Example 4-9. A condition-only `for` statement

```
i := 1
for i < 100 {
        fmt.Println(i)
        i = i * 2
}
```

The Infinite for Statement

The third `for` statement format does away with the condition too. Go has a version of a `for` loop that loops forever. If you learned to program in the 1980s, your first program was probably an infinite loop in BASIC that printed `HELLO` to the screen forever:

```
10 PRINT "HELLO"
20 GOTO 10
```

Example 4-10 shows the Go version of this program. You can run it locally or try it out on The Go Playground or in the *sample_code/infinite_for* directory in the Chapter 4 repository.

Example 4-10. Infinite looping nostalgia

```
package main

import "fmt"

func main() {
    for {
        fmt.Println("Hello")
    }
}
```

Running this program gives you the same output that filled the screens of millions of Commodore 64s and Apple][s:

```
Hello
Hello
Hello
Hello
Hello
Hello
Hello
...
```

Press Ctrl-C when you are tired of walking down memory lane.

If you run Example 4-10 on The Go Playground, you'll find that it will stop execution after a few seconds. As a shared resource, the playground doesn't allow any one program to run for too long.

break and continue

How do you get out of an infinite `for` loop without using the keyboard or turning off your computer? That's the job of the `break` statement. It exits the loop immediately, just like the `break` statement in other languages. Of course, you can use `break` with any `for` statement, not just the infinite `for` statement.

Go has no equivalent of the `do` keyword in Java, C, and JavaScript. If you want to iterate at least once, the cleanest way is to use an infinite `for` loop that ends with an `if` statement. If you have some Java code, for example, that uses a `do/while` loop:

```
do {
    // things to do in the loop
} while (CONDITION);
```

the Go version looks like this:

```
for {
    // things to do in the loop
    if !CONDITION {
        break
    }
}
```

Note that the condition has a leading `!` to *negate* the condition from the Java code. The Go code is specifying how to *exit* the loop, while the Java code specifies how to stay in it.

Go also includes the `continue` keyword, which skips over the rest of the `for` loop's body and proceeds directly to the next iteration. Technically, you don't need a `continue` statement. You could write code like Example 4-11.

Example 4-11. Confusing code

```
for i := 1; i <= 100; i++ {
    if i%3 == 0 {
        if i%5 == 0 {
            fmt.Println("FizzBuzz")
        } else {
            fmt.Println("Fizz")
        }
    } else if i%5 == 0 {
        fmt.Println("Buzz")
    } else {
        fmt.Println(i)
    }
}
```

But this is not idiomatic. Go encourages short `if` statement bodies, as left-aligned as possible. Nested code is more difficult to follow. Using a `continue` statement makes it easier to understand what's going on. Example 4-12 shows the code from the previous example, rewritten to use `continue` instead.

Example 4-12. Using `continue` to make code clearer

```
for i := 1; i <= 100; i++ {
    if i%3 == 0 && i%5 == 0 {
        fmt.Println("FizzBuzz")
        continue
    }
    if i%3 == 0 {
        fmt.Println("Fizz")
        continue
    }
    if i%5 == 0 {
        fmt.Println("Buzz")
        continue
    }
    fmt.Println(i)
}
```

As you can see, replacing chains of `if/else` statements with a series of `if` statements that use `continue` makes the conditions line up. This improves the layout of your conditions, which means your code is easier to read and understand.

The for-range Statement

The fourth `for` statement format is for iterating over elements in some of Go's built-in types. It is called a `for-range` loop and resembles the iterators found in other languages. This section shows how to use a `for-range` loop with strings, arrays, slices, and maps. When I cover channels in Chapter 12, I will talk about how to use them with `for-range` loops.

You can use a `for-range` loop only to iterate over the built-in compound types and user-defined types that are based on them.

First, let's take a look at using a `for-range` loop with a slice. You can try out the code in Example 4-13 on The Go Playground or in the `forRangeKeyValue` function in *main.go* in the *sample_code/for_range* directory in the Chapter 4 repository.

Example 4-13. The `for-range` loop

```
evenVals := []int{2, 4, 6, 8, 10, 12}
for i, v := range evenVals {
    fmt.Println(i, v)
}
```

Running this code produces the following output:

```
0 2
1 4
2 6
3 8
4 10
5 12
```

What makes a `for-range` loop interesting is that you get two loop variables. The first variable is the position in the data structure being iterated, while the second is the value at that position. The idiomatic names for the two loop variables depend on what is being looped over. When looping over an array, slice, or string, an `i` for *index* is commonly used. When iterating through a map, `k` (for *key*) is used instead.

The second variable is frequently called `v` for *value*, but is sometimes given a name based on the type of the values being iterated. Of course, you can give the variables any names that you like. If the body of the loop contains only a few statements, single-letter variable names work well. For longer (or nested) loops, you'll want to use more descriptive names.

What if you don't need to use the first variable within your `for-range` loop? Remember, Go requires you to access all declared variables, and this rule applies to the ones declared as part of a `for` loop too. If you don't need to access the key, use an underscore (_) as the variable's name. This tells Go to ignore the value.

Let's rewrite the slice ranging code to not print out the position. You can run the code in Example 4-14 on The Go Playground or in the `forRangeIgnoreKey` function in *main.go* in the *sample_code/for_range* directory in the Chapter 4 repository.

Example 4-14. Ignoring the slice index in a `for-range` loop

```
evenVals := []int{2, 4, 6, 8, 10, 12}
for _, v := range evenVals {
    fmt.Println(v)
}
```

Running this code produces the following output:

```
2
4
6
8
10
12
```

Anytime you are in a situation where a value is returned, but you want to ignore it, use an underscore to hide the value. You'll see the underscore pattern again when I talk about functions in Chapter 5 and packages in Chapter 10.

What if you want the key but don't want the value? In this situation, Go allows you to just leave off the second variable. This is valid Go code:

```
uniqueNames := map[string]bool{"Fred": true, "Raul": true, "Wilma": true}
for k := range uniqueNames {
    fmt.Println(k)
}
```

The most common reason for iterating over the key is when a map is being used as a set. In those situations, the value is unimportant. However, you can also leave off the value when iterating over arrays or slices. This is rare, as the usual reason for iterating over a linear data structure is to access the data. If you find yourself using this format for an array or slice, there's an excellent chance that you have chosen the wrong data structure and should consider refactoring.

When you look at channels in Chapter 12, you'll see a situation where a `for-range` loop returns only a single value each time the loop iterates.

Iterating over maps

There's something interesting about how a `for-range` loop iterates over a map. You can run the code in Example 4-15 on The Go Playground or in the *sample_code/iterate_map* directory in the Chapter 4 repository.

Example 4-15. Map iteration order varies

```
m := map[string]int{
    "a": 1,
    "c": 3,
    "b": 2,
}

for i := 0; i < 3; i++ {
    fmt.Println("Loop", i)
    for k, v := range m {
        fmt.Println(k, v)
    }
}
```

When you build and run this program, the output varies. Here is one possibility:

```
Loop 0
c 3
b 2
a 1
Loop 1
a 1
c 3
b 2
Loop 2
b 2
a 1
c 3
```

The order of the keys and values varies; some runs may be identical. This is actually a security feature. In earlier Go versions, the iteration order for keys in a map was usually (but not always) the same if you inserted the same items into a map. This caused two problems:

- People would write code that assumed that the order was fixed, and this code would break at weird times.
- If maps always hash items to the exact same values, and you know that a server is storing user data in a map, you can slow down a server with an attack called *Hash DoS* by sending it specially crafted data with keys that all hash to the same bucket.

To prevent both of these problems, the Go team made two changes to the map implementation. First, they modified the hash algorithm for maps to include a random number that's generated every time a map variable is created. Next, they made the order of a `for-range` iteration over a map vary a bit each time the map is looped over. These two changes make it far harder to implement a Hash DoS attack.

This rule has one exception. To make it easier to debug and log maps, the formatting functions (like `fmt.Println`) always output maps with their keys in ascending sorted order.

Iterating over strings

As I mentioned earlier, you can also use a string with a `for-range` loop. Let's take a look. You can run the code in Example 4-16 on your computer or on The Go Playground or in the *sample_code/iterate_string* directory in the Chapter 4 repository.

Example 4-16. Iterating over strings

```
samples := []string{"hello", "apple_π!"}
for _, sample := range samples {
    for i, r := range sample {
        fmt.Println(i, r, string(r))
    }
    fmt.Println()
}
```

The output when the code iterates over the word "hello" has no surprises:

```
0 104 h
1 101 e
2 108 l
3 108 l
4 111 o
```

In the first column is the index; in the second, the numeric value of the letter; and in the third is the numeric value of the letter type converted to a string.

Looking at the result for "apple_π!" is more interesting:

```
0 97 a
1 112 p
2 112 p
3 108 l
4 101 e
5 95 _
6 960 π
8 33 !
```

Notice two things about this output. First, notice that the first column skips the number 7. Second, the value at position 6 is 960. That's far larger than what can fit in a byte. But in Chapter 3, you saw that strings were made out of bytes. What's going on?

What you are seeing is special behavior from iterating over a string with a `for-range` loop. It iterates over the *runes*, not the *bytes*. Whenever a `for-range` loop encounters a multibyte rune in a string, it converts the UTF-8 representation into a single 32-bit number and assigns it to the value. The offset is incremented by the number of bytes in the rune. If the `for-range` loop encounters a byte that doesn't represent a valid UTF-8 value, the Unicode replacement character (hex value 0xfffd) is returned instead.

Use a `for-range` loop to access the runes in a string in order. The first variable holds the number of bytes from the beginning of the string, but the type of the second variable is rune.

The for-range value is a copy

You should be aware that each time the `for-range` loop iterates over your compound type, it *copies* the value from the compound type to the value variable. *Modifying the value variable will not modify the value in the compound type*. Example 4-17 shows a quick program to demonstrate this. You can try it out on The Go Playground or in the `forRangeIsACopy` function in *main.go* in the *sample_code/for_range* directory in the Chapter 4 repository.

Example 4-17. Modifying the value doesn't modify the source

```go
evenVals := []int{2, 4, 6, 8, 10, 12}
for _, v := range evenVals {
    v *= 2
}
fmt.Println(evenVals)
```

Running this code gives the following output:

```
[2 4 6 8 10 12]
```

In versions of Go before 1.22, the value variable is created once and is reused on each iteration through the `for` loop. Since Go 1.22, the default behavior is to create a new index and value variable on each iteration through the `for` loop. This change may not seem important, but it prevents a common bug. When I talk about goroutines and `for-range` loops in "Goroutines, for Loops, and Varying Variables" on page 298, you'll see that prior to Go 1.22, if you launched goroutines in a `for-range` loop, you needed to be careful in how you passed the index and value to the goroutines, or you'd get surprisingly wrong results.

Because this is a backward-breaking change (even if it is a change that eliminates a common bug), you can control whether to enable this behavior by specifying the Go version in the `go` directive in the *go.mod* file for your module. I talk about this in greater detail in "Using go.mod" on page 224.

Just as with the other three forms of the `for` statement, you can use `break` and `continue` with a `for-range` loop.

Labeling Your for Statements

By default, the `break` and `continue` keywords apply to the `for` loop that directly contains them. What if you have nested `for` loops and want to exit or skip over an iterator of an outer loop? Let's look at an example. You're going to modify the earlier string iterating program to stop iterating through a string as soon as it hits a letter "l." You can run the code in Example 4-18 on The Go Playground or in the *sample_code/for_label* directory in the Chapter 4 repository.

Example 4-18. Labels

```go
func main() {
    samples := []string{"hello", "apple_π!"}
outer:
    for _, sample := range samples {
        for i, r := range sample {
            fmt.Println(i, r, string(r))
            if r == 'l' {
                continue outer
            }
        }
        fmt.Println()
    }
}
```

Notice that the label `outer` is indented by `go fmt` to the same level as the surrounding function. Labels are always indented to the same level as the braces for the block. This makes them easier to notice. Running the program gives the following output:

```
0 104 h
1 101 e
2 108 l
0 97 a
1 112 p
2 112 p
3 108 l
```

Nested `for` loops with labels are rare. They are most commonly used to implement algorithms similar to the following pseudocode:

```go
outer:
    for _, outerVal := range outerValues {
        for _, innerVal := range outerVal {
            // process innerVal
            if invalidSituation(innerVal) {
                continue outer
            }
        }
        // here we have code that runs only when all of the
        // innerVal values were successfully processed
    }
```

Choosing the Right for Statement

Now that I've covered all forms of the `for` statement, you might be wondering when to use which format. Most of the time, you're going to use the `for-range` format. A `for-range` loop is the best way to walk through a string, since it properly gives you back runes instead of bytes. You have also seen that a `for-range` loop works well for iterating through slices and maps, and you'll see in Chapter 12 that channels work naturally with `for-range` as well.

Favor a `for-range` loop when iterating over all the contents of an instance of one of the built-in compound types. It avoids a great deal of boilerplate code that's required when you use an array, slice, or map with one of the other `for` loop styles.

When should you use the complete `for` loop? The best place for it is when you aren't iterating from the first element to the last element in a compound type. While you could use some combination of `if`, `continue`, and `break` within a `for-range` loop, a standard `for` loop is a clearer way to indicate the start and end of your iteration. Compare these two code snippets, both of which iterate over the second through the second-to-last elements in an array. First the `for-range` loop:

```
evenVals := []int{2, 4, 6, 8, 10}
for i, v := range evenVals {
    if i == 0 {
        continue
    }
    if i == len(evenVals)-1 {
        break
    }
    fmt.Println(i, v)
}
```

And here's the same code, with a standard `for` loop:

```
evenVals := []int{2, 4, 6, 8, 10}
for i := 1; i < len(evenVals)-1; i++ {
    fmt.Println(i, evenVals[i])
}
```

The standard `for` loop code is both shorter and easier to understand.

This pattern does not work for skipping over the beginning of a string. Remember, a standard `for` loop doesn't properly handle multibyte characters. If you want to skip over some of the runes in a string, you need to use a `for-range` loop so that it will properly process runes for you.

The remaining two `for` statement formats are used less frequently. The condition-only `for` loop is, like the `while` loop it replaces, useful when you are looping based on a calculated value.

The infinite `for` loop is useful in some situations. The body of the `for` loop should always contain a `break` or `return` because you'll rarely want to loop forever. Real-world programs should bound iteration and fail gracefully when operations cannot be completed. As shown previously, an infinite `for` loop can be combined with an `if` statement to simulate the `do` statement that's present in other languages. An infinite `for` loop is also used to implement some versions of the *iterator* pattern, which you will look at when I review the standard library in "io and Friends" on page 319.

switch

Like many C-derived languages, Go has a `switch` statement. Most developers in those languages avoid `switch` statements because of their limitations on values that can be switched on and the default fall-through behavior. But Go is different. It makes `switch` statements useful.

For those readers who are more familiar with Go, I'm going to cover *expression switch* statements in this chapter. I'll discuss *type switch* statements when I talk about interfaces in Chapter 7.

At first glance, `switch` statements in Go don't look all that different from how they appear in C/C++, Java, or JavaScript, but there are a few surprises. Let's take a look at a sample `switch` statement. You can run the code in Example 4-19 on The Go Playground or in the `basicSwitch` function in `main.go` in the *sample_code/switch* directory in the Chapter 4 repository.

Example 4-19. The `switch` statement

```
words := []string{"a", "cow", "smile", "gopher",
    "octopus", "anthropologist"}
```

```
for _, word := range words {
    switch size := len(word); size {
    case 1, 2, 3, 4:
        fmt.Println(word, "is a short word!")
    case 5:
        wordLen := len(word)
        fmt.Println(word, "is exactly the right length:", wordLen)
    case 6, 7, 8, 9:
    default:
        fmt.Println(word, "is a long word!")
    }
}
```

When you run this code, you get the following output:

```
a is a short word!
cow is a short word!
smile is exactly the right length: 5
anthropologist is a long word!
```

I'll go over the features of the `switch` statement to explain the output. As is the case with `if` statements, you don't put parentheses around the value being compared in a `switch`. Also as if an `if` statement, you can declare a variable that's scoped to all branches of the `switch` statement. In this case, you are scoping the variable `size` to all cases in the `switch` statement.

All `case` clauses (and the optional `default` clause) are contained inside a set of braces. But you should note that you don't put braces around the contents of the `case` clauses. You can have multiple lines inside a `case` (or `default`) clause, and they are all considered to be part of the same block.

Inside `case 5:`, you declare `wordLen`, a new variable. Since this is a new block, you can declare new variables within it. Just like any other block, any variables declared within a `case` clause's block are visible only within that block.

If you are used to putting a `break` statement at the end of every `case` in your `switch` statements, you'll be happy to notice that they are gone. By default, cases in `switch` statements in Go don't fall through. This is more in line with the behavior in Ruby or (if you are an old-school programmer) Pascal.

This prompts the question: if cases don't fall through, what do you do if there are multiple values that should trigger the exact same logic? In Go, you separate multiple matches with commas, as you do when matching 1, 2, 3, and 4 or 6, 7, 8, and 9. That's why you get the same output for both `a` and `cow`.

Which leads to the next question: if you don't have fall-through, and you have an empty case (as you do in the sample program when the length of your argument is 6, 7, 8, or 9 characters), what happens? In Go, *an empty case means nothing happens*.

That's why you don't see any output from your program when you use *octopus* or *gopher* as the parameter.

For the sake of completeness, Go does include a `fallthrough` keyword, which lets one case continue on to the next one. Please think twice before implementing an algorithm that uses it. If you find yourself needing to use `fallthrough`, try to restructure your logic to remove the dependencies between cases.

In the sample program, you are switching on the value of an integer, but that's not all you can do. You can switch on any type that can be compared with `==`, which includes all built-in types except slices, maps, channels, functions, and structs that contain fields of these types.

Even though you don't need to put a `break` statement at the end of each `case` clause, you can use them when you want to exit early from a `case`. However, the need for a `break` statement might indicate that you are doing something too complicated. Consider refactoring your code to remove it.

There is one more place where you might find yourself using a `break` statement in a `case` in a `switch` statement. If you have a `switch` statement inside a `for` loop, and you want to break out of the `for` loop, put a label on the `for` statement and put the name of the label on the `break`. If you don't use a label, Go assumes that you want to break out of the `case`. Let's look at a quick example where you want to break out of the `for` loop once it reaches 7. You can run the code in Example 4-20 on The Go Playground or in the `missingLabel` function in *main.go* in the *sample_code/switch* directory in the Chapter 4 repository.

Example 4-20. The case of the missing label

```go
func main() {
    for i := 0; i < 10; i++ {
        switch i {
        case 0, 2, 4, 6:
            fmt.Println(i, "is even")
        case 3:
            fmt.Println(i, "is divisible by 3 but not 2")
        case 7:
            fmt.Println("exit the loop!")
            break
        default:
            fmt.Println(i, "is boring")
        }
    }
}
```

Running this code produces the following output:

```
0 is even
1 is boring
2 is even
3 is divisible by 3 but not 2
4 is even
5 is boring
6 is even
exit the loop!
8 is boring
9 is boring
```

That's not what is intended. The goal was to break out of the `for` loop when it got a 7, but the `break` was interpreted as exiting the `case`. To resolve this, you need to introduce a label, just as you did when breaking out of a nested `for` loop. First, you label the `for` statement:

```
loop:
    for i := 0; i < 10; i++ {
```

Then you use the label on your break:

```
break loop
```

You can see these changes on The Go Playground or in the `labeledBreak` function in *main.go* in the *sample_code/switch* directory in the Chapter 4 repository. When you run it again, you get the expected output:

```
0 is even
1 is boring
2 is even
3 is divisible by 3 but not 2
4 is even
5 is boring
6 is even
exit the loop!
```

Blank Switches

You can use `switch` statements in another, more powerful way. Just as Go allows you to leave out parts from a `for` statement's declaration, you can write a `switch` statement that doesn't specify the value that you're comparing against. This is called a *blank switch*. A regular `switch` only allows you to check a value for equality. A blank `switch` allows you to use any boolean comparison for each `case`. You can try out the code in Example 4-21 on The Go Playground or in the `basicBlankSwitch` function in *main.go* in the *sample_code/blank_switch* directory in the Chapter 4 repository.

Example 4-21. The blank `switch`

```
words := []string{"hi", "salutations", "hello"}
for _, word := range words {
    switch wordLen := len(word); {
    case wordLen < 5:
        fmt.Println(word, "is a short word!")
    case wordLen > 10:
        fmt.Println(word, "is a long word!")
    default:
        fmt.Println(word, "is exactly the right length.")
    }
}
```

When you run this program, you get the following output:

```
hi is a short word!
salutations is a long word!
hello is exactly the right length.
```

Just as with a regular `switch` statement, you can optionally include a short variable declaration as part of your blank `switch`. But unlike a regular `switch`, you can write logical tests for your cases. Blank switches are pretty cool, but don't overdo them. If you find that you have written a blank `switch` where all your cases are equality comparisons against the same variable:

```
switch {
case a == 2:
    fmt.Println("a is 2")
case a == 3:
    fmt.Println("a is 3")
case a == 4:
    fmt.Println("a is 4")
default:
    fmt.Println("a is ", a)
}
```

you should replace it with an expression `switch` statement:

```
switch a {
case 2:
    fmt.Println("a is 2")
case 3:
    fmt.Println("a is 3")
case 4:
    fmt.Println("a is 4")
default:
    fmt.Println("a is ", a)
}
```

Choosing Between if and switch

As a matter of functionality, there isn't much difference between a series of `if/else` statements and a blank `switch` statement. Both allow a series of comparisons. So, when should you use `switch`, and when should you use a set of `if` or `if/else` statements? A `switch` statement, even a blank `switch`, indicates that a relationship exists between the values or comparisons in each case. To demonstrate the difference in clarity, rewrite the FizzBuzz program from Example 4-11 using a blank `switch`, as shown in Example 4-22. You can also find this code in the *sample_code/simplest_fizzbuzz* directory in the Chapter 4 repository.

Example 4-22. Rewriting a series of `if` statements with a blank `switch`

```
for i := 1; i <= 100; i++ {
    switch {
    case i%3 == 0 && i%5 == 0:
        fmt.Println("FizzBuzz")
    case i%3 == 0:
        fmt.Println("Fizz")
    case i%5 == 0:
        fmt.Println("Buzz")
    default:
        fmt.Println(i)
    }
}
```

Most people would agree that this is the most readable version. There's no more need for `continue` statements, and the default behavior is made explicit with the `default` case.

Of course, nothing in Go prevents you from doing all sorts of unrelated comparisons on each `case` in a blank `switch`. However, this is not idiomatic. If you find yourself in a situation where you want to do this, use a series of `if/else` statements (or perhaps consider refactoring your code).

Favor blank `switch` statements over `if/else` chains when you have multiple related cases. Using a `switch` makes the comparisons more visible and reinforces that they are a related set of concerns.

goto—Yes, goto

Go has a fourth control statement, but chances are, you will never use it. Ever since Edsger Dijkstra wrote "Go To Statement Considered Harmful" in 1968, the `goto` statement has been the black sheep of the coding family. There are good reasons for this. Traditionally, `goto` was dangerous because it could jump to nearly anywhere in a program; you could jump into or out of a loop, skip over variable definitions, or into the middle of a set of statements in an `if` statement. This made it difficult to understand what a `goto`-using program did.

Most modern languages don't include `goto`. Yet Go has a `goto` statement. You should still do what you can to avoid using it, but it has some uses, and the limitations that Go places on it make it a better fit with structured programming.

In Go, a `goto` statement specifies a labeled line of code, and execution jumps to it. However, you can't jump anywhere. Go forbids jumps that skip over variable declarations and jumps that go into an inner or parallel block.

The program in Example 4-23 shows two illegal `goto` statements. You can attempt to run it on The Go Playground or in the *sample_code/broken_goto* directory in the Chapter 4 repository.

Example 4-23. Go's `goto` has rules

```
func main() {
    a := 10
    goto skip
    b := 20
skip:
    c := 30
    fmt.Println(a, b, c)
    if c > a {
        goto inner
    }
    if a < b {
    inner:
        fmt.Println("a is less than b")
    }
}
```

Trying to run this program produces the following errors:

```
goto skip jumps over declaration of b at ./main.go:8:4
goto inner jumps into block starting at ./main.go:15:11
```

So what should you use `goto` for? Mostly, you shouldn't. Labeled `break` and `continue` statements allow you to jump out of deeply nested loops or skip iteration. The program in Example 4-24 has a legal `goto` and demonstrates one of the few valid use cases. You can also find this code in the *sample_code/good_goto* directory in the Chapter 4 repository.

Example 4-24. A reason to use `goto`

```
func main() {
    a := rand.Intn(10)
    for a < 100 {
        if a%5 == 0 {
            goto done
        }
        a = a*2 + 1
    }
    fmt.Println("do something when the loop completes normally")
done:
    fmt.Println("do complicated stuff no matter why we left the loop")
    fmt.Println(a)
}
```

This example is contrived, but it shows how `goto` can make a program clearer. In this simple case, there is some logic that you don't want to run in the middle of the function, but you do want to run at the end of the function. There are ways to do this without `goto`. You could set up a boolean flag or duplicate the complicated code after the `for` loop instead of having a `goto`, but both approaches have drawbacks. Littering your code with boolean flags to control the logic flow is arguably the same functionality as the `goto` statement, just more verbose. Duplicating complicated code is problematic because it makes your code harder to maintain. These situations are rare, but if you cannot find a way to restructure your logic, using a `goto` like this actually improves your code.

If you want to see a real-world example, you can take a look at the `floatBits` method in the file *atof.go* in the `strconv` package in the standard library. It's too long to include in its entirety, but the method ends with this code:

```
overflow:
    // ±Inf
    mant = 0
    exp = 1<<flt.expbits - 1 + flt.bias
    overflow = true

out:
    // Assemble bits.
    bits := mant & (uint64(1)<<flt.mantbits - 1)
    bits |= uint64((exp-flt.bias)&(1<<flt.expbits-1)) << flt.mantbits
    if d.neg {
        bits |= 1 << flt.mantbits << flt.expbits
    }
    return bits, overflow
```

Before these lines, there are several condition checks. Some require the code after the `overflow` label to run, while other conditions require skipping that code and going directly to `out`. Depending on the condition, there are `goto` statements that jump to `overflow` or `out`. You could probably come up with a way to avoid the `goto` statements, but they all make the code harder to understand.

You should try very hard to avoid using `goto`. But in the rare situations where it makes your code more readable, it is an option.

Exercises

Now it's time to apply everything you've learned about control structures and blocks in Go. You can find answers to these exercises in the Chapter 4 repository.

1. Write a `for` loop that puts 100 random numbers between 0 and 100 into an `int` slice.
2. Loop over the slice you created in exercise 1. For each value in the slice, apply the following rules:
   a. If the value is divisible by 2, print "Two!"
   b. If the value is divisible by 3, print "Three!"
   c. IIf the value is divisible by 2 and 3, print "Six!". Don't print anything else.
   d. Otherwise, print "Never mind".
3. Start a new program. In `main`, declare an `int` variable called `total`. Write a `for` loop that uses a variable named `i` to iterate from 0 (inclusive) to 10 (exclusive). The body of the `for` loop should be as follows:

   ```
   total := total + i
   fmt.Println(total)
   ```

   After the `for` loop, print out the value of `total`. What is printed out? What is the likely bug in this code?

Wrapping Up

This chapter covered a lot of important topics for writing idiomatic Go. You've learned about blocks, shadowing, and control structures, and how to use them correctly. At this point, you're able to write simple Go programs that fit within the `main` function. It's time to move on to larger programs, using functions to organize your code.

CHAPTER 5
Functions

So far, your programs have been limited to a few lines in the `main` function. It's time to get bigger. In this chapter, you're going to learn how to write functions in Go and see all the interesting things you can do with them.

Declaring and Calling Functions

The basics of Go functions are familiar to anyone who has programmed in other languages with first-class functions, like C, Python, Ruby, or JavaScript. (Go also has methods, which I'll cover in Chapter 7.) Just as with control structures, Go adds its own twist on function features. Some are improvements, and others are experiments that should be avoided. I'll cover both in this chapter.

You've already seen functions being declared and used. Every Go program starts from a `main` function, and you've been calling the `fmt.Println` function to print to the screen. Since a `main` function doesn't take in parameters or return values, let's see what it looks like when a function does:

```go
func div(num int, denom int) int {
    if denom == 0 {
        return 0
    }
    return num / denom
}
```

Let's look at all the new things in this code sample. A function declaration has four parts: the keyword `func`, the name of the function, the input parameters, and the return type. The input parameters are listed in parentheses, separated by commas, with the parameter name first and the type second. Go is a typed language, so you must specify the types of the parameters. The return type is written between the input parameter's closing parenthesis and the opening brace for the function body.

Just like other languages, Go has a `return` keyword for returning values from a function. If a function returns a value, you *must* supply a `return`. If a function returns nothing, a `return` statement is not needed at the end of the function. The `return` keyword is needed in a function that returns nothing only if you are exiting from the function before the last line.

The `main` function has no input parameters or return values. When a function has no input parameters, use empty parentheses (`()`). When a function returns nothing, you write nothing between the input parameter's closing parenthesis and the opening brace for the function body:

```go
func main() {
    result := div(5, 2)
    fmt.Println(result)
}
```

The code for this simple program is in the *sample_code/simple_div* directory in the Chapter 5 repository.

Calling a function should be familiar to experienced developers. On the right side of the `:=`, you call the `div` function with the values 5 and 2. On the left side, you assign the returned value to the variable `result`.

When you have two or more consecutive input parameters of the same type, you can specify the type once for all of them like this:

```go
func div(num, denom int) int {
```

Simulating Named and Optional Parameters

Before getting to the unique function features that Go has, I'll mention two that Go *doesn't* have: named and optional input parameters. With one exception that I will cover in the next section, you must supply all the parameters for a function. If you want to emulate named and optional parameters, define a struct that has fields that match the desired parameters, and pass the struct to your function. Example 5-1 shows a snippet of code that demonstrates this pattern.

Example 5-1. Using a struct to simulate named parameters

```go
type MyFuncOpts struct {
    FirstName string
    LastName  string
    Age       int
}

func MyFunc(opts MyFuncOpts) error {
    // do something here
}

func main() {
    MyFunc(MyFuncOpts{
        LastName: "Patel",
        Age:      50,
    })
    MyFunc(MyFuncOpts{
        FirstName: "Joe",
        LastName:  "Smith",
    })
}
```

The code for this program is in the *sample_code/named_optional_parameters* directory in the Chapter 5 repository.

In practice, not having named and optional parameters isn't a limitation. A function shouldn't have more than a few parameters, and named and optional parameters are mostly useful when a function has many inputs. If you find yourself in that situation, your function is quite possibly too complicated.

Variadic Input Parameters and Slices

You've been using `fmt.Println` to print results to the screen and you've probably noticed that it allows any number of input parameters. How does it do that? Like many languages, Go supports *variadic parameters*. The variadic parameter *must* be the last (or only) parameter in the input parameter list. You indicate it with three dots (`...`) *before* the type. The variable that's created within the function is a slice of the specified type. You use it just like any other slice. Let's see how they work by writing a program that adds a base number to a variable number of parameters and returns the result as a slice of `int`. You can run this program on The Go Playground or in the *sample_code/variadic* directory in the Chapter 5 repository. First, write the variadic function:

```
func addTo(base int, vals ...int) []int {
    out := make([]int, 0, len(vals))
    for _, v := range vals {
        out = append(out, base+v)
    }
    return out
}
```

And now call it in a few ways:

```
func main() {
    fmt.Println(addTo(3))
    fmt.Println(addTo(3, 2))
    fmt.Println(addTo(3, 2, 4, 6, 8))
    a := []int{4, 3}
    fmt.Println(addTo(3, a...))
    fmt.Println(addTo(3, []int{1, 2, 3, 4, 5}...))
}
```

As you can see, you can supply however many values you want for the variadic parameter or no values at all. Since the variadic parameter is converted to a slice, you can supply a slice as the input. However, you must put three dots (`...`) *after* the variable or slice literal. If you do not, it is a compile-time error.

When you build and run this program, you get this output:

```
[]
[5]
[5 7 9 11]
[7 6]
[4 5 6 7 8]
```

Multiple Return Values

The first difference that you'll see between Go and other languages is that Go allows for multiple return values. Let's add a small feature to the previous division program. You're going to return both the dividend and the remainder from the function. Here's the updated function:

```go
func divAndRemainder(num, denom int) (int, int, error) {
    if denom == 0 {
        return 0, 0, errors.New("cannot divide by zero")
    }
    return num / denom, num % denom, nil
}
```

There are a few changes to support multiple return values. When a Go function returns multiple values, the types of the return values are listed in parentheses, separated by commas. Also, if a function returns multiple values, you must return all of them, separated by commas. Don't put parentheses around the returned values; that's a compile-time error.

There's something else that you haven't seen yet: creating and returning an `error`. If you want to learn more about errors, skip ahead to Chapter 9. For now, you need to know only that you use Go's multiple return value support to return an `error` if something goes wrong in a function. If the function completes successfully, you return `nil` for the error's value. By convention, the `error` is always the last (or only) value returned from a function.

Calling the updated function looks like this:

```go
func main() {
    result, remainder, err := divAndRemainder(5, 2)
    if err != nil {
        fmt.Println(err)
        os.Exit(1)
    }
    fmt.Println(result, remainder)
}
```

The code for this program is in the *sample_code/updated_div* directory in the Chapter 5 repository.

I talked about assigning multiple values at once in "var Versus :=" on page 28. Here you are using that feature to assign the results of a function call to three variables. On the right side of the `:=`, you call the `divAndRemainder` function with the values 5 and 2. On the left side, you assign the returned values to the variables `result`, `remainder`, and `err`. You check to see if there was an error by comparing `err` to `nil`.

Multiple Return Values Are Multiple Values

If you are familiar with Python, you might think that multiple return values are like Python functions returning a tuple that's optionally destructured if the tuple's values are assigned to multiple variables. Example 5-2 shows some sample code run in the Python interpreter.

Example 5-2. Multiple return values in Python are destructured tuples

```
>>> def div_and_remainder(n,d):
...   if d == 0:
...     raise Exception("cannot divide by zero")
...   return n / d, n % d
>>> v = div_and_remainder(5,2)
>>> v
(2.5, 1)
>>> result, remainder = div_and_remainder(5,2)
>>> result
2.5
>>> remainder
1
```

In Python, you can assign all the values returned to a single variable or to multiple variables. That's not how Go works. You must assign each value returned from a function. If you try to assign multiple return values to one variable, you get a compile-time error.

Ignoring Returned Values

What if you call a function and don't want to use all the returned values? As covered in "Unused Variables" on page 32, Go does not allow unused variables. If a function returns multiple values, but you don't need to read one or more of the values, assign the unused values to the name `_`. For example, if you weren't going to read `remainder`, you would write the assignment as `result, _, err := divAndRemainder(5, 2)`.

Surprisingly, Go does let you implicitly ignore *all* of the return values for a function. You can write `divAndRemainder(5,2)`, and the returned values are dropped. You have actually been doing this since the earliest examples: `fmt.Println` returns two values, but it is idiomatic to ignore them. In almost all other cases, you should make it explicit that you are ignoring return values by using underscores.

Use _ whenever you don't need to read a value that's returned by a function.

Named Return Values

In addition to letting you return more than one value from a function, Go allows you to specify *names* for your return values. Rewrite the `divAndRemainder` function one more time, this time using named return values:

```go
func divAndRemainder(num, denom int) (result int, remainder int, err error) {
    if denom == 0 {
        err = errors.New("cannot divide by zero")
        return result, remainder, err
    }
    result, remainder = num/denom, num%denom
    return result, remainder, err
}
```

When you supply names to your return values, what you are doing is predeclaring variables that you use within the function to hold the return values. They are written as a comma-separated list within parentheses. *You must surround named return values with parentheses, even if there is only a single return value*. Named return values are initialized to their zero values when created. This means that you can return them before any explicit use or assignment.

If you want to name only *some* of the return values, you can do so by using _ as the name for any return values you want to remain nameless.

One important thing to note: the name that's used for a named returned value is local to the function; it doesn't enforce any name outside of the function. It is perfectly legal to assign the return values to variables of different names:

```
func main() {
    x, y, z := divAndRemainder(5, 2)
    fmt.Println(x, y, z)
}
```

While named return values can sometimes help clarify your code, they do have some potential corner cases. First is the problem of shadowing. Just as with any other variable, you can shadow a named return value. Be sure that you are assigning to the return value and not to a shadow of it.

The other problem with named return values is that you don't have to return them. Let's take a look at another variation on `divAndRemainder`. You can run it on The Go Playground or in the `divAndRemainderConfusing` function in *main.go* in the *sample_code/named_div* directory in the Chapter 5 repository:

```
func divAndRemainder(num, denom int) (result int, remainder int, err error) {
    // assign some values
    result, remainder = 20, 30
    if denom == 0 {
        return 0, 0, errors.New("cannot divide by zero")
    }
    return num / denom, num % denom, nil
}
```

Notice that you assigned values to `result` and `remainder` and then returned different values directly. Before running this code, try to guess what happens when 5 and 2 are passed to this function. The result might surprise you:

```
2 1
```

The values from the `return` statement were returned even though they were never assigned to the named return parameters. That's because the Go compiler inserts code that assigns whatever is returned to the return parameters. The named return parameters give a way to declare an *intent* to use variables to hold the return values, but don't *require* you to use them.

Some developers like to use named return parameters because they provide additional documentation. However, I find them of limited value. Shadowing makes them confusing, as does simply ignoring them. Named return parameters are essential in one situation. I will talk about that when I cover `defer` later in the chapter.

Blank Returns—Never Use These!

If you use named return values, you need to be aware of one severe misfeature in Go: blank (sometimes called *naked*) returns. If you have named return values, you can just write `return` without specifying the values that are returned. This returns the last values assigned to the named return values. Rewrite the `divAndRemainder` function one last time, this time using blank returns:

```go
func divAndRemainder(num, denom int) (result int, remainder int, err error) {
    if denom == 0 {
        err = errors.New("cannot divide by zero")
        return
    }
    result, remainder = num/denom, num%denom
    return
}
```

Using blank returns makes a few additional changes to the function. When there's invalid input, the function returns immediately. Since no values were assigned to `result` and `remainder`, their zero values are returned. If you are returning the zero values for your named return values, be sure they make sense. Also note that you still have to put a `return` at the end of the function. Even though the function is using blank returns, this function returns values. Leaving out `return` is a compile-time error.

At first, you might find blank returns handy since they allow you to avoid some typing. However, most experienced Go developers consider blank returns a bad idea because they make it harder to understand data flow. Good software is clear and readable; it's obvious what is happening. When you use a blank return, the reader of your code needs to scan back through the program to find the last value assigned to the return parameters to see what is actually being returned.

If your function returns values, *never* use a blank return. It can make it very confusing to figure out what value is actually returned.

Functions Are Values

Just as in many other languages, functions in Go are values. The type of a function is built out of the keyword `func` and the types of the parameters and return values. This combination is called the *signature* of the function. Any function that has the exact same number and types of parameters and return values meets the type signature.

Since functions are values, you can declare a function variable:

```go
var myFuncVariable func(string) int
```

myFuncVariable can be assigned any function that has a single parameter of type string and returns a single value of type int. Here's a longer example:

```go
func f1(a string) int {
    return len(a)
}

func f2(a string) int {
    total := 0
    for _, v := range a {
        total += int(v)
    }
    return total
}

func main() {
    var myFuncVariable func(string) int
    myFuncVariable = f1
    result := myFuncVariable("Hello")
    fmt.Println(result)

    myFuncVariable = f2
    result = myFuncVariable("Hello")
    fmt.Println(result)
}
```

You can run this program on The Go Playground or in the *sample_code/func_value* directory in the Chapter 5 repository. The output is:

```
5
500
```

The default zero value for a function variable is nil. Attempting to run a function variable with a nil value results in a panic (which is covered in "panic and recover" on page 218).

Having functions as values allows you to do some clever things, such as build a simple calculator using functions as values in a map. Let's see how this works. The following code is available on The Go Playground or in the *sample_code/calculator* directory in the Chapter 5 repository. First, create a set of functions that all have the same signature:

```go
func add(i int, j int) int { return i + j }

func sub(i int, j int) int { return i - j }

func mul(i int, j int) int { return i * j }

func div(i int, j int) int { return i / j }
```

Next, create a map to associate a math operator with each function:

```
var opMap = map[string]func(int, int) int{
    "+": add,
    "-": sub,
    "*": mul,
    "/": div,
}
```

Finally, try out the calculator with a few expressions:

```
func main() {
    expressions := [][]string{
        {"2", "+", "3"},
        {"2", "-", "3"},
        {"2", "*", "3"},
        {"2", "/", "3"},
        {"2", "%", "3"},
        {"two", "+", "three"},
        {"5"},
    }
    for _, expression := range expressions {
        if len(expression) != 3 {
            fmt.Println("invalid expression:", expression)
            continue
        }
        p1, err := strconv.Atoi(expression[0])
        if err != nil {
            fmt.Println(err)
            continue
        }
        op := expression[1]
        opFunc, ok := opMap[op]
        if !ok {
            fmt.Println("unsupported operator:", op)
            continue
        }
        p2, err := strconv.Atoi(expression[2])
        if err != nil {
            fmt.Println(err)
            continue
        }
        result := opFunc(p1, p2)
        fmt.Println(result)
    }
}
```

You're using the `strconv.Atoi` function in the standard library to convert a `string` to an `int`. The second value returned by this function is an `error`. Just as before, you check for errors that are returned by functions and handle error conditions properly.

You use `op` as the key to the `opMap` map, and assign the value associated with the key to the variable `opFunc`. The type of `opFunc` is `func(int, int) int`. If there wasn't a function in the map associated with the provided key, you print an error message and skip the rest of the loop. You then call the function assigned to the `opFunc` variable with the `p1` and `p2` variables that you decoded earlier. Calling a function in a variable looks just like calling a function directly.

When you run this program, you can see the simple calculator at work:

```
5
-1
6
0
unsupported operator: %
strconv.Atoi: parsing "two": invalid syntax
invalid expression: [5]
```

Don't write fragile programs. The core logic for this example is relatively short. Of the 22 lines inside the `for` loop, 6 of them implement the actual algorithm, and the other 16 are for error checking and data validation. You might be tempted to not validate incoming data or check errors, but doing so produces unstable, unmaintainable code. Error handling is what separates the professionals from the amateurs.

Function Type Declarations

Just as you can use the `type` keyword to define a `struct`, you can use it to define a function type too (I'll go into more details on type declarations in Chapter 7):

```
type opFuncType func(int,int) int
```

You can then rewrite the `opMap` declaration to look like this:

```
var opMap = map[string]opFuncType {
    // same as before
}
```

You don't have to modify the functions at all. Any function that has two input parameters of type `int` and a single return value of type `int` automatically meets the type and can be assigned as a value in the map.

What's the advantage of declaring a function type? One use is documentation. It's useful to give something a name if you are going to refer to it multiple times. You will see another use in "Function Types Are a Bridge to Interfaces" on page 173.

Anonymous Functions

You can not only assign functions to variables, but also define new functions within a function and assign them to variables. Here's a program to demonstrate this, which you can run on The Go Playground. The code is also available in the *sample_code/anon_func* directory in the Chapter 5 repository:

```go
func main() {
    f := func(j int) {
        fmt.Println("printing", j, "from inside of an anonymous function")
    }
    for i := 0; i < 5; i++ {
        f(i)
    }
}
```

Inner functions are *anonymous*; they don't have a name. You declare an anonymous function with the keyword `func` immediately followed by the input parameters, the return values, and the opening brace. It is a compile-time error to try to put a function name between `func` and the input parameters.

Just like any other function, an anonymous function is called by using parentheses. In this example, you are passing the `i` variable from the `for` loop in here. It is assigned to the `j` input parameter of the anonymous function.

The program gives the following output:

```
printing 0 from inside of an anonymous function
printing 1 from inside of an anonymous function
printing 2 from inside of an anonymous function
printing 3 from inside of an anonymous function
printing 4 from inside of an anonymous function
```

You don't have to assign an anonymous function to a variable. You can write them inline and call them immediately. The previous program can be rewritten into this:

```go
func main() {
    for i := 0; i < 5; i++ {
        func(j int) {
            fmt.Println("printing", j, "from inside of an anonymous function")
        }(i)
    }
}
```

You can run this example on The Go Playground or in the *sample_code/anon_func* directory in the Chapter 5 repository.

Now, this is not something that you would normally do. If you are declaring and executing an anonymous function immediately, you might as well get rid of the anonymous function and just call the code. However, declaring anonymous functions without assigning them to variables is useful in two situations: `defer` statements and launching goroutines. I'll talk about `defer` statements in a bit. Goroutines are covered in Chapter 12.

Since you can declare variables at the package scope, you can also declare package scope variables that are assigned anonymous functions:

```
var (
    add = func(i, j int) int { return i + j }
    sub = func(i, j int) int { return i - j }
    mul = func(i, j int) int { return i * j }
    div = func(i, j int) int { return i / j }
)

func main() {
    x := add(2, 3)
    fmt.Println(x)
}
```

Unlike a normal function definition, you can assign a new value to a package-level anonymous function:

```
func main() {
    x := add(2, 3)
    fmt.Println(x)
    changeAdd()
    y := add(2, 3)
    fmt.Println(y)
}

func changeAdd() {
    add = func(i, j int) int { return i + j + j }
}
```

Running this code gives the following output:

```
5
8
```

You can try this sample on The Go Playground. The code is also in the *sample_code/package_level_anon* directory in the Chapter 5 repository.

Before using a package-level anonymous function, be very sure you need this capability. Package-level state should be immutable to make data flow easier to understand. If a function's meaning changes while a program is running, it becomes difficult to understand not just how data flows, but how it is processed.

Closures

Functions declared inside functions are special; they are *closures*. This is a computer science word that means that functions declared inside functions are able to access and modify variables declared in the outer function. Let's look at a quick example to see how this works. You can find the code on The Go Playground. The code is also in the *sample_code/closure* directory in the Chapter 5 repository:

```go
func main() {
    a := 20
    f := func() {
        fmt.Println(a)
        a = 30
    }
    f()
    fmt.Println(a)
}
```

Running this program gives the following output:

```
20
30
```

The anonymous function assigned to `f` can read and write `a`, even though `a` is not passed in to the function.

Just as with any inner scope, you can shadow a variable inside a closure. If you change the code to:

```go
func main() {
    a := 20
    f := func() {
        fmt.Println(a)
        a := 30
        fmt.Println(a)
    }
    f()
    fmt.Println(a)
}
```

this will print out the following:

```
20
30
20
```

Using `:=` instead of `=` inside the closure creates a new `a` that ceases to exist when the closure exits. When working with inner functions, be careful to use the correct assignment operator, especially when multiple variables are on the lefthand side. You can try this code on The Go Playground. The code is also in the *sample_code/closure_shadow* directory in the Chapter 5 repository.

This inner function and closure stuff might not seem all that useful at first. What benefit do you get from making mini-functions within a larger function? Why does Go have this feature?

One thing that closures allow you to do is to limit a function's scope. If a function is going to be called from only one other function, but it's called multiple times, you can use an inner function to "hide" the called function. This reduces the number of declarations at the package level, which can make it easier to find an unused name.

If you have a piece of logic that is repeated multiple times within a function, a closure can be used to remove that repetition. I wrote a simple Lisp interpreter with a `Scan` function that processes an input string to find the parts of a Lisp program. It relies on two closures, `buildCurToken` and `update`, to make the code shorter and easier to understand. You can see it on GitHub.

Closures really become interesting when they are passed to other functions or returned from a function. They allow you to take the variables within your function and use those values *outside* of your function.

Passing Functions as Parameters

Since functions are values and you can specify the type of a function using its parameter and return types, you can pass functions as parameters into functions. If you aren't used to treating functions like data, you might need a moment to think about the implications of creating a closure that references local variables and then passing that closure to another function. It's a very useful pattern that appears several times in the standard library.

One example is sorting slices. The `sort` package in the standard library has a function called `sort.Slice`. It takes in any slice and a function that is used to sort the slice that's passed in. Let's see how it works by sorting a slice of a struct using two different fields.

The `sort.Slice` function predates the addition of generics to Go, so it does some internal magic to make it work with any kind of slice. I'll talk about this magic more in Chapter 16.

Let's see how to use closures to sort the same data different ways. You can run this code on The Go Playground. The code is also in the *sample_code/sort_sample* directory in the Chapter 5 repository. First, define a simple type, a slice of values of that type, and print out the slice:

```
type Person struct {
    FirstName string
    LastName  string
    Age       int
}

people := []Person{
    {"Pat", "Patterson", 37},
    {"Tracy", "Bobdaughter", 23},
    {"Fred", "Fredson", 18},
}
fmt.Println(people)
```

Next, sort the slice by last name and print out the results:

```
// sort by last name
sort.Slice(people, func(i, j int) bool {
    return people[i].LastName < people[j].LastName
})
fmt.Println(people)
```

The closure that's passed to `sort.Slice` has two parameters, `i` and `j`, but within the closure, `people` is used, so you can sort it by the `LastName` field. In computer science terms, `people` is *captured* by the closure. Next you do the same, sorting by the `Age` field:

```
// sort by age
sort.Slice(people, func(i, j int) bool {
    return people[i].Age < people[j].Age
})
fmt.Println(people)
```

Running this code gives the following output:

```
[{Pat Patterson 37} {Tracy Bobdaughter 23} {Fred Fredson 18}]
[{Tracy Bobdaughter 23} {Fred Fredson 18} {Pat Patterson 37}]
[{Fred Fredson 18} {Tracy Bobdaughter 23} {Pat Patterson 37}]
```

The `people` slice is changed by the call to `sort.Slice`. I talk about this briefly in "Go Is Call by Value" on page 114 and in more detail in the next chapter.

Passing functions as parameters to other functions is often useful for performing different operations on the same kind of data.

Returning Functions from Functions

In addition to using a closure to pass some function state to another function, you can also return a closure from a function. Let's demonstrate this by writing a function that returns a multiplier function. You can run this program on The Go Playground. The code is also in the *sample_code/makeMult* directory in the Chapter 5 repository. Here is a function that returns a closure:

```
func makeMult(base int) func(int) int {
    return func(factor int) int {
        return base * factor
    }
}
```

And here is how the function is used:

```
func main() {
    twoBase := makeMult(2)
    threeBase := makeMult(3)
    for i := 0; i < 3; i++ {
        fmt.Println(twoBase(i), threeBase(i))
    }
}
```

Running this program gives the following output:

```
0 0
2 3
4 6
```

Now that you've seen closures in action, you might wonder how often they are used by Go developers. It turns out that they are surprisingly useful. You saw how they are used to sort slices. A closure is also used to efficiently search a sorted slice with `sort.Search`. As for returning closures, you will see this pattern used when you build middleware for a web server in "Middleware" on page 340. Go also uses closures to implement resource cleanup, via the `defer` keyword.

If you spend any time with programmers who use functional programming languages like Haskell, you might hear the term *higher-order functions*. That's a fancy way to say that a function has a function for an input parameter or a return value. As a Go developer, you are as cool as they are!

defer

Programs often create temporary resources, like files or network connections, that need to be cleaned up. This cleanup has to happen, no matter how many exit points a function has, or whether a function completed successfully or not. In Go, the cleanup code is attached to the function with the `defer` keyword.

Let's take a look at how to use `defer` to release resources. You'll do this by writing a simple version of `cat`, the Unix utility for printing the contents of a file. You can't pass in arguments on The Go Playground, but you can find the code for this example in the *sample_code/simple_cat* directory in the Chapter 5 repository:

```
func main() {
    if len(os.Args) < 2 {
        log.Fatal("no file specified")
    }
    f, err := os.Open(os.Args[1])
    if err != nil {
        log.Fatal(err)
    }
    defer f.Close()
    data := make([]byte, 2048)
    for {
        count, err := f.Read(data)
        os.Stdout.Write(data[:count])
        if err != nil {
            if err != io.EOF {
                log.Fatal(err)
            }
            break
        }
    }
}
```

This example introduces a few new features that I cover in more detail in later chapters. Feel free to read ahead to learn more.

First, you make sure that a filename was specified on the command line by checking the length of `os.Args`, a slice in the `os` package. The first value in `os.Args` is the name of the program. The remaining values are the arguments passed to the program. You check that the length of `os.Args` is at least 2 to determine whether the argument to the program was provided. If it wasn't, use the `Fatal` function in the `log` package to print a message and exit the program. Next, you acquire a read-only file handle with the `Open` function in the `os` package. The second value that's returned by `Open` is an error. If there's a problem opening the file, you print the error message and exit the program. As mentioned earlier, I'll talk about errors in Chapter 9.

Once you know there is a valid file handle, you need to close it after you use it, no matter how you exit the function. To ensure that the cleanup code runs, you use the `defer` keyword, followed by a function or method call. In this case, you use the `Close` method on the file variable. (I cover `at` methods in Go in Chapter 7.) Normally, a function call runs immediately, but `defer` delays the invocation until the surrounding function exits.

You read from a file handle by passing a slice of bytes into the `Read` method on a file variable. I'll cover how to use this method in detail in "io and Friends" on page 319, but `Read` returns the number of bytes that were read into the slice and an error. If an error occurs, you check whether it's an end-of-file marker. If you are at the end of the file, you use `break` to exit the `for` loop. For all other errors, you report it and exit immediately, using `log.Fatal`. I'll talk a little more about slices and function parameters in "Go Is Call by Value" on page 114 and go into details on this pattern when I discuss pointers in the next chapter.

Building and running the program from within the *simple_cat* directory produces the following result:

```
$ go build
$ ./simple_cat simple_cat.go
package main

import (
    "io"
    "log"
    "os"
)
...
```

You should know a few more things about `defer`. First, you can use a function, method, or closure with `defer`. (When I mention functions with `defer`, mentally expand that to "functions, methods, or closures.")

You can `defer` multiple functions in a Go function. They run in last-in, first-out (LIFO) order; the last `defer` registered runs first.

The code within `defer` functions runs *after* the return statement. As I mentioned, you can supply a function with input parameters to a `defer`. The input parameters are evaluated immediately and their values are stored until the function runs.

Here's a quick example that demonstrates both of these features of `defer`:

```go
func deferExample() int {
    a := 10
    defer func(val int) {
        fmt.Println("first:", val)
    }(a)
    a = 20
    defer func(val int) {
        fmt.Println("second:", val)
    }(a)
    a = 30
    fmt.Println("exiting:", a)
    return a
}
```

Running this code gives the following output:

```
exiting: 30
second: 20
first: 10
```

You can run this on The Go Playground. It is also available in the *sample_code/defer_example* directory in the Chapter 5 repository.

You can supply a function that returns values to a `defer`, but there's no way to read those values:

```go
func example() {
    defer func() int {
        return 2 // there's no way to read this value
    }()
}
```

You might be wondering whether there's a way for a deferred function to examine or modify the return values of its surrounding function. There is, and it's the best reason to use named return values. It allows your code to take actions based on an error. When I talk about errors in Chapter 9, I will discuss a pattern that uses `defer` to add contextual information to an error returned from a function. Let's look at a way to handle database transaction cleanup using named return values and `defer`:

```go
func DoSomeInserts(ctx context.Context, db *sql.DB, value1, value2 string)
                  (err error) {
    tx, err := db.BeginTx(ctx, nil)
    if err != nil {
        return err
    }
    defer func() {
        if err == nil {
            err = tx.Commit()
        }
        if err != nil {
            tx.Rollback()
        }
    }()
    _, err = tx.ExecContext(ctx, "INSERT INTO FOO (val) values $1", value1)
    if err != nil {
        return err
    }
    // use tx to do more database inserts here
    return nil
}
```

I'm not going to cover Go's database support in this book, but the standard library includes extensive support for databases in the `database/sql` package. In the example function, you create a transaction to do a series of database inserts. If any of them fails, you want to roll back (not modify the database). If all of them succeed, you want to commit (store the database changes). You use a closure with `defer` to check whether `err` has been assigned a value. If it hasn't, you run `tx.Commit`, which could also return an error. If it does, the value `err` is modified. If any database interaction returned an error, you call `tx.Rollback`.

New Go developers tend to forget the set of parentheses after the braces when specifying a function for `defer`. It is a compile-time error to leave them out, and eventually the habit sets in. It helps to remember that supplying parentheses allows you to specify values that will be passed into the function when it runs.

A common pattern in Go is for a function that allocates a resource to also return a closure that cleans up the resource. In the *sample_code/simple_cat_cancel* directory in the Chapter 5 repository, there is a rewrite of the simple `cat` program that does this. First you write a helper function that opens a file and returns a closure:

```
func getFile(name string) (*os.File, func(), error) {
    file, err := os.Open(name)
    if err != nil {
        return nil, nil, err
    }
    return file, func() {
        file.Close()
    }, nil
}
```

The helper function returns a file, a function, and an error. That `*` means that a file reference in Go is a pointer. I'll talk more about that in the next chapter.

Now in `main`, you use the `getFile` function:

```
f, closer, err := getFile(os.Args[1])
if err != nil {
    log.Fatal(err)
}
defer closer()
```

Because Go doesn't allow unused variables, returning the `closer` from the function means that the program will not compile if the function is not called. That reminds the user to use `defer`. As covered earlier, you put parentheses after `closer` when you `defer` it.

Using defer can feel strange if you are used to a language that uses a block within a function to control when a resource is cleaned up, like the try/catch/finally blocks in Java, JavaScript, and Python or the begin/rescue/ensure blocks in Ruby.

The downside to these resource-cleanup blocks is that they create another level of indentation in your function, and that makes the code harder to read. It's not just my opinion that nested code is harder to follow. In research described in a 2017 paper in *Empirical Software Engineering*, Vard Antinyan et al. discovered that "Of… eleven proposed code characteristics, only two markedly influence complexity growth: the nesting depth and the lack of structure."

Research on what makes a program easier to read and understand isn't new. You can find papers that are many decades old, including a paper from 1983 by Richard Miara et al. that tries to figure out the right amount of indentation to use (according to their results, two to four spaces).

Go Is Call by Value

You might hear people say that Go is a *call-by-value* language and wonder what that means. It means that when you supply a variable for a parameter to a function, Go *always* makes a copy of the value of the variable. Let's take a look. You can run this code on The Go Playground. It is also in the *sample_code/pass_value_type* directory in the Chapter 5 repository. First, you define a simple struct:

```go
type person struct {
    age  int
    name string
}
```

Next, you write a function that takes in an int, a string, and a person, and modifies their values:

```go
func modifyFails(i int, s string, p person) {
    i = i * 2
    s = "Goodbye"
    p.name = "Bob"
}
```

You then call this function from main and see whether the modifications stick:

```go
func main() {
    p := person{}
    i := 2
    s := "Hello"
    modifyFails(i, s, p)
    fmt.Println(i, s, p)
}
```

As the name of the function indicates, running this code shows that a function won't change the values of the parameters passed into it:

```
2 Hello {0 }
```

I included the `person` struct to show that this isn't true just for primitive types. If you have programming experience in Java, JavaScript, Python, or Ruby, you might find the struct behavior strange. After all, those languages let you modify the fields in an object when you pass an object as a parameter to a function. The reason for the difference is something I will cover when I talk about pointers.

The behavior is a little different for maps and slices. Let's see what happens when you try to modify them within a function. You can run this code on The Go Playground. It is also in the *sample_code/pass_map_slice* directory in the Chapter 5 repository. You're going to write a function to modify a map parameter and a function to modify a slice parameter:

```go
func modMap(m map[int]string) {
    m[2] = "hello"
    m[3] = "goodbye"
    delete(m, 1)
}

func modSlice(s []int) {
    for k, v := range s {
        s[k] = v * 2
    }
    s = append(s, 10)
}
```

You then call these functions from `main`:

```go
func main() {
    m := map[int]string{
        1: "first",
        2: "second",
    }
    modMap(m)
    fmt.Println(m)

    s := []int{1, 2, 3}
    modSlice(s)
    fmt.Println(s)
}
```

When you run this code, you'll see something interesting:

```
map[2:hello 3:goodbye]
[2 4 6]
```

For the map, it's easy to explain what happens: any changes made to a map parameter are reflected in the variable passed into the function. For a slice, it's more complicated. You can modify any element in the slice, but you can't lengthen the slice. This is true for maps and slices that are passed directly into functions as well as map and slice fields in structs.

This program leads to the question: why do maps and slices behave differently than other types? It's because maps and slices are both implemented with pointers. I'll go into more detail in the next chapter.

Every type in Go is a value type. It's just that sometimes the value is a pointer.

Call by value is one reason that Go's limited support for constants is only a minor handicap. Since variables are passed by value, you can be sure that calling a function doesn't modify the variable whose value was passed in (unless the variable is a slice or map). In general, this is a good thing. It makes it easier to understand the flow of data through your program when functions don't modify their input parameters and instead return newly computed values.

While this approach is easy to understand, at times you need to pass something mutable to a function. What do you do then? That's when you need a pointer.

Exercises

These exercises test your knowledge of functions in Go and how to use them. Solutions are available in the *exercise_solutions* directory in the Chapter 5 repository.

1. The simple calculator program doesn't handle one error case: division by zero. Change the function signature for the math operations to return both an `int` and an `error`. In the `div` function, if the divisor is `0`, return `errors.New("division by zero")` for the error. In all other cases, return `nil`. Adjust the `main` function to check for this error.
2. Write a function called `fileLen` that has an input parameter of type `string` and returns an `int` and an `error`. The function takes in a filename and returns the number of bytes in the file. If there is an error reading the file, return the error. Use `defer` to make sure the file is closed properly.
3. Write a function called `prefixer` that has an input parameter of type `string` and returns a function that has an input parameter of type `string` and returns a `string`. The returned function should prefix its input with the string passed into `prefixer`. Use the following `main` function to test `prefixer`:

```
func main() {
    helloPrefix := prefixer("Hello")
    fmt.Println(helloPrefix("Bob")) // should print Hello Bob
    fmt.Println(helloPrefix("Maria")) // should print Hello Maria
}
```

Wrapping Up

In this chapter, you've looked at functions in Go, how they are similar to functions in other languages, and their unique features. In the next chapter, you're going to look at pointers, find out that they aren't nearly as scary as many new Go developers expect them to be, and learn how to take advantage of them to write efficient programs.

CHAPTER 6

Pointers

Now that you've seen variables and functions, it's time to learn about pointer syntax. Then I'll clarify the behavior of pointers in Go by comparing them to the behavior of classes in other languages. You'll also learn how and when to use pointers, how memory is allocated in Go, and how using pointers and values properly makes Go programs faster and more efficient.

A Quick Pointer Primer

A *pointer* is a variable that holds the location in memory where a value is stored. If you've taken computer science courses, you might have seen a graphic to represent the way variables are stored in memory. The representation of the following two variables would look something like Figure 6-1:

```
var x int32 = 10
var y bool = true
```

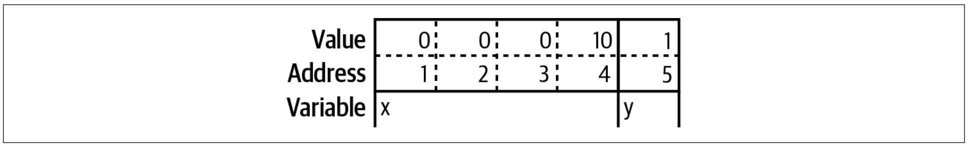


Figure 6-1. Storing two variables in memory

Every variable is stored in one or more contiguous memory locations, called *addresses*. Different types of variables can take up different amounts of memory. In this example, you have two variables, x, which is a 32-bit int, and y, which is a boolean. Storing a 32-bit int requires four bytes, so the value for x is stored in four bytes, starting at address 1 and ending at address 4. A boolean requires only a single byte (you need only a bit to represent `true` or `false`, but the smallest amount of memory that can be independently addressed is a byte), so the value for `y` is stored in one byte at address 5, with `true` represented by the value 1.

A pointer is a variable that contains the address where another variable is stored. Figure 6-2 demonstrates how the following pointers are stored in memory:

```
var x int32 = 10
var y bool = true
pointerX := &x
pointerY := &y
var pointerZ *string
```

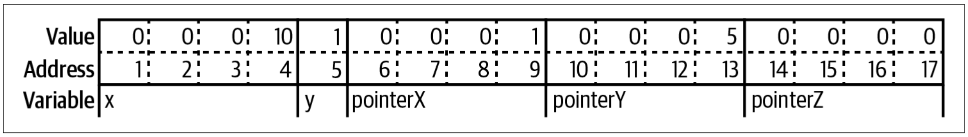


Figure 6-2. Storing pointers in memory

While different types of variables can take up different numbers of memory locations, every pointer, no matter what type it is pointing to, is always the same number of memory locations. The examples in this chapter use 4-byte pointers, but many modern computers use 8 bytes for a pointer. A pointer holds a number that indicates the location in memory where the data being pointed to is stored. That number is called the *address*. Our pointer to `x`, `pointerX`, is stored at location 6 and has the value 1, the address of `x`. Similarly, our pointer to `y`, `pointerY`, is stored at location 10 and has the value 5, the address of `y`. The last pointer, `pointerZ`, is stored at location 14 and has the value 0, because it doesn't point to anything.

The zero value for a pointer is `nil`. You've seen `nil` a few times before, as the zero value for slices, maps, and functions. All these types are implemented with pointers. (Two more types, channels and interfaces, are also implemented with pointers. You'll look at them in detail in "A Quick Lesson on Interfaces" on page 157 and "Channels" on page 291.) As I covered in Chapter 3, `nil` is an untyped identifier that represents the lack of a value for certain types. Unlike `NULL` in C, `nil` is not another name for 0; you can't convert it back and forth with a number.

As alluded to in Chapter 4, `nil` is defined in the universe block. Because `nil` is a value defined in the universe block, it can be shadowed. Never name a variable or function `nil`, unless you are trying to trick your coworker and are unconcerned about your annual review.

Go's pointer syntax is partially borrowed from C and C++. Since Go has a garbage collector, most memory management pain is removed. Furthermore, some tricks that you can do with pointers in C and C++, including *pointer arithmetic*, are not allowed in Go.

> The Go standard library does have an `unsafe` package that lets you do some low-level operations on data structures. While pointer manipulation is used in C for common operations, it is exceedingly rare for Go developers to use `unsafe`. You'll take a quick look at it in Chapter 16.

The `&` is the *address* operator. It precedes a value type and returns the address where the value is stored:

```
x := "hello"
pointerToX := &x
```

The `*` is the *indirection* operator. It precedes a variable of pointer type and returns the pointed-to value. This is called *dereferencing*:

```
x := 10
pointerToX := &x
fmt.Println(pointerToX)  // prints a memory address
fmt.Println(*pointerToX) // prints 10
z := 5 + *pointerToX
fmt.Println(z)           // prints 15
```

Before dereferencing a pointer, you must make sure that the pointer is non-nil. Your program will panic if you attempt to dereference a `nil` pointer:

```
var x *int
fmt.Println(x == nil) // prints true
fmt.Println(*x)       // panics
```

A *pointer type* is a type that represents a pointer. It is written with a `*` before a type name. A pointer type can be based on any type:

```
x := 10
var pointerToX *int
pointerToX = &x
```

The built-in function `new` creates a pointer variable. It returns a pointer to a zero-value instance of the provided type:

```
var x = new(int)
fmt.Println(x == nil) // prints false
fmt.Println(*x)       // prints 0
```

The new function is rarely used. For structs, use an & before a struct literal to create a pointer instance. You can't use an & before a primitive literal (numbers, booleans, and strings) or a constant because they don't have memory addresses; they exist only at compile time. When you need a pointer to a primitive type, declare a variable and point to it:

```
x := &Foo{}
var y string
z := &y
```

Not being able to take the address of a constant is sometimes inconvenient. If you have a struct with a field of a pointer to a primitive type, you can't assign a literal directly to the field:

```
type person struct {
    FirstName  string
    MiddleName *string
    LastName   string
}

p := person{
  FirstName:  "Pat",
  MiddleName: "Perry", // This line won't compile
  LastName:   "Peterson",
}
```

Compiling this code returns the error:

```
cannot use "Perry" (type string) as type *string in field value
```

If you try to put an & before "Perry", you'll get the error message:

```
cannot take the address of "Perry"
```

There are two ways around this problem. The first is to do what was shown previously, which is to introduce a variable to hold the constant value. The second way is to write a generic helper function that takes in a parameter of any type and returns a pointer to that type:

```
func makePointer[T any](t T) *T {
    return &t
}
```

With that function, you can now write:

```
p := person{
  FirstName:  "Pat",
  MiddleName: makePointer("Perry"), // This works
  LastName:   "Peterson",
}
```

Why does this work? When you pass a constant to a function, the constant is copied to a parameter, which is a variable. Since it's a variable, it has an address in memory. The function then returns the variable's memory address. Writing generic functions is covered in Chapter 8.

Use a helper function to turn a constant value into a pointer.

Don't Fear the Pointers

The first rule of pointers is to not be afraid of them. If you are used to Java, JavaScript, Python, or Ruby, you might find pointers intimidating. However, pointers are actually the familiar behavior for classes. It's the nonpointer structs in Go that are unusual.

In Java and JavaScript, there is a difference in the behavior between primitive types and classes (Python and Ruby don't have primitive values but use immutable instances to simulate them). When a primitive value is assigned to another variable or passed to a function or method, any changes made to the other variable aren't reflected in the original, as shown in Example 6-1.

Example 6-1. Assigning primitive variables doesn't share memory in Java

```java
int x = 10;
int y = x;
y = 20;
System.out.println(x); // prints 10
```

However, let's take a look at what happens when an instance of a class is assigned to another variable or passed to a function or method (the code in Example 6-2 is written in Python, but you can find similar code for Java, JavaScript, and Ruby in the *sample_code/language_pointer_examples* directory in the Chapter 6 repository).

Example 6-2. Passing a class instance into a function

```python
class Foo:
    def __init__(self, x):
        self.x = x


def outer():
    f = Foo(10)
    inner1(f)
    print(f.x)
    inner2(f)
    print(f.x)
    g = None
    inner2(g)
    print(g is None)


def inner1(f):
    f.x = 20


def inner2(f):
    f = Foo(30)


outer()
```

Running this code prints the following output:

```
20
20
True
```

That's because the following scenarios are true in Java, Python, JavaScript, and Ruby:

- If you pass an instance of a class to a function and you change the value of a field, the change is reflected in the variable that was passed in.
- If you reassign the parameter, the change is *not* reflected in the variable that was passed in.
- If you pass `nil`/`null`/`None` for a parameter value, setting the parameter itself to a new value doesn't modify the variable in the calling function.

Some people explain this behavior by saying that class instances are passed by reference in these languages. This is untrue. If they were being passed by reference, scenarios two and three would change the variable in the calling function. These languages are always pass-by-value, just as in Go.

What you are seeing is that every instance of a class in these languages is implemented as a pointer. When a class instance is passed to a function or method, the value being copied is the pointer to the instance. Since `outer` and `inner1` are referring to the same memory, changes made to fields in `f` in `inner1` are reflected in the variable in `outer`. When `inner2` reassigns `f` to a new class instance, this creates a separate instance and does not affect the variable in `outer`.

When you use a pointer variable or parameter in Go, you see the exact same behaviors. The difference between Go and these languages is that Go gives you the *choice* to use pointers or values for both primitives and structs. Most of the time, you should use a value. Values make it easier to understand how and when your data is modified. A secondary benefit is that using values reduces the amount of work that the garbage collector has to do. I'll talk about that in "Reducing the Garbage Collector's Workload" on page 136.

Pointers Indicate Mutable Parameters

As you've already seen, Go constants provide names for literal expressions that can be calculated at compile time. Go has no mechanism to declare that other kinds of values are immutable. Modern software engineering embraces immutability. MIT's course on Software Construction sums up the reasons: "[I]mmutable types are safer from bugs, easier to understand, and more ready for change. Mutability makes it harder to understand what your program is doing, and much harder to enforce contracts."

The lack of immutable declarations in Go might seem problematic, but the ability to choose between value and pointer parameter types addresses the issue. As the Software Construction course materials go on to explain: "[U]sing mutable objects is just fine if you are using them entirely locally within a method, and with only one reference to the object." Rather than declare that some variables and parameters are immutable, Go developers use pointers to indicate that a parameter is mutable.

Since Go is a call-by-value language, the values passed to functions are copies. For nonpointer types like primitives, structs, and arrays, this means that the called function cannot modify the original. Since the called function has a copy of the original data, the original data's immutability is guaranteed.

I'll talk about passing maps and slices to functions in "The Difference Between Maps and Slices" on page 131.

However, if a pointer is passed to a function, the function gets a copy of the pointer. This still points to the original data, which means that the original data can be modified by the called function.

This has a couple of related implications.

The first implication is that when you pass a `nil` pointer to a function, you cannot make the value non-nil. You can reassign the value only if there was a value already assigned to the pointer. While confusing at first, it makes sense. Since the memory location was passed to the function via call-by-value, you can't change the memory address, any more than you could change the value of an `int` parameter. You can demonstrate this with the following program:

```
func failedUpdate(g *int) {
    x := 10
    g = &x
}

func main() {
    var f *int // f is nil
    failedUpdate(f)
    fmt.Println(f) // prints nil
}
```

The flow through this code is shown in Figure 6-3.

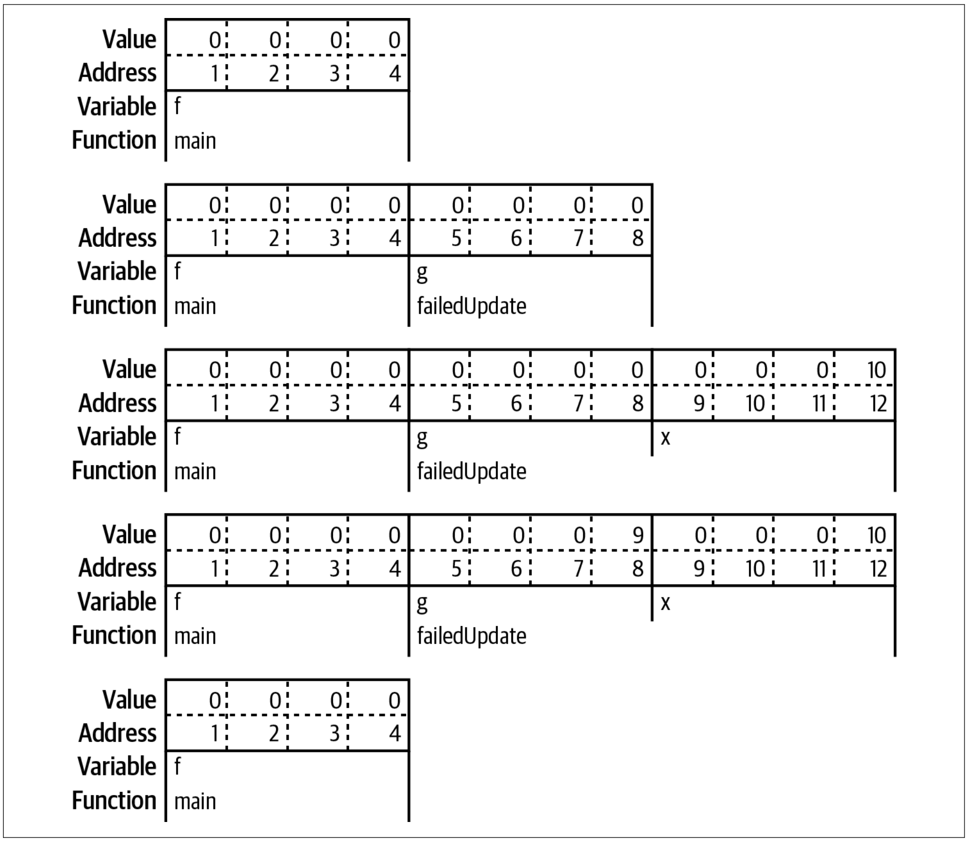


Figure 6-3. Failing to update a `nil` pointer

You start with a nil variable f in main. When you call failedUpdate, you copy the value of f, which is nil, into the parameter named g. This means that g is also set to nil. You then declare a new variable x within failedUpdate with the value 10. Next, you change g in failedUpdate to point to x. This does not change the f in main, and when you exit failedUpdate and return to main, f is still nil.

The second implication of copying a pointer is that if you want the value assigned to a pointer parameter to still be there when you exit the function, you must dereference the pointer and set the value. If you change the pointer, you have changed the copy, not the original. Dereferencing puts the new value in the memory location pointed to by both the original and the copy. Here's a short program that shows how this works:

```
func failedUpdate(px *int) {
    x2 := 20
    px = &x2
}

func update(px *int) {
    *px = 20
}

func main() {
    x := 10
    failedUpdate(&x)
    fmt.Println(x) // prints 10
    update(&x)
    fmt.Println(x) // prints 20
}
```

The flow through this code is shown in Figure 6-4.

In this example, you start with x in main set to 10. When you call failedUpdate, you copy the address of x into the parameter px. Next, you declare x2 in failedUpdate, set to 20. You then point px in failedUpdate to the address of x2. When you return to main, the value of x is unchanged. When you call update, you copy the address of x into px again. However, this time you change the value of what px in update points to, the variable x in main. When you return to main, x has been changed.

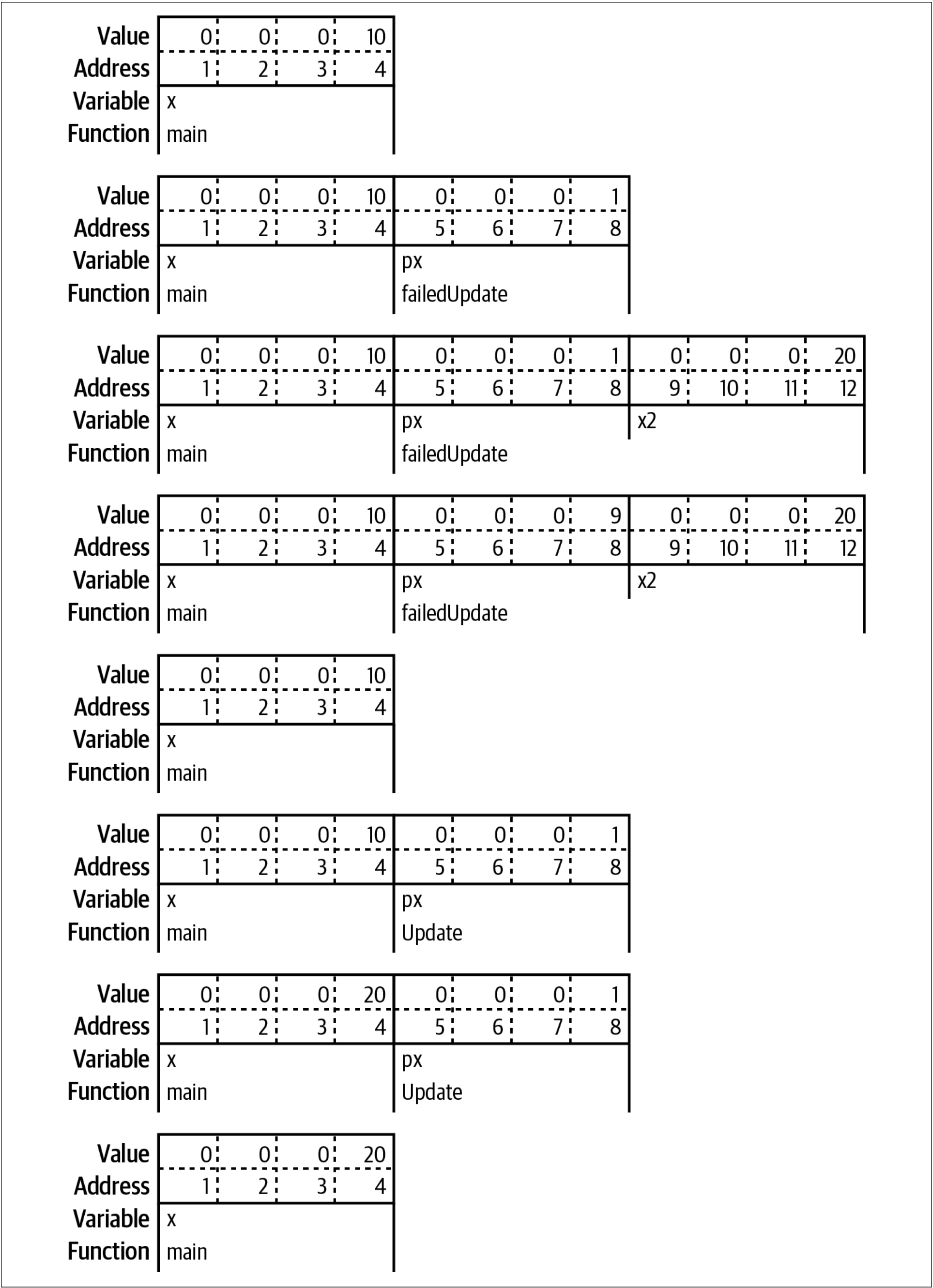


Figure 6-4. The wrong way and the right way to update a pointer

Pointers Are a Last Resort

That said, you should be careful when using pointers in Go. As discussed earlier, they make it harder to understand data flow and can create extra work for the garbage collector. Rather than populating a struct by passing a pointer to it into a function, have the function instantiate and return the struct (see Examples 6-3 and 6-4).

Example 6-3. Don't do this

```go
func MakeFoo(f *Foo) error {
  f.Field1 = "val"
  f.Field2 = 20
  return nil
}
```

Example 6-4. Do this

```go
func MakeFoo() (Foo, error) {
  f := Foo{
    Field1: "val",
    Field2: 20,
  }
  return f, nil
}
```

The only time you should use pointer parameters to modify a variable is when the function expects an interface. You see this pattern when working with JSON (I'll talk more about the JSON support in Go's standard library in "encoding/json" on page 327):

```go
f := struct {
  Name string `json:"name"`
  Age int `json:"age"`
}{}
err := json.Unmarshal([]byte(`{"name": "Bob", "age": 30}`), &f)
```

The `Unmarshal` function populates a variable from a slice of bytes containing JSON. It is declared to take a slice of bytes and an `any` parameter. The value passed in for the `any` parameter must be a pointer. If it is not, an error is returned.

Why do you pass a pointer into `Unmarshal` instead of having it return a value? There are two reasons. First, this function predates the addition of generics to Go, and without generics (which I'll talk about in detail in Chapter 8), there is no way to know what type of value to create and return.

The second reason is that passing in a pointer gives you control over memory allocation. Iterating over data and converting it from JSON to a Go struct is a common design pattern, so `Unmarshal` is optimized for this case. If the `Unmarshal` function returned a value and `Unmarshal` was called in a loop, one struct instance would be created on each loop iteration. This creates a lot more work for the garbage collector, which slows down your program. You'll see another use of this pattern when you look at "Slices as Buffers" on page 135, and I'll talk more about efficient memory usage in "Reducing the Garbage Collector's Workload" on page 136.

Because JSON integration is so common, this API is sometimes treated as a common case by new Go developers, instead of the exception that it should be.

When returning values from a function, you should favor value types. Use a pointer type as a return type only if there is state within the data type that needs to be modified. When you look at I/O in "io and Friends" on page 319, you'll see that with buffers for reading or writing data. In addition, some data types used with concurrency must always be passed as pointers. You'll see those in Chapter 12.

Pointer Passing Performance

If a struct is large enough, using a pointer to the struct as either an input parameter or a return value improves performance. The time to pass a pointer into a function is constant for all data sizes, roughly one nanosecond. This makes sense, as the size of a pointer is the same for all data types. Passing a value into a function takes longer as the data gets larger. It takes about 0.7 milliseconds once the value gets to be around 10 megabytes of data.

The behavior for returning a pointer versus returning a value is more interesting. For data structures that are smaller than 10 megabytes, it is actually *slower* to return a pointer type than a value type. For example, a 100-byte data structure takes around 10 nanoseconds to be returned, but a pointer to that data structure takes about 30 nanoseconds. As your data structures get larger, the performance advantage flips. It takes nearly 1.5 milliseconds to return 10 megabytes of data, but a little less than half a millisecond to return a pointer to it.

You should be aware that these are very short times. For the vast majority of cases, the difference between using a pointer and a value won't affect your program's performance. But if you are passing megabytes of data between functions, consider using a pointer even if the data is meant to be immutable.

All these numbers are from an i7-8700 computer with 32 GB of RAM. Different CPUs can produce different crossover points. For example, on an Apple M1 CPU with 16 GB of RAM, it is faster to return a pointer (5 microseconds) than a value (8 microseconds) at sizes of around 100 kilobytes. You can run your own performance tests with the code in the *sample_code/pointer_perf* directory in the Chapter 6 repository. Run the command `go test ./... -bench=.` to find your own results. (Benchmarks are covered in "Using Benchmarks" on page 393.)

The Zero Value Versus No Value

Go pointers are also commonly used to indicate the difference between a variable or field that's been assigned the zero value and a variable or field that hasn't been assigned a value at all. If this distinction matters in your program, use a `nil` pointer to represent an unassigned variable or struct field.

Because pointers also indicate mutability, be careful when using this pattern. Rather than return a pointer set to `nil` from a function, use the comma ok idiom that you saw for maps, and return a value type and a boolean.

Remember, if a `nil` pointer is passed into a function via a parameter or a field on a parameter, you cannot set the value within the function, as there's nowhere to store the value. If a non-nil value is passed in for the pointer, do not modify it unless you document the behavior.

Again, JSON conversions are the exception that proves the rule. When converting data back and forth from JSON (yes, I'll talk more about the JSON support in Go's standard library in "encoding/json" on page 327), you often need a way to differentiate between the zero value and not having a value assigned at all. Use a pointer value for fields in the struct that are nullable.

When not working with JSON (or other external protocols), resist the temptation to use a pointer field to indicate no value. While a pointer does provide a handy way to indicate no value, if you are not going to modify the value, you should use a value type instead, paired with a boolean.

The Difference Between Maps and Slices

As you saw in the previous chapter, any modifications made to a map that's passed to a function are reflected in the original variable that was passed in. Now that you know about pointers, you can understand why: within the Go runtime, a map is implemented as a pointer to a struct. Passing a map to a function means that you are copying a pointer.

Because of this, you should consider carefully before using maps for input parameters or return values, especially on public APIs. On an API-design level, maps are a bad choice because they say nothing about the values contained within; nothing explicitly defines any keys in the map, so the only way to know what they are is to trace through the code. From the standpoint of immutability, maps are bad because the only way to know what ended up in the map is to trace through all the functions that interact with it. This prevents your API from being self-documenting. If you are used to dynamic languages, don't use a map as a replacement for another language's lack of structure. Go is a strongly typed language; rather than passing a map around, use a struct.

(You'll learn another reason to prefer structs when I talk about memory layout in "Reducing the Garbage Collector's Workload" on page 136.)

A map input parameter or return value is the correct choice in certain situations. A struct requires you to name its fields at compile time. If the keys for your data aren't known at compile time, a map is ideal.

Meanwhile, passing a slice to a function has more complicated behavior: any modification to the slice's contents is reflected in the original variable, but using `append` to change the length isn't reflected in the original variable, even if the slice has a capacity greater than its length. That's because a slice is implemented as a struct with three fields: an `int` field for length, an `int` field for capacity, and a pointer to a block of memory. Figure 6-5 demonstrates the relationship.

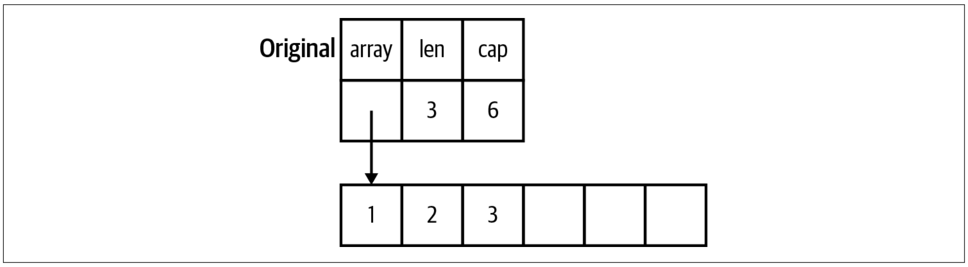


Figure 6-5. The memory layout of a slice

When a slice is copied to a different variable or passed to a function, a copy is made of the length, capacity, and the pointer. Figure 6-6 shows how both slice variables point to the same memory.

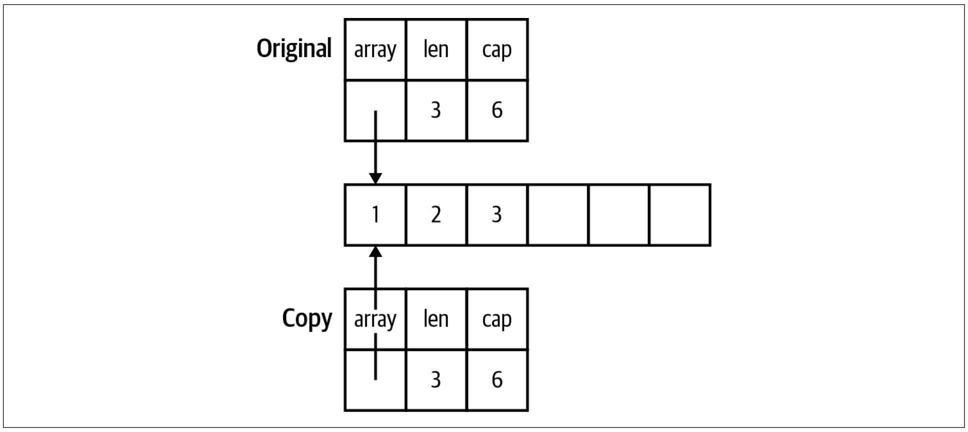


Figure 6-6. The memory layout of a slice and its copy

Changing the values in the slice changes the memory that the pointer points to, so the changes are seen in both the copy and the original. You see in Figure 6-7 how this looks in memory.

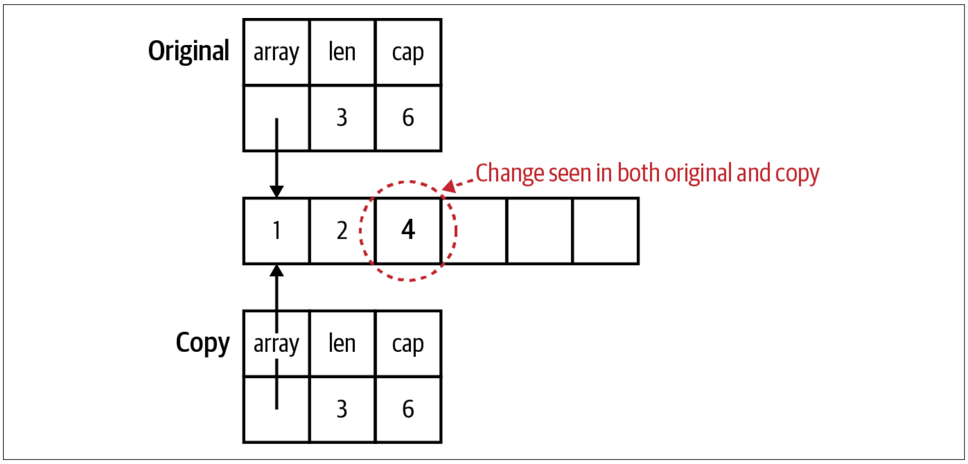


Figure 6-7. Modifying the contents of a slice

If the slice copy is appended to and there *is* enough capacity in the slice for the new values, the length changes in the copy, and the new values are stored in the block of memory that's shared by the copy and the original. However, the length in the original slice remains unchanged. The Go runtime prevents the original slice from seeing those values since they are beyond the length of the original slice. Figure 6-8 highlights the values that are visible in one slice variable but not in the other.

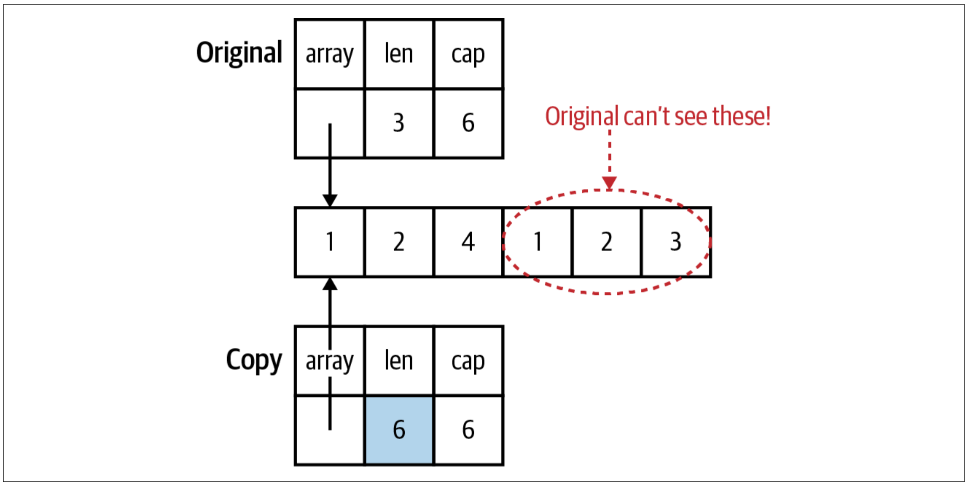


Figure 6-8. Changing the length is invisible in the original

If the slice copy is appended to and there *isn't* enough capacity in the slice for the new values, a new, bigger block of memory is allocated, values are copied over, and the pointer, length, and capacity fields in the copy are updated. Changes to the pointer, length, and capacity are not reflected in the original, because they are only in the copy. Figure 6-9 shows how each slice variable now points to a different memory block.

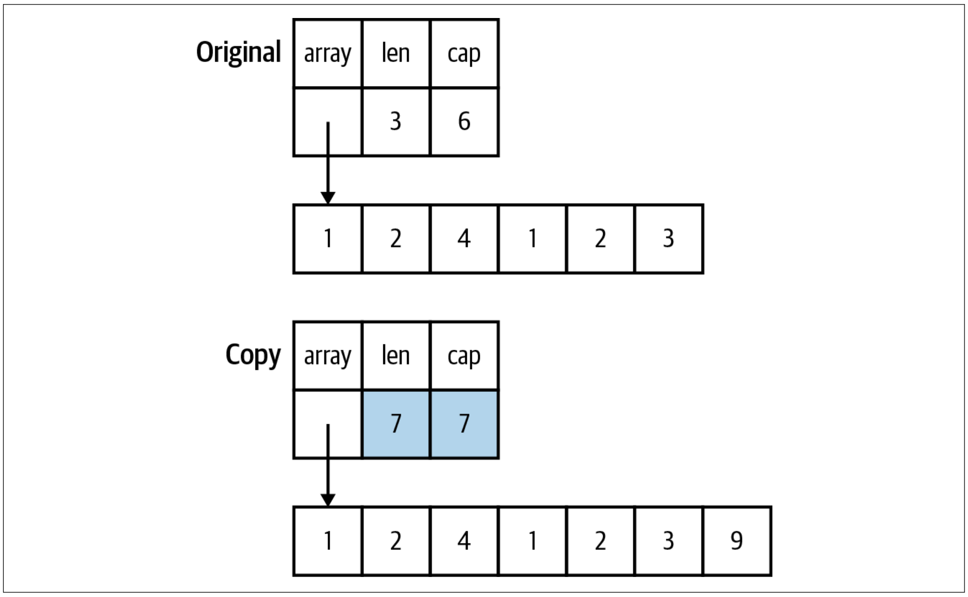


Figure 6-9. Changing the capacity changes the storage

The result is that a slice that's passed to a function can have its contents modified, but the slice can't be resized. As the only usable linear data structure, slices are frequently passed around in Go programs. By default, you should assume that a slice is not modified by a function. Your function's documentation should specify whether it modifies the slice's contents.

> The reason you can pass a slice of any size to a function is that the data type that's passed to the function is the same for any size slice: a struct of two `int` values and a pointer. The reason you can't write a function that takes an array of any size is that the entire array is passed to the function, not just a pointer to the data.

There is one situation where the ability to modify the contents (but not the size) of a slice input parameter is very useful. This makes them ideal for reusable buffers.

Slices as Buffers

When reading data from an external resource (like a file or a network connection), many languages use code like this:

```
r = open_resource()
while r.has_data() {
  data_chunk = r.next_chunk()
  process(data_chunk)
}
close(r)
```

The problem with this pattern is that every time you iterate through that `while` loop, you allocate another `data_chunk` even though each one is used only once. This creates lots of unnecessary memory allocations, just as I discussed in "Pointers Are a Last Resort" on page 129 when looking at the `Unmarshal` function. Garbage-collected languages handle those allocations for you automatically, but the work still needs to be done to clean them up when you are done processing.

Even though Go is a garbage-collected language, writing idiomatic Go means avoiding unneeded allocations. Rather than returning a new allocation each time you read from a data source, you create a slice of bytes once and use it as a buffer to read data from the data source:

```go
file, err := os.Open(fileName)
if err != nil {
    return err
}
defer file.Close()
data := make([]byte, 100)
for {
    count, err := file.Read(data)
    process(data[:count])
    if err != nil {
        if errors.Is(err, io.EOF) {
            return nil
        }
        return err
    }
}
```

Remember that you can't change the length or capacity of a slice when it is passed into a function, but you can change the contents up to the current length. In this code, you create a buffer of 100 bytes, and each time through the loop, you copy the next block of bytes (up to 100) into the slice. You then pass the populated portion of the buffer to `process`. If an error happens (other than `io.EOF`, a special-case error that indicates there is no more data to read), it is returned. When `io.EOF` is returned as the error, there is no more data and the function returns `nil`. You'll look at more details about I/O in "io and Friends" on page 319 and error handling is covered in Chapter 9.

Reducing the Garbage Collector's Workload

Using buffers is just one example of how you reduce the work done by the garbage collector. When programmers talk about "garbage," what they mean is "data that has no more pointers pointing to it." Once there are no more pointers pointing to some data, the memory that this data takes up can be reused. If the memory isn't recovered, the program's memory usage would continue to grow until the computer ran out of RAM. The job of a garbage collector is to automatically detect unused memory and recover it so it can be reused. It is fantastic that Go has a garbage collector, because decades of experience have shown that it is very difficult for people to properly manage memory manually. But just because you have a garbage collector doesn't mean you should create lots of garbage.

If you've spent time learning how programming languages are implemented, you've probably learned about the *heap* and the stack. If you're unfamiliar, here's how a stack works. A *stack* is a consecutive block of memory. Every function call in a thread of execution shares the same stack. Allocating memory on the stack is fast and simple. A *stack pointer* tracks the last location where memory was allocated. Allocating additional memory is done by changing the value of the stack pointer. When a function is invoked, a new *stack frame* is created for the function's data. Local variables are stored on the stack, along with parameters passed into a function. Each new variable moves the stack pointer by the size of the value. When a function exits, its return values are copied back to the calling function via the stack, and the stack pointer is moved back to the beginning of the stack frame for the exited function, deallocating all the stack memory that was used by that function's local variables and parameters.

Since version 1.17, Go uses a combination of registers (a small set of very high-speed memory that's directly on the CPU) and the stack to pass values into and out of functions. It's faster and more complicated, but the general concepts of stack-only function calls still apply.

To store something on the stack, you have to know exactly how big it is at compile time. When you look at the value types in Go (primitive values, arrays, and structs), they all have one thing in common: you know exactly how much memory they take at compile time. This is why the size is considered part of the type for an array. Because their sizes are known, they can be allocated on the stack instead of the heap. The size of a pointer type is also known, and it is also stored on the stack.

Go is unusual in that it can increase the size of a stack while the program is running. This is possible because each goroutine has its own stack and goroutines are managed by the Go runtime, not by the underlying operating system (I discuss goroutines when I talk about concurrency in Chapter 12). This has advantages (Go stacks start small and use less memory) and disadvantages (when the stack needs to grow, all data on the stack needs to be copied, which is slow). It's also possible to write worst-case-scenario code that causes the stack to grow and shrink over and over.

The rules are more complicated when it comes to the data that the pointer points to. In order for Go to allocate the data the pointer points to on the stack, several conditions must be true. The data must be a local variable whose data size is known at compile time. The pointer cannot be returned from the function. If the pointer is passed into a function, the compiler must be able to ensure that these conditions still hold. If the size isn't known, you can't make space for it by moving the stack pointer. If the pointer variable is returned, the memory that the pointer points to will no longer be valid when the function exits. When the compiler determines that the data can't be stored on the stack, we say that the data the pointer points to *escapes* the stack, and the compiler stores the data on the heap.

The heap is the memory that's managed by the garbage collector (or by hand in languages like C and C++). I won't discuss the details of garbage collector algorithm implementation, but they are much more complicated than moving a stack pointer. Any data that's stored on the heap is valid as long as it can be tracked back to a pointer type variable on a stack. Once there are no more variables on the stack pointing to that data, either directly or via a chain of pointers, the data becomes *garbage*, and it's the job of the garbage collector to clear it out. This program on The Go Playground demonstrates when data on the heap becomes garbage.

A common source of bugs in C programs is returning a pointer to a local variable. In C, this results in a pointer pointing to invalid memory. The Go compiler is smarter. When it sees that a pointer to a local variable is returned, the local variable's value is stored on the heap.

The *escape analysis* done by the Go compiler isn't perfect. In some cases, data that could be stored on the stack escapes to the heap. However, the compiler has to be conservative; it can't take the chance of leaving a value on the stack when it might need to be on the heap because leaving a reference to invalid data causes memory corruption. Newer Go releases improve escape analysis.

You might be wondering: what's so bad about storing things on the heap? Two problems arise related to performance. First, the garbage collector takes time to do its work. It isn't trivial to keep track of all available chunks of free memory on the heap or to track which used blocks of memory still have valid pointers. This is time that's taken away from doing the processing that your program is written to do. Many garbage-collection algorithms have been written, and they can be placed into two rough categories: those that are designed for higher throughput (find the most garbage possible in a single scan) or lower latency (finish the garbage scan as quickly as possible). Jeffrey Dean, the genius behind many of Google's engineering successes, cowrote a paper in 2013 called "The Tail at Scale". It argues that systems should be optimized for latency, to keep response times low. The garbage collector used by the Go runtime favors low latency. Each garbage-collection cycle is designed to "stop the world" (i.e., pause your program) for fewer than 500 microseconds. However, if your Go program creates lots of garbage, the garbage collector won't be able to find all the garbage during a cycle, slowing the collector and increasing memory usage.

If you are interested in the implementation details, you may want to listen to the talk Rick Hudson gave at the International Symposium on Memory Management in 2018, describing the history and implementation of the Go garbage collector.

The second problem deals with the nature of computer hardware. RAM might mean "random access memory," but the fastest way to read from memory is to read it sequentially. A slice of structs in Go has all the data laid out sequentially in memory. This makes it fast to load and fast to process. A slice of pointers to structs (or structs whose fields are pointers) has its data scattered across RAM, making it far slower to read and process. Forrest Smith wrote an in-depth blog post that explores how much this can affect performance. His numbers indicate that it's roughly two orders of magnitude slower to access data via pointers stored randomly in RAM.

This approach of writing software that's aware of the hardware it's running on is called *mechanical sympathy*. The term comes from the world of car racing, where the idea is that a driver who understands what the car is doing can best squeeze the last bits of performance out of it. In 2011, Martin Thompson began applying the term to software development. Following best practices in Go gives it to you automatically.

Compare Go's approach to Java's. In Java, local variables and parameters are stored in the stack, just as in Go. However, as discussed earlier, objects in Java are implemented as pointers. For every object variable instance, only the pointer to it is allocated on the stack; the data within the object is allocated on the heap. Only primitive values (numbers, booleans, and chars) are stored entirely on the stack. This means that the garbage collector in Java has to do a great deal of work. It also means that implementations of the `List` interface in Java are built using a pointer to an array of pointers. Even though they *look* like a linear data structure, reading from them actually involves bouncing through memory, which is highly inefficient. There are similar behaviors for the sequential data types in Python, Ruby, and JavaScript. To work around all this inefficiency, the Java Virtual Machine includes some very clever garbage collectors that do lots of work, some optimized for throughput, some for latency, and all with configuration settings to tune them for the best performance. The virtual machines for Python, Ruby, and JavaScript are less optimized, and their performance suffers accordingly.

Now you can see why Go encourages you to use pointers sparingly. You reduce the garbage collector's workload by making sure that as much as possible is stored on the stack. Slices of structs or primitive types have their data lined up sequentially in memory for rapid access. And when the garbage collector does do work, it is optimized to return quickly rather than gather the most garbage. The key to making this approach work is to simply create less garbage in the first place. While focusing on optimizing memory allocations can feel like premature optimization, the idiomatic approach in Go is also the most efficient.

If you want to learn more about heap versus stack allocation and escape analysis in Go, excellent blog posts cover the topic, including ones by Bill Kennedy of Ardan Labs and Achille Roussel and Rick Branson of Segment.

Tuning the Garbage Collector

A garbage collector doesn't immediately reclaim memory as soon as it is no longer referenced. Doing so would seriously impact performance. Instead, it lets the garbage pile up for a bit. The heap almost always contains both live data and memory that's no longer needed. The Go runtime provides users a couple of settings to control the heap's size. The first is the `GOGC` environment variable. The garbage collector looks at the heap size at the end of a garbage-collection cycle and uses the formula `CURRENT_HEAP_SIZE + CURRENT_HEAP_SIZE*GOGC/100` to calculate the heap size that needs to be reached to trigger the next garbage-collection cycle.

The `GOGC` heap size calculation is a little more complicated than just described. It takes into account not just the heap size, but the sizes of all the stacks of all the goroutines and the memory set aside to hold package-level variables. Most of the time, the heap size is far bigger than the size of these other memory areas, but in some situations they do have an effect.

By default, `GOGC` is set to `100`, which means that the heap size that triggers the next collection is roughly double the heap size at the end of the current collection. Setting `GOGC` to a smaller value will decrease the target heap size, and setting it to a larger value will increase it. As a rough estimate, doubling the value of `GOGC` will halve the amount of CPU time spent on GC.

Setting `GOGC` to `off` disables garbage collection. This will make your programs run faster. However, turning off garbage collection on a long-running process will potentially use all available memory on your computer. This is not usually considered optimal behavior.

The second garbage-collection setting specifies a limit on the total amount of memory your Go program is allowed to use. Java developers are likely familiar with the `-Xmx` JVM argument, and `GOMEMLIMIT` is similar. By default, it is disabled (technically, it is set to `math.MaxInt64`, but it's unlikely that your computer has that much memory). The value for `GOMEMLIMIT` is specified in bytes, but you can optionally use the suffixes `B`, `KiB`, `MiB`, `GiB`, and `TiB`. For example, `GOMEMLIMIT=3GiB` sets the memory limit to 3 gibibytes (which is equal to 3,221,225,472 bytes).

> If you haven't seen these suffixes before, they are the official power-of-two analogues of the more commonly used power-of-ten KB, MB, GB, and TB. KiB is equal to 2^{10}, MiB is equal to 2^{20}, and so on. It is technically correct to use KiB, MiB, and friends when dealing with computers.

It might seem counterintuitive that limiting the maximum amount of memory could improve a program's performance, but there are good reasons this flag was added. The primary reason is that computers (or virtual machines or containers) don't have infinite RAM. If a sudden, temporary spike occurs in memory usage, relying on `GOGC` alone might result in the maximum heap size exceeding the amount of available memory. This can cause memory to swap to disk, which is very slow. Depending on your operating system and its settings, it might crash your program. Specifying a maximum memory limit prevents the heap from growing beyond the computer's resources.

`GOMEMLIMIT` is a *soft* limit that can be exceeded in certain circumstances. A common problem occurs in garbage-collected systems when the collector is unable to free up enough memory to get within a memory limit or the garbage-collection cycles are rapidly being triggered because a program is repeatedly hitting the limit. Called *thrashing*, this results in a program that does nothing other than run the garbage collector. If the Go runtime detects that thrashing is starting to happen, it chooses to end the current garbage-collection cycle and exceed the limit. This does mean that you should set `GOMEMLIMIT` below the absolute maximum amount of available memory so you have spare capacity.

If you specify a value for `GOMEMLIMIT`, you could set `GOGC` to `off` and not run out of memory, but this may not produce the desired performance effect. You are likely to find yourself trading frequent, very short pauses for infrequent, longer pauses. If you are running a web service, this produces inconsistent response times, which was one of the behaviors that Go's garbage collection was designed to avoid.

The best option is to use these two environment variables together to ensure both a reasonable pace for garbage collection and a maximum that should be respected. You can learn more about how to use GOGC and GOMEMLIMIT by reading "A Guide to the Go Garbage Collector" from Go's development team.

Exercises

Now that you have learned about pointers and memory in Go, work through these exercises to reinforce using pointers effectively. You can find answers to these exercises in the Chapter 6 repository.

1. Create a struct named `Person` with three fields: `FirstName` and `LastName` of type `string` and `Age` of type `int`. Write a function called `MakePerson` that takes in `firstName`, `lastName`, and `age` and returns a `Person`. Write a second function `MakePersonPointer` that takes in `firstName`, `lastName`, and `age` and returns a `*Person`. Call both from `main`. Compile your program with `go build -gcflags="-m"`. This both compiles your code and prints out which values escape to the heap. Are you surprised about what escapes?
2. Write two functions. The `UpdateSlice` function takes in a `[]string` and a `string`. It sets the last position in the passed-in slice to the passed-in `string`. At the end of `UpdateSlice`, print the slice after making the change. The `GrowSlice` function also takes in a `[]string` and a `string`. It appends the `string` onto the slice. At the end of `GrowSlice`, print the slice after making the change. Call these functions from `main`. Print out the slice before each function is called and after each function is called. Do you understand why some changes are visible in `main` and why some changes are not?
3. Write a program that builds a `[]Person` with 10,000,000 entries (they could all be the same names and ages). See how long it takes to run. Change the value of `GOGC` and see how that affects the time it takes for the program to complete. Set the environment variable `GODEBUG=gctrace=1` to see when garbage collections happen and see how changing `GOGC` changes the number of garbage collections. What happens if you create the slice with a capacity of 10,000,000?

Wrapping Up

This chapter peeked under the covers a bit to help you understand pointers, what they are, how to use them, and, most importantly, when to use them. In the next chapter, you'll take a look at Go's implementation of methods, interfaces, and types, how they differ from other languages, and the power they possess.

CHAPTER 7

Types, Methods, and Interfaces

As you saw in earlier chapters, Go is a statically typed language with both built-in types and user-defined types. Like most modern languages, Go allows you to attach methods to types. It also has type abstraction, allowing you to write code that invokes methods without explicitly specifying the implementation.

However, Go's approach to methods, interfaces, and types is very different from that of most other languages in common use today. Go is designed to encourage the best practices advocated by software engineers, avoiding inheritance while encouraging composition. In this chapter, you'll take a look at types, methods, and interfaces, and see how to use them to build testable and maintainable programs.

Types in Go

Back in "Structs" on page 61, you saw how to define a struct type:

```
type Person struct {
    FirstName string
    LastName  string
    Age       int
}
```

This should be read as declaring a user-defined type with the name `Person` to have the *underlying type* of the struct literal that follows. In addition to struct literals, you can use any primitive type or compound type literal to define a concrete type. Here are a few examples:

```
type Score int
type Converter func(string)Score
type TeamScores map[string]Score
```

Go allows you to declare a type at any block level, from the package block down. However, you can access the type only from within its scope. The only exceptions are types exported from other packages. I'll talk more about those in Chapter 10.

To make it easier to talk about types, I'll define a couple of terms. An *abstract type* is one that specifies *what* a type should do but not *how* it is done. A *concrete type* specifies what and how. This means that tthe type has a specified way to store its data and provides an implementation of any methods declared on the type. While all types in Go are either abstract or concrete, some languages allow hybrid types, such as abstract classes or interfaces with default methods in Java.

Methods

Like most modern languages, Go supports methods on user-defined types.

The methods for a type are defined at the package block level:

```go
type Person struct {
    FirstName string
    LastName  string
    Age       int
}

func (p Person) String() string {
    return fmt.Sprintf("%s %s, age %d", p.FirstName, p.LastName, p.Age)
}
```

Method declarations look like function declarations, with one addition: the *receiver* specification. The receiver appears between the keyword `func` and the name of the method. Like all other variable declarations, the receiver name appears before the type. By convention, the receiver name is a short abbreviation of the type's name, usually its first letter. It is nonidiomatic to use `this` or `self`.

There is one key difference between declaring methods and functions: methods can be defined *only* at the package block level, while functions can be defined inside any block.

Just like functions, method names cannot be overloaded. You can use the same method names for different types, but you can't use the same method name for two different methods on the same type. While this philosophy feels limiting when coming from languages that have method overloading, not reusing names is part of Go's philosophy of making clear what your code is doing.

I'll talk more about packages in Chapter 10, but be aware that methods must be declared in the same package as their associated type; Go doesn't allow you to add methods to types you don't control. While you can define a method in a different file within the same package as the type declaration, it is best to keep your type definition and its associated methods together so that it's easy to follow the implementation.

Method invocations should look familiar to those who have used methods in other languages:

```go
p := Person{
    FirstName: "Fred",
    LastName:  "Fredson",
    Age:       52,
}
output := p.String()
```

Pointer Receivers and Value Receivers

As I covered in Chapter 6, Go uses parameters of pointer type to indicate that a parameter might be modified by the function. The same rules apply for method receivers too. They can be *pointer receivers* (the type is a pointer) or *value receivers* (the type is a value type). The following rules help you determine when to use each kind of receiver:

- If your method modifies the receiver, you *must* use a pointer receiver.
- If your method needs to handle `nil` instances (see "Code Your Methods for nil Instances" on page 148), then it *must* use a pointer receiver.
- If your method doesn't modify the receiver, you *can* use a value receiver.

Whether you use a value receiver for a method that doesn't modify the receiver depends on the other methods declared on the type. When a type has *any* pointer receiver methods, a common practice is to be consistent and use pointer receivers for *all* methods, even the ones that don't modify the receiver.

Here's some simple code to demonstrate pointer and value receivers. It starts with a type that has two methods on it, one using a value receiver, the other with a pointer receiver:

```go
type Counter struct {
    total       int
    lastUpdated time.Time
}

func (c *Counter) Increment() {
    c.total++
    c.lastUpdated = time.Now()
}
```

```
func (c Counter) String() string {
    return fmt.Sprintf("total: %d, last updated: %v", c.total, c.lastUpdated)
}
```

You can then try out these methods with the following code. You can run it yourself on The Go Playground or use the code in the *sample_code/pointer_value* directory in the Chapter 7 repository:

```
var c Counter
fmt.Println(c.String())
c.Increment()
fmt.Println(c.String())
```

You should see the following output:

```
total: 0, last updated: 0001-01-01 00:00:00 +0000 UTC
total: 1, last updated: 2009-11-10 23:00:00 +0000 UTC m=+0.000000001
```

One thing you might notice is that you were able to call the pointer receiver method even though `c` is a value type. When you use a pointer receiver with a local variable that's a value type, Go automatically takes the address of the local variable when calling the method. In this case, `c.Increment()` is converted to `(&c).Increment()`.

If you call a value receiver on a pointer variable, Go automatically dereferences the pointer when calling the method. In the code:

```
c := &Counter{}
fmt.Println(c.String())
c.Increment()
fmt.Println(c.String())
```

the call `c.String()` is silently converted to `(*c).String()`.

If you call a value receiver method with pointer instance whose value is `nil`, your code will compile but will panic at runtime (I discuss panics in "panic and recover" on page 218).

Be aware that the rules for passing values to functions still apply. If you pass a value type to a function and call a pointer receiver method on the passed value, you are invoking the method on a *copy*. You can try out the following code on The Go Playground or use the code in the *sample_code/update_wrong* directory in the Chapter 7 repository:

```
func doUpdateWrong(c Counter) {
    c.Increment()
    fmt.Println("in doUpdateWrong:", c.String())
}

func doUpdateRight(c *Counter) {
    c.Increment()
    fmt.Println("in doUpdateRight:", c.String())
}

func main() {
    var c Counter
    doUpdateWrong(c)
    fmt.Println("in main:", c.String())
    doUpdateRight(&c)
    fmt.Println("in main:", c.String())
}
```

When you run this code, you'll get the following output:

```
in doUpdateWrong: total: 1, last updated: 2009-11-10 23:00:00 +0000 UTC
    m=+0.000000001
in main: total: 0, last updated: 0001-01-01 00:00:00 +0000 UTC
in doUpdateRight: total: 1, last updated: 2009-11-10 23:00:00 +0000 UTC
    m=+0.000000001
in main: total: 1, last updated: 2009-11-10 23:00:00 +0000 UTC m=+0.000000001
```

The parameter in `doUpdateRight` is of type `*Counter`, which is a pointer instance. As you can see, you can call both `Increment` and `String` on it. Go considers both pointer and value receiver methods to be in the *method set* for a pointer instance. For a value instance, only the value receiver methods are in the method set. This seems like a pedantic detail right now, but I'll come back to it when talking about interfaces in just a bit.

This can be confusing to new Go programmers (and, to be honest, to not-so-new Go programmers), but Go's automatic conversion from pointer types to value types, and vice versa, is purely syntactic sugar. It is independent of the method set concept. Alexey Gronskiy has written a blog post that explores in detail why the method set of pointer instances have both pointer and value receiver methods, but the method set of value instances has only value receiver methods.

One final note: do not write getter and setter methods for Go structs unless you need them to meet an interface (I'll start covering interfaces in "A Quick Lesson on Interfaces" on page 157). Go encourages you to directly access a field. Reserve methods for business logic. The exceptions are when you need to update multiple fields as a single operation or when the update isn't a straightforward assignment of a new value. The `Increment` method defined earlier demonstrates both of these properties.

Code Your Methods for nil Instances

The previous section covered pointer receivers, which might make you wonder what happens when you call a method on a `nil` instance. In most languages, this produces some sort of error. (Objective-C allows you to call a method on a `nil` instance, but it always does nothing.)

Go does something a little different. It actually tries to invoke the method. As mentioned earlier, if it's a method with a value receiver, you'll get a panic, since there is no value being pointed to by the pointer. If it's a method with a pointer receiver, it can work if the method is written to handle the possibility of a `nil` instance.

In some cases, expecting a `nil` receiver makes the code simpler. Here's an implementation of a binary tree that takes advantage of `nil` values for the receiver:

```
type IntTree struct {
    val         int
    left, right *IntTree
}

func (it *IntTree) Insert(val int) *IntTree {
    if it == nil {
        return &IntTree{val: val}
    }
    if val < it.val {
        it.left = it.left.Insert(val)
    } else if val > it.val {
        it.right = it.right.Insert(val)
    }
    return it
}

func (it *IntTree) Contains(val int) bool {
    switch {
    case it == nil:
        return false
    case val < it.val:
        return it.left.Contains(val)
    case val > it.val:
        return it.right.Contains(val)
    default:
        return true
    }
}
```

The `Contains` method doesn't modify the `*IntTree`, but it is declared with a pointer receiver. This demonstrates the rule mentioned previously about supporting a `nil` receiver. A method with a value receiver can't check for `nil` and, as mentioned earlier, panics if invoked with a `nil` receiver.

The following code uses the tree. You can try it out on The Go Playground or use the code in the *sample_code/tree* directory in the Chapter 7 repository:

```go
func main() {
    var it *IntTree
    it = it.Insert(5)
    it = it.Insert(3)
    it = it.Insert(10)
    it = it.Insert(2)
    fmt.Println(it.Contains(2))  // true
    fmt.Println(it.Contains(12)) // false
}
```

It's very clever that Go allows you to call a method on a `nil` receiver, and there are situations where it is useful, like the previous tree node example. However, most of the time it's not very useful. Pointer receivers work like pointer function parameters; it's a copy of the pointer that's passed into the method. Just like `nil` parameters passed to functions, if you change the copy of the pointer, you haven't changed the original. This means you can't write a pointer receiver method that handles `nil` and makes the original pointer non-nil.

If your method has a pointer receiver and won't work for a `nil` receiver, you have to decide how your method should handle a `nil` receiver. One choice is to treat it as a fatal flaw, like trying to access a position in a slice beyond its length. In that case, don't do anything and let the code panic. (Also make sure you write good tests, as discussed in Chapter 15.) If a `nil` receiver is something that is recoverable, check for `nil` and return an error (I discuss errors in Chapter 9).

Methods Are Functions Too

Methods in Go are so much like functions that you can use a method as a replacement for a function anytime there's a variable or parameter of a function type.

Let's start with this simple type:

```go
type Adder struct {
    start int
}

func (a Adder) AddTo(val int) int {
    return a.start + val
}
```

You create an instance of the type in the usual way and invoke its method:

```go
myAdder := Adder{start: 10}
fmt.Println(myAdder.AddTo(5)) // prints 15
```

You can also assign the method to a variable or pass it to a parameter of type func(int)int. This is called a *method value*:

```
f1 := myAdder.AddTo
fmt.Println(f1(10))           // prints 20
```

A method value is a bit like a closure, since it can access the values in the fields of the instance from which it was created.

You can also create a function from the type itself. This is called a *method expression*:

```
f2 := Adder.AddTo
fmt.Println(f2(myAdder, 15))  // prints 25
```

In a method expression, the first parameter is the receiver for the method; the function signature is func(Adder, int) int.

Method values and method expressions aren't clever corner cases. You'll see one way to use them when you look at dependency injection in "Implicit Interfaces Make Dependency Injection Easier" on page 174.

Functions Versus Methods

Since you can use a method as a function, you might wonder when you should declare a function and when you should use a method.

The differentiator is whether your function depends on other data. As I've covered several times, package-level state should be effectively immutable. Anytime your logic depends on values that are configured at startup or changed while your program is running, those values should be stored in a struct, and that logic should be implemented as a method. If your logic depends only on the input parameters, it should be a function.

Type Declarations Aren't Inheritance

In addition to declaring types based on built-in Go types and struct literals, you can also declare a user-defined type based on another user-defined type:

```
type HighScore Score
type Employee Person
```

Many concepts can be considered "object-oriented," but one stands out: *inheritance*. With inheritance, the state and methods of a *parent* type are declared to be available on a *child* type, and values of the child type can be substituted for the parent type.[1]

1 For the computer scientists in the audience, I realize that subtyping is not inheritance. However, most programming languages use inheritance to implement subtyping, so the definitions are often conflated in popular usage.

Declaring a type based on another type looks a bit like inheritance but isn't. The two types have the same underlying type, but that's all. The types have no hierarchy. In languages with inheritance, a child instance can be used anywhere the parent instance is used. The child instance also has all the methods and data structures of the parent instance. That's not the case in Go. You can't assign an instance of type `HighScore` to a variable of type `Score`, or vice versa, without a type conversion, nor can you assign either of them to a variable of type `int` without a type conversion. Furthermore, any methods defined on `Score` aren't defined on `HighScore`:

```go
// assigning untyped constants is valid
var i int = 300
var s Score = 100
var hs HighScore = 200
hs = s                  // compilation error!
s = i                   // compilation error!
s = Score(i)            // ok
hs = HighScore(s)       // ok
```

User-defined types whose underlying types are built-in types can be assigned literals and constants compatible with the underlying type. They can also be used with the operators for those types:

```go
var s Score = 50
scoreWithBonus := s + 100 // type of scoreWithBonus is Score
```

A type conversion between types that share an underlying type keeps the same underlying storage but associates different methods.

Types Are Executable Documentation

While it's well understood that you should declare a struct type to hold a set of related data, it's less clear when you should declare a user-defined type based on other built-in types or one user-defined type that's based on another user-defined type. The short answer is that types are documentation. They make code clearer by providing a name for a concept and describing the kind of data that is expected. It's clearer for someone reading your code when a method has a parameter of type `Percentage` than of type `int`, and it's harder for it to be invoked with an invalid value.

The same logic applies when declaring one user-defined type based on another user-defined type. When you have the same underlying data, but different sets of operations to perform, make two types. Declaring one as being based on the other avoids some repetition and makes it clear that the two types are related.

iota Is for Enumerations—Sometimes

Many programming languages have the concept of enumerations, which allow you to specify that a type can have only a limited set of values. Go doesn't have an enumeration type. Instead, it has `iota`, which lets you assign an increasing value to a set of constants.

> The concept of `iota` comes from the programming language APL (which stood for "A Programming Language"). To generate a list of the first three positive integers in APL, you write `ι3`, where `ι` is the lowercase Greek letter iota.
>
> APL is famous for being so reliant on its own custom notation that it required computers with a special keyboard. For example, (~R∈R∘.×R)/R←1↓ιR is an APL program to find all the prime numbers up to the value of the variable R.
>
> It may seem ironic that a language as focused on readability as Go would borrow a concept from a language that is concise to a fault, but this is why you should learn multiple programming languages: you can find inspiration everywhere.

When using `iota`, the best practice is to first define a type based on `int` that will represent all the valid values:

```go
type MailCategory int
```

Next, use a `const` block to define a set of values for your type:

```go
const (
    Uncategorized MailCategory = iota
    Personal
    Spam
    Social
    Advertisements
)
```

The first constant in the `const` block has the type specified, and its value is set to `iota`. Every subsequent line has neither the type nor a value assigned to it. When the Go compiler sees this, it repeats the type and the assignment to all the subsequent constants in the block, which is `iota`. The value of `iota` increments for each constant defined in the `const` block, starting with `0`. This means that `0` is assigned to the first constant (`Uncategorized`), 1 to the second constant (`Personal`), and so on. When a new `const` block is created, `iota` is set back to 0.

The value of `iota` increments for each constant in the `const` block, whether or not `iota` is used to define the value of a constant. The following code demonstrates what happens when `iota` is used intermittently in a `const` block:

```go
const (
    Field1 = 0
    Field2 = 1 + iota
    Field3 = 20
    Field4
    Field5 = iota
)

func main() {
    fmt.Println(Field1, Field2, Field3, Field4, Field5)
}
```

You can run this code on The Go Playground and see the (perhaps unexpected) result:

```
0 2 20 20 4
```

`Field2` is assigned `2` because `iota` has a value of `1` on the second line in the `const` block. `Field4` is assigned `20` because it has no type or value explicitly assigned, so it gets the value of the previous line with a type and assignment. Finally, `Field5` gets the value `4` because it is the fifth line and `iota` starts counting from `0`.

This is the best advice I've seen on `iota`:

> Don't use *iota* for defining constants where its values are explicitly defined (elsewhere). For example, when implementing parts of a specification and the specification says which values are assigned to which constants, you should explicitly write the constant values. Use *iota* for "internal" purposes only. That is, where the constants are referred to by name rather than by value. That way, you can optimally enjoy *iota* by inserting new constants at any moment in time / location in the list without the risk of breaking everything.
>
> —Danny van Heumen

The important thing to understand is that nothing in Go will stop you (or anyone else) from creating additional values of your type. Furthermore, if you insert a new identifier in the middle of your list of literals, all subsequent ones will be renumbered. This will break your application in a subtle way if those constants represented values in another system or in a database. Given these two limitations, `iota`-based enumerations make sense only when you care about being able to differentiate between a set of values and don't particularly care what the value is behind the scenes. If the actual value matters, specify it explicitly.

Because you can assign a literal expression to a constant, you'll see sample code that suggests you should use `iota` for cases like this:

```
type BitField int

const (
    Field1 BitField = 1 << iota // assigned 1
    Field2                      // assigned 2
    Field3                      // assigned 4
    Field4                      // assigned 8
)
```

While this is clever, be careful when using this pattern. If you do so, document what you are doing. As mentioned previously, using `iota` with constants is fragile when you care about the value. You don't want a future maintainer to insert a new constant in the middle of the list and break your code.

Be aware that `iota` starts numbering from 0. If you are using your set of constants to represent different configuration states, the zero value might be useful. You saw this earlier in the `MailCategory` type. When mail first arrives, it is uncategorized, so the zero value makes sense. If there isn't a sensical default value for your constants, a common pattern is to assign the first `iota` value in the constant block to _ or to a constant that indicates the value is invalid. This makes it easy to detect when a variable has not been properly initialized.

Use Embedding for Composition

The software engineering advice "Favor object composition over class inheritance" dates back to at least the 1994 book *Design Patterns* by Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides (Addison-Wesley), better known as the Gang of Four book. While Go doesn't have inheritance, it encourages code reuse via built-in support for composition and promotion:

```
type Employee struct {
    Name         string
    ID           string
}

func (e Employee) Description() string {
    return fmt.Sprintf("%s (%s)", e.Name, e.ID)
}

type Manager struct {
    Employee
    Reports []Employee
}

func (m Manager) FindNewEmployees() []Employee {
    // do business logic
}
```

Note that `Manager` contains a field of type `Employee`, but no name is assigned to that field. This makes `Employee` an *embedded field*. Any fields or methods declared on an embedded field are *promoted* to the containing struct and can be invoked directly on it. That makes the following code valid:

```
m := Manager{
    Employee: Employee{
        Name: "Bob Bobson",
        ID:   "12345",
    },
    Reports: []Employee{},
}
fmt.Println(m.ID)            // prints 12345
fmt.Println(m.Description()) // prints Bob Bobson (12345)
```

You can embed any type within a struct, not just another struct. This promotes the methods on the embedded type to the containing struct.

If the containing struct has fields or methods with the same name as an embedded field, you need to use the embedded field's type to refer to the obscured fields or methods. If you have types defined like this:

```
type Inner struct {
    X int
}

type Outer struct {
    Inner
    X int
}
```

you can access the `X` on `Inner` only by specifying `Inner` explicitly:

```
o := Outer{
    Inner: Inner{
        X: 10,
    },
    X: 20,
}
fmt.Println(o.X)       // prints 20
fmt.Println(o.Inner.X) // prints 10
```

Embedding Is Not Inheritance

Built-in embedding support is rare in programming languages (I'm not aware of another popular language that supports it). Many developers who are familiar with inheritance (which is available in many languages) try to understand embedding by treating it as inheritance. That way lies tears. You cannot assign a variable of type `Manager` to a variable of type `Employee`. If you want to access the `Employee` field in `Manager`, you must do so explicitly. You can run the following code on The Go Playground or use the code in the *sample_code/embedding* directory in the Chapter 7 repository:

```
var eFail Employee = m        // compilation error!
var eOK Employee = m.Employee // ok!
```

You'll get the error:

```
cannot use m (type Manager) as type Employee in assignment
```

Furthermore, Go has no *dynamic dispatch* for concrete types. The methods on the embedded field have no idea they are embedded. If you have a method on an embedded field that calls another method on the embedded field, and the containing struct has a method of the same name, the method on the embedded field is invoked, not the method on the containing struct. This behavior is demonstrated in the following code, which you can run on The Go Playground, or use the code in the *sample_code/no_dispatch* directory in the Chapter 7 repository:

```
type Inner struct {
    A int
}

func (i Inner) IntPrinter(val int) string {
    return fmt.Sprintf("Inner: %d", val)
}

func (i Inner) Double() string {
    return i.IntPrinter(i.A * 2)
}

type Outer struct {
    Inner
    S string
}

func (o Outer) IntPrinter(val int) string {
    return fmt.Sprintf("Outer: %d", val)
}

func main() {
    o := Outer{
        Inner: Inner{
            A: 10,
        },
        S: "Hello",
    }
    fmt.Println(o.Double())
}
```

Running this code produces the following output:

```
Inner: 20
```

While embedding one concrete type inside another won't allow you to treat the outer type as the inner type, the methods on an embedded field do count toward the *method set* of the containing struct. This means they can make the containing struct implement an interface.

A Quick Lesson on Interfaces

While Go's concurrency model (which I cover in Chapter 12) gets all the publicity, the real star of Go's design is its implicit interfaces, the only abstract type in Go. Let's see what makes them so great.

Let's start by taking a quick look at how to declare interfaces. At their core, interfaces are simple. Like other user-defined types, you use the `type` keyword.

Here's the definition of the `Stringer` interface in the `fmt` package:

```
type Stringer interface {
    String() string
}
```

In an interface declaration, an interface literal appears after the name of the interface type. It lists the methods that must be implemented by a concrete type to meet the interface. The methods defined by an interface are the method set of the interface. As I covered in "Pointer Receivers and Value Receivers" on page 145, the method set of a pointer instance contains the methods defined with both pointer and value receivers, while the method set of a value instance contains only the methods with value receivers. Here's a quick example using the `Counter` struct defined previously:

```
type Incrementer interface {
    Increment()
}

var myStringer fmt.Stringer
var myIncrementer Incrementer
pointerCounter := &Counter{}
valueCounter := Counter{}

myStringer = pointerCounter    // ok
myStringer = valueCounter      // ok
```

```
myIncrementer = pointerCounter // ok
myIncrementer = valueCounter   // compile-time error!
```

Trying to compile this code results in the error `cannot use valueCounter (variable of type Counter) as Incrementer value in assignment: Counter does not implement Incrementer (method Increment has pointer receiver)`.

You can try this code on The Go Playground or use the code in the *sample_code/method_set* directory in the Chapter 7 repository.

Like other types, interfaces can be declared in any block.

Interfaces are usually named with "er" endings. You've already seen `fmt.Stringer`, but there are many more, including `io.Reader`, `io.Closer`, `io.ReadCloser`, `json.Marshaler`, and `http.Handler`.

Interfaces Are Type-Safe Duck Typing

So far, nothing that's been said about the Go interface is much different from interfaces in other languages. What makes Go's interfaces special is that they are implemented *implicitly*. As you've seen with the `Counter` struct type and the `Incrementer` interface type that you've used in previous examples, a concrete type does not declare that it implements an interface. If the method set for a concrete type contains all the methods in the method set for an interface, the concrete type implements the interface. Therefore, that the concrete type can be assigned to a variable or field declared to be of the type of the interface.

This implicit behavior makes interfaces the most interesting thing about types in Go, because they enable both type safety and decoupling, bridging the functionality in both static and dynamic languages.

To understand why, let's talk about why languages have interfaces. Earlier I mentioned that *Design Patterns* taught developers to favor composition over inheritance. Another piece of advice from the book is "Program to an interface, not an implementation." Doing so allows you to depend on behavior, not on implementation, allowing you to swap implementations as needed. This allows your code to evolve over time, as requirements inevitably change.

Dynamically typed languages like Python, Ruby, and JavaScript don't have interfaces. Instead, those developers use *duck typing*, which is based on the expression "If it walks like a duck and quacks like a duck, it's a duck." The concept is that you can pass an instance of a type as a parameter to a function as long as the function can find a method to invoke that it expects:

```
class Logic:
    def process(self, data):
        # business logic
```

```
def program(logic):
    # get data from somewhere
    logic.process(data)

logicToUse = Logic()
program(logicToUse)
```

Duck typing might sound weird at first, but it's been used to build large and successful systems. If you program in a statically typed language, this sounds like utter chaos. Without an explicit type being specified, it's hard to know exactly what functionality should be expected. As new developers move on to a project or the existing developers forget what the code is doing, they have to trace through the code to identify the actual dependencies.

Java developers use a different pattern. They define an interface, create an implementation of the interface, but refer to the interface only in the client code:

```
public interface Logic {
    String process(String data);
}

public class LogicImpl implements Logic {
    public String process(String data) {
        // business logic
    }
}

public class Client {
    private final Logic logic;
    // this type is the interface, not the implementation

    public Client(Logic logic) {
        this.logic = logic;
    }

    public void program() {
        // get data from somewhere
        this.logic.process(data);
    }
}

public static void main(String[] args) {
    Logic logic = new LogicImpl();
    Client client = new Client(logic);
    client.program();
}
```

Dynamic language developers look at the explicit interfaces in Java and don't see how you can possibly refactor your code over time when you have explicit dependencies.

Switching to a new implementation from a different provider means rewriting your code to depend on a new interface.

Go's developers decided that both groups are right. If your application is going to grow and change over time, you need flexibility to change implementation. However, in order for people to understand what your code is doing (as new people work on the same code over time), you also need to specify what the code depends on. That's where implicit interfaces come in. Go code is a blend of the previous two styles:

```
type LogicProvider struct {}

func (lp LogicProvider) Process(data string) string {
    // business logic
}

type Logic interface {
    Process(data string) string
}

type Client struct{
    L Logic
}

func(c Client) Program() {
    // get data from somewhere
    c.L.Process(data)
}

main() {
    c := Client{
        L: LogicProvider{},
    }
    c.Program()
}
```

The Go code provides an interface, but only the caller (`Client`) knows about it; nothing is declared on `LogicProvider` to indicate that it meets the interface. This is sufficient to both allow a new logic provider in the future and provide executable documentation to ensure that any type passed into the client will match the client's need.

Interfaces specify what callers need. The client code defines the interface to specify what functionality it requires.

This doesn't mean that interfaces can't be shared. You've already seen several interfaces in the standard library that are used for input and output. Having a standard interface is powerful; if you write your code to work with `io.Reader` and `io.Writer`, it will function correctly whether it is writing to a file on local disk or a value in memory.

Furthermore, using standard interfaces encourages the *decorator pattern*. It is common in Go to write factory functions that take in an instance of an interface and return another type that implements the same interface. For example, say you have a function with the following definition:

```go
func process(r io.Reader) error
```

You can process data from a file with the following code:

```go
r, err := os.Open(fileName)
if err != nil {
    return err
}
defer r.Close()
return process(r)
```

The `os.File` instance returned by `os.Open` meets the `io.Reader` interface and can be used in any code that reads in data. If the file is gzip-compressed, you can wrap the `io.Reader` in another `io.Reader`:

```go
r, err := os.Open(fileName)
if err != nil {
    return err
}
defer r.Close()
gz, err := gzip.NewReader(r)
if err != nil {
    return err
}
defer gz.Close()
return process(gz)
```

Now the exact same code that was reading from an uncompressed file is reading from a compressed file instead.

If an interface in the standard library describes what your code needs, use it! Commonly used interfaces include `io.Reader`, `io.Writer`, and `io.Closer`.

It's perfectly fine for a type that meets an interface to specify additional methods that aren't part of the interface. One set of client code may not care about those methods, but others do. For example, the `io.File` type also meets the `io.Writer` interface. If your code cares only about reading from a file, use the `io.Reader` interface to refer to the file instance and ignore the other methods.

Embedding and Interfaces

Embedding is not only for structs. You can also embed an interface in an interface. For example, the `io.ReadCloser` interface is built out of an `io.Reader` and an `io.Closer`:

```go
type Reader interface {
	Read(p []byte) (n int, err error)
}

type Closer interface {
	Close() error
}

type ReadCloser interface {
	Reader
	Closer
}
```

Just as you can embed a concrete type in a struct, you can also embed an interface in a struct. You'll see a use for this in "Using Stubs in Go" on page 397.

Accept Interfaces, Return Structs

You'll often hear experienced Go developers say that your code should "Accept interfaces, return structs." This phrase was most likely coined by Jack Lindamood in his 2016 blog post "Preemptive Interface Anti-Pattern in Go". It means that the business logic invoked by your functions should be invoked via interfaces, but the output of your functions should be a concrete type. I've already covered why functions should accept interfaces: they make your code more flexible and explicitly declare the exact functionality being used.

The primary reason your functions should return concrete types is they make it easier to gradually update a function's return values in new versions of your code. When a concrete type is returned by a function, new methods and fields can be added without breaking existing code that calls the function, because the new fields and methods are ignored. The same is not true for an interface. Adding a new method to an interface means that all existing implementations of that interface must be updated, or your code breaks. In semantic versioning terms, this is the difference between a minor release that is backward compatible and a major release, which is backward breaking. If you are exposing an API that's consumed by other people (either inside your organization or as part of an open source project), avoiding backward-breaking changes keeps your users happy.

In some rare situations, the least bad option is to have your functions return interfaces. For example, the `database/sql/driver` package in the standard library defines a set of interfaces that define what a database driver must provide. It is the responsibility of the database driver author to provide concrete implementations of these interfaces, so almost all methods on all interfaces defined in `database/sql/driver` return interfaces. Starting in Go 1.8, database drivers are expected to support additional features. The standard library has a compatibility promise, so the existing interfaces can't be updated with new methods, and the existing methods on these interfaces can't be updated to return different types. The solution is to leave the existing interfaces alone, define new interfaces that describe the new functionality, and tell database driver authors that they should implement both the old and new methods on their concrete types.

This leads to the question of how to check whether these new methods are present and how to access them if they are. You'll learn how in "Type Assertions and Type Switches" on page 167.

Rather than writing a single factory function that returns different instances behind an interface based on input parameters, try to write separate factory functions for each concrete type. In some situations (such as a parser that can return one or more kinds of tokens), it's unavoidable and you have no choice but to return an interface.

Errors are an exception to this rule. As you'll see in Chapter 9, Go functions and methods can declare a return parameter of the `error` interface type. In the case of `error`, it's quite likely that different implementations of the interface could be returned, so you need to use an interface to handle all possible options, as interfaces are the only abstract type in Go.

This pattern has one potential drawback. As I discussed in "Reducing the Garbage Collector's Workload" on page 136, reducing heap allocations improves performance by reducing the amount of work for the garbage collector. Returning a struct avoids a heap allocation, which is good. However, when invoking a function with parameters of interface types, a heap allocation occurs for each interface parameter. Figuring out the trade-off between better abstraction and better performance should be done over the life of your program. Write your code so that it is readable and maintainable. If you find that your program is too slow *and* you have profiled it *and* you have determined that the performance problems are due to a heap allocation caused by an interface parameter, then you should rewrite the function to use a concrete type parameter. If multiple implementations of an interface are passed into the function, this will mean creating multiple functions with repeated logic.

Developers who come from a C++ or Rust background might try using generics as a way to get the compiler to generate specialized functions. As of Go 1.21, this will probably not produce faster code. I'll cover why in "Idiomatic Go and Generics" on page 199.

Interfaces and nil

When discussing pointers in Chapter 6, I also talked about `nil`, the zero value for pointer types. You can also use `nil` to represent the zero value for an interface instance, but it's not as simple as it is for concrete types.

Understanding the relationship between interfaces and `nil` requires understanding a little bit about how interfaces are implemented. In the Go runtime, interfaces are implemented as a struct with two pointer fields, one for the value and one for the type of the value. As long as the type field is non-nil, the interface is non-nil. (Since you cannot have a variable without a type, if the value pointer is non-nil, the type pointer is always non-nil.)

In order for an interface to be considered `nil`, *both* the type and the value must be `nil`. The following code prints out `true` on the first two lines and `false` on the last:

```go
var pointerCounter *Counter
fmt.Println(pointerCounter == nil) // prints true
var incrementer Incrementer
fmt.Println(incrementer == nil) // prints true
incrementer = pointerCounter
fmt.Println(incrementer == nil) // prints false
```

You can run this code for yourself on The Go Playground or use the code in the *sample_code/interface_nil* directory in the Chapter 7 repository.

What `nil` indicates for a variable with an interface type is whether you can invoke methods on it. As I covered earlier, you can invoke methods on `nil` concrete instances, so it makes sense that you can invoke methods on an interface variable that was assigned a `nil` concrete instance. If an interface variable is `nil`, invoking any methods on it triggers a panic (which I'll discuss in "panic and recover" on page 218). If an interface variable is non-nil, you can invoke methods on it. (But note that if the value is `nil` and the methods of the assigned type don't properly handle `nil`, you could still trigger a panic.)

Since an interface instance with a non-nil type is not equal to `nil`, it is not straightforward to tell whether the value associated with the interface is `nil` when the type is non-nil. You must use reflection (which I'll discuss in "Use Reflection to Check If an Interface's Value Is nil" on page 417) to find out.

Interfaces Are Comparable

In Chapter 3, you learned about comparable types, the ones that can be checked for equality with ==. You might be surprised to learn that interfaces are comparable. Just as an interface is equal to nil only if its type and value fields are both nil, two instances of an interface type are equal only if their types are equal and their values are equal. This suggests a question: what happens if the type isn't comparable? Let's use a simple example to explore this concept. Start with an interface definition and a couple of implementations of that interface:

```go
type Doubler interface {
    Double()
}

type DoubleInt int

func (d *DoubleInt) Double() {
    *d = *d * 2
}

type DoubleIntSlice []int

func (d DoubleIntSlice) Double() {
    for i := range d {
        d[i] = d[i] * 2
    }
}
```

The Double method on DoubleInt is declared with a pointer receiver because you are modifying the value of the int. You can use a value receiver for the Double method on DoubleIntSlice because, as covered in "The Difference Between Maps and Slices" on page 131, you can change the value of an item in a parameter that is a slice type. The *DoubleInt type is comparable (all pointer types are), and the DoubleIntSlice type is not comparable (slices aren't comparable).

You also have a function that takes in two parameters of type Doubler and prints if they are equal:

```go
func DoublerCompare(d1, d2 Doubler) {
    fmt.Println(d1 == d2)
}
```

You now define four variables:

```go
var di DoubleInt = 10
var di2 DoubleInt = 10
var dis = DoubleIntSlice{1, 2, 3}
var dis2 = DoubleIntSlice{1, 2, 3}
```

Now, you're going to call this function three times. The first call is as follows:

```
DoublerCompare(&di, &di2)
```

This prints out `false`. The types match (both are `*DoubleInt`), but you are comparing pointers, not values, and the pointers point to different instances.

Next, you compare a `*DoubleInt` with a `DoubleIntSlice`:

```
DoublerCompare(&di, dis)
```

This prints out `false`, because the types do not match.

Finally, you get to the problematic case:

```
DoublerCompare(dis, dis2)
```

This code compiles without issue, but triggers a panic at runtime:

```
panic: runtime error: comparing uncomparable type main.DoubleIntSlice
```

The entire program is available in the *sample_code/comparable* directory in the Chapter 7 repository.

Also be aware that the key of a map must be comparable, so a map can be defined to have an interface as a key:

```
m := map[Doubler]int{}
```

If you add a key-value pair to this map and the key isn't comparable, that will also trigger a panic.

Given this behavior, be careful when using `==` or `!=` with interfaces or using an interface as a map key, as it's easy to accidentally generate a panic that will crash your program. Even if all your interface implementations are currently comparable, you don't know what will happen when someone else uses or modifies your code, and there's no way to specify that an interface can be implemented only by comparable types. If you want to be extra safe, you can use the `Comparable` method on `reflect.Value` to inspect an interface before using it with `==` or `!=`. (You'll learn more about reflection in "Reflection Lets You Work with Types at Runtime" on page 410).

The Empty Interface Says Nothing

Sometimes in a statically typed language, you need a way to say that a variable could store a value of any type. Go uses an *empty interface*, `interface{}`, to represent this:

```
var i interface{}
i = 20
i = "hello"
i = struct {
    FirstName string
    LastName string
} {"Fred", "Fredson"}
```

`interface{}` isn't special case syntax. An empty interface type simply states that the variable can store any value whose type implements zero or more methods. This just happens to match every type in Go.

To improve readability, Go added `any` as a type alias for `interface{}`. Legacy code (written before `any` was added in Go 1.18) used `interface{}`, but stick with `any` for new code.

Because an empty interface doesn't tell you anything about the value it represents, you can't do a lot with it. One common use of `any` is as a placeholder for data of uncertain schema that's read from an external source, like a JSON file:

```go
data := map[string]any{}
contents, err := os.ReadFile("testdata/sample.json")
if err != nil {
    return err
}
json.Unmarshal(contents, &data)
// the contents are now in the data map
```

User-created data containers that were written before generics were added to Go use an empty interface to store a value. (I'll talk about generics in Chapter 8.) An example in the standard library is `container/list`. Now that generics are part of Go, please use them for any newly created data containers.

If you see a function that takes in an empty interface, it's likely using reflection (which I'll talk about in Chapter 16) to either populate or read the value. In the preceding example, the second parameter of the `json.Unmarshal` function is declared to be of type `any`.

These situations should be relatively rare. Avoid using `any`. As you've seen, Go is designed as a strongly typed language and attempts to work around this are unidiomatic.

If you find yourself in a situation where you had to store a value into an empty interface, you might be wondering how to read the value back again. To do that, you need to learn about type assertions and type switches.

Type Assertions and Type Switches

Go provides two ways to see if a variable of an interface type has a specific concrete type or if the concrete type implements another interface. Let's start by looking at type assertions. A *type assertion* names the concrete type that implemented the interface, or names another interface that is also implemented by the concrete type whose value is stored in the interface. You can try it out on The Go Playground or in the `typeAssert` function in *main.go* in the *sample_code/type_assertions* directory in the Chapter 7 repository:

```
type MyInt int

func main() {
    var i any
    var mine MyInt = 20
    i = mine
    i2 := i.(MyInt)
    fmt.Println(i2 + 1)
}
```

In the preceding code, the variable `i2` is of type `MyInt`.

You might wonder what happens if a type assertion is wrong. In that case, your code panics. You can try it out on The Go Playground or in the `typeAssertPanicWrongType` function in *main.go* in the *sample_code/type_assertions* directory in the Chapter 7 repository:

```
i2 := i.(string)
fmt.Println(i2)
```

Running this code produces the following panic:

```
panic: interface conversion: interface {} is main.MyInt, not string
```

As you've already seen, Go is very careful about concrete types. Even if two types share an underlying type, a type assertion must match the type of the value stored in the interface. The following code panics. You can try it out on The Go Playground or in the `typeAssertPanicTypeNotIdentical` function in *main.go* in the *sample_code/type_assertions* directory in the Chapter 7 repository:

```
i2 := i.(int)
fmt.Println(i2 + 1)
```

Obviously, crashing is not desired behavior. You avoid this by using the comma ok idiom, just as you saw in "The comma ok Idiom" on page 58 when detecting whether a zero value was in a map. You can see this in the `typeAssertCommaOK` function in *main.go* in the *sample_code/type_assertions* directory in the Chapter 7 repository:

```
i2, ok := i.(int)
if !ok {
    return fmt.Errorf("unexpected type for %v",i)
}
fmt.Println(i2 + 1)
```

The boolean `ok` is set to `true` if the type conversion was successful. If it was not, `ok` is set to `false` and the other variable (in this case `i2`) is set to its zero value. You then handle the unexpected condition within an `if` statement. I'll talk more about error handling in Chapter 9.

A type assertion is very different from a type conversion. Conversions change a value to a new type, while assertions reveal the type of the value stored in the interface. Type conversions can be applied to both concrete types and interfaces. Type assertions can be applied only to interface types. All type assertions are checked at runtime, so they can fail at runtime with a panic if you don't use the comma ok idiom. Most type conversions are checked at compile time, so if they are invalid, your code won't compile. (Type conversions between slices and array pointers can fail at runtime and don't support the comma ok idiom, so be careful when using them!)

Even if you are absolutely certain that your type assertion is valid, use the comma ok idiom version. You don't know how other people (or you in six months) will reuse your code. Sooner or later, your unvalidated type assertions will fail at runtime.

When an interface could be one of multiple possible types, use a *type switch* instead:

```go
func doThings(i any) {
    switch j := i.(type) {
    case nil:
        // i is nil, type of j is any
    case int:
        // j is of type int
    case MyInt:
        // j is of type MyInt
    case io.Reader:
        // j is of type io.Reader
    case string:
        // j is a string
    case bool, rune:
        // i is either a bool or rune, so j is of type any
    default:
        // no idea what i is, so j is of type any
    }
}
```

A type `switch` looks a lot like the `switch` statement that you saw way back in "switch" on page 84. Instead of specifying a boolean operation, you specify a variable of an interface type and follow it with `.(type)`. Usually, you assign the variable being checked to another variable that's valid only within the `switch`.

Since the purpose of a type switch is to derive a new variable from an existing one, it is idiomatic to assign the variable being switched on to a variable of the same name (`i := i.(type)`), making this one of the few places where shadowing is a good idea. To make the comments more readable, this example doesn't use shadowing.

The type of the new variable depends on which case matches. You can use `nil` for one case to see if the interface has no associated type. If you list more than one type on a case, the new variable is of type `any`. Just as with a `switch` statement, you can have a `default` case that matches when no specified type does. Otherwise, the new variable has the type of the case that matches.

While the examples so far have used the `any` interface with type assertions and type switches, you can uncover the concrete type from all interface types.

If you *don't* know the type of the value stored in an interface, you need to use reflection. I'll talk more about reflection in Chapter 16.

Use Type Assertions and Type Switches Sparingly

While being able to extract the concrete implementation from an interface variable might seem handy, you should use these techniques infrequently. For the most part, treat a parameter or return value as the type that was supplied and not what else it could be. Otherwise, your function's API isn't accurately declaring the types it needs to perform its task. If you needed a different type, it should be specified.

That said, type assertions and type switches are useful in some use cases. One common use of a type assertion is to see if the concrete type behind the interface also implements another interface. This allows you to specify optional interfaces. For example, the standard library uses this technique to allow more efficient copies when the `io.Copy` function is called. This function has two parameters of types `io.Writer` and `io.Reader` and calls the `io.copyBuffer` function to do its work. If the `io.Writer` parameter also implements `io.WriterTo`, or the `io.Reader` parameter also implements `io.ReaderFrom`, most of the work in the function can be skipped:

```go
// copyBuffer is the actual implementation of Copy and CopyBuffer.
// if buf is nil, one is allocated.
func copyBuffer(dst Writer, src Reader, buf []byte) (written int64, err error) {
    // If the reader has a WriteTo method, use it to do the copy.
    // Avoids an allocation and a copy.
    if wt, ok := src.(WriterTo); ok {
        return wt.WriteTo(dst)
    }
    // Similarly, if the writer has a ReadFrom method, use it to do the copy.
    if rt, ok := dst.(ReaderFrom); ok {
        return rt.ReadFrom(src)
    }
    // function continues...
}
```

Another place optional interfaces are used is when evolving an API. As was covered in "Accept Interfaces, Return Structs" on page 162, the API for the database drivers has changed over time. One of the reasons for this change is the addition of the context, which is discussed in Chapter 14. Context is a parameter that's passed to functions that provides, among other things, a standard way to manage cancellation. It was added to Go in version 1.7, which means older code doesn't support it. This includes older database drivers.

In Go 1.8, new context-aware analogues of existing interfaces were defined in the `database/sql/driver` package. For example, the `StmtExecContext` interface defines a method called `ExecContext`, which is a context-aware replacement for the `Exec` method in `Stmt`. When an implementation of `Stmt` is passed into standard library database code, it checks whether it also implements `StmtExecContext`. If it does, `ExecContext` is invoked. If not, the Go standard library provides a fallback implementation of the cancellation support provided by newer code:

```
func ctxDriverStmtExec(ctx context.Context, si driver.Stmt,
                       nvdargs []driver.NamedValue) (driver.Result, error) {
    if siCtx, is := si.(driver.StmtExecContext); is {
        return siCtx.ExecContext(ctx, nvdargs)
    }
    // fallback code is here
}
```

This optional interface technique has one drawback. You saw earlier that it is common for implementations of interfaces to use the decorator pattern to wrap other implementations of the same interface to layer behavior. The problem is that if an optional interface is implemented by one of the wrapped implementations, you cannot detect it with a type assertion or type switch. For example, the standard library includes a `bufio` package that provides a buffered reader. You can buffer any other `io.Reader` implementation by passing it to the `bufio.NewReader` function and using the returned `*bufio.Reader`. If the passed-in `io.Reader` also implemented `io.ReaderFrom`, wrapping it in a buffered reader prevents the optimization.

You also see this when handling errors. As mentioned earlier, they implement the `error` interface. Errors can include additional information by wrapping other errors. A type switch or type assertion cannot detect or match wrapped errors. If you want different behaviors to handle different concrete implementations of a returned error, use the `errors.Is` and `errors.As` functions to test for and access the wrapped error.

Type switch statements provide the ability to differentiate between multiple implementations of an interface that require different processing. They are most useful when only certain possible valid types can be supplied for an interface. Be sure to include a default case in the type switch to handle implementations that aren't known at development time. This protects you if you forget to update your type switch statements when adding new interface implementations:

```go
func walkTree(t *treeNode) (int, error) {
    switch val := t.val.(type) {
    case nil:
        return 0, errors.New("invalid expression")
    case number:
        // we know that t.val is of type number, so return the
        // int value
        return int(val), nil
    case operator:
        // we know that t.val is of type operator, so
        // find the values of the left and right children, then
        // call the process() method on operator to return the
        // result of processing their values.
        left, err := walkTree(t.lchild)
        if err != nil {
            return 0, err
        }
        right, err := walkTree(t.rchild)
        if err != nil {
            return 0, err
        }
        return val.process(left, right), nil
    default:
        // if a new treeVal type is defined, but walkTree wasn't updated
        // to process it, this detects it
        return 0, errors.New("unknown node type")
    }
}
```

You can see the complete implementation on The Go Playground or in the *sample_code/type_switch* directory in the Chapter 7 repository.

You can further protect yourself from unexpected interface implementations by making the interface unexported and at least one method unexported. If the interface is exported, it can be embedded in a struct in another package, making the struct implement the interface. I'll talk more about packages and exporting identifiers in Chapter 10.

Function Types Are a Bridge to Interfaces

I haven't talked about one last thing with type declarations. Once you understand the concept of declaring a method on a struct, you can start to see how a user-defined type with an underlying type of `int` or `string` can have a method as well. After all, a method provides business logic that interacts with the state of an instance, and integers and strings have state as well.

Go, however, allows methods on *any* user-defined type, including user-defined function types. This sounds like an academic corner case, but they are actually very useful. They allow functions to implement interfaces. The most common usage is for HTTP handlers. An HTTP handler processes an HTTP server request. It's defined by an interface:

```
type Handler interface {
    ServeHTTP(http.ResponseWriter, *http.Request)
}
```

By using a type conversion to `http.HandlerFunc`, any function that has the signature `func(http.ResponseWriter,*http.Request)` can be used as an `http.Handler`:

```
type HandlerFunc func(http.ResponseWriter, *http.Request)

func (f HandlerFunc) ServeHTTP(w http.ResponseWriter, r *http.Request) {
    f(w, r)
}
```

This lets you implement HTTP handlers using functions, methods, or closures using the exact same code path as the one used for other types that meet the `http.Handler` interface.

Functions in Go are first-class concepts, and as such, they are often passed as parameters into functions. Meanwhile, Go encourages small interfaces, and an interface of only one method could easily replace a parameter of a function type. The question becomes: when should your function or method specify an input parameter of a function type, and when should you use an interface?

If your single function is likely to depend on many other functions or other state that's not specified in its input parameters, use an interface parameter and define a function type to bridge a function to the interface. That's what's done in the `http` package; a `Handler` is likely just the entry point for a chain of calls that needs to be configured. However, if it's a simple function (like the one used in `sort.Slice`), then a parameter of a function type is a good choice.

Implicit Interfaces Make Dependency Injection Easier

In the preface, I compared writing software to building bridges. One of the things that software has in common with physical infrastructure is that any program used for a lengthy period of time by multiple people will need maintenance. While programs don't wear out, developers are often asked to update programs to fix bugs, add features, and run in new environments. Therefore, you should structure your programs in ways that make them easier to modify. Software engineers talk about *decoupling* code, so that changes to different parts of a program have no effect on one another.

One of the techniques that has been developed to ease decoupling is called *dependency injection*. Dependency injection is the concept that your code should explicitly specify the functionality it needs to perform its task. It's quite a bit older than you might think; in 1996, Robert Martin wrote an article called "The Dependency Inversion Principle".

One of the surprising benefits of Go's implicit interfaces is that they make dependency injection an excellent way to decouple your code. While developers in other languages often use large, complicated frameworks to inject their dependencies, the truth is that it is easy to implement dependency injection in Go without any additional libraries. Let's work through a simple example to see how to use implicit interfaces to compose applications via dependency injection.

To understand this concept better and see how to implement dependency injection in Go, you'll build a very simple web application. (I'll talk more about Go's built-in HTTP server support in "The Server" on page 337; consider this a preview.) Start by writing a small utility function, a logger:

```go
func LogOutput(message string) {
    fmt.Println(message)
}
```

Another thing your app needs is a data store. Let's create a simple one:

```go
type SimpleDataStore struct {
    userData map[string]string
}

func (sds SimpleDataStore) UserNameForID(userID string) (string, bool) {
    name, ok := sds.userData[userID]
    return name, ok
}
```

Also define a factory function to create an instance of a `SimpleDataStore`:

```go
func NewSimpleDataStore() SimpleDataStore {
    return SimpleDataStore{
        userData: map[string]string{
            "1": "Fred",
            "2": "Mary",
            "3": "Pat",
        },
    }
}
```

Next, write some business logic that looks up a user and says hello or goodbye. Your business logic needs some data to work with, so it requires a data store. You also want your business logic to log when it is invoked, so it depends on a logger. However, you don't want to force it to depend on `LogOutput` or `SimpleDataStore`, because you might want to use a different logger or data store later. What your business logic needs are interfaces to describe what it depends on:

```go
type DataStore interface {
    UserNameForID(userID string) (string, bool)
}

type Logger interface {
    Log(message string)
}
```

To make your `LogOutput` function meet this interface, you define a function type with a method on it:

```go
type LoggerAdapter func(message string)

func (lg LoggerAdapter) Log(message string) {
    lg(message)
}
```

By a stunning coincidence, `LoggerAdapter` and `SimpleDataStore` happen to meet the interfaces needed by your business logic, but neither type has any idea that it does.

Now that you have the dependencies defined, let's look at the implementation of your business logic:

```go
type SimpleLogic struct {
    l  Logger
    ds DataStore
}

func (sl SimpleLogic) SayHello(userID string) (string, error) {
    sl.l.Log("in SayHello for " + userID)
    name, ok := sl.ds.UserNameForID(userID)
    if !ok {
        return "", errors.New("unknown user")
    }
    return "Hello, " + name, nil
}

func (sl SimpleLogic) SayGoodbye(userID string) (string, error) {
    sl.l.Log("in SayGoodbye for " + userID)
    name, ok := sl.ds.UserNameForID(userID)
    if !ok {
        return "", errors.New("unknown user")
    }
    return "Goodbye, " + name, nil
}
```

You have a `struct` with two fields: one a `Logger`, the other a `DataStore`. Nothing in `SimpleLogic` mentions the concrete types, so there's no dependency on them. There's no problem if you later swap in new implementations from an entirely different provider, because the provider has nothing to do with your interface. This is very different from explicit interfaces in languages like Java. Even though Java uses an interface to decouple the implementation from the interface, the explicit interfaces bind the client and the provider together. This makes replacing a dependency in Java (and other languages with explicit interfaces) far more difficult than it is in Go.

When you want a `SimpleLogic` instance, you call a factory function, passing in interfaces and returning a struct:

```go
func NewSimpleLogic(l Logger, ds DataStore) SimpleLogic {
    return SimpleLogic{
        l:    l,
        ds: ds,
    }
}
```

The fields in `SimpleLogic` are unexported. This means they can be accessed only by code within the same package as `SimpleLogic`. You can't enforce immutability in Go, but limiting which code can access these fields makes their accidental modification less likely. I'll talk more about exported and unexported identifiers in Chapter 10.

Now you get to your API. You're going to have only a single endpoint, `/hello`, which says hello to the person whose user ID is supplied. (Please do not use query parameters in your real applications for authentication information; this is just a quick sample.) Your controller needs business logic that says hello, so you define an interface for that:

```go
type Logic interface {
    SayHello(userID string) (string, error)
}
```

This method is available on your `SimpleLogic` struct, but once again, the concrete type is not aware of the interface. Furthermore, the other method on `SimpleLogic`, `SayGoodbye`, is not in the interface because your controller doesn't care about it. The interface is owned by the client code, so its method set is customized to the needs of the client code:

```
type Controller struct {
    l     Logger
    logic Logic
}

func (c Controller) SayHello(w http.ResponseWriter, r *http.Request) {
    c.l.Log("In SayHello")
    userID := r.URL.Query().Get("user_id")
    message, err := c.logic.SayHello(userID)
    if err != nil {
        w.WriteHeader(http.StatusBadRequest)
        w.Write([]byte(err.Error()))
        return
    }
    w.Write([]byte(message))
}
```

Just as you have factory functions for your other types, let's write one for the `Controller`:

```
func NewController(l Logger, logic Logic) Controller {
    return Controller{
        l:     l,
        logic: logic,
    }
}
```

Again, you accept interfaces and return structs.

Finally, you wire up all your components in your `main` function and start your server:

```
func main() {
    l := LoggerAdapter(LogOutput)
    ds := NewSimpleDataStore()
    logic := NewSimpleLogic(l, ds)
    c := NewController(l, logic)
    http.HandleFunc("/hello", c.SayHello)
    http.ListenAndServe(":8080", nil)
}
```

You can find the complete code for this application in the *sample_code/dependency_injection* directory in the Chapter 7 repository.

The `main` function is the only part of the code that knows what all the concrete types actually are. If you want to swap in different implementations, this is the only place that needs to change. Externalizing the dependencies via dependency injection means that you limit the changes that are needed to evolve your code over time.

Dependency injection is also a great pattern for making testing easier. It shouldn't be surprising, since writing unit tests is effectively reusing your code in a different environment, one that constrains the inputs and outputs to validate functionality. For example, you can validate the logging output in a test by injecting a type that captures the log output and meets the `Logger` interface. I'll talk about this more in Chapter 15.

The line `http.HandleFunc("/hello", c.SayHello)` demonstrates two points I talked about earlier.

First, you are treating the `SayHello` method as a function.

Second, the `http.HandleFunc` function takes in a function and converts it to an `http.HandlerFunc` function type, which declares a method to meet the `http.Handler` interface, which is the type used to represent a request handler in Go. You took a method from one type and converted it into another type with its own method. That's pretty neat.

Wire

If you feel that writing dependency injection code by hand is too much work, you can use Wire, a dependency injection helper written by Google. Wire uses code generation to automatically create the concrete type declarations that you wrote yourself in `main`.

Go Isn't Particularly Object-Oriented (and That's Great)

Now that you've taken a look at the idiomatic use of types in Go, you can see that categorizing Go as a particular style of language is difficult. It clearly isn't a strictly procedural language. At the same time, Go's lack of method overriding, inheritance, or, well, objects means that it is also not a particularly object-oriented language. Go has function types and closures, but it isn't a functional language either. If you attempt to shoehorn Go into one of these categories, the result is nonidiomatic code.

If you had to label Go's style, the best word to use is *practical*. It borrows concepts from many places with the overriding goal of creating a language that is simple, readable, and maintainable by large teams for many years.

Exercises

In these exercises, you're going to build a program that uses what you've learned about types, methods, and interfaces. Answers are available in the *exercise_solutions* directory in the Chapter 7 repository.

1. You have been asked to manage a basketball league and are going to write a program to help you. Define two types. The first one, called `Team`, has a field for

the name of the team and a field for the player names. The second type is called `League` and has a field called `Teams` for the teams in the league and a field called `Wins` that maps a team's name to its number of wins.

2. Add two methods to `League`. The first method is called `MatchResult`. It takes four parameters: the name of the first team, its score in the game, the name of the second team, and its score in the game. This method should update the `Wins` field in `League`. Add a second method to `League` called `Ranking` that returns a slice of the team names in order of wins. Build your data structures and call these methods from the `main` function in your program using some sample data.
3. Define an interface called `Ranker` that has a single method called `Ranking` that returns a slice of strings. Write a function called `RankPrinter` with two parameters, the first of type `Ranker` and the second of type `io.Writer`. Use the `io.WriteString` function to write the values returned by `Ranker` to the `io.Writer`, with a newline separating each result. Call this function from `main`.

Wrapping Up

In this chapter, you learned about types, methods, interfaces, and their best practices. In the next chapter, you'll learn about generics, which improve readability and maintainability by allowing you to reuse logic and custom-written containers with different types.

CHAPTER 8

Generics

"Don't repeat yourself" is common software engineering advice. It's better to reuse a data structure or a function than it is to re-create it, because it's hard to keep code changes in sync between duplicated code. In a strongly typed language like Go, the type of every function parameter and every struct field must be known at compile time. This strictness enables the compiler to help validate that your code is correct, but sometimes when you'll want to reuse the logic in a function or the fields in a struct with different types. Go provides this functionality via type parameters, which are colloquially referred to as *generics*. In this chapter you'll learn why people want generics, what Go's implementation of generics can do, what generics can't do, and how to use them properly.

Generics Reduce Repetitive Code and Increase Type Safety

Go is a statically typed language, which means that the types of variables and parameters are checked when the code is compiled. Built-in types (maps, slices, channels) and functions (such as `len`, `cap`, or `make`) are able to accept and return values of different concrete types, but until Go 1.18, user-defined Go types and functions could not.

If you are accustomed to dynamically typed languages, where types are not evaluated until the code runs, you might not understand what the fuss is about generics, and you might be a bit unclear on what they are. It helps to think of them as "type parameters." So far in this book, you've seen functions that take in parameters whose values are specified when the function is called. In "Multiple Return Values" on page 96, the function `divAndRemainder` has two `int` parameters and returns two `int` values:

```
func divAndRemainder(num, denom int) (int, int, error) {
    if denom == 0 {
        return 0, 0, errors.New("cannot divide by zero")
    }
    return num / denom, num % denom, nil
}
```

Similarly, you create structs by specifying the type for the fields when the struct is declared. Here, Node has a field of type int and another field of type *Node:

```
type Node struct {
    val  int
    next *Node
}
```

In some situations, however, it's useful to write functions or structs that leave the specific *type* of a parameter or field unspecified until it is used.

The case for generic types is easy to understand. In "Code Your Methods for nil Instances" on page 148, you looked at a binary tree for ints. If you want a binary tree for strings or float64s and want type safety, you have a few options. The first possibility is writing a custom tree for each type, but having that much duplicated code is verbose and error-prone.

Without generics, the only way to avoid duplicated code would be to modify your tree implementation so that it uses an interface to specify how to order values. The interface would look like this:

```
type Orderable interface {
    // Order returns:
    // a value < 0 when the Orderable is less than the supplied value,
    // a value > 0 when the Orderable is greater than the supplied value,
    // and 0 when the two values are equal.
    Order(any) int
}
```

Now that you have Orderable, you can modify your Tree implementation to support it:

```
type Tree struct {
    val         Orderable
    left, right *Tree
}

func (t *Tree) Insert(val Orderable) *Tree {
    if t == nil {
        return &Tree{val: val}
    }

    switch comp := val.Order(t.val); {
    case comp < 0:
        t.left = t.left.Insert(val)
    case comp > 0:
        t.right = t.right.Insert(val)
    }
    return t
}
```

With an `OrderableInt` type, you can then insert `int` values:

```
type OrderableInt int

func (oi OrderableInt) Order(val any) int {
    return int(oi - val.(OrderableInt))
}

func main() {
    var it *Tree
    it = it.Insert(OrderableInt(5))
    it = it.Insert(OrderableInt(3))
    // etc...
}
```

While this code works correctly, it doesn't allow the compiler to validate that the values inserted into your data structure are all the same. If you also had an `OrderableString` type:

```
type OrderableString string

func (os OrderableString) Order(val any) int {
    return strings.Compare(string(os), val.(string))
}
```

the following code compiles:

```
var it *Tree
it = it.Insert(OrderableInt(5))
it = it.Insert(OrderableString("nope"))
```

The `Order` function uses `any` to represent the value that's passed in. This effectively short-circuits one of Go's primary advantages: checking compile-time type safety. When you compile code that attempts to insert an `OrderableString` into a `Tree` that already contains an `OrderableInt`, the compiler accepts the code. However, the program panics when run:

```
panic: interface conversion: interface {} is main.OrderableInt, not string
```

You can try out this code in the *sample_code/non_generic_tree* directory in the Chapter 8 repository.

With generics, there's a way to implement a data structure once for multiple types and detect incompatible data at compile time. You'll see how to properly use them in just a bit.

While data structures without generics are inconvenient, the real limitation is in writing functions. Several implementation decisions in Go's standard library were made because generics weren't originally part of the language. For example, rather than write multiple functions to handle different numeric types, Go implements functions like `math.Max`, `math.Min`, and `math.Mod` using `float64` parameters, which have a range big enough to represent nearly every other numeric type exactly. (The exceptions are an `int`, `int64`, or `uint` with a value greater than $2^{53} - 1$ or less than $-2^{53} - 1$.)

Some other things are impossible without generics. You cannot create a new instance of a variable that's specified by an interface, nor can you specify that two parameters of the same interface type are also of the same concrete type. Without generics, you cannot write a function to process a slice of any type without resorting to reflection and giving up some performance along with compile-time type safety (this is how `sort.Slice` works). This meant that before generics were introduced to Go, functions that operate on slices (like `map`, `reduce`, and `filter`) would be repeatedly implemented for each type of slice. While simple algorithms are easy enough to copy, many (if not most) software engineers find it grating to duplicate code simply because the compiler isn't smart enough to do it automatically.

Introducing Generics in Go

Since the first announcement of Go, people have called for generics to be added to the language. Russ Cox, the development lead for Go, wrote a blog post in 2009 to explain why generics weren't initially included. Go emphasizes a fast compiler, readable code, and good execution time, and none of the generics implementations that they were aware of would allow them to include all three. After a decade studying the problem, the Go team has a workable approach, which is outlined in the Type Parameters Proposal.

You can see how generics work in Go by looking at a stack. If you don't have a computer science background, a stack is a data type where values are added and removed in LIFO order. It's like a pile of dishes waiting to be washed; the ones that were placed first are at the bottom, and you get to them only by working through the ones that were added later. Let's see how to make a stack using generics:

```go
type Stack[T any] struct {
    vals []T
}

func (s *Stack[T]) Push(val T) {
    s.vals = append(s.vals, val)
}

func (s *Stack[T]) Pop() (T, bool) {
    if len(s.vals) == 0 {
        var zero T
        return zero, false
    }
    top := s.vals[len(s.vals)-1]
    s.vals = s.vals[:len(s.vals)-1]
    return top, true
}
```

There are a few things to note. First, you have `[T any]` after the type declaration. Type parameter information is placed within brackets and has two parts. The first part is the type parameter name. You can pick any name for the type parameter, but using capital letters is customary. The second part is the *type constraint*, which uses a Go interface to specify which types are valid. If any type is usable, this is specified with the universe block identifier `any`, which you first saw in "The Empty Interface Says Nothing" on page 166. Inside the `Stack` declaration, you declare `vals` to be of type `[]T`.

Next, look at the method declarations. Just as you used `T` in your `vals` declaration, you do the same here. You also refer to the type in the receiver section with `Stack[T]` instead of `Stack`.

Finally, generics make zero value handling a little interesting. In `Pop`, you can't just return `nil`, because that's not a valid value for a value type, like `int`. The easiest way to get a zero value for a generic is to simply declare a variable with `var` and return it, since by definition, `var` always initializes its variable to the zero value if no other value is assigned.

Using a generic type is similar to using a nongeneric one:

```
func main() {
    var intStack Stack[int]
    intStack.Push(10)
    intStack.Push(20)
    intStack.Push(30)
    v, ok := intStack.Pop()
    fmt.Println(v, ok)
}
```

The only difference is that when you declare your variable, you include the type that you want to use with your `Stack`—in this case, `int`. If you try to push a string onto your stack, the compiler will catch it. Adding the line:

```
intStack.Push("nope")
```

produces the compiler error:

```
cannot use "nope" (untyped string constant) as int value
  in argument to intStack.Push
```

You can try out the generic stack on The Go Playground or in the *sample_code/stack* directory in the Chapter 8 repository.

Add another method to your stack to tell you if the stack contains a value:

```go
func (s Stack[T]) Contains(val T) bool {
    for _, v := range s.vals {
        if v == val {
            return true
        }
    }
    return false
}
```

Unfortunately, this does not compile. It gives an error:

```
invalid operation: v == val (type parameter T is not comparable with ==)
```

Just as `interface{}` doesn't say anything, neither does `any`. You can only store values of `any` type and retrieve them. To use `==`, you need a different type. Since nearly all Go types can be compared with `==` and `!=`, a new built-in interface called `comparable` is defined in the universe block. If you change the definition of `Stack` to use `comparable`:

```go
type Stack[T comparable] struct {
    vals []T
}
```

you can then use your new method:

```go
func main() {
    var s Stack[int]
    s.Push(10)
    s.Push(20)
    s.Push(30)
    fmt.Println(s.Contains(10))
    fmt.Println(s.Contains(5))
}
```

This prints out the following:

```
true
false
```

You can try out this updated stack on The Go Playground or in the *sample_code/comparable_stack* directory in the Chapter 8 repository.

Later, you'll see how to make a generic binary tree. First, I'll cover some additional concepts: *generic functions*, how generics work with interfaces, and *type terms*.

Generic Functions Abstract Algorithms

As I have hinted, you can also write generic functions. Earlier I mentioned that not having generics made it difficult to write map, reduce, and filter implementations that work for all types. Generics make it easy. Here are implementations from the type parameters proposal:

```
// Map turns a []T1 to a []T2 using a mapping function.
// This function has two type parameters, T1 and T2.
// This works with slices of any type.
func Map[T1, T2 any](s []T1, f func(T1) T2) []T2 {
    r := make([]T2, len(s))
    for i, v := range s {
        r[i] = f(v)
    }
    return r
}

// Reduce reduces a []T1 to a single value using a reduction function.
func Reduce[T1, T2 any](s []T1, initializer T2, f func(T2, T1) T2) T2 {
    r := initializer
    for _, v := range s {
        r = f(r, v)
    }
    return r
}

// Filter filters values from a slice using a filter function.
// It returns a new slice with only the elements of s
// for which f returned true.
func Filter[T any](s []T, f func(T) bool) []T {
    var r []T
    for _, v := range s {
        if f(v) {
            r = append(r, v)
        }
    }
    return r
}
```

Functions place their type parameters after the function name and before the variable parameters. `Map` and `Reduce` have two type parameters, both of `any` type, while `Filter` has one. When you run the code:

```
words := []string{"One", "Potato", "Two", "Potato"}
filtered := Filter(words, func(s string) bool {
    return s != "Potato"
})
fmt.Println(filtered)
lengths := Map(filtered, func(s string) int {
    return len(s)
})
fmt.Println(lengths)
sum := Reduce(lengths, 0, func(acc int, val int) int {
    return acc + val
})
fmt.Println(sum)
```

you get the output:

```
[One Two]
[3 3]
6
```

Try it for yourself on The Go Playground or in the *sample_code/map_filter_reduce* directory in the Chapter 8 repository.

Generics and Interfaces

You can use any interface as a type constraint, not just `any` and `comparable`. For example, say you wanted to make a type that holds any two values of the same type, as long as the type implements `fmt.Stringer`. Generics make it possible to enforce this at compile time:

```
type Pair[T fmt.Stringer] struct {
    Val1 T
    Val2 T
}
```

You can also create interfaces that have type parameters. For example, here's an interface with a method that compares against a value of the specified type and returns a `float64`. It also embeds `fmt.Stringer`:

```
type Differ[T any] interface {
    fmt.Stringer
    Diff(T) float64
}
```

You'll use these two types to create a comparison function. The function takes in two `Pair` instances that have fields of type `Differ`, and returns the `Pair` with the closer values:

```
func FindCloser[T Differ[T]](pair1, pair2 Pair[T]) Pair[T] {
    d1 := pair1.Val1.Diff(pair1.Val2)
    d2 := pair2.Val1.Diff(pair2.Val2)
    if d1 < d2 {
        return pair1
    }
    return pair2
}
```

Note that FindCloser takes in Pair instances that have fields that meet the Differ interface. Pair requires that its fields are both of the same type and that the type meets the fmt.Stringer interface; this function is more selective. If the fields in a Pair instance don't meet Differ, the compiler will prevent you from using that Pair instance with FindCloser.

Now define a couple of types that meet the Differ interface:

```go
type Point2D struct {
    X, Y int
}

func (p2 Point2D) String() string {
    return fmt.Sprintf("{%d,%d}", p2.X, p2.Y)
}

func (p2 Point2D) Diff(from Point2D) float64 {
    x := p2.X - from.X
    y := p2.Y - from.Y
    return math.Sqrt(float64(x*x) + float64(y*y))
}

type Point3D struct {
    X, Y, Z int
}

func (p3 Point3D) String() string {
    return fmt.Sprintf("{%d,%d,%d}", p3.X, p3.Y, p3.Z)
}

func (p3 Point3D) Diff(from Point3D) float64 {
    x := p3.X - from.X
    y := p3.Y - from.Y
    z := p3.Z - from.Z
    return math.Sqrt(float64(x*x) + float64(y*y) + float64(z*z))
}
```

And here's what it looks like to use this code:

```go
func main() {
    pair2Da := Pair[Point2D]{Point2D{1, 1}, Point2D{5, 5}}
    pair2Db := Pair[Point2D]{Point2D{10, 10}, Point2D{15, 5}}
    closer := FindCloser(pair2Da, pair2Db)
    fmt.Println(closer)

    pair3Da := Pair[Point3D]{Point3D{1, 1, 10}, Point3D{5, 5, 0}}
    pair3Db := Pair[Point3D]{Point3D{10, 10, 10}, Point3D{11, 5, 0}}
    closer2 := FindCloser(pair3Da, pair3Db)
    fmt.Println(closer2)
}
```

Run it for yourself on The Go Playground or in the *sample_code/generic_interface* directory in the Chapter 8 repository.

Use Type Terms to Specify Operators

One more thing needs to be represented with generics: operators. The `divAndRemainder` function works fine with `int`, but using it with other integer types requires type casting, and `uint` allows you to represent values that are too big for an `int`. If you want to write a generic version of `divAndRemainder`, you need a way to specify that you can use `/` and `%`. Go generics do that with a *type element*, which is composed of one or more *type terms* within an interface:

```go
type Integer interface {
    int | int8 | int16 | int32 | int64 |
        uint | uint8 | uint16 | uint32 | uint64 | uintptr
}
```

In "Embedding and Interfaces" on page 162, you learned about embedding interfaces to indicate that the method set of the containing interface includes the methods of the embedded interface. Type elements specify which types can be assigned to a type parameter and which operators are supported. They list concrete types separated by `|`. The allowed operators are the ones that are valid for *all* of the listed types. The modulus (`%`) operator is valid only for integers, so we list all integer types. (You can leave off `byte` and `rune` because they are type aliases for `uint8` and `int32`, respectively.)

Be aware that interfaces with type elements are valid only as type constraints. It is a compile-time error to use them as the type for a variable, field, return value, or parameter.

Now you can write your generic version of `divAndRemainder` and use it with the built-in `uint` type (or any of the other types listed in `Integer`):

```go
func divAndRemainder[T Integer](num, denom T) (T, T, error) {
    if denom == 0 {
        return 0, 0, errors.New("cannot divide by zero")
    }
    return num / denom, num % denom, nil
}

func main() {
    var a uint = 18_446_744_073_709_551_615
    var b uint = 9_223_372_036_854_775_808
    fmt.Println(divAndRemainder(a, b))
}
```

By default, type terms match exactly. If you try to use `divAndRemainder` with a user-defined type whose underlying type is one of the types listed in `Integer`, you'll get an error. This code:

```
type MyInt int
var myA MyInt = 10
var myB MyInt = 20
fmt.Println(divAndRemainder(myA, myB))
```

produces the following error:

```
MyInt does not satisfy Integer (possibly missing ~ for int in Integer)
```

The error text gives a hint for how to solve this problem. If you want a type term to be valid for any type that has the type term as its underlying type, put a ~ before the type term. This changes the definition of `Integer` as follows:

```
type Integer interface {
    ~int | ~int8 | ~int16 | ~int32 | ~int64 |
        ~uint | ~uint8 | ~uint16 | ~uint32 | ~uint64 | ~uintptr
}
```

You can look at the generic version of the `divAndRemainder` function on The Go Playground or in the *sample_code/type_terms* directory in the Chapter 8 repository.

The addition of type terms allows you to define a type that lets you write generic comparison functions:

```
type Ordered interface {
    ~int | ~int8 | ~int16 | ~int32 | ~int64 |
        ~uint | ~uint8 | ~uint16 | ~uint32 | ~uint64 | ~uintptr |
        ~float32 | ~float64 |
        ~string
}
```

The `Ordered` interface lists all types that support the ==, !=, <, >, <=, and >= operators. Having a way to specify that a variable represents an orderable type is so useful that Go 1.21 added the `cmp` package, which defines this `Ordered` interface. The package also defines two comparison functions. The `Compare` function returns either –1, 0, or 1, depending on whether its first parameter is less than, equal to, or greater than its second parameter, and the `Less` function returns `true` if its first parameter is less than its second parameter.

It is legal to have both type elements and method elements in an interface used for a type parameter. For example, you could specify that a type must have an underlying type of `int` and a `String() string` method:

```
type PrintableInt interface {
    ~int
    String() string
}
```

Be aware that Go will let you declare a type parameter interface that is impossible to actually instantiate. If you had used `int` instead of `~int` in `PrintableInt`, there would be no valid type that meets it, since `int` has no methods. This might seem bad, but the compiler still comes to your rescue. If you declare a type or function with an impossible type parameter, any attempt to use it causes a compiler error. Assume you declare these types:

```
type ImpossiblePrintableInt interface {
    int
    String() string
}

type ImpossibleStruct[T ImpossiblePrintableInt] struct {
    val T
}

type MyInt int

func (mi MyInt) String() string {
    return fmt.Sprint(mi)
}
```

Even though you cannot instantiate `ImpossibleStruct`, the compiler has no problem with any of these declarations. However, once you try using `ImpossibleStruct`, the compiler complains. This code:

```
s := ImpossibleStruct[int]{10}
s2 := ImpossibleStruct[MyInt]{10}
```

produces the following compile-time errors:

```
int does not implement ImpossiblePrintableInt (missing String method)
MyInt does not implement ImpossiblePrintableInt (possibly missing ~ for
int in constraint ImpossiblePrintableInt)
```

Try this on The Go Playground or in the *sample_code/impossible* directory in the Chapter 8 repository.

In addition to built-in primitive types, type terms can also be slices, maps, arrays, channels, structs, or even functions. They are most useful when you want to ensure that a type parameter has a specific underlying type and one or more methods.

Type Inference and Generics

Just as Go supports type inference when using the `:=` operator, it also supports type inference to simplify calls to generic functions. You can see this in the calls to `Map`, `Filter`, and `Reduce` earlier. In some situations, type inference isn't possible (for example, when a type parameter is used only as a return value). When that happens, all type arguments must be specified. Here's a slightly silly bit of code that demonstrates a situation where type inference doesn't work:

```go
type Integer interface {
    int | int8 | int16 | int32 | int64 | uint | uint8 | uint16 | uint32 | uint64
}

func Convert[T1, T2 Integer](in T1) T2 {
    return T2(in)
}

func main() {
    var a int = 10
    b := Convert[int, int64](a) // can't infer the return type
    fmt.Println(b)
}
```

Try it out on The Go Playground or in the *sample_code/type_inference* directory in the Chapter 8 repository.

Type Elements Limit Constants

Type elements also specify which constants can be assigned to variables of the generic type. Like operators, the constants need to be valid for all the type terms in the type element. There are no constants that can be assigned to every listed type in `Ordered`, so you cannot assign a constant to a variable of that generic type. If you use the `Integer` interface, the following code will not compile, because you cannot assign the value 1,000 to an 8-bit integer:

```go
// INVALID!
func PlusOneThousand[T Integer](in T) T {
    return in + 1_000
}
```

However, this is valid:

```go
// VALID
func PlusOneHundred[T Integer](in T) T {
    return in + 100
}
```

Combining Generic Functions with Generic Data Structures

Let's return to the binary tree example and see how to combine everything you've learned to make a single tree that works for any concrete type.

The secret is to realize that what your tree needs is a single generic function that compares two values and tells you their order:

```go
type OrderableFunc [T any] func(t1, t2 T) int
```

Now that you have `OrderableFunc`, you can modify your tree implementation slightly. First, you're going to split it into two types, `Tree` and `Node`:

```go
type Tree[T any] struct {
    f    OrderableFunc[T]
    root *Node[T]
}

type Node[T any] struct {
    val         T
    left, right *Node[T]
}
```

You construct a new `Tree` with a constructor function:

```go
func NewTree[T any](f OrderableFunc[T]) *Tree[T] {
    return &Tree[T]{
        f: f,
    }
}
```

`Tree` 's methods are very simple, because they just call `Node` to do all the real work:

```go
func (t *Tree[T]) Add(v T) {
    t.root = t.root.Add(t.f, v)
}

func (t *Tree[T]) Contains(v T) bool {
    return t.root.Contains(t.f, v)
}
```

The `Add` and `Contains` methods on `Node` are very similar to what you've seen before. The only difference is that the function you are using to order your elements is passed in:

```go
func (n *Node[T]) Add(f OrderableFunc[T], v T) *Node[T] {
    if n == nil {
        return &Node[T]{val: v}
    }
    switch r := f(v, n.val); {
    case r <= -1:
        n.left = n.left.Add(f, v)
    case r >= 1:
        n.right = n.right.Add(f, v)
    }
    return n
}

func (n *Node[T]) Contains(f OrderableFunc[T], v T) bool {
    if n == nil {
        return false
    }
    switch r := f(v, n.val); {
    case r <= -1:
        return n.left.Contains(f, v)
    case r >= 1:
        return n.right.Contains(f, v)
    }
    return true
}
```

Now you need a function that matches the `OrderedFunc` definition. Luckily, you've already seen one: `Compare` in the `cmp` package. When you use it with your `Tree`, it looks like this:

```
t1 := NewTree(cmp.Compare[int])
t1.Add(10)
t1.Add(30)
t1.Add(15)
fmt.Println(t1.Contains(15))
fmt.Println(t1.Contains(40))
```

For structs, you have two options. You can write a function:

```
type Person struct {
    Name string
    Age int
}

func OrderPeople(p1, p2 Person) int {
    out := cmp.Compare(p1.Name, p2.Name)
    if out == 0 {
        out = cmp.Compare(p1.Age, p2.Age)
    }
    return out
}
```

Then you can pass that function in when you create your tree:

```
t2 := NewTree(OrderPeople)
t2.Add(Person{"Bob", 30})
t2.Add(Person{"Maria", 35})
t2.Add(Person{"Bob", 50})
fmt.Println(t2.Contains(Person{"Bob", 30}))
fmt.Println(t2.Contains(Person{"Fred", 25}))
```

Instead of using a function, you can also supply a method to `NewTree`. As I talked about in "Methods Are Functions Too" on page 149, you can use a method expression to treat a method like a function. Let's do that here. First, write the method:

```go
func (p Person) Order(other Person) int {
    out := cmp.Compare(p.Name, other.Name)
    if out == 0 {
        out = cmp.Compare(p.Age, other.Age)
    }
    return out
}
```

And then use it:

```go
t3 := NewTree(Person.Order)
t3.Add(Person{"Bob", 30})
t3.Add(Person{"Maria", 35})
t3.Add(Person{"Bob", 50})
fmt.Println(t3.Contains(Person{"Bob", 30}))
fmt.Println(t3.Contains(Person{"Fred", 25}))
```

You can find the code for this tree on The Go Playground or in the *sample_code/generic_tree* directory in the Chapter 8 repository.

More on comparable

As you saw in "Interfaces Are Comparable" on page 165, interfacesare one of the comparable types in Go. This means that you need to be careful when using == and `!=` with variables of the interface type. If the underlying type of the interface is not comparable, your code panics at runtime.

This pothole still exists when using the `comparable` interface with generics. Say you've defined an interface and a couple of implementations:

```go
type Thinger interface {
    Thing()
}

type ThingerInt int

func (t ThingerInt) Thing() {
    fmt.Println("ThingInt:", t)
}

type ThingerSlice []int

func (t ThingerSlice) Thing() {
    fmt.Println("ThingSlice:", t)
}
```

You also define a generic function that accepts only values that are comparable:

```
func Comparer[T comparable](t1, t2 T) {
    if t1 == t2 {
        fmt.Println("equal!")
    }
}
```

It's legal to call this function with variables of type int or ThingerInt:

```
var a int = 10
var b int = 10
Comparer(a, b) // prints true

var a2 ThingerInt = 20
var b2 ThingerInt = 20
Comparer(a2, b2) // prints true
```

The compiler won't allow you to call this function with variables of type ThingerSlice (or []int):

```
var a3 ThingerSlice = []int{1, 2, 3}
var b3 ThingerSlice = []int{1, 2, 3}
Comparer(a3, b3) // compile fails: "ThingerSlice does not satisfy comparable"
```

However, it's perfectly legal to call it with variables of type Thinger. If you use ThingerInt, the code compiles and works as expected:

```
var a4 Thinger = a2
var b4 Thinger = b2
Comparer(a4, b4) // prints true
```

But you can also assign ThingerSlice to variables of type Thinger. That's where things go wrong:

```
a4 = a3
b4 = b3
Comparer(a4, b4) // compiles, panics at runtime
```

The compiler won't stop you from building this code, but if you run it, your program will panic with the message `panic: runtime error: comparing uncomparable type main.ThingerSlice` (see "panic and recover" on page 218 for more information). You can try this code yourself on The Go Playground or in the *sample_code/more_comparable* directory in the Chapter 8 repository.

For more technical details on how comparable types and generics interact and why this design decision was made, read the blog post "All Your Comparable Types" from Robert Griesemer on the Go team.

Things That Are Left Out

Go remains a small, focused language, and the generics implementation for Go doesn't include many features that are found in generics implementations in other languages. This section describes some of the features that are not in the initial implementation of Go generics.

While you can build a single tree that works with both user-defined and built-in types, languages like Python, Ruby, and C++ solve this problem in a different way. They include *operator overloading*, which allows user-defined types to specify implementations for operators. Go will not be adding this feature. This means that you can't use `range` to iterate over user-defined container types or `[]` to index into them.

There are good reasons for leaving out operator overloading. For one thing, Go has a surprisingly large number of operators. Go also doesn't have function or method overloading, and you'd need a way to specify different operator functionality for different types. Furthermore, operator overloading can lead to code that's harder to follow as developers invent clever meanings for symbols (in C++, << means "shift bits left" for some types and "write the value on the right to the value on the left" for others). These are the sorts of readability issues that Go tries to avoid.

Another useful feature that's been left out of the initial Go generics implementation is additional type parameters on methods. Looking back on the `Map`/`Reduce`/`Filter` functions, you might think they'd be useful as methods, like this:

```
type functionalSlice[T any] []T

// THIS DOES NOT WORK
func (fs functionalSlice[T]) Map[E any](f func(T) E) functionalSlice[E] {
    out := make(functionalSlice[E], len(fs))
    for i, v := range fs {
        out[i] = f(v)
    }
    return out
}

// THIS DOES NOT WORK
func (fs functionalSlice[T]) Reduce[E any](start E, f func(E, T) E) E {
    out := start
    for _, v := range fs {
        out = f(out, v)
    }
    return out
}
```

which you could use like this:

```
var numStrings = functionalSlice[string]{"1", "2", "3"}
sum := numStrings.Map(func(s string) int {
    v, _ := strconv.Atoi(s)
    return v
}).Reduce(0, func(acc int, cur int) int {
    return acc + cur
})
```

Unfortunately for fans of functional programming, this does not work. Rather than chaining method calls together, you need to either nest function calls or use the much more readable approach of invoking the functions one at a time and assigning the intermediate values to variables. The type parameter proposal goes into detail on the reasons for excluding parameterized methods.

Go also has no variadic type parameters. As discussed in "Variadic Input Parameters and Slices" on page 95, to implement a function that takes in a varying number of parameters, you specify that the last parameter type starts with `...`. For example, there's no way to specify some sort of type pattern to those variadic parameters, such as alternating `string` and `int`. All variadic variables must match a single declared type, which can be generic or not.

Other features left out of Go generics are more esoteric. These include the following:

Specialization
: A function or method can be overloaded with one or more type-specific versions in addition to the generic version. Since Go doesn't have overloading, this feature is not under consideration.

Currying
: Allows you to partially instantiate a function or type based on another generic function or type by specifying some of the type parameters.

Metaprogramming
: Allows you to specify code that runs at compile time to produce code that runs at runtime.

Idiomatic Go and Generics

Adding generics clearly changes some of the advice for how to use Go idiomatically. The use of `float64` to represent any numeric type will end. You should use `any` instead of `interface{}` to represent an unspecified type in a data structure or function parameter. You can handle different slice types with a single function. But don't feel the need to switch all your code over to using type parameters immediately. Your old code will still work as new design patterns are invented and refined.

It's still too early to judge the long-term impact of generics on performance. As of this writing, there's no impact on compilation time. The Go 1.18 compiler was slower than previous versions, but the compiler in Go 1.20 resolved this issue.

Some research has also been done on the runtime impact of generics. Vicent Marti wrote a detailed blog post exploring cases where generics result in slower code and the implementation details that explain why this is so. Conversely, Eli Bendersky wrote a blog post that shows that generics make sorting algorithms faster.

In particular, do not change a function that has an interface parameter into a function with a generic type parameter in hopes of improving performance. For example, converting this trivial function:

```go
type Ager interface {
    age() int
}

func doubleAge(a Ager) int {
    return a.age() * 2
}
```

into:

```go
func doubleAgeGeneric[T Ager](a T) int {
    return a.age() * 2
}
```

makes the function call about 30% slower in Go 1.20. (For a nontrivial function, there's no significant performance difference.) You can run the benchmarks using the code in the *sample_code/perf* directory in the Chapter 8 repository.

This might be surprising for developers experienced with generics in other languages. In C++, for example, the compiler uses generics on abstract data types to turn what is normally a runtime operation (figuring out which concrete type is being used) into a compile-time one, generating a unique function for each concrete type. This makes the resulting binary larger but also faster. As Vicent explains in his blog post, the current Go compiler generates only unique functions for different underlying types. Furthermore, all pointer types share a single generated function. To differentiate between the different types that are passed in to shared generated functions, the compiler adds additional runtime lookups. This causes the slowdown in performance.

Again, as the generics implementation matures in future versions of Go, expect runtime performance to improve. As always, the goal is to write maintainable programs that are fast enough to meet your needs. Use the benchmarking and profiling tools that are discussed in "Using Benchmarks" on page 393 to measure and improve your code.

Adding Generics to the Standard Library

The initial release of generics in Go 1.18 was very conservative. It added the new interfaces `any` and `comparable` to the universe block, but no API changes occurred in the standard library to support generics. A stylistic change has been made; virtually all uses of `interface{}` in the standard library were replaced with `any`.

Now that the Go community is more comfortable with generics, we are starting to see more changes. Starting with Go 1.21, the standard library includes functions that use generics to implement common algorithms for slices, maps, and concurrency. In Chapter 3, I covered the `Equal` and `EqualFunc` functions in the `slices` and `maps` packages. Other functions in these packages simplify slice and map manipulation. The `Insert`, `Delete`, and `DeleteFunc` functions in the `slices` package allow developers to avoid building some surprisingly tricky slice-handling code. The `maps.Clone` function takes advantage of the Go runtime to provide a faster way to create a shallow copy of a map. In "Run Code Exactly Once" on page 308, you'll learn about `sync.OnceValue` and `sync.OnceValues`, which use generics to build functions that are invoked only once and return one or two values. Prefer using functions in these packages over writing your own implementations. Future versions of the standard library will likely include additional new functions and types that take advantage of generics.

Future Features Unlocked

Generics might be the basis for other future features. One possibility is *sum types*. Just as type elements are used to specify the types that can be substituted for a type parameter, they could also be used for interfaces in variable parameters. This would enable some interesting features. Today, Go has a problem with a common situation in JSON: a field that can be a single value or a list of values. Even with generics, the only way to handle this is with a field of type `any`. Adding sum types would allow you to create an interface specifying that a field could be a string, a slice of strings, and nothing else. A type switch could then completely enumerate every valid type, improving type safety. This ability to specify a bounded set of types allows many modern languages (including Rust and Swift) to use sum types to represent enums. Given the weakness of Go's current enum features, this might be an attractive solution, but it will take time for these ideas to be evaluated and explored.

Exercises

Now that you've seen how generics work, apply them to solve the following problems. Solutions are available in the *exercise_solutions* directory in the Chapter 8 repository.

1. Write a generic function that doubles the value of any integer or float that's passed in to it. Define any needed generic interfaces.
2. Define a generic interface called `Printable` that matches a type that implements `fmt.Stringer` and has an underlying type of `int` or `float64`. Define types that meet this interface. Write a function that takes in a `Printable` and prints its value to the screen using `fmt.Println`.
3. Write a generic singly linked list data type. Each element can hold a comparable value and has a pointer to the next element in the list. The methods to implement are as follows:

   ```
   // adds a new element to the end of the linked list
   Add(T)
   // adds an element at the specified position in the linked list
   Insert(T, int)
   // returns the position of the supplied value, -1 if it's not present
   Index (T) int
   ```

Wrapping Up

In this chapter, you took a look at generics and how to use them to simplify your code. It's still early days for generics in Go. It will be exciting to see how they help grow the language while still maintaining the spirit that makes Go special.

In the next chapter, you are going to learn how to properly use one of Go's most controversial features: errors.

CHAPTER 9
Errors

Error handling is one of the biggest challenges for developers moving to Go from other languages. For those used to exceptions, Go's approach feels anachronistic. But solid software engineering principles underlie Go's approach. In this chapter, you'll learn how to work with errors in Go. You'll also take a look at `panic` and `recover`, Go's system for handling errors that should stop execution.

How to Handle Errors: The Basics

As was covered briefly in Chapter 5, Go handles errors by returning a value of type `error` as the last return value for a function. This is entirely by convention, but it is such a strong convention that it should never be breached. When a function executes as expected, `nil` is returned for the error parameter. If something goes wrong, an error value is returned instead. The calling function then checks the error return value by comparing it to `nil`, handling the error, or returning an error of its own. A simple function with error handling looks like this:

```go
func calcRemainderAndMod(numerator, denominator int) (int, int, error) {
    if denominator == 0 {
        return 0, 0, errors.New("denominator is 0")
    }
    return numerator / denominator, numerator % denominator, nil
}
```

A new error is created from a string by calling the `New` function in the `errors` package. Error messages should not be capitalized nor should they end with punctuation or a newline. In most cases, you should set the other return values to their zero values when a non-nil error is returned. You'll see an exception to this rule when I cover sentinel errors.

Unlike languages with exceptions, Go doesn't have special constructs to detect if an error was returned. When a function returns an error, use an `if` statement to check the error variable to see if it is non-nil:

```go
func main() {
    numerator := 20
    denominator := 3
    remainder, mod, err := calcRemainderAndMod(numerator, denominator)
    if err != nil {
        fmt.Println(err)
        os.Exit(1)
    }
    fmt.Println(remainder, mod)
}
```

You can try out this code in the *sample_code/error_basics* directory in the Chapter 9 repository.

`error` is a built-in interface that defines a single method:

```go
type error interface {
    Error() string
}
```

Anything that implements this interface is considered an error. The reason you return `nil` from a function to indicate that no error occurred is that `nil` is the zero value for any interface type.

There are two very good reasons that Go uses a returned error instead of thrown exceptions. First, exceptions add at least one new code path through the code. These paths are sometimes unclear, especially in languages whose functions don't include a declaration that an exception is possible. This produces code that crashes in surprising ways when exceptions aren't properly handled, or, even worse, code that doesn't crash but whose data is not properly initialized, modified, or stored.

The second reason is more subtle but demonstrates how Go's features work together. The Go compiler requires all variables to be read. Making errors returned values forces developers to either check and handle error conditions or make it explicit that they are ignoring errors by using an underscore (_) for the returned error value.

Exception handling may produce shorter code, but having fewer lines doesn't necessarily make code easier to understand or maintain. As you've seen, idiomatic Go favors clear code, even if it takes more lines.

Another thing to note is how code flows in Go. The error handling is indented inside an `if` statement. The business logic is not. This gives a quick visual clue to which code is along the "golden path" and which code is the exceptional condition.

The second situation is a reused `err` variable. The Go compiler requires every variable to be read at least once. It doesn't require that *every* write to a variable is read. If you use an `err` variable multiple times, you have to read it only once to make the compiler happy. In "staticcheck" on page 268, you'll see a way to detect this.

Use Strings for Simple Errors

Go's standard library provides two ways to create an error from a string. The first is the `errors.New` function. It takes in a `string` and returns an `error`. This string is returned when you call the `Error` method on the returned error instance. If you pass an error to `fmt.Println`, it calls the `Error` method automatically:

```go
func doubleEven(i int) (int, error) {
    if i % 2 != 0 {
        return 0, errors.New("only even numbers are processed")
    }
    return i * 2, nil
}

func main() {
    result, err := doubleEven(1)
    if err != nil {
        fmt.Println(err) // prints "only even numbers are processed"
    }
    fmt.Println(result)
}
```

The second way is to use the `fmt.Errorf` function. This function allows you to include runtime information in the error message by using the `fmt.Printf` verbs to format an error string. Like `errors.New`, this string is returned when you call the `Error` method on the returned error instance:

```go
func doubleEven(i int) (int, error) {
    if i % 2 != 0 {
        return 0, fmt.Errorf("%d isn't an even number", i)
    }
    return i * 2, nil
}
```

You can find this code in the *sample_code/string_error* directory in the Chapter 9 repository.

Sentinel Errors

Some errors are meant to signal that processing cannot continue because of a problem with the current state. In his blog post "Don't Just Check Errors, Handle Them

Gracefully", Dave Cheney, a developer who has been active in the Go community for many years, coined the term *sentinel errors* to describe these:

> The name descends from the practice in computer programming of using a specific value to signify that no further processing is possible. So too with Go, we use specific values to signify an error.

Sentinel errors are one of the few variables that are declared at the package level. By convention, their names start with `Err` (with the notable exception of `io.EOF`). They should be treated as read-only; there's no way for the Go compiler to enforce this, but it is a programming error to change their value.

Sentinel errors are usually used to indicate that you cannot start or continue processing. For example, the standard library includes a package for processing ZIP files, `archive/zip`. This package defines several sentinel errors, including `ErrFormat`, which is returned when data that doesn't represent a ZIP file is passed in. Try out this code on The Go Playground or in the *sample_code/sentinel_error* directory in the Chapter 9 repository:

```go
func main() {
    data := []byte("This is not a zip file")
    notAZipFile := bytes.NewReader(data)
    _, err := zip.NewReader(notAZipFile, int64(len(data)))
    if err == zip.ErrFormat {
        fmt.Println("Told you so")
    }
}
```

Another example of a sentinel error in the standard library is `rsa.ErrMessageTooLong` in the `crypto/rsa` package. It indicates that a message cannot be encrypted because it is too long for the provided public key. The sentinel error `context.Canceled` is covered in Chapter 14.

Be sure you need a sentinel error before you define one. Once you define one, it is part of your public API, and you have committed to it being available in all future backward-compatible releases. It's far better to reuse one of the existing ones in the standard library or to define an error type that includes information about the condition that caused the error to be returned (you'll see how to do that in the next section). But if you have an error condition that indicates a specific state has been reached in your application where no further processing is possible and no additional information needs to be used to explain the error state, a sentinel error is the correct choice.

How do you test for a sentinel error? As you can see in the preceding code sample, use == to test whether the error was returned when calling a function whose documentation explicitly says it returns a sentinel error. In "Is and As" on page 214, I discuss how to check for sentinel errors in other situations.

Using Constants for Sentinel Errors

In "Constant Errors", Dave Cheney proposes that constants would make useful sentinel errors. You'd have a type like this in a package (I'll talk about creating packages in Chapter 10):

```
package consterr

type Sentinel string

func(s Sentinel) Error() string {
    return string(s)
}
```

Then you'd use it like this:

```
package mypkg

const (
    ErrFoo = consterr.Sentinel("foo error")
    ErrBar = consterr.Sentinel("bar error")
)
```

This looks like a function call, but it's actually casting a string literal to a type that implements the `error` interface. Changing the values of `ErrFoo` and `ErrBar` would be impossible. At first glance, this looks like a good solution.

However, this practice isn't considered idiomatic. If you used the same type to create constant errors across packages, two errors would be equal if their error strings are equal. They'd also be equal to a string literal with the same value. Meanwhile, an error created with `errors.New` is equal only to itself or to variables explicitly assigned its value. You almost certainly do not want to make errors in different packages equal to each other; otherwise, why declare two different errors? (You could avoid this by creating a nonpublic error type in every package, but that's a lot of boilerplate.)

The sentinel error pattern is another example of the Go design philosophy. Sentinel errors should be rare, so they can be handled by convention instead of language rules. Yes, they are public package-level variables. This makes them mutable, but it's highly unlikely someone would accidentally reassign a public variable in a package. In short, it's a corner case that is handled by other features and patterns. The Go philosophy is that it's better to keep the language simple and trust the developers and tooling than it is to add features.

So far, all the errors that you've seen are strings. But Go errors can contain more information. Let's see how.

Errors Are Values

Since `error` is an interface, you can define your own errors that include additional information for logging or error handling. For example, you might want to include a status code as part of the error to indicate the kind of error that should be reported back to the user. This lets you avoid string comparisons (whose text might change) to determine error causes. Let's see how this works. First, define your own enumeration to represent the status codes:

```
type Status int

const (
    InvalidLogin Status = iota + 1
    NotFound
)
```

Next, define a `StatusErr` to hold this value:

```
type StatusErr struct {
    Status    Status
    Message   string
}

func (se StatusErr) Error() string {
    return se.Message
}
```

Now you can use `StatusErr` to provide more details about what went wrong:

```
func LoginAndGetData(uid, pwd, file string) ([]byte, error) {
    token, err := login(uid, pwd)
    if err != nil {
        return nil, StatusErr{
            Status:    InvalidLogin,
            Message: fmt.Sprintf("invalid credentials for user %s", uid),
        }
    }
    data, err := getData(token, file)
    if err != nil {
        return nil, StatusErr{
            Status:    NotFound,
            Message: fmt.Sprintf("file %s not found", file),
        }
    }
    return data, nil
}
```

You can find this code in the *sample_code/custom_error* directory in the Chapter 9 repository.

Even when you define your own custom error types, always use `error` as the return type for the error result. This allows you to return different types of errors from your function and allows callers of your function to choose not to depend on the specific error type.

If you are using your own error type, be sure you don't return an uninitialized instance. Let's see what happens if you do. Try out the following code on The Go Playground or in the *sample_code/return_custom_error* directory in the Chapter 9 repository:

```
func GenerateErrorBroken(flag bool) error {
    var genErr StatusErr
    if flag {
        genErr = StatusErr{
            Status: NotFound,
        }
    }
    return genErr
}

func main() {
    err := GenerateErrorBroken(true)
    fmt.Println("GenerateErrorBroken(true) returns non-nil error:", err != nil)
    err = GenerateErrorBroken(false)
    fmt.Println("GenerateErrorBroken(false) returns non-nil error:", err != nil)
}
```

Running this program produces the following output:

```
true
true
```

This isn't a pointer type versus value type issue; if you declared `genErr` to be of type `*StatusErr`, you'd see the same output. The reason `err` is non-nil is that `error` is an interface. As I discussed in "Interfaces and nil" on page 164, for an interface to be considered `nil`, both the underlying type and the underlying value must be `nil`. Whether or not `genErr` is a pointer, the underlying type part of the interface is not `nil`.

You can fix this in two ways. The most common approach is to explicitly return `nil` for the error value when a function completes successfully:

```
func GenerateErrorOKReturnNil(flag bool) error {
    if flag {
        return StatusErr{
            Status: NotFound,
        }
    }
    return nil
}
```

This has the advantage of not requiring you to read through code to make sure that the error variable on the `return` statement is correctly defined.

Another approach is to make sure that any local variable that holds an `error` is of type `error`:

```go
func GenerateErrorUseErrorVar(flag bool) error {
    var genErr error
    if flag {
        genErr = StatusErr{
            Status: NotFound,
        }
    }
    return genErr
}
```

When using custom errors, never define a variable to be of the type of your custom error. Either explicitly return `nil` when no error occurs or define the variable to be of type `error`.

As was covered in "Use Type Assertions and Type Switches Sparingly" on page 170, don't use a type assertion or a type switch to access the fields and methods of a custom error. Instead, use `errors.As`, which is discussed in "Is and As" on page 214.

Wrapping Errors

When an error is passed back through your code, you often want to add information to it. This can be the name of the function that received the error or the operation it was trying to perform. When you preserve an error while adding information, it is called *wrapping* the error. When you have a series of wrapped errors, it is called an *error tree*.

A function in the Go standard library wraps errors, and you've already seen it. The `fmt.Errorf` function has a special verb, `%w`. Use this to create an error whose formatted string includes the formatted string of another error and which contains the original error as well. The convention is to write `: %w` at the end of the error format string and to make the error to be wrapped the last parameter passed to `fmt.Errorf`.

The standard library also provides a function for unwrapping errors, the `Unwrap` function in the `errors` package. You pass it an error, and it returns the wrapped error if there is one. If there isn't, it returns `nil`. Here's a quick program that demonstrates wrapping with `fmt.Errorf` and unwrapping with `errors.Unwrap`. You can run it on The Go Playground or in the *sample_code/wrap_error* directory in the Chapter 9 repository:

```
func fileChecker(name string) error {
    f, err := os.Open(name)
    if err != nil {
        return fmt.Errorf("in fileChecker: %w", err)
    }
    f.Close()
    return nil
}

func main() {
    err := fileChecker("not_here.txt")
    if err != nil {
        fmt.Println(err)
        if wrappedErr := errors.Unwrap(err); wrappedErr != nil {
            fmt.Println(wrappedErr)
        }
    }
}
```

When you run this program, you see the following output:

```
in fileChecker: open not_here.txt: no such file or directory
open not_here.txt: no such file or directory
```

You don't usually call `errors.Unwrap` directly. Instead, you use `errors.Is` and `errors.As` to find a specific wrapped error. I'll talk about these two functions in the next section.

If you want to wrap an error with your custom error type, your error type needs to implement the method `Unwrap`. This method takes in no parameters and returns an `error`. Here's an update to the error that you defined earlier to demonstrate how this works. You can find it in the *sample_code/custom_wrapped_error* directory in the Chapter 9 repository:

```
type StatusErr struct {
    Status  Status
    Message string
    Err     error
}

func (se StatusErr) Error() string {
    return se.Message
}

func (se StatusErr) Unwrap() error {
    return se.Err
}
```

Now you can use `StatusErr` to wrap underlying errors:

```
func LoginAndGetData(uid, pwd, file string) ([]byte, error) {
    token, err := login(uid,pwd)
    if err != nil {
        return nil, StatusErr {
            Status: InvalidLogin,
            Message: fmt.Sprintf("invalid credentials for user %s",uid),
            Err: err,
        }
    }
    data, err := getData(token, file)
    if err != nil {
        return nil, StatusErr {
            Status: NotFound,
            Message: fmt.Sprintf("file %s not found",file),
            Err: err,
        }
    }
    return data, nil
}
```

Not all errors need to be wrapped. A library can return an error that means processing cannot continue, but the error message contains implementation details that aren't needed in other parts of your program. In this situation, it is perfectly acceptable to create a brand-new error and return that instead. Understand the situation and determine what needs to be returned.

If you want to create a new error that contains the message from another error, but don't want to wrap it, use `fmt.Errorf` to create an error but use the `%v` verb instead of `%w`:

```
err := internalFunction()
if err != nil {
    return fmt.Errorf("internal failure: %v", err)
}
```

Wrapping Multiple Errors

Sometimes a function generates multiple errors that should be returned. For example, if you wrote a function to validate the fields in a struct, it would be better to return an error for each invalid field. Since the standard function signature returns `error` and not `[]error`, you need to merge multiple errors into a single error. That's what the `errors.Join` function is for:

```
type Person struct {
    FirstName string
    LastName  string
    Age       int
}
```

```
func ValidatePerson(p Person) error {
    var errs []error
    if len(p.FirstName) == 0 {
        errs = append(errs, errors.New("field FirstName cannot be empty"))
    }
    if len(p.LastName) == 0 {
        errs = append(errs, errors.New("field LastName cannot be empty"))
    }
    if p.Age < 0 {
        errs = append(errs, errors.New("field Age cannot be negative"))
    }
    if len(errs) > 0 {
        return errors.Join(errs...)
    }
    return nil
}
```

You can find this code in the *sample_code/join_error* directory in the Chapter 9 repository.

Another way to merge multiple errors is to pass multiple `%w` verbs to `fmt.Errorf`:

```
err1 := errors.New("first error")
err2 := errors.New("second error")
err3 := errors.New("third error")
err := fmt.Errorf("first: %w, second: %w, third: %w", err1, err2, err3)
```

You can implement your own `error` type that supports multiple wrapped errors. To do so, implement the `Unwrap` method but have it return `[]error` instead of `error`:

```
type MyError struct {
    Code   int
    Errors []error
}

type (m MyError) Error() string {
    return errors.Join(m.Errors...).Error()
}

func (m MyError) Unwrap() []error {
    return m.Errors
}
```

Go doesn't support method overloading, so you can't create a single type that provides both implementations of `Unwrap`. Also note that the `errors.Unwrap` function will return `nil` if you pass it an error that implements the `[]error` variant of `Unwrap`. This is another reason you shouldn't call the `errors.Unwrap` function directly.

If you need to handle errors that may wrap zero, one, or multiple errors, use this code as a basis. You can find it in the *sample_code/custom_wrapped_multi_error* directory in the Chapter 9 repository:

```
var err error
err = funcThatReturnsAnError()
switch err := err.(type) {
case interface {Unwrap() error}:
    // handle single error
    innerErr := err.Unwrap()
    // process innerErr
case interface {Unwrap() []error}:
    //handle multiple wrapped errors
    innerErrs := err.Unwrap()
    for _, innerErr := range innerErrs {
        // process each innerErr
    }
default:
    // handle no wrapped error
}
```

Since the standard library doesn't define interfaces to represent errors with either `Unwrap` variant, this code uses anonymous interfaces in a type switch to match the methods and access the wrapped errors. Before writing your own code, see if you can use `errors.Is` and `errors.As` to examine your error trees. Let's see how they work.

Is and As

Wrapping errors is a useful way to get additional information about an error, but it introduces problems. If a sentinel error is wrapped, you cannot use == to check for it, nor can you use a type assertion or type switch to match a wrapped custom error. Go solves this problem with two functions in the `errors` package, `Is` and `As`.

To check whether the returned error or any errors that it wraps match a specific sentinel error instance, use `errors.Is`. It takes in two parameters: the error being checked and the instance you are comparing it against. The `errors.Is` function returns `true` if any error in the error tree matches the provided sentinel error. You'll write a short program to see `errors.Is` in action. You can run it yourself on The Go Playground or in the *sample_code/is_error* directory in the Chapter 9 repository:

```
func fileChecker(name string) error {
    f, err := os.Open(name)
    if err != nil {
        return fmt.Errorf("in fileChecker: %w", err)
    }
    f.Close()
    return nil
}

func main() {
    err := fileChecker("not_here.txt")
    if err != nil {
        if errors.Is(err, os.ErrNotExist) {
            fmt.Println("That file doesn't exist")
        }
    }
}
```

Running this program produces the following output:

```
That file doesn't exist
```

By default, `errors.Is` uses `==` to compare each wrapped error with the specified error. If this does not work for an error type that you define (for example, if your error is a noncomparable type), implement the `Is` method on your error:

```
type MyErr struct {
    Codes []int
}

func (me MyErr) Error() string {
    return fmt.Sprintf("codes: %v", me.Codes)
}

func (me MyErr) Is(target error) bool {
    if me2, ok := target.(MyErr); ok {
        return slices.Equal(me.Codes, me2.Codes)
    }
    return false
}
```

(The `slices.Equal` function was mentioned back in "Slices" on page 39.)

Another use for defining your own `Is` method is to allow comparisons against errors that aren't identical instances. You might want to pattern match your errors, specifying a filter instance that matches errors that have some of the same fields. Define a new error type, `ResourceErr`:

```
type ResourceErr struct {
    Resource     string
    Code         int
}

func (re ResourceErr) Error() string {
    return fmt.Sprintf("%s: %d", re.Resource, re.Code)
}
```

If you want two `ResourceErr` instances to match when either field is set, you can do so by writing a custom `Is` method:

```
func (re ResourceErr) Is(target error) bool {
    if other, ok := target.(ResourceErr); ok {
        ignoreResource := other.Resource == ""
        ignoreCode := other.Code == 0
        matchResource := other.Resource == re.Resource
        matchCode := other.Code == re.Code
        return matchResource && matchCode ||
            matchResource && ignoreCode ||
            ignoreResource && matchCode
    }
    return false
}
```

Now you can find, for example, all errors that refer to the database, no matter the code:

```
if errors.Is(err, ResourceErr{Resource: "Database"}) {
    fmt.Println("The database is broken:", err)
    // process the codes
}
```

You can see this code on The Go Playground or in the *sample_code/custom_is_error_pattern_match* directory in the Chapter 9 repository.

The `errors.As` function allows you to check whether a returned error (or any error it wraps) matches a specific type. It takes in two parameters. The first is the error being examined, and the second is a pointer to a variable of the type that you are looking for. If the function returns `true`, an error in the error tree was found that matched, and that matching error is assigned to the second parameter. If the function returns `false`, no match was found in the error tree. Try it out with `MyErr`:

```
err := AFunctionThatReturnsAnError()
var myErr MyErr
if errors.As(err, &myErr) {
    fmt.Println(myErr.Codes)
}
```

Note that you use `var` to declare a variable of a specific type set to the zero value. You then pass a pointer to this variable into `errors.As`.

You don't have to pass a pointer to a variable of an error type as the second parameter to `errors.As`. You can pass a pointer to an interface to find an error that meets the interface:

```
err := AFunctionThatReturnsAnError()
var coder interface {
    CodeVals() []int
}
if errors.As(err, &coder) {
    fmt.Println(coder.CodeVals())
}
```

The example uses an anonymous interface, but any interface type is acceptable. You can find both `errors.As` examples in the *sample_code/custom_as_error* directory in the Chapter 9 repository.

If the second parameter to `errors.As` is anything other than a pointer to an error or a pointer to an interface, the method panics.

Just as you can override the default `errors.Is` comparison with an `Is` method, you can override the default `errors.As` comparison with an `As` method on your error. Implementing an `As` method is nontrivial and requires reflection (I will talk about reflection in Go in Chapter 16). You should do it only in unusual circumstances, such as when you want to match an error of one type and return another.

Use `errors.Is` when you are looking for a specific *instance* or specific *values*. Use `errors.As` when you are looking for a specific *type*.

Wrapping Errors with defer

Sometimes you find yourself wrapping multiple errors with the same message:

```go
func DoSomeThings(val1 int, val2 string) (string, error) {
    val3, err := doThing1(val1)
    if err != nil {
        return "", fmt.Errorf("in DoSomeThings: %w", err)
    }
    val4, err := doThing2(val2)
    if err != nil {
        return "", fmt.Errorf("in DoSomeThings: %w", err)
    }
    result, err := doThing3(val3, val4)
    if err != nil {
        return "", fmt.Errorf("in DoSomeThings: %w", err)
    }
    return result, nil
}
```

You can simplify this code by using `defer`:

```go
func DoSomeThings(val1 int, val2 string) (_ string, err error) {
    defer func() {
        if err != nil {
            err = fmt.Errorf("in DoSomeThings: %w", err)
        }
    }()
    val3, err := doThing1(val1)
    if err != nil {
        return "", err
    }
    val4, err := doThing2(val2)
    if err != nil {
        return "", err
    }
    return doThing3(val3, val4)
}
```

You have to name the return values so that you can refer to `err` in the deferred function. If you name a single return value, you must name all of them, so you use an underscore here for the string return value that isn't explicitly assigned.

In the `defer` closure, the code checks whether an error was returned. If so, it reassigns the error to a new error that wraps the original error with a message indicating which function detected the error.

This pattern works well when you are wrapping every error with the same message. If you want to customize the wrapping error with more detail, put both the specific and the general message in every `fmt.Errorf`.

panic and recover

Previous chapters have mentioned panics in passing without going into any details on what they are. A *panic* is similar to an `Error` in Java or Python. It is a state generated by the Go runtime whenever it is unable to figure out what should happen next. This is almost always due to a programming error, like an attempt to read past the end of a slice or passing a negative size to `make`. The Go runtime also panics if it detects bugs in itself, such as the garbage collector misbehaving. However, I've never seen this happen. If there's a panic, blame the runtime last.

As soon as a panic happens, the current function exits immediately, and any `defer`s attached to the current function start running. When those `defer`s complete, the `defer`s attached to the calling function run, and so on, until `main` is reached. The program then exits with a message and a stack trace.

If there is a panic in a goroutine other than the main goroutine (goroutines are covered in "Goroutines" on page 289), the chain of defers ends at the function used to launch the goroutine. A program exits if *any* goroutine panics without being recovered.

If any situations in your programs are unrecoverable, you can create your own panics. The built-in function `panic` takes one parameter, which can be of any type. Usually, it is a string. Following is a trivial program that panics; you can run it on The Go Playground or in the *sample_code/panic* directory in the Chapter 9 repository:

```go
func doPanic(msg string) {
    panic(msg)
}

func main() {
    doPanic(os.Args[0])
}
```

Running this code produces the following output:

```
panic: /tmpfs/play

goroutine 1 [running]:
main.doPanic(...)
    /tmp/sandbox567884271/prog.go:6
main.main()
    /tmp/sandbox567884271/prog.go:10 +0x5f
```

As you can see, a `panic` prints out its message followed by a stack trace.

Go provides a way to capture a `panic` to provide a more graceful shutdown or to prevent shutdown at all. The built-in `recover` function is called from within a `defer` to check whether a `panic` happened. If there was a `panic`, the value assigned to the `panic` is returned. Once a `recover` happens, execution continues normally. Let's take a look with another sample program. Run it on The Go Playground or in the *sample_code/panic_recover* directory in the Chapter 9 repository:

```go
func div60(i int) {
    defer func() {
        if v := recover(); v != nil {
            fmt.Println(v)
        }
    }()
    fmt.Println(60 / i)
}

func main() {
    for _, val := range []int{1, 2, 0, 6} {
        div60(val)
    }
}
```

There's a specific pattern for using `recover`. You register a function with `defer` to handle a potential `panic`. You call `recover` within an `if` statement and check whether a non-nil value was found. You must call `recover` from within a `defer` because once a `panic` happens, only deferred functions are run.

Running this code produces the following output:

```
60
30
runtime error: integer divide by zero
10
```

Since `recover` uses a non-nil value to detect whether a `panic` happened, a clever reader might raise the question: *What happens if you call `panic(nil)` and there's a `recover`?* In code compiled with Go versions before 1.21, the answer was "nothing great." In those versions, `recover` stops a `panic` from propagating, but no message or data indicates what happened. Starting with Go 1.21, a `panic(nil)` call is identical to `panic(new(runtime.PanicNilError))`.

While `panic` and `recover` look a lot like exception handling in other languages, they are not intended to be used that way. Reserve panics for fatal situations and use `recover` as a way to gracefully handle these situations. If your program panics, be careful about trying to continue executing after the panic. You'll rarely want to keep your program running after a `panic` occurs. If the `panic` was triggered because the computer is out of a resource like memory or disk space, the safest thing to do is use `recover` to log the situation to monitoring software and shut down with `os.Exit(1)`. If a programming error caused the panic, you can try to continue, but you'll likely hit the same problem again. In the preceding sample program, it would be idiomatic to check for division by zero and return an error if one was passed in.

The reason you don't rely on `panic` and `recover` is that `recover` doesn't make clear *what* could fail. It just ensures that *if* something fails, you can print out a message and continue. Idiomatic Go favors code that explicitly outlines the possible failure conditions over shorter code that handles anything while saying nothing.

Using `recover` is recommended in one situation. If you are creating a library for third parties, do not let panics escape the boundaries of your public API. If a `panic` is possible, a public function should use `recover` to convert the `panic` into an error, return it, and let the calling code decide what to do with them.

> While the HTTP server built into Go recovers from panics in handlers, David Symonds said in a GitHub comment that as of 2015, this is now considered a mistake by the Go team.

Getting a Stack Trace from an Error

One of the reasons that new Go developers are tempted to use `panic` and `recover` is they want to get a stack trace when something goes wrong. By default, Go doesn't provide that. As I've shown, you can use error wrapping to build a call stack by hand, but some third-party libraries with error types generate those stacks automatically (see Chapter 10 to learn how to incorporate third-party code in your program). Cockroachdb provides a third-party library with functions for wrapping errors with stack traces.

By default, the stack trace is not printed out. If you want to see the stack trace, use `fmt.Printf` and the verbose output verb (`%+v`). Check the documentation to learn more.

When you have a stack trace in your error, the output includes the full path to the file on the computer where the program was compiled. If you don't want to expose the path, use the `-trimpath` flag when building your code. This replaces the full path with the package.

Exercises

Look at the code in the *sample_code/exercise* directory in the Chapter 9 repository. You are going to modify this code in each of these exercises. It works correctly, but improvements should be made to its error handling.

1. Create a sentinel error to represent an invalid ID. In `main`, use `errors.Is` to check for the sentinel error, and print a message when it is found.
2. Define a custom error type to represent an empty field error. This error should include the name of the empty `Employee` field. In `main`, use `errors.As` to check for this error. Print out a message that includes the field name.
3. Rather than returning the first error found, return back a single error that contains all errors discovered during validation. Update the code in `main` to properly report multiple errors.

Wrapping Up

This chapter covered errors in Go, what they are, how to define your own, and how to examine them. You also took a look at `panic` and `recover`. The next chapter discusses packages and modules, how to use third-party code in your programs, and how to publish your own code for others to use.

CHAPTER 10
Modules, Packages, and Imports

Most modern programming languages have a system for organizing code into namespaces and libraries, and Go is no exception. As you've seen while exploring other features, Go introduces some new approaches to this old idea. In this chapter, you'll learn how to organize code with packages and modules, how to import them, how to work with third-party libraries, and how to create libraries of your own.

Repositories, Modules, and Packages

Library management in Go is based around three concepts: repositories, modules, and packages. A *repository* is familiar to all developers. It is a place in a version control system where the source code for a project is stored. A *module* is a bundle of Go source code that's distributed and versioned as a single unit. Modules are stored in a repository. Modules consist of one or more *packages*, which are directories of source code. Packages give a module organization and structure.

While you can store more than one module in a repository, it is discouraged. Everything within a module is versioned together. Maintaining two modules in one repository requires you to track separate versions for two different modules in a single repository.

Unfortunately, different programming languages use these words to represent different concepts. While packages in Java and Go are similar, a Java repository is a centralized place to store multiple *artifacts* (the analogue of a Go module). Node.js and Go swap the meanings of the terms: a Node.js package is similar to what Go calls a module, and a Go package is similar to a Node.js module. The terminology certainly can be confusing at first, but as you get more comfortable with Go, the terms will seem more familiar.

Before using code from packages outside the standard library, you need to make sure that you have a properly created module. Every module has a globally unique identifier. This is not unique to Go. Java defines globally unique package declarations by using the reverse domain name convention (`com.`*`companyname`*`.`*`projectname`*`.library`).

In Go, this name is called a *module path*. It is usually based on the repository where the module is stored. For example, you can find Proteus, a module I wrote to simplify relational database access in Go, at *https://github.com/jonbodner/proteus*. It has a module path of *github.com/jonbodner/proteus*.

Back in "Your First Go Program" on page 3, you created a module whose name was `hello_world`, which is obviously not globally unique. This is fine if you are creating a module for local use only. If you put a module with a nonunique name into a source code repository, it cannot be imported by another module.

Using go.mod

A directory tree of Go source code becomes a module when there's a valid *go.mod* file in it. Rather than create this file manually, use the subcommands of the `go mod` command to manage modules. The command `go mod init` *`MODULE_PATH`* creates the *go.mod* file that makes the current directory the root of a module. The *`MODULE_PATH`* is the globally unique name that identifies your module. The module path is case-sensitive. To reduce confusion, do not use uppercase letters within it.

Take a look at the contents of a *go.mod* file:

```
module github.com/learning-go-book-2e/money

go 1.21

require (
    github.com/learning-go-book-2e/formatter v0.0.0-20220918024742-18...
    github.com/shopspring/decimal v1.3.1
)

require (
    github.com/fatih/color v1.13.0 // indirect
    github.com/mattn/go-colorable v0.1.9 // indirect
    github.com/mattn/go-isatty v0.0.14 // indirect
    golang.org/x/sys v0.0.0-20210630005230-0f9fa26af87c // indirect
)
```

Every *go.mod* file starts with a `module` directive that consists of the word `module` and the module's unique path. Next, the *go.mod* file specifies the minimum compatible version of Go with the `go` directive. All source code within the module must be compatible with the specified version. For example, if you specify the (rather old) version `1.12`, the compiler will not let you use underscores within numeric literals, because that feature was added in Go 1.13.

Use the go Directive to Manage Go Build Versions

What happens if the `go` directive specifies a version of Go that's newer than what's installed? If you have Go 1.20 or earlier installed, the newer Go version is ignored and you get the features of the installed version. If you have Go 1.21 or newer installed, the default behavior is to download the newer version of Go and use it to build your code. You can control this behavior in Go 1.21 and newer with the `toolchain` directive and the `GOTOOLCHAIN` environment variable. You can assign them the following values:

- `auto`, which downloads newer versions of Go. (This is the default behavior of Go 1.21 and later.)
- `local`, which restores the behavior of Go releases before 1.21.
- A specific Go version (such as `go1.20.4`), which means that specific version will be downloaded and used to build the program.

For example, the command line `GOTOOLCHAIN=go1.18 go build` will build your Go program with Go 1.18, downloading it if necessary.

If both the `GOTOOLCHAIN` environment variable and the `toolchain` directive are set, the value assigned to `GOTOOLCHAIN` is used.

Complete details on the `go` directive, the `toolchain` directive, and the `GOTOOLCHAIN` environment variable are found in the official Go toolchain documentation.

As discussed in "The for-range value is a copy" on page 81, Go 1.22 introduces the first backward-breaking change to the language. When using Go 1.22 or later, if the `go` directive is set to `1.22` or higher, a `for` loop creates a new index and value variable on each iteration. This behavior is applied per module. The value of the `go` directive in each imported module determines the language level for that module. ("Importing Third-Party Code" on page 240 describes how to use and manage multiple modules in your programs.)

You can see this difference with a short example. You can find the code in the *sample_code/loop_test* directory in the Chapter 10 repository.

The code in *loop.go* is simple:

```
func main() {
    x := []int{1, 2, 3, 4, 5}
    for _, v := range x {
        fmt.Printf("%p\n", &v)
    }
}
```

If you haven't seen it before, the `%p` verb in the `fmt` formatting language returns the memory location of a pointer. The repository has the `go` directive in its *go.mod* file set to `1.21`. Building and running the program gives the following output:

```
140000140a8
140000140a8
140000140a8
140000140a8
140000140a8
```

When built using older versions of Go, the program prints out the same memory address five times. (The memory addresses might differ from what's shown here, but all will be the same value.)

Change the value of the `go` directive in *go.mod* to `1.22` and rebuild and rerun the program. You will now get this output:

```
1400000e0b0
1400000e0b8
1400000e0d0
1400000e0d8
1400000e0e0
```

Notice that every memory address value is different, indicating that a new variable was created on each iteration. (The memory addresses might differ from what's shown here, but each one will be a different value.)

The require Directive

The next sections in a *go.mod* file are the `require` directives. The `require` directives are present only if your module has dependencies. They list the modules that your module depends on and the minimum version required for each one. The first `require` section lists the direct dependencies of your module. The second one lists the dependencies of the dependencies of your module. Each line in this section ends with an `// indirect` comment. There's no functional difference between modules marked as indirect and those that aren't; it's just documentation for people when they look at the *go.mod* file. Direct dependencies are marked as indirect in one situation, and I will discuss it when I talk about the ways to use `go get`. In "Importing Third-Party Code" on page 240, you'll learn more about adding and managing the dependencies of your module.

While the `module`, `go`, and `require` directives are the ones most commonly used in a *go.mod* file, there are three others directives as well. I will cover the `replace` and `exclude` directives in "Overriding Dependencies" on page 254, and I'll cover the `retract` directive in "Retracting a Version of Your Module" on page 255.

Building Packages

Now that you've learned how to make your directory of code into a module, it's time to start using packages to organize your code. You'll start by seeing how `import` works, move on to creating and organizing packages, and then look at some of the features of Go's packages, both good and bad.

Importing and Exporting

The example programs have been using the `import` statement in Go even though I haven't discussed what it does and how importing in Go differs from other languages. Go's `import` statement allows you to access exported constants, variables, functions, and types in another package. A package's exported identifiers (an *identifier* is the name of a variable, constant, type, function, method, or a field in a struct) cannot be accessed from another current package without an `import` statement.

This leads to the question, how do you export an identifier in Go? Rather than use a special keyword, Go uses *capitalization* to determine whether a package-level identifier is visible outside the package where it is declared. An identifier whose name starts with an uppercase letter is *exported*. Conversely, an identifier whose name starts with a lowercase letter or underscore can be accessed only from within the package where it is declared. (Identifiers in Go can't start with a digit but can contain them.)

Anything you export is part of your package's API. Before you export an identifier, be sure that you intend to expose it to clients. Document all exported identifiers and keep them backward compatible unless you are intentionally making a major version change (see "Versioning Your Module" on page 252 for more information).

Creating and Accessing a Package

Making packages in Go is easy. Let's look at a small program to demonstrate this. You can find it in the *package_example* directory for this book. Inside *package_example*, you'll see two additional directories, *math* and *do-format*. In *math*, there's a file called *math.go* with the following contents:

```go
package math

func Double(a int) int {
    return a * 2
}
```

The first line of the file is called the *package clause*. It consists of the keyword `package` and the name for the package. The package clause is always the first nonblank, noncomment line in a Go source file.

In the *do-format* directory is a file called *formatter.go* with the following contents:

```
package format

import "fmt"

func Number(num int) string {
    return fmt.Sprintf("The number is %d", num)
}
```

Note that the package name is `format` in the package clause, but it's in the *do-format* directory. How to interact with this package will be covered very shortly.

Finally, the following contents are in the file *main.go* in the root directory:

```
package main

import (
    "fmt"

    "github.com/learning-go-book-2e/package_example/do-format"
    "github.com/learning-go-book-2e/package_example/math"
)

func main() {
    num := math.Double(2)
    output := format.Number(num)
    fmt.Println(output)
}
```

The first line of this file is familiar. All the programs before this chapter have put `package main` as the first line in the code. I'll talk more about what this means in a bit.

Next is the import section. It imports three packages. The first is `fmt`, which is in the standard library. You've done this in previous chapters. The next two imports refer to the packages within the program. You must specify an *import path* when importing from anywhere besides the standard library. The import path consists of the module path followed by the path to the package within the module. For example, the import `"github.com/learning-go-book-2e/package_example/math"` has the module path `github.com/learning-go-book-2e/package_example`, while `/math` is the path to the package within the module.

It is a compile-time error to import a package but not use any of the identifiers exported by the package. This ensures that the binary produced by the Go compiler includes only code that's actually used in the program.

You might come across obsolete documentation on the web that mentions relative path import paths. They do not work with modules. (And were a bad idea, anyway.)

When you run this program, you'll see the following output:

```
$ go build
$ ./package_example
The number is 4
```

The `main` function called the `Double` function in the `math` package by prefixing the function name with the package name. You've seen this in previous chapters when calling functions in the standard library. You also call the `Number` function in the `format` package. You might wonder where this `format` package came from, since the import says `github.com/learning-go-book-2e/package_example/do-format`.

Every Go file in a directory must have an identical package clause. (You'll see one tiny exception to this rule in "Testing Your Public API" on page 377.) You imported the `format` package with the import path *github.com/learning-go-book-2e/package_example/do-format*. That's because *the name of a package is determined by its package clause, not its import path.*

As a general rule, you should make the name of the package match the name of the directory that contains the package. It is hard to discover a package's name if it does not match the containing directory. However, in a few situations you'll use a different name for the package than for the directory.

The first is something you have been doing all along without realizing it. You declare a package to be a starting point for a Go application by using the special package name `main`. Since you cannot import the `main` package, this doesn't produce confusing import statements.

The other reasons for having a package name not match your directory name are less common. If your directory name contains a character that's not valid in a Go identifier, then you must choose a package name that's different from your directory name. In your case, `do-format` is not a valid identifier name, so it's replaced with `format`. It's better to avoid this by never creating a directory with a name that's not a valid identifier.

The final reason for creating a directory whose name doesn't match the package name is to support versioning using directories. I'll talk about this more in "Versioning Your Module" on page 252.

As was discussed in "Blocks" on page 67, package names in `import` statements are in the *file block*. If you use exported symbols from one package in two different files in another package, you must import the first package in both files in the second package.

Naming Packages

Package names should be descriptive. Rather than have a package called `util`, create a package name that describes the functionality provided by the package. For example, say you have two helper functions: one to extract all names from a string and another to format names properly. Don't create two functions in a `util` package called `ExtractNames` and `FormatNames`. If you do, every time you use these functions, they will be referred to as `util.ExtractNames` and `util.FormatNames`, and that `util` package tells you nothing about what the functions do.

One option is to create one function called `Names` in a package called `extract` and a second function called `Names` in a package called `format`. It's OK for these two functions to have the same name, because they will always be disambiguated by their package names. The first will be referred to as `extract.Names` when imported, and the second will be referred to as `format.Names`.

An even better option is to think about parts of speech. A function or method does something, so it should be a verb or action word. A package would be a noun, a name for the kind of item that is created or modified by the functions in the package. By following these rules, you would create a package called `names` with two functions, `Extract` and `Format`. The first would then be referred to as `names.Extract` and the second would be `names.Format`.

You should also avoid repeating the name of the package in the names of functions and types within the package. Don't name your function `ExtractNames` when it is in the `names` package. The exception to this rule occurs when the name of the identifier is the same as the name of the package. For example, the package `sort` in the standard library has a function called `Sort`, and the `context` package defines the `Context` interface.

Overriding a Package's Name

Sometimes you'll find yourself importing two packages whose names collide. For example, the standard library includes two packages for generating random numbers; one is cryptographically secure (`crypto/rand`), and the other is not (`math/rand`). The regular generator is fine when you aren't generating random numbers for encryption, but you need to seed it with an unpredictable value. A common pattern is to seed a regular random number generator with a value from a cryptographic generator. In Go, both packages have the same name (`rand`). When that happens, you provide an alternate name for one package within the current file. Try out this code on The Go

Playground or in the *sample_code/package_name_override* directory in the Chapter 10 repository. First, look at the import section:

```
import (
    crand "crypto/rand"
    "encoding/binary"
    "fmt"
    "math/rand"
)
```

You import `crypto/rand` with the name `crand`. This overrides the name `rand` that's declared within the package. You then import `math/rand` normally. When you look at the `seedRand` function, you see that you access identifiers in `math/rand` with the `rand` prefix, and use the `crand` prefix with the `crypto/rand` package:

```
func seedRand() *rand.Rand {
    var b [8]byte
    _, err := crand.Read(b[:])
    if err != nil {
        panic("cannot seed with cryptographic random number generator")
    }
    r := rand.New(rand.NewSource(int64(binary.LittleEndian.Uint64(b[:]))))
    return r
}
```

You can use two other symbols as a package name. The package name `.` (dot) places all the exported identifiers in the imported package into the current package's namespace; you don't need a prefix to refer to them. This is discouraged because it makes your source code less clear. You can no longer tell whether something is defined in the current package or whether it was imported by simply looking at its name.

You can also use `_` (underscore) as the package name. You'll explore what this does when I talk about `init` in "Avoiding the init Function if Possible" on page 239.

As I discussed in "Shadowing Variables" on page 68, package names can be shadowed. Declaring variables, types, or functions with the same name as a package makes the package inaccessible within the block with that declaration. If this is unavoidable (for example, a newly imported package has a name that conflicts with an existing identifier), override the package's name to resolve the conflict.

Documenting Your Code with Go Doc Comments

An important part of creating a module for others to use is documenting it properly. Go has its own format for writing comments that are automatically converted into documentation. It's called *Go Doc* format, and it's very simple. Here are the rules:

- Place the comment directly before the item being documented, with no blank lines between the comment and the declaration of the item.
- Start each line of the comment with double slashes (//), followed by a space. While it's legal to use /* and */ to mark your comment block, it is idiomatic to use double slashes.
- The first word in the comment for a symbol (a function, type, constant, variable, or method) should be the name of the symbol. You can also use "A" or "An" before the symbol name to help make the comment text grammatically correct.
- Use a blank comment line (double slashes and a newline) to break your comment into multiple paragraphs.

As I'll talk about in "Using pkg.go.dev" on page 251, you can view public documentation online in HTML format. If you want to make your documents look a little snazzier, there are a couple of ways to format it:

- If you want your comment to contain some preformatted content (such as a table or source code), put an additional space after the double slashes to indent the lines with the content.
- If you want a header in your comment, put a `#` and a space after the double slashes. Unlike with Markdown, you cannot use multiple `#` characters to make different levels of headers.
- To make a link to another package (whether or not it is in the current module), put the package path within brackets (`[` and `]`).
- To link to an exported symbol, place its name in brackets. If the symbol is in another package, use `[pkgName.SymbolName]`.
- If you include a raw URL in your comment, it will be converted into a link.
- If you want to include text that links to a web page, put the text within brackets (`[` and `]`). At the end of the comment block, declare the mappings between your text and their URLs with the format `// [`*`TEXT`*`]: `*`URL`*. You'll see a sample of this in a moment.

Comments before the package declaration create package-level comments. If you have lengthy comments for the package (such as the extensive formatting documentation in the `fmt` package), the convention is to put the comments in a file in your package called *doc.go*.

Let's go through a well-commented file, starting with the package-level comment in Example 10-1.

Example 10-1. A package-level comment

```go
// Package convert provides various utilities to
// make it easy to convert money from one currency to another.
package convert
```

Next, place a comment on an exported struct (see Example 10-2). Notice that it starts with the name of the struct.

Example 10-2. A struct comment

```go
// Money represents the combination of an amount of money
// and the currency the money is in.
//
// The value is stored using a [github.com/shopspring/decimal.Decimal]
type Money struct {
    Value    decimal.Decimal
    Currency string
}
```

Finally, there is a comment on a function (see Example 10-3).

Example 10-3. A well-commented function

```go
// Convert converts the value of one currency to another.
//
// It has two parameters: a Money instance with the value to convert,
// and a string that represents the currency to convert to. Convert returns
// the converted currency and any errors encountered from unknown or unconvertible
// currencies.
//
// If an error is returned, the Money instance is set to the zero value.
//
// Supported currencies are:
//   - USD - US Dollar
//   - CAD - Canadian Dollar
//   - EUR - Euro
//   - INR - Indian Rupee
//
// More information on exchange rates can be found at [Investopedia].
//
// [Investopedia]: https://www.investopedia.com/terms/e/exchangerate.asp
func Convert(from Money, to string) (Money, error) {
    // ...
}
```

Go includes a command-line tool called `go doc` that displays godocs. The command `go doc` *`PACKAGE_NAME`* displays the documentation for the specified package and a list of the identifiers in the package. Use `go doc` *`PACKAGE_NAME.IDENTIFIER_NAME`* to display the documentation for a specific identifier in the package.

If you want to preview your documentation's HTML formatting before it is published on the web, use `pkgsite`. This is the same program that powers `pkg.go.dev` (which I will talk about later in the chapter). To install `pkgsite`, use this command:

```
$ go install golang.org/x/pkgsite/cmd/pkgsite@latest
```

(I will talk more about `go install` in "Adding Third-Party Tools with go install" on page 264).

To view your source code's comments rendered as HTML, go to the root of your module and run this:

```
$ pkgsite
```

Then go to *http://localhost:8080* to view your project and its source code.

You can find even more details about comments and potential pitfalls by reading through the official Go Doc Comments documentation.

Make sure you comment your code properly. At the very least, any exported identifier should have a comment. In "Using Code-Quality Scanners" on page 267, you will look at some third-party tools that can report missing comments on exported identifiers.

Using the internal Package

Sometimes you want to share a function, type, or constant among packages in your module, but you don't want to make it part of your API. Go supports this via the special `internal` package name.

When you create a package called `internal`, the exported identifiers in that package and its subpackages are accessible only to the direct parent package of `internal` and the sibling packages of `internal`. Let's look at an example to see how this works. You can find the code on GitHub. The directory tree is shown in Figure 10-1.

You've declared a simple function in the *internal.go* file in the `internal` package:

```go
func Doubler(a int) int {
    return a * 2
}
```

You can access this function from *foo.go* in the `foo` package and from *sibling.go* in the `sibling` package.

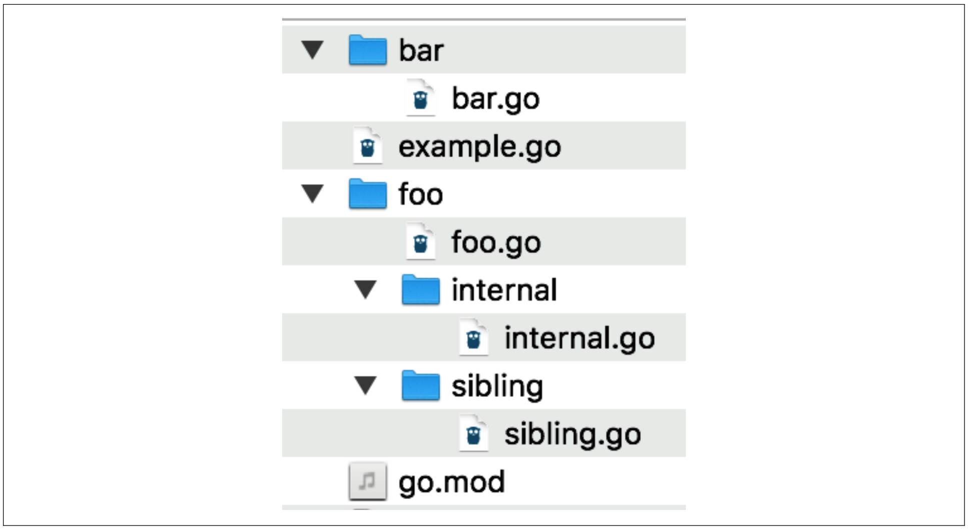


Figure 10-1. The file tree for `internal_package_example`

Be aware that attempting to use the internal function from *bar.go* in the `bar` package or from *example.go* in the root package results in a compilation error:

```
$ go build ./...
package github.com/learning-go-book-2e/internal_example
example.go:3:8: use of internal package
github.com/learning-go-book-2e/internal_example/foo/internal not allowed

package github.com/learning-go-book-2e/internal_example/bar
bar/bar.go:3:8: use of internal package
github.com/learning-go-book-2e/internal_example/foo/internal not allowed
```

Avoiding Circular Dependencies

Two of the goals of Go are a fast compiler and easy-to-understand source code. To support this, Go does not allow you to have a *circular dependency* between packages. If package A imports package B, directly or indirectly, package B cannot import package A, directly or indirectly.

Let's look at a quick example to explain the concept. You can find the code in the *sample_code/circular_dependency_example* directory in the Chapter 10 repository. There are two packages, `pet` and `person`. In *pet.go* in the `pet` package, you have this:

```
import "github.com/learning-go-book-2e/ch10/sample_code/
circular_dependency_example/person"

var owners = map[string]person.Person{
        "Bob":   {"Bob", 30, "Fluffy"},
        "Julia": {"Julia", 40, "Rex"},
}
```

While in *person.go* in the `person` package, you have this:

```
import "github.com/learning-go-book-2e/ch10/sample_code/
circular_dependency_example/pet"

var pets = map[string]pet.Pet{
        "Fluffy": {"Fluffy", "Cat", "Bob"},
        "Rex":    {"Rex", "Dog", "Julia"},
}
```

If you try to build this program, you'll get an error:

```
$ go build ./sample_code/circular_dependency_example
package github.com/learning-go-book-2e/ch10/sample_code/
    circular_dependency_example
        imports github.com/learning-go-book-2e/ch10/sample_code/
        circular_dependency_example/person
        imports github.com/learning-go-book-2e/ch10/sample_code/
        circular_dependency_example/pet
        imports github.com/learning-go-book-2e/ch10/sample_code/
        circular_dependency_example/person: import cycle not allowed
```

If you find yourself with a circular dependency, you have a few options. In some cases, this is caused by splitting up packages too finely. If two packages depend on each other, there's a good chance they should be merged into a single package. You can merge the `person` and `pet` packages into a single package, and that solves your problem.

If you have a good reason to keep your packages separated, it may be possible to move just the items that cause the circular dependency to one of the two packages or to a new package.

Organizing Your Module

There's no official way to structure the Go packages in your module, but several patterns have emerged over the years. They are guided by the principle that you should focus on making your code easy to understand and maintain.

When your module is small, keep all your code in a single package. As long as no other modules depend on your module, there is no harm in delaying organization.

As your module grows, you'll want to impose some order to make your code more readable. The first question to ask is what type of module you are creating. You can group modules into two broad categories: those that are intended as a single application and those that are primarily intended as libraries. If you are sure that your module is intended to be used only as an application, make the root of the project the `main` package. The code in the `main` package should be minimal; place all your logic in an *internal* directory, and the code in the `main` function will simply invoke code within *internal*. This way, you can ensure that no one is going to create a module that depends on your application's implementation.

If you want your module to be used as a library, the root of your module should have a package name that matches the repository name. This makes sure that the import name matches the package name. To make this work, you must ensure that your repository name is a valid Go identifier. In particular, you cannot use a hyphen as a word separator in your repository name, because a hyphen is not a valid character in a package name.

It's not uncommon for library modules to have one or more applications included with them as utilities. In this case, create a directory called *cmd* at the root of your module. Within *cmd*, create one directory for each binary built from your module. For example, you might have a module that contains both a web application and a command-line tool that analyzes data in the web application's database. Use `main` as the package name within each of these directories.

For more detailed information, this blog post by Eli Bendersky provides good advice on how you should structure a simple Go module.

As projects get more complicated, you'll be tempted to break up your packages. Make sure to organize your code to limit the dependencies among packages. One common pattern is to organize your code by slices of functionality. For example, if you wrote a shopping site in Go, you might place all the code for customer management in one package and all the code for inventory management in another. This style limits the dependencies among packages, which makes it easier to later refactor a single web application into multiple microservices. This style is in contrast to the way that many Java applications are organized, with all the business logic in one package, all the database logic in another package, and the data transfer objects in a third.

When developing a library, take advantage of the `internal` package. If you create multiple packages within a module and they are outside an `internal` package, exporting a symbol so it can be used by another package in your module means it can also be used by *anyone* who imports your module. There's a principle in software engineering called Hyrum's law: "With a sufficient number of users of an API, it does not matter what you promise in the contract: all observable behaviors of your system will be depended on by somebody." Once something is part of your API, you have a responsibility to continue supporting it until you decide to make a new version that's not backward compatible. You will learn how to do this in "Updating to Incompatible Versions" on page 248. If you have some symbols that you want to share only within your module, put them in `internal`. If you change your mind, you can always move the package out of `internal` later.

For a good overview of Go project structure advice, watch Kat Zien's talk from GopherCon 2018, "How Do You Structure Your Go Apps".

The "golang-standards" GitHub repository claims to be the "standard" module layout. Russ Cox, the development lead for Go, has publicly stated that it is not endorsed by the Go team and that the structure it recommends is in fact an antipattern. Please do not cite this repository as a way to organize your code.

Gracefully Renaming and Reorganizing Your API

After using a module for a while, you might realize that its API is not ideal. You might want to rename some of the exported identifiers or move them to another package within your module. To avoid a backward-breaking change, don't remove the original identifiers; provide an alternate name instead.

This is easy with a function or method. You declare a function or method that calls the original. For a constant, simply declare a new constant with the same type and value, but a different name.

If you want to rename or move an exported type, you use an alias. Quite simply, an *alias* is a new name for a type. You saw in Chapter 7 how to use the `type` keyword to declare a new type based on an existing one. You also use the `type` keyword to declare an alias. Let's say you have a type called `Foo`:

```go
type Foo struct {
    x int
    S string
}

func (f Foo) Hello() string {
    return "hello"
}

func (f Foo) goodbye() string {
    return "goodbye"
}
```

If you want to allow users to access `Foo` by the name `Bar`, all you need to do is this:

```go
type Bar = Foo
```

To create an alias, use the `type` keyword, the name of the alias, an equals sign, and the name of the original type. The alias has the same fields and methods as the original type.

The alias can even be assigned to a variable of the original type without a type conversion:

```go
func MakeBar() Bar {
    bar := Bar{
        x: 20,
        S: "Hello",
    }
    var f Foo = bar
    fmt.Println(f.Hello())
    return bar
}
```

One important point to remember: an alias is just another name for a type. If you want to add new methods or change the fields in an aliased struct, you must add them to the original type.

You can alias a type that's defined in the same package as the original type or in a different package. You can even alias a type from another module. There is one drawback to an alias in another package: you cannot use an alias to refer to the unexported methods and fields of the original type. This limitation makes sense, as aliases exist to allow a gradual change to a package's API, and the API consists only of the exported parts of the package. To work around this limitation, call code in the type's original package to manipulate unexported fields and methods.

Two kinds of exported identifiers can't have alternate names. The first is a package-level variable. The second is a field in a struct. Once you choose a name for an exported struct field, there's no way to create an alternate name.

Avoiding the init Function if Possible

When you read Go code, it is usually clear which methods and functions are called. One of the reasons Go doesn't have method overriding or function overloading is to make it easier to understand what code is running. However, there is a way to set up state in a package without explicitly calling anything: the `init` function. When you declare a function named `init` that takes no parameters and returns no values, it runs the first time the package is referenced by another package. Since `init` functions do not have any inputs or outputs, they can work only by side effect, interacting with package-level functions and variables.

The `init` function has another unique feature. Go allows you to declare multiple `init` functions in a single package, or even in a single file in a package. There's a documented order for running multiple `init` functions in a single package, but rather than remembering it, it's better to simply avoid them.

Some packages, like database drivers, use `init` functions to register the database driver. However, you don't use any of the identifiers in the package. As mentioned earlier, Go doesn't allow you to have unused imports. To work around this, Go allows *blank imports*, where the name assigned to an import is the underscore (_). Just as an underscore allows you to skip an unused return value from a function, a blank import triggers the `init` function in a package but doesn't give you access to any of the exported identifiers in the package:

```
import (
    "database/sql"

    _ "github.com/lib/pq"
)
```

This pattern is considered obsolete because it's unclear that a registration operation is being performed. Go's compatibility guarantee for its standard library means that you are stuck using it to register database drivers and image formats, but if you have a registry pattern in your own code, register your plug-ins explicitly.

The primary use of `init` functions today is to initialize package-level variables that can't be configured in a single assignment. It's a bad idea to have mutable state at the top level of a package, since it makes it harder to understand how data flows through your application. That means that any package-level variables configured via `init` should be *effectively immutable*. While Go doesn't provide a way to enforce that their value does not change, you should make sure that your code does not change them. If you have package-level variables that need to be modified while your program is running, see if you can refactor your code to put that state into a struct that's initialized and returned by a function in the package.

The nonexplicit invocation of `init` functions means that you should document their behavior. For example, a package with an `init` function that loads files or accesses the network should call this out in a package-level comment so that security-conscious users of your code aren't surprised by unexpected I/O.

Working with Modules

You've seen how to work with packages within a single module, and now it's time to see how to integrate with third-party modules and the packages within them. After that, you'll learn about publishing and versioning your own modules and Go's centralized services: pkg.go.dev, the module proxy, and the checksum database.

Importing Third-Party Code

So far, you've imported packages from the standard library like `fmt`, `errors`, `os`, and `math`. Go uses the same import system to integrate packages from third parties. Unlike many other compiled languages, Go always builds applications from source code into a single binary file. This includes the source code of your module and the source code of all the modules on which your module depends. (The Go compiler is smart enough to not include unreferenced packages in the binary it produces.) Just as you saw when you imported a package from within your own module, when you import a third-party package, you specify the location in the source code repository where the package is located.

Let's look at an example. I mentioned back in Chapter 2 that you should never use floating-point numbers when you need an exact representation of a decimal number. If you do need an exact representation, one good option is the `decimal` module from ShopSpring. You are also going to look at a simple formatting module that I've written for this book. Both of these modules are used in a small program in the money repository for the book. This program calculates the price of an item with the tax included and prints the output in a neat format.

The following code is in *main.go*:

```
package main

import (
    "fmt"
    "log"
    "os"

    "github.com/learning-go-book-2e/formatter"
    "github.com/shopspring/decimal"
)

func main() {
    if len(os.Args) < 3 {
        fmt.Println("Need two parameters: amount and percent")
        os.Exit(1)
    }
    amount, err := decimal.NewFromString(os.Args[1])
    if err != nil {
        log.Fatal(err)
    }
    percent, err := decimal.NewFromString(os.Args[2])
    if err != nil {
        log.Fatal(err)
    }
    percent = percent.Div(decimal.NewFromInt(100))
    total := amount.Add(amount.Mul(percent)).Round(2)
    fmt.Println(formatter.Space(80, os.Args[1], os.Args[2],
                                total.StringFixed(2)))
}
```

The two imports `github.com/learning-go-book-2e/formatter` and `github.com/shopspring/decimal` specify third-party imports. Note that they include the location of the package in the repository. Once they're imported, you access the exported items in these packages just like any other imported package.

Before building the application, look at the *go.mod* file. Its contents should be as follows:

```
module github.com/learning-go-book-2e/money

go 1.20
```

If you try to do a build, you get the following message:

```
$ go build
main.go:8:2: no required module provides package
    github.com/learning-go-book-2e/formatter; to add it:
        go get github.com/learning-go-book-2e/formatter
main.go:9:2: no required module provides package
    github.com/shopspring/decimal; to add it:
        go get github.com/shopspring/decimal
```

As the errors indicate, you cannot build the program until you add references to the third-party modules to your *go.mod* file. The `go get` command downloads modules and updates the *go.mod* file. You have two options when using `go get`. The simplest option is to tell `go get` to scan your module's source code and add any modules that are found in `import` statements to *go.mod*:

```
$ go get ./...
go: downloading github.com/shopspring/decimal v1.3.1
go: downloading github.com/learning-go-book-2e/formatter
    v0.0.0-20220918024742-1835a89362c9
go: downloading github.com/fatih/color v1.13.0
go: downloading github.com/mattn/go-colorable v0.1.9
go: downloading github.com/mattn/go-isatty v0.0.14
go: downloading golang.org/x/sys v0.0.0-20210630005230-0f9fa26af87c
go: added github.com/fatih/color v1.13.0
go: added github.com/learning-go-book-2e/formatter
    v0.0.0-20220918024742-1835a89362c9
go: added github.com/mattn/go-colorable v0.1.9
go: added github.com/mattn/go-isatty v0.0.14
go: added github.com/shopspring/decimal v1.3.1
go: added golang.org/x/sys v0.0.0-20210630005230-0f9fa26af87c
```

Because the location of the package is in the source code, `go get` is able to get the package's module and download it. If you look in the *go.mod* file now, you'll see this:

```
module github.com/learning-go-book-2e/money

go 1.20

require (
    github.com/learning-go-book-2e/formatter v0.0.0-20220918024742-1835a89362c9
    github.com/shopspring/decimal v1.3.1
)

require (
    github.com/fatih/color v1.13.0 // indirect
    github.com/mattn/go-colorable v0.1.9 // indirect
    github.com/mattn/go-isatty v0.0.14 // indirect
    golang.org/x/sys v0.0.0-20210630005230-0f9fa26af87c // indirect
)
```

The first `require` section of the *go.mod* file lists the modules that you've imported into your module. After the module name is a version number. In the case of the `formatter` module, it doesn't have a version tag, so Go makes up a *pseudoversion*.

You also see a second `require` directive section that has modules with an *indirect* comment. One of these modules (`github.com/fatih/color`) is directly used by `formatter`. It, in turn, depends on the other three modules in the second `require` directive section. All the modules used by all your module's dependencies (and your dependencies' dependencies, and so on) are included in the *go.mod* file for your module. The ones that are used only in dependencies are marked as indirect.

In addition to updating *go.mod*, a *go.sum* file is created. For each module in the dependency tree of your project, the *go.sum* file has one or two entries: one with the module, its version, and a hash of the module; the other with the hash of the *go.mod* file for the module. Here's what the *go.sum* file looks like:

```
github.com/fatih/color v1.13.0 h1:8LOYc1KYPPmyKMuN8QV2DNRWNbLo6LZ0iLs...
github.com/fatih/color v1.13.0/go.mod h1:kLAiJbzzSOZDVNGyDpeOxJ47H46q...
github.com/learning-go-book-2e/formatter v0.0.0-20220918024742-1835a8...
github.com/learning-go-book-2e/formatter v0.0.0-20220918024742-1835a8...
github.com/mattn/go-colorable v0.1.9 h1:sqDoxXbdeALODt0DAeJCVp38ps9Zo...
github.com/mattn/go-colorable v0.1.9/go.mod h1:u6P/XSegPjTcexA+o6vUJr...
github.com/mattn/go-isatty v0.0.12/go.mod h1:cbi8OIDigv2wuxKPP5vlRcQ1...
github.com/mattn/go-isatty v0.0.14 h1:yVuAays6BHfxijgZPzw+3Zlu5yQgKGP...
github.com/mattn/go-isatty v0.0.14/go.mod h1:7GGIvUiUoEMVVmxf/4nioHXj...
github.com/shopspring/decimal v1.3.1 h1:2Usl1nmF/WZucqkFZhnfFYxxxu8LG...
github.com/shopspring/decimal v1.3.1/go.mod h1:DKyhrW/HYNuLGql+MJL6WC...
golang.org/x/sys v0.0.0-20200116001909-b77594299b42/go.mod h1:h1NjWce...
golang.org/x/sys v0.0.0-20200223170610-d5e6a3e2c0ae/go.mod h1:h1NjWce...
golang.org/x/sys v0.0.0-20210630005230-0f9fa26af87c h1:F1jZWGFhYfh0Ci...
golang.org/x/sys v0.0.0-20210630005230-0f9fa26af87c/go.mod h1:oPkhp1M...
```

You'll see what these hashes are used for in "Module Proxy Servers" on page 259. You might also notice that there are multiple versions of some of the dependencies. I'll talk about that in "Minimal Version Selection" on page 247.

Let's validate that your modules are now set up correctly. Run `go build` again, and then run the `money` binary and pass it some arguments:

```
$ go build
$ ./money 99.99 7.25
99.99           7.25                                             107.24
```

This sample program was checked in without *go.sum* and with an incomplete *go.mod*. This was done so you could see what happens when these files are populated. When committing your own modules to source control, always include up-to-date *go.mod* and *go.sum* files. Doing so specifies exactly what versions of your dependencies are being used. This enables *repeatable builds*; when anyone else (including your future self) builds this module, they will get the exact same binary.

As I mentioned, there's another way to use `go get`. Instead of telling it to scan your source code to discover modules, you can pass the module paths to `go get`. To see this work, roll back the changes to your *go.mod* file and remove the *go.sum* file. On Unix-like systems, the following commands will do this:

```
$ git restore go.mod
$ rm go.sum
```

Now, pass the module paths to `go get` directly:

```
$ go get github.com/learning-go-book-2e/formatter
go: added github.com/learning-go-book-2e/
    formatter v0.0.0-20200921021027-5abc380940ae
$ go get github.com/shopspring/decimal
go: added github.com/shopspring/decimal v1.3.1
```

Sharp-eyed readers might have noticed that when we used `go get` a second time, the `go: downloading` messages weren't displayed. The reason is that Go maintains a *module cache* on your local computer. Once a version of a module is downloaded, a copy is kept in the cache. Source code is pretty compact, and drives are pretty large, so this isn't usually a concern. However, if you want to delete the module cache, use the command `go clean -modcache`.

Take a look at the contents of *go.mod*, and they'll look a little different than before:

```
module github.com/learning-go-book-2e/money

go 1.20

require (
    github.com/fatih/color v1.13.0 // indirect
    github.com/learning-go-book-2e/
    formatter v0.0.0-20220918024742-1835a89362c9 // indirect
    github.com/mattn/go-colorable v0.1.9 // indirect
    github.com/mattn/go-isatty v0.0.14 // indirect
    github.com/shopspring/decimal v1.3.1 // indirect
    golang.org/x/sys v0.0.0-20210630005230-0f9fa26af87c // indirect
)
```

Notice that all the imports are marked as *indirect*, not just the ones that came from `formatter`. When you run `go get` and pass it a module name, it doesn't check your source code to see whether the module you specified is used within your main module. Just to be safe, it adds an indirect comment.

If you want to fix this label automatically, use the command `go mod tidy`. It scans your source code and synchronizes the *go.mod* and *go.sum* files with your module's source code, adding and removing module references. It also makes sure that the indirect comments are correct.

You might be wondering why you would want to bother using `go get` with a module name. The reason is that it allows you to update the version of an individual module.

Working with Versions

Let's see how Go's module system uses versions. I've written a simple module that you're going to use in another tax-collection program. In *main.go*, there are the following third-party imports:

```
"github.com/learning-go-book-2e/simpletax"
"github.com/shopspring/decimal"
```

As before, the sample program wasn't checked in with *go.mod*, and *go.sum* updated, so you could see what happens. When the program is built, you see the following:

```
$ go get ./...
go: downloading github.com/learning-go-book-2e/simpletax v1.1.0
go: added github.com/learning-go-book-2e/simpletax v1.1.0
go: added github.com/shopspring/decimal v1.3.1
$ go build
```

The *go.mod* file has been updated:

```
module github.com/learning-go-book-2e/region_tax

go 1.20

require (
    github.com/learning-go-book-2e/simpletax v1.1.0
    github.com/shopspring/decimal v1.3.1
)
```

There is also a *go.sum* file with hashes for your dependencies. Run the code and see whether it's working:

```
$ ./region_tax 99.99 12345
2022/09/19 22:04:38 unknown zip: 12345
```

That looks like an unexpected answer. The latest version of the module might have a bug. By default, Go picks the latest version of a dependency when you add it to your module. However, one of the things that makes versioning useful is that you can specify an earlier version of a module. First, you can see what versions of the module are available with the `go list` command:

```
$ go list -m -versions github.com/learning-go-book-2e/simpletax
github.com/learning-go-book-2e/simpletax v1.0.0 v1.1.0
```

By default, the `go list` command lists the packages that are used in your module. The `-m` flag changes the output to list the modules instead, and the `-versions` flag changes `go list` to report on the available versions for the specified module. In this case, you see that there are two versions, v1.0.0 and v1.1.0. Let's downgrade to version v1.0.0 and see if that fixes your problem. You do that with the `go get` command:

```
$ go get github.com/learning-go-book-2e/simpletax@v1.0.0
go: downloading github.com/learning-go-book-2e/simpletax v1.0.0
go: downgraded github.com/learning-go-book-2e/simpletax v1.1.0 => v1.0.0
```

The `go get` command lets you work with modules, updating the versions of your dependencies.

Now if you look at *go.mod*, you'll see that the version has been changed:

```
module github.com/learning-go-book-2e/region_tax

go 1.20

require (
    github.com/learning-go-book-2e/simpletax v1.0.0
    github.com/shopspring/decimal v1.3.1
)
```

You also see in *go.sum* that it contains both versions of `simpletax`:

```
github.com/learning-go-book-2e/simpletax v1.0.0 h1:KZU8aXRCHkvgFmBWkV...
github.com/learning-go-book-2e/simpletax v1.0.0/go.mod h1:lR4YYZwbDTI...
github.com/learning-go-book-2e/simpletax v1.1.0 h1:sG83gscauX/b8yKKY9...
github.com/learning-go-book-2e/simpletax v1.1.0/go.mod h1:lR4YYZwbDTI...
```

This is fine; if you change a module's version or even remove a module from your module, an entry for it might still remain in *go.sum*. This doesn't cause problems.

When you build and run the code again, the bug is fixed:

```
$ go build
$ ./region_tax 99.99 12345
107.99
```

Semantic Versioning

Software has had version numbers from time immemorial, but there has been little consistency in what version numbers mean. The version numbers attached to Go modules follow the rules of *semantic versioning*, also known as *SemVer*. By requiring semantic versioning for modules, Go makes its module management code simpler while ensuring that users of a module understand what a new release promises.

If you aren't familiar with SemVer, check out the full specification. The very short explanation is that semantic versioning divides a version number into three parts: the *major* version, the *minor* version, and the *patch* version, which are written as `major.minor.patch` and preceded by a `v`. The patch version number is incremented when fixing a bug; the minor version number is incremented (and the patch version is set back to 0) when a new, backward-compatible feature is added; and the major version number is incremented (and minor and patch are set back to 0) when making a change that breaks backward compatibility.

Minimal Version Selection

At some point, your module will depend on two or more modules that all depend on the same module. As often happens, these modules declare that they depend on different minor or patch versions of that module. How does Go resolve this?

The module system uses the principle of *minimal version selection*: you will always get the lowest version of a dependency that is declared to work in all the *go.mod* files across all your dependencies. Let's say that your module directly depends on modules A, B, and C. All three of these modules depend on module D. The *go.mod* file for module A declares that it depends on v1.1.0, module B declares that it depends on v1.2.0, and module C declares that it depends on v1.2.3. Go will import module D only once, and it will choose version v1.2.3, as that, in the words of the Go Modules Reference, is the minimum version that satisfies all requirements.

You can see this in action with your sample program from "Importing Third-Party Code" on page 240. The command `go mod graph` shows the dependency graph of your module and all its dependencies. Here are a few lines of its output:

```
github.com/learning-go-book-2e/money github.com/fatih/color@v1.13.0
github.com/learning-go-book-2e/money github.com/mattn/go-colorable@v0.1.9
github.com/learning-go-book-2e/money github.com/mattn/go-isatty@v0.0.14
github.com/fatih/color@v1.13.0 github.com/mattn/go-colorable@v0.1.9
github.com/fatih/color@v1.13.0 github.com/mattn/go-isatty@v0.0.14
github.com/mattn/go-colorable@v0.1.9 github.com/mattn/go-isatty@v0.0.12
```

Each line lists two modules, the first being the parent and the second being the dependency and its version. You'll notice the `github.com/fatih/color` module is declared to depend on version v0.0.14 of `github.com/mattn/go-isatty`, while `github.com/mattn/go-colorable` depends on v0.0.12. The Go compiler selects version v0.0.14 to use, because it is the minimal version that meets all requirements. This occurs even though, as of this writing, the latest version of `github.com/mattn/go-isatty` is v0.0.16. Your minimal version requirement is met with v0.0.14, so that's what is used.

This system isn't perfect. You might find that while module A works with version v1.1.0 of module D, it does not work with version v1.2.3. What do you do then? Go's answer is that you need to contact the module authors to fix their incompatibilities. The *import compatibility rule* says, "If an old package and a new package have the same import path, the new package must be backward compatible with the old package." All minor and patch versions of a module must be backward compatible. If they aren't, it's a bug. In our hypothetical example, either module D needs to be fixed because it broke backward compatibility, or module A needs to be fixed because it made a faulty assumption about the behavior of module D.

You might not find this answer satisfying, but it's honest. Some build systems, like npm, will include multiple versions of the same package. This can introduce its own set of bugs, especially when there is package-level state. It also increases the size of your application. In the end, some things are better solved by community than code.

Updating to Compatible Versions

What if you explicitly want to upgrade a dependency? Let's assume that after writing the initial program, there are three more versions of `simpletax`. The first fixes problems in the initial v1.1.0 release. Since it's a bug patch release with no new functionality, it would be released as v1.1.1. The second keeps the current functionality but also adds a new function. It would get the version number v1.2.0. Finally, the third fixes a bug that was found in version v1.2.0. It has the version number v1.2.1.

To upgrade to the bug patch release for the current minor version, use the command `go get -u=patch github.com/learning-go-book-2e/simpletax`. Since you had downgraded to v1.0.0, you would remain on that version, because there is no patch version with the same minor version.

Upgrade to version v1.1.0 by using `go get github.com/learning-go-book-2e/simpletax@v1.1.0` and then run `go get -u=patch github.com/learning-go-book-2e/simpletax`. This upgrades the version to v1.1.1.

Finally, use the command `go get -u github.com/learning-go-book-2e/simpletax` to get the most recent version of `simpletax`. That upgrades you to version v1.2.1.

Updating to Incompatible Versions

Let's go back to the program. You're expanding to Canada, and luckily, a version of the `simpletax` module handles both the US and Canada. However, this version has a slightly different API than the previous one, so its version is v2.0.0.

To handle incompatibility, Go modules follow the *semantic import versioning* rule. This rule has two parts:

- The major version of the module must be incremented.
- For all major versions besides 0 and 1, the path to the module must end in v*N*, where *N* is the major version.

The path changes because an import path uniquely identifies a package. By definition, incompatible versions of a package are not the same package. Using different paths means that you can import two incompatible versions of a package into different parts of your program, allowing you to upgrade gracefully.

Let's see how this changes the program. First, change the import of `simpletax` to this:

```
"github.com/learning-go-book-2e/simpletax/v2"
```

This changes your import to refer to the v2 module.

Next, change the code in `main` to the following:

```go
func main() {
    amount, err := decimal.NewFromString(os.Args[1])
    if err != nil {
        log.Fatal(err)
    }
    zip := os.Args[2]
    country := os.Args[3]
    percent, err := simpletax.ForCountryPostalCode(country, zip)
    if err != nil {
        log.Fatal(err)
    }
    total := amount.Add(amount.Mul(percent)).Round(2)
    fmt.Println(total)
}
```

The program is now reading a third parameter from the command line, which is the country code. The program also calls a different function in the `simpletax` package. When you run `go get ./...`, the dependency is automatically updated:

```
$ go get ./...
go: downloading github.com/learning-go-book-2e/simpletax/v2 v2.0.0
go: added github.com/learning-go-book-2e/simpletax/v2 v2.0.0
```

Build and run the program to see the new output:

```
$ go build
$ ./region_tax 99.99 M4B1B4 CA
112.99
$ ./region_tax 99.99 12345 US
107.99
```

When you look at the *go.mod* file, you'll see that the new version of `simpletax` is included:

```
module github.com/learning-go-book-2e/region_tax

go 1.20

require (
    github.com/learning-go-book-2e/simpletax v1.0.0
    github.com/learning-go-book-2e/simpletax/v2 v2.0.0
    github.com/shopspring/decimal v1.3.1
)
```

And *go.sum* has been updated as well:

```
github.com/learning-go-book-2e/simpletax v1.0.0 h1:KZU8aXRCHkvgFmBWkV...
github.com/learning-go-book-2e/simpletax v1.0.0/go.mod h1:lR4YYZwbDTI...
github.com/learning-go-book-2e/simpletax v1.1.0 h1:sG83gscauX/b8yKKY9...
github.com/learning-go-book-2e/simpletax v1.1.0/go.mod h1:lR4YYZwbDTI...
github.com/learning-go-book-2e/simpletax/v2 v2.0.0 h1:EUFWy1BBA2omgkm...
github.com/learning-go-book-2e/simpletax/v2 v2.0.0/go.mod h1:yGLh6ngH...
github.com/shopspring/decimal v1.3.1 h1:2Usl1nmF/WZucqkFZhnfFYxxxu8LG...
github.com/shopspring/decimal v1.3.1/go.mod h1:DKyhrW/HYNuLGql+MJL6WC...
```

The old versions of `simpletax` are still referenced, even though they are no longer used. Use `go mod tidy` to remove those unused versions. Then you'll see only v2.0.0 of `simpletax` referenced in *go.mod* and *go.sum*.

Vendoring

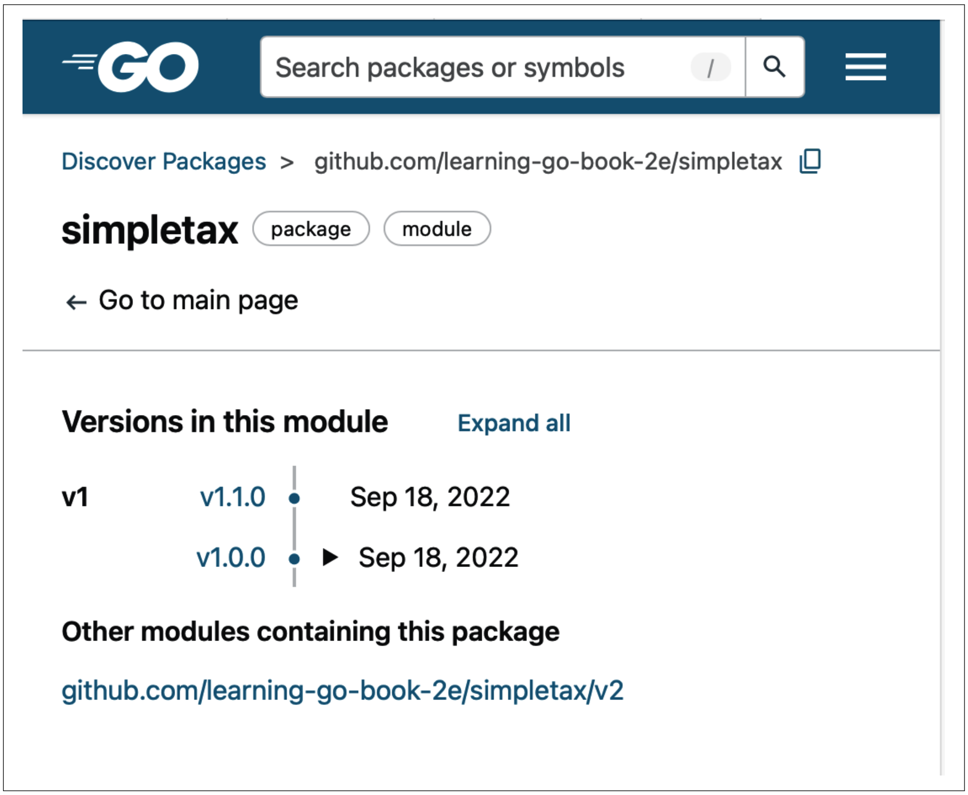
To ensure that a module always builds with identical dependencies, some organizations like to keep copies of their dependencies inside their module. This is known as *vendoring*. It's enabled by running the command `go mod vendor`. This creates a directory called *vendor* at the top level of your module that contains all your module's dependencies. These dependencies are used in place of the module cache stored on your computer.

If new dependencies are added to *go.mod* or versions of existing dependencies are upgraded with `go get`, you need to run `go mod vendor` again to update the *vendor* directory. If you forget to do this, `go build`, `go run`, and `go test` will display an error message and refuse to run.

Older Go dependency management systems required vendoring, but with the advent of Go modules and proxy servers (see "Module Proxy Servers" on page 259 for details), the practice is falling out of favor. One reason you might still want to vendor is that it can make building your code faster and more efficient when working with some CI/CD (continuous integration/continuous delivery) pipelines. If a pipeline's build servers are ephemeral, the module cache may not be preserved. Vendoring dependencies allows these pipelines to avoid making multiple network calls to download dependencies every time a build is triggered. The downside is that it dramatically increases the size of your codebase in version control.

Using pkg.go.dev

While there isn't a single centralized repository of Go modules, there is a single service that gathers together documentation on Go modules. The Go team has created a site called *pkg.go.dev* that automatically indexes open source Go modules. For each module, the package index publishes the godocs, the license used, the *README*, the module's dependencies, and what open source modules depend on the module. You can see the info that *pkg.go.dev* has on your `simpletax` module in Figure 10-2.


GO
Search packages or symbols
/
Discover Packages > github.com/learning-go-book-2e/simpletax
simpletax
package
module
← Go to main page

Versions in this module — Expand all

v1 — v1.1.0 — Sep 18, 2022
v1.0.0 — ▶ Sep 18, 2022

Other modules containing this package

github.com/learning-go-book-2e/simpletax/v2

Figure 10-2. Use pkg.go.dev to find and learn about third-party modules

Publishing Your Module

Making your module available to other people is as simple as putting it in a version control system. This is true whether you are releasing your module as open source on a public version control system like GitHub or a private one that's hosted by you or within a company. Since Go programs build from source code and use a repository path to identify themselves, there's no need to explicitly upload your module to a central library repository, as you do for Maven Central or npm. Make sure you check in both your *go.mod* file and your *go.sum* file.

While most Go developers use Git for version control, Go also supports Subversion, Mercurial, Bazaar, and Fossil. By default, Git and Mercurial can be used for public repositories, and any of the supported version control systems can be used for private repositories. For details, check out the version control system documentation for Go modules.

When releasing an open source module, you should include a file named *LICENSE* in the root of your repository that specifies the open source license under which you are releasing your code. It's FOSS is a good resource for learning more about the various kinds of open source licenses.

Roughly speaking, you can divide open source licenses into two categories: permissive (which allows users of your code to keep their code private) and nonpermissive (which requires users of your code to make their code open source). While the license you choose is up to you, the Go community favors permissive licenses, such as BSD, MIT, and Apache. Since Go compiles third-party code directly into every application, the use of a nonpermissive license like the GPL would require people who use your code to release their code as open source as well. For many organizations, this is not acceptable.

One final note: do not write your own license. Few people will trust that it has been properly reviewed by a lawyer, and they can't tell what claims you are making on their module.

Versioning Your Module

Whether your module is public or private, you should properly version your module so that it works correctly with Go's module system. As long as you are adding functionality or patching bugs, the process is simple. Store your changes in your source code repository, then apply a tag that follows the semantic versioning rules I discussed in "Semantic Versioning" on page 246.

Go's semantic versioning supports the concept of *pre-releases*. Let's assume that the current version of your module is tagged `v1.3.4`. You are working on version 1.4.0, which is not quite done, but you want to try importing it into another module. What you should do is append a hyphen (-) to the end of your version tag, followed by an identifier for the pre-release build. In this case, use a tag like `v1.4.0-beta1` to indicate beta 1 of version 1.4.0 or `v1.4.0-rc2` to indicate release candidate 2. If you want to depend on a pre-release candidate, you must specify its version explicitly in `go get`, as Go will not automatically select a pre-release version.

If you reach a point where you need to break backward compatibility, the process is more complicated. As you saw when importing version 2 of the `simpletax` module, a backward-breaking change requires a different import path. There are a few steps to take.

First you need to choose a way to store your new version. Go supports two ways for creating the different import paths:

- Create a subdirectory within your module named *vN*, where *N* is the major version of your module. For example, if you are creating version 2 of your module, call this directory *v2*. Copy your code into this subdirectory, including the *README* and *LICENSE* files.
- Create a branch in your version control system. You can put either the old code or the new code on the new branch. Name the branch *vN* if you are putting the new code on the branch, or *vN-1* if you are putting the old code there. For example, if you are creating version 2 of your module and want to put version 1 code on the branch, name the branch *v1*.

After you decide how to store your new code, you need to change the import path in the code in your subdirectory or branch. The module path in your *go.mod* file must end with */vN*, and all the imports within your module must use */vN* as well. Going through all your code can be tedious, but Marwan Sulaiman has created a tool that automates the work. Once the paths are fixed, go ahead and implement your changes.

Technically, you could just change *go.mod* and your import statements, tag your main branch with the latest version, and not bother with a subdirectory or versioned branch. However, this is not a good practice, as it makes it unclear where to find older major versions of your module.

When you are ready to publish your new code, place a tag on your repository that looks like v*N*.0.0. If you are using the subdirectory system or keeping the latest code on your main branch, tag the main branch. If you are placing your new code on a different branch, tag that branch instead.

You can find more details on updating your code to an incompatible version in the post "Go Modules: v2 and Beyond" on The Go Blog and in "Developing a Major Version Update" on the Go developer website.

Overriding Dependencies

Forks happen. While there's a bias against forking in the open source community, sometimes a module stops being maintained or you want to experiment with changes that aren't accepted by the module's owner. A `replace` directive redirects all references to a module across all your module's dependencies and replaces them with the specified fork of the module. It looks like this:

```
replace github.com/jonbodner/proteus => github.com/someone/my_proteus v1.0.0
```

The original module location is specified on the left side of the `=>` and the replacement on the right. The right side must have a version specified, but specifying a version is optional for the left side. If a version is specified on the left side, only that specific version will be replaced. If the version is not specified, any version of the original module will be replaced with the specific version of the fork.

A `replace` directive can also refer to a path on your local filesystem:

```
replace github.com/jonbodner/proteus => ../projects/proteus
```

With a local `replace` directive, the module version must be omitted from the right side.

Avoid using local `replace` directives. They provided a way to modify multiple modules simultaneously before the invention of Go workspaces, but now they are a potential source of broken modules. (I will cover workspaces shortly.) If you share your module via version control, a module with local references in `replace` directives will probably not build for anyone else, since you cannot guarantee that other people will have the replacement modules in the same locations on their drive.

You also might want to block a specific version of a module from being used. Perhaps it has a bug or is incompatible with your module. Go provides the `exclude` directive to prevent a specific version of a module from being used:

```
exclude github.com/jonbodner/proteus v0.10.1
```

When a module version is excluded, any mentions of that module version in any dependent module are ignored. If a module version is excluded and it's the only version of that module that's required in your module's dependencies, use `go get` to add an indirect import of a different version of the module to your module's *go.mod* file so that your module still compiles.

Retracting a Version of Your Module

Sooner or later, you will accidentally publish a version of your module that you don't want anyone to use. Perhaps it was released by accident before testing was complete. Maybe after its release, a critical vulnerability is discovered and no one should use it any more. No matter the reason, Go provides a way for you to indicate that certain versions of a module should be ignored. This is done by adding a `retract` directive to the *go.mod* file of your module. It consists of the word `retract` and the semantic version that should no longer be used. If a range of versions shouldn't be used, you can exclude all versions in that range by placing the upper and lower bounds within brackets, separated by a comma. While it's not required, you should include a comment after a version or version range to explain the reason for the retraction.

If you wish to retract multiple nonsequential versions, you can specify them with multiple `retract` directives. In the examples shown, version 1.5.0 is excluded, as are all versions from 1.7.0 to 1.8.5, inclusive:

```
retract v1.5.0 // not fully tested
retract [v1.7.0, v.1.8.5] // posts your cat photos to LinkedIn w/o permission
```

Adding a `retract` directive to *go.mod* requires you to create a new version of your module. If the new version contains only the retraction, you should retract it as well.

When a version is retracted, existing builds that specified the version will continue to work, but `go get` and `go mod tidy` will not upgrade to them. They will no longer appear as options when you use the `go list` command. If the most recent version of a module is retracted, it will no longer be matched with `@latest`; the highest unretracted version will match instead.

While `retract` can be confused with `exclude`, there's a very important difference. You use `retract` to prevent others from using specific versions of *your* module. An `exclude` directive blocks you from using versions of another module.

Using Workspaces to Modify Modules Simultaneously

There's one drawback to using your source code repository and its tags as a way to track your dependencies and their versions. If you want to make changes to two (or more) modules simultaneously, and you want to experiment with those changes across modules, you need a way to use a local copy of a module instead of the version in the source code repository.

You can find obsolete advice online to try to solve this issue with temporary `replace` directives in *go.mod* that point to local directories. Do not do this! It's too easy to forget to undo these changes before committing and pushing your code. Workspaces were introduced to avoid this antipattern.

Go uses *workspaces* to address this issue. A workspace allows you to have multiple modules downloaded to your computer, and references between those modules will automatically resolve to the local source code instead of the code hosted in your repository.

This section assumes that you have a GitHub account. If you don't, you can still follow along. I'm going to use the organization name `learning-go-book-2e`, but you should replace it with your GitHub account name or organization.

Let's start with two sample modules. Create a *my_workspace* directory and in that directory, create two more directories, *workspace_lib* and *workspace_app*. In the *workspace_lib* directory, run `go mod init github.com/learning-go-book-2e/workspace_lib`. Create a file called *lib.go* with the following content:

```go
package workspace_lib

func AddNums(a, b int) int {
    return a + b
}
```

In the *workspace_app* directory, run `go mod init github.com/learning-go-book-2e/workspace_app`. Create a file called *app.go* with the following contents:

```go
package main

import (
    "fmt"
    "github.com/learning-go-book-2e/workspace_lib"
)

func main() {
    fmt.Println(workspace_lib.AddNums(2, 3))
}
```

In previous sections, you used `go get ./...` to add `require` directives to *go.mod*. Let's see what happens if you try it here:

```
$ go get ./...
github.com/learning-go-book-2e/workspace_app imports
    github.com/learning-go-book-2e/workspace_lib: cannot find module
        providing package github.com/learning-go-book-2e/workspace_lib
```

Since *workspace_lib* hasn't been pushed to GitHub yet, you can't pull it in. If you try to run `go build`, you will get a similar error:

```
$ go build
app.go:5:2: no required module provides
    package github.com/learning-go-book-2e/workspace_lib; to add it:
        go get github.com/learning-go-book-2e/workspace_lib
```

Let's take advantage of workspaces to allow *workplace_app* to see the local copy of *workspace_lib*. Go to the *my_workspace* directory and run the following commands:

```
$ go work init ./workspace_app
$ go work use ./workspace_lib
```

This creates a *go.work* file in *my_workspace* with the following contents:

```
go 1.20

use (
    ./workspace_app
    ./workspace_lib
)
```

The *go.work* file is meant for your local computer only. Do not commit it to source control!

Now if you build *workspace_app*, everything works:

```
$ cd workspace_app
$ go build
$ ./workspace_app
5
```

Now that you are sure that *workspace_lib* does the right thing, it can be pushed to GitHub. In GitHub, create an empty public repository called `workspace_lib` and then run the following commands in the *workspace_lib* directory:

```
$ git init
$ git add .
$ git commit -m "first commit"
$ git remote add origin git@github.com:learning-go-book-2e/workspace_lib.git
$ git branch -M main
$ git push -u origin main
```

After running these commands, go to *https://github.com/learning-go-book-2e/workspace_lib/releases/new* (replacing "learning-go-book-2e" with your account or organization), and create a new release with the tag v0.1.0.

Now if you go back to the *workspace_app* directory and run `go get ./...`, the `require` directive is added, because there is a public module that can be downloaded:

```
$ go get ./...
go: downloading github.com/learning-go-book-2e/workspace_lib v0.1.0
go: added github.com/learning-go-book-2e/workspace_lib v0.1.0
$ cat go.mod
module github.com/learning-go-book-2e/workspace_app

go 1.20

require github.com/learning-go-book-2e/workspace_lib v0.1.0
```

You can validate that your code is working with the public module by setting the environment variable `GOWORK=off` and building your application:

```
$ rm workspace_app
$ GOWORK=off go build
$ ./workspace_app
5
```

Even though there is now a `require` directive referring to the public module, you can continue to make updates in our local workspace and they will be used instead. In *workspace_lib*, modify the *lib.go* file and add the following function:

```
func SubNums(a, b int) int {
    return a - b
}
```

In *workspace_app*, modify the *app.go* file and add the following line to the end of the `main` function:

```
    fmt.Println(workspace_lib.SubNums(2,3))
```

Now run `go build` and see it use the local module instead of the public one:

```
$ go build
$ ./workspace_app
5
-1
```

Once you have made the edits and want to release your software, you need to update the version information in your modules' *go.mod* files to refer to the updated code. This requires you to commit your modules to source control in dependency order:

1. Choose a modified module that has no dependencies on any of the modified modules in your workspace.
2. Commit this module to your source code repository.
3. Create a new version tag on the newly committed module in your source code repository.

4. Use `go get` to update the version specified in *go.mod* in the modules that depend on the newly committed module.
5. Repeat the first four steps until all modified modules are committed.

If you have to make changes to *workspace_lib* in the future and want to test them in *workspace_app* without pushing back to GitHub and creating lots of temporary versions, you can `git pull` the latest versions of the modules into your workspace again and make your updates.

Module Proxy Servers

Rather than relying on a single, central repository for libraries, Go uses a hybrid model. Every Go module is stored in a source code repository, like GitHub or GitLab. But by default, `go get` doesn't fetch code directly from source code repositories. Instead, it sends requests to a *proxy server* run by Google. When the proxy server receives the `go get` request, it checks its cache to see if there has been a request for this module version before. If so, it returns the cached information. If a module or a version of a module isn't cached on the proxy server, it downloads the module from the module's repository, stores a copy, and returns the module. This allows the proxy server to keep copies of every version of virtually all public Go modules.

In addition to the proxy server, Google also maintains a *checksum database*. It stores information on every version of every module cached by the proxy server. Just as the proxy server protects you from a module or a version of a module being removed from the internet, the checksum database protects you against modifications to a version of a module. This could be malicious (someone has hijacked a module and slipped in malicious code), or it could be inadvertent (a module maintainer fixes a bug or adds a new feature and reuses an existing version tag). In either case, you don't want to use a module version that has changed because you won't be building the same binary and don't know what the effects are on your application.

Every time you download a module via `go get` or `go mod tidy`, the Go tools calculate a hash for the module and contact the checksum database to compare the calculated hash to the hash stored for that module's version. If they don't match, the module isn't installed.

Specifying a Proxy Server

Some people object to sending requests for third-party libraries to Google. There are a few options:

- You can disable proxying entirely by setting the `GOPROXY` environment variable to `direct`. You'll download modules directly from their repositories, but if you depend on a version that's removed from the repository, you won't be able to access it.

- You can run your own proxy server. Both Artifactory and Sonatype have Go proxy server support built into their enterprise repository products. The Athens Project provides an open source proxy server. Install one of these products on your network and then point `GOPROXY` to the URL.

Using Private Repositories

Most organizations keep their code in private repositories. If you want to use a private module in another Go module, you can't request it from Google's proxy server. Go will fall back to checking the private repository directly, but you might not want to leak the names of private servers and repositories to external services.

If you are using your own proxy server, or if you have disabled proxying, this isn't an issue. Running a private proxy server has some additional benefits. First, it speeds up downloading of third-party modules, as they are cached in your company's network. If accessing your private repositories requires authentication, using a private proxy server means that you don't have to worry about exposing authentication information in your CI/CD pipeline. The private proxy server is configured to authenticate to your private repositories (see the authentication configuration documentation for Athens), while the calls to the private proxy server are unauthenticated.

If you are using a public proxy server, you can set the `GOPRIVATE` environment variable to a comma-separated list of your private repositories. For example, if you set `GOPRIVATE` to:

```
GOPRIVATE=*.example.com,company.com/repo
```

any module stored in a repository that's located at any subdomain of *example.com* or at a URL that starts with *company.com/repo* will be downloaded directly.

Additional Details

The Go Team has a complete Go Modules Reference available online. In addition to the content in this chapter, the Module Reference also covers topics like using version control systems besides Git, the structure and API of the module cache, additional environment variables for controlling module lookup behavior, and the REST API for the module proxy and checksum database.

Exercises

1. Create a module in your own public repository. This module has a single function named `Add` with two `int` parameters and one `int` return value. This function adds the two parameters together and returns them. Make this version v1.0.0.
2. Add godoc comments to your module that describe the package and the `Add` function. Be sure to include a link to *https://www.mathsisfun.com/numbers/addition.html* in your `Add` function godoc. Make this version v1.0.1.
3. Change `Add` to make it generic. Import the `golang.org/x/exp/constraints` package. Combine the `Integer` and `Float` types in that package to create an interface called `Number`. Rewrite `Add` to take in two parameters of type `Number` and return a value of type `Number`. Version your module again. Because this is a backward-breaking change, this should be v2.0.0 of your module.

Wrapping Up

In this chapter, you've learned how to organize code and interact with the ecosystem of Go source code. You've seen how modules work, how to organize your code into packages, how to use third-party modules, and how to release modules of your own. In the next chapter, you're going to take a look at more of the development tools that are included with Go, learn about some essential third-party tools, and explore some techniques to give you better control over your build process.

CHAPTER 11

Go Tooling

A programming language doesn't exist in isolation. For it to be useful, tools must help the developer turn source code into an executable. Since Go is intended to address the problems that software engineers face today and to help them build quality software, careful thought has been put into tooling that simplifies tasks that are often difficult with other development platforms. This includes improvements in how you build, format, update, validate, and distribute, and even how your users will install your code.

I have already covered many of the bundled Go tools: `go vet`, `go fmt`, `go mod`, `go get`, `go list`, `go work`, `go doc`, and `go build`. The testing support provided by the `go test` tool is so extensive, it is covered by itself in Chapter 15. In this chapter, you will explore additional tools that make Go development great, both from the Go team and from third parties.

Using go run to Try Out Small Programs

Go is a compiled language, which means that before Go code is run, it must be converted into an executable file. This is in contrast to interpreted languages like Python or JavaScript, which allow you to write a quick script to test an idea and execute it immediately. Having that rapid feedback cycle is important, so Go provides similar functionality via the `go run` command. It builds and executes a program in one step. Let's go back to the first program from Chapter 1. Put it in a file called *hello.go*:

```
package main

import "fmt"

func main() {
    fmt.Println("Hello, world!")
}
```

(You can also find this code in the Chapter 11 repository in the *sample_code/gorun* directory.)

Once the file is saved, use the `go run` command to build and execute it:

```
go run hello.go
Hello, world!
```

If you look inside the directory after running the `go run` command, you see that no binary has been saved there; the only file in the directory is the *hello.go* file you just created. Where did the executable go (no pun intended)?

The `go run` command does, in fact, compile your code into a binary. However, the binary is built in a temporary directory. The `go run` command builds the binary, executes the binary from that temporary directory, and then deletes the binary after your program finishes. This makes the `go run` command useful for testing out small programs or using Go like a scripting language.

Use `go run` when you want to treat a Go program like a script and run the source code immediately.

Adding Third-Party Tools with go install

While some people choose to distribute their Go programs as precompiled binaries, tools written in Go can also be built from source and installed on your computer via the `go install` command.

As you saw in "Publishing Your Module" on page 251, Go modules are identified via their source code repositories. The `go install` command takes an argument, which is the path to the main package in a module's source code repository, followed by an `@` and the version of the tool you want (if you just want to get the latest version, use `@latest`). It then downloads, compiles, and installs the tool.

Always be sure to include the `@version` or `@latest` after the name of the package that you are installing! If you don't, it triggers a variety of confusing behaviors and is almost certainly not what you want to do. You either get an error message (if the current directory is not in a module, or if the current directory is a module, but the package isn't referenced in the module's *go.mod* file), or it installs the package version mentioned in *go.mod*.

By default, `go install` places binaries into the *go/bin* directory within your home directory. Set the *GOBIN* environment variable to change this location. It is strongly recommended that you add the `go install` directory to your executable search path (this is done by modifying the *PATH* environment variable on both Unix and Windows). For simplicity, all the examples in this chapter assume that you've added this directory.

Other environment variables are recognized by the `go` tool. You can get a complete list, along with a brief description of each variable, using the `go help environment` command. Many of them control low-level behavior that can be safely ignored. I'll point out the relevant ones as needed.

Some online resources tell you to set the `GOROOT` or `GOPATH` environment variables. `GOROOT` specifies the location where your Go development environment is installed, and `GOPATH` was used to store all Go source code, both your own and third-party dependencies. Setting these variables is no longer necessary; the `go` tool figures out `GOROOT` automatically, and `GOPATH`-based development has been superseded by modules.

Let's look at a quick example. Jaana Dogan created a great Go tool called `hey` that load tests HTTP servers. You can point it at the website of your choosing or an application that you've written. Here's how to install `hey` with the `go install` command:

```
$ go install github.com/rakyll/hey@latest
go: downloading github.com/rakyll/hey v0.1.4
go: downloading golang.org/x/net v0.0.0-20181017193950-04a2e542c03f
go: downloading golang.org/x/text v0.3.0
```

This downloads `hey` and all its dependencies, builds the program, and installs the binary in your Go binary directory.

As I covered in "Module Proxy Servers" on page 259, the contents of Go repositories are cached in proxy servers. Depending on the repository and the values in your `GOPROXY` environment variable, `go install` may download from a proxy or directly from a repository. If `go install` downloads directly from a repository, it relies on command-line tools being installed on your computer. For example, you must have Git installed to download from GitHub.

Now that you have built and installed `hey`, you can run it with the following:

```
$ hey https://go.dev

Summary:
  Total:        2.1272 secs
  Slowest:      1.4227 secs
  Fastest:      0.0573 secs
  Average:      0.3467 secs
  Requests/sec: 94.0181
```

If you have already installed a tool and want to update it to a newer version, rerun `go install` with the newer version specified or with `@latest`:

```
$ go install github.com/rakyll/hey@latest
```

Of course, you don't need to leave programs installed via `go install` in the *go/bin* directory; they are regular executable binaries and can be stored anywhere on your computer. Likewise, you don't have to distribute programs written in Go using `go install`; you can put a binary up for download. However, `go install` is convenient for Go developers, and it has become the method of choice for distributing third-party developer tools.

Improving Import Formatting with goimports

An enhanced version of `go fmt` called `goimports` also cleans up your import statements. It puts them in alphabetical order, removes unused imports, and attempts to guess any unspecified imports. Its guesses are sometimes inaccurate, so you should insert imports yourself.

You can download `goimports` with the command `go install golang.org/x/tools/cmd/goimports@latest`. You run it across your project with this command:

```
$ goimports -l -w .
```

The `-l` flag tells `goimports` to print the files with incorrect formatting to the console. The `-w` flag tells `goimports` to modify the files in place. The `.` specifies the files to be scanned: everything in the current directory and all its subdirectories.

The packages under `golang.org/x` are part of the Go Project but outside the main Go tree. While useful, they are developed under looser compatibility requirements than the Go standard library and may introduce backward-breaking changes. Some packages in the standard library, such as the context package that is covered in Chapter 14, started out in `golang.org/x`. The `pkgsite` tool that was covered in "Documenting Your Code with Go Doc Comments" on page 231 is also located there. You can see the other packages in the "Sub-repositories" section.

Using Code-Quality Scanners

Back in "go vet" on page 7, you looked at the built-in tool `go vet`, which scans source code for common programming errors. Many third-party tools can check code style and scan for potential bugs that are missed by `go vet`. These tools are often called *linters*.[1] In addition to likely programming errors, some of the changes suggested by these tools include properly naming variables, formatting error messages, and placing comments on public methods and types. These aren't errors since they don't keep your programs from compiling or make your program run incorrectly, but they do flag situations where you are writing nonidiomatic code.

When you add linters to your build process, follow the old maxim "trust, but verify." Since the kinds of issues that linters find are fuzzier, they sometimes have false positives and false negatives. This means you don't *have* to make the changes that they suggest, but you should take the suggestions seriously. Go developers expect code to look a certain way and follow certain rules, and if your code does not, it sticks out.

If you find a linter's suggestion to be unhelpful, each linting tool allows you to add a comment to your source code that blocks the errant result (the format of the comment varies from linter to linter; check each tool's documentation to learn what to write). Your comment should also include an explanation of why you are ignoring the linter's finding, so code reviewers (and future you, when you look back on your source code in six months) understand your reasoning.

1 The term "linter" comes from the original `lint` program written by Steve Johnson when he was on the Unix team at Bell Labs and described in his 1978 paper. The name comes from the tiny bits of fabric that come off clothes in a dryer and are captured by a filter. He saw his program as being like a filter capturing small errors.

staticcheck

If you had to pick one third-party scanner, use `staticcheck`. It is supported by many companies that are active in the Go community, includes more than 150 code-quality checks, and tries to produce few to no false positives. It is installed via `go install honnef.co/go/tools/cmd/staticcheck@latest`. Invoke it with `staticcheck ./...` to examine your module.

Here's an example of something that `staticcheck` finds that `go vet` does not:

```
package main

import "fmt"

func main() {
    s := fmt.Sprintf("Hello")
    fmt.Println(s)
}
```

(You can also find this code in the *sample_code/staticcheck_test* directory in the Chapter 11 repository.)

If you run `go vet` on this code, it doesn't find anything wrong. But, `staticcheck` notices a problem:

```
$ staticcheck ./...
main.go:6:7: unnecessary use of fmt.Sprintf (S1039)
```

Pass the code in parentheses to `staticcheck` with the `-explain` flag for an explanation of the issue:

```
$ staticcheck -explain S1039
Unnecessary use of fmt.Sprint

Calling fmt.Sprint with a single string argument is unnecessary
and identical to using the string directly.

Available since
    2020.1

Online documentation
    https://staticcheck.io/docs/checks#S1039
```

Another common issue that `staticcheck` finds is unused assignments to variables. While the Go compiler requires all variables to be read *once*, it doesn't check that *every* value assigned to a variable is read. It is a common practice to reuse an `err` variable when there are multiple function calls within a function. If you forget to write `if err != nil` after one of those function invocations, the compiler won't be able to help you. However, `staticcheck` can. This code compiles without a problem:

```
func main() {
	err := returnErr(false)
	if err != nil {
		fmt.Println(err)
	}
	err = returnErr(true)
	fmt.Println("end of program")
}
```

(This code is in the Chapter 11 repository in the *sample_code/check_err* directory.)

Running `staticcheck` finds the mistake:

```
$ staticcheck ./...
main.go:13:2: this value of err is never used (SA4006)
main.go:13:8: returnErr doesn't have side effects and its return value is
ignored (SA4017)
```

There are two related issues on line 13. The first is that the error returned by `returnErr` is never read. The second is that the `returnErr` function's output (the error) is being ignored.

revive

Another good linting option is `revive`. It is based on `golint`, a tool that used to be maintained by the Go team. Install `revive` with the command `go install github.com/mgechev/revive@latest`. By default, it enables only the rules that were present in `golint`. It can find style and code-quality issues like exported identifiers that don't have comments, variables that don't follow naming conventions, or error return values that aren't the last return value.

With a configuration file, you can turn on many more rules. For example, to enable a check for shadowing of universe block identifiers, create a file named *built_in.toml* with the following contents:

```
[rule.redefines-builtin-id]
```

If you scan the following code:

```
package main

import "fmt"

func main() {
    true := false
    fmt.Println(true)
}
```

you'll get this warning:

```
$ revive -config built_in.toml ./...
main.go:6:2: assignment creates a shadow of built-in identifier true
```

(You can also find this code in the Chapter 11 repository in the *sample_code/revive_test* directory.)

Other rules that can be enabled are focused on opinionated code organization, like limiting the number of lines in a function or number of public structs in a file. There are even rules for evaluating the complexity of the logic in a function. Check out the `revive` documentation and its supported rules.

golangci-lint

Finally, if you'd rather take the buffet approach to tool selection, there's `golangci-lint`. It is designed to make it as efficient as possible to configure and run over 50 code-quality tools, including `go vet`, `staticcheck`, and `revive`.

While you can use `go install` to install `golangci-lint`, it is recommended that you download a binary version instead. Follow the installation instructions on the website. Once it is installed, you run `golangci-lint`:

```
$ golangci-lint run
```

Back in "Unused Variables" on page 32, you looked at a program with variables set to values that were never read, and I mentioned that `go vet` and the go compiler were unable to detect these issues. Neither `staticcheck` nor `revive` catches this problem. However, one of the tools bundled with `golangci-lint` does:

```
$ golangci-lint run
main.go:6:2: ineffectual assignment to x (ineffassign)
    x := 10
    ^
main.go:9:2: ineffectual assignment to x (ineffassign)
    x = 30
    ^
```

You can also use `golangci-lint` to provide shadowing checks that go beyond what `revive` can do. Configure `golangci-lint` to detect shadowing of both universe block identifiers and identifiers within your own code by putting the following configuration into a file named *.golangci.yml* in the directory where you run `golangci-lint`:

```
linters:
  enable:
    - govet
    - predeclared

linters-settings:
  govet:
    check-shadowing: true
    settings:
      shadow:
        strict: true
    enable-all: true
```

With these settings, running `golangci-lint` on this code

```
package main

import "fmt"

var b = 20

func main() {
    true := false
    a := 10
    b := 30
    if true {
        a := 20
        fmt.Println(a)
    }
    fmt.Println(a, b)
}
```

detects the following issues:

```
$ golangci-lint run
main.go:5:5: var `b` is unused (unused)
var b = 20
    ^
main.go:10:2: shadow: declaration of "b" shadows declaration at line 5 (govet)
    b := 30
    ^
main.go:12:3: shadow: declaration of "a" shadows declaration at line 9 (govet)
        a := 20
        ^
main.go:8:2: variable true has same name as predeclared identifier (predeclared)
    true := false
    ^
```

(You can find both `golangci-lint` code samples in the Chapter 11 repository in the *sample_code/golangci-lint_test* directory.)

Because `golangci-lint` runs so many tools (as of this writing, it runs 7 different tools by default and allows you to enable more than 50 more), it's inevitable that your team may disagree with some of its suggestions. Review the documentation to understand what each tool can do. Once you come to agreement on which linters to enable, update the *.golangci.yml* file at the root of your module and commit it to source control. Check out the documentation for the file format.

While `golangci-lint` allows you to have a configuration file in your home directory, don't put one there if you are working with other developers. Unless you enjoy adding hours of silly arguments to your code reviews, you want to make sure that everyone is using the same code-quality tests and formatting rules.

I recommend that you start using `go vet` as a required part of your automated build process. Add `staticcheck` next since it produces few false positives. When you are interested in configuring tools and setting code-quality standards, look at `revive`, but be aware that it might have false positives and false negatives, so you can't require your team to fix every issue it reports. Once you are used to their recommendations, try out `golangci-lint` and tweak its settings until it works for your team.

Using govulncheck to Scan for Vulnerable Dependencies

One kind of code quality isn't enforced by the tools you've looked at so far: software vulnerabilities. Having a rich ecosystem of third-party modules is fantastic, but clever hackers find security vulnerabilities in libraries and exploit them. Developers patch these bugs when they are reported, but how do you ensure that the software that uses a vulnerable version of a library is updated to the fixed version?

The Go team has released a tool called `govulncheck` to address this situation. It scans through your dependencies and finds known vulnerabilities in both the standard library and in third-party libraries imported into your module. These vulnerabilities are reported in a public database maintained by the Go team. You can install it with this:

```
$ go install golang.org/x/vuln/cmd/govulncheck@latest
```

Let's take a look at a small program to see the vulnerability checker in action. First, download the repository. The source code in *main.go* is very simple. It imports a third-party YAML library and uses it to load a small YAML string into a struct:

```go
func main() {
    info := Info{}

    err := yaml.Unmarshal([]byte(data), &info)
    if err != nil {
        fmt.Printf("error: %v\n", err)
        os.Exit(1)
    }
    fmt.Printf("%+v\n", info)
}
```

The *go.mod* file contains the required modules and their versions:

```
module github.com/learning-go-book-2e/vulnerable
```

```
go 1.20

require gopkg.in/yaml.v2 v2.2.7

require gopkg.in/check.v1 v1.0.0-20201130134442-10cb98267c6c // indirect
```

Let's see what happens when you run `govulncheck` on this project:

```
$ govulncheck ./...
Using go1.21 and govulncheck@v1.0.0 with vulnerability data from
    https://vuln.go.dev (last modified 2023-07-27 20:09:46 +0000 UTC).

Scanning your code and 49 packages across 1 dependent module
    for known vulnerabilities...

Vulnerability #1: GO-2020-0036
    Excessive resource consumption in YAML parsing in gopkg.in/yaml.v2
  More info: https://pkg.go.dev/vuln/GO-2020-0036
  Module: gopkg.in/yaml.v2
    Found in: gopkg.in/yaml.v2@v2.2.7
    Fixed in: gopkg.in/yaml.v2@v2.2.8
    Example traces found:
      #1: main.go:25:23: vulnerable.main calls yaml.Unmarshal

Your code is affected by 1 vulnerability from 1 module.
```

This module is using an old and vulnerable version of the YAML package. `govulncheck` helpfully gives the exact line in the codebase that calls the problematic code.

If `govulncheck` knows there a vulnerability in a module that your code uses, but can't find an explicit call to the buggy part of the module, you'll get a less severe warning. The message informs you of the library's vulnerability and what version resolves the issue, but it will also let you know that your module is likely not affected.

Let's update to a fixed version and see if that solves the problem:

```
$ go get -u=patch gopkg.in/yaml.v2
go: downloading gopkg.in/yaml.v2 v2.2.8
go: upgraded gopkg.in/yaml.v2 v2.2.7 => v2.2.8
$ govulncheck ./...
Using go1.21and govulncheck@v1.0.0 with vulnerability data from
    https://vuln.go.dev (last modified 2023-07-27 20:09:46 +0000 UTC).

Scanning your code and 49 packages across 1 dependent module
    for known vulnerabilities...

No vulnerabilities found.
```

Remember, you should always strive for the smallest possible change to your project's dependencies since that makes it less likely that a change in a dependency breaks your code. For that reason, update to the most recent patch version for v2.2.*x*, which is v2.2.8. When `govulncheck` is run again, there are no known issues.

While `govulncheck` currently requires a `go install` to download it, it likely will be added to the standard toolset eventually. In the meantime, be sure to install and run it against your projects as a regular part of your builds. You can learn more about it in the blog post that announced it.

Embedding Content into Your Program

Many programs are distributed with directories of support files; you might have web page templates or some standard data that's loaded when a program starts. If a Go program needs support files, you could include a directory of files, but this takes away one of the advantages of Go: its ability to compile to a single binary that's easy to ship and distribute. However, there's another option. You can embed the contents of the files within your Go binary by using `go:embed` comments.

You can find a program demonstrating embedding on GitHub in the *sample_code/embed_passwords* directory in the Chapter 11 repository. It checks to see if a password is one of the 10,000 most commonly used passwords. Rather than write that list of passwords directly into the source code, you're going to embed it.

The code in *main.go* is straightforward:

```go
package main

import (
    _ "embed"
    "fmt"
    "os"
    "strings"
)

//go:embed passwords.txt
var passwords string

func main() {
    pwds := strings.Split(passwords, "\n")
    if len(os.Args) > 1 {
        for _, v := range pwds {
            if v == os.Args[1] {
                fmt.Println("true")
                os.Exit(0)
            }
        }
        fmt.Println("false")
    }
}
```

You must do two things to enable embedding. First, the `embed` package must be imported. The Go compiler uses this import as a flag to indicate that embedding should be enabled. Because this sample code isn't referring to anything exported from the `embed` package, you use a blank import, which was discussed in "Avoiding the init Function if Possible" on page 239. The only symbol exported from `embed` is `FS`. You'll see it in the next example.

Next, you place a magic comment directly before each package-level variable that holds the contents of a file. This comment must start with `go:embed`, with no space between the slashes and `go:embed`. The comment must also be on the line directly before the variable. (Technically, it is legal to have blank lines or other, nonmagic comments between the embedding comment and the variable declaration, but don't do it.) In this sample, you are embedding the contents of *passwords.txt* into the package-level variable named `passwords`. It is idiomatic to treat a variable with an embedded value as immutable. As mentioned earlier, you can embed into only a package-level variable. The variable must be of type `string`, `[]byte`, or `embed.FS`. If you have a single file, it's simplest to use `string` or `[]byte`.

If you need to place one or more directories of files into your program, use a variable of type `embed.FS`. This type implements three interfaces defined in the `io/fs` package: `FS`, `ReadDirFS`, and `ReadFileFS`. This allows an instance of `embed.FS` to represent a virtual filesystem. The following program provides a simple command-line help system. If you don't provide a help file, it lists all available files. If you specify a file that's not present, it returns an error:

```go
package main

import (
    "embed"
    "fmt"
    "io/fs"
    "os"
    "strings"
)

//go:embed help
var helpInfo embed.FS

func main() {
    if len(os.Args) == 1 {
        printHelpFiles()
        os.Exit(0)
    }
    data, err := helpInfo.ReadFile("help/" + os.Args[1])
    if err != nil {
        fmt.Println(err)
        os.Exit(1)
    }
    fmt.Println(string(data))
}
```

You can find this code, along with the sample help files, in the *sample_code/help_system* directory in the Chapter 11 repository.

Here's the output when you build and run this program:

```
$ go build
$ ./help_system
contents:
advanced/topic1.txt
advanced/topic2.txt
info.txt

$ ./help_system advanced/topic1.txt
This is advanced topic 1.

$ ./help_system advanced/topic3.txt
open help/advanced/topic3.txt: file does not exist
```

You should notice a couple of things. First, you no longer need to use a blank import for `embed`, since you are using `embed.FS`. Second, the directory name is part of the filesystem that's embedded. The users of this program don't enter the "help/" prefix, so you have to prepend it in the call to `ReadFile`.

The `printHelpFiles` function shows how you can treat an embedded virtual filesystem just like a real one:

```
func printHelpFiles() {
    fmt.Println("contents:")
    fs.WalkDir(helpInfo, "help",
        func(path string, d fs.DirEntry, err error) error {
            if !d.IsDir() {
                _, fileName, _ := strings.Cut(path, "/")
                fmt.Println(fileName)
            }
            return nil
        })
}
```

You use the `WalkDir` function in `io/fs` to walk through the embedded filesystem. `WalkDir` takes in an instance of `fs.FS`, a path to start at, and a function. This function is called for every file and directory in the filesystem, starting from the specified path. If the `fs.DirEntry` is not a directory, you print out its full pathname, removing the `help/` prefix by using `strings.Cut`.

There are a few more things to know about file embedding. While all the examples have been text files, you can embed binary files as well. You can also embed multiple files or directories into a single `embed.FS` variable by specifying their names, separated by spaces. When embedding a file or directory that has a space in its name, put the name in quotes.

In addition to exact file and directory names, you can use wildcards and ranges to specify the names of the files and directories you want to embed. The syntax is defined in the documentation for the Match function in the `path` package in the standard library, but it follows common conventions. For example, `*` matches 0 or more characters, and `?` matches a single character.

All embedding specifications, whether or not they use match patterns, are checked by the compiler. If they aren't valid, compilation fails. Here are the ways a pattern can be invalid:

- If the specified name or pattern doesn't match a file or directory
- If you specify multiple filenames or patterns for a `string` or `[]byte` variable
- If you specify a pattern for a `string` or `[]byte` variable and it matches more than one file

Embedding Hidden Files

Including files in a directory tree that start with `.` or `_` is a little complicated. Many operating systems consider these to be hidden files, so they are not included by default when a directory name is specified. However, you can override this behavior in two ways. The first is to put `/*` after the name of a directory you want to embed. This will include all hidden files within the root directory, but it will not include hidden files in its subdirectories. To include all hidden files in all subdirectories, put `all:` before the name of the directory.

This sample program (which you can find in the *sample_code/embed_hidden* directory in the Chapter 11 repository) makes this easier to understand. In the sample, the directory *parent_dir* contains two files, *.hidden* and *visible*, and one subdirectory, *child_dir*. The *child_dir* subdirectory contains two files, *.hidden* and *visible*.

Here is the code for the program:

```
//go:embed parent_dir
var noHidden embed.FS

//go:embed parent_dir/*
var parentHiddenOnly embed.FS

//go:embed all:parent_dir
var allHidden embed.FS
```

```
func main() {
    checkForHidden("noHidden", noHidden)
    checkForHidden("parentHiddenOnly", parentHiddenOnly)
    checkForHidden("allHidden", allHidden)
}

func checkForHidden(name string, dir embed.FS) {
    fmt.Println(name)
    allFileNames := []string{
        "parent_dir/.hidden",
        "parent_dir/child_dir/.hidden",
    }
    for _, v := range allFileNames {
        _, err := dir.Open(v)
        if err == nil {
            fmt.Println(v, "found")
        }
    }
    fmt.Println()
}
```

The output of the program is shown here:

```
noHidden

parentHiddenOnly
parent_dir/.hidden found

allHidden
parent_dir/.hidden found
parent_dir/child_dir/.hidden found
```

Using go generate

The `go generate` tool is a little different, because it doesn't do anything by itself. When you run `go generate`, it looks for specially formatted comments in your source code and runs programs specified in those comments. While you could use `go generate` to run anything at all, it is most commonly used by developers to run tools that (unsurprisingly, given the name) generate source code. This could be from analyzing existing code and adding functionality or processing schemas and making source code out of it.

A good example of something that can be automatically converted to code are Protocol Buffers, sometimes called *protobufs*. Protobuf is a popular binary format that is used by Google to store and transmit data. When working with protobufs, you write a *schema*, which is a language-independent description of the data structure. Developers who want to write programs to interact with data in protobuf format run tools that process the schema and produce language-specific data structures to hold the data and language-specific functions to read and write data in protobuf format.

Let's see how this works in Go. You can find a sample module in the proto_generate repo. The module contains a protobuf schema file called *person.proto*:

```
syntax = "proto3";

message Person {
  string name = 1;
  int32 id = 2;
  string email = 3;
}
```

While making a struct that implements `Person` would be easy, writing the code to convert back and forth from the binary format is difficult. Let's use tools from Google to do the hard work and invoke them with `go generate`. You need to install two things. The first is the `protoc` binary for your computer (see the installation instructions. Next, use `go install` to install the Go protobuf plug-ins:

```
$ go install google.golang.org/protobuf/cmd/protoc-gen-go@v1.28
```

In *main.go*, there is the magic comment that's processed by `go generate`:

```
//go:generate protoc -I=. --go_out=.
  --go_opt=module=github.com/learning-go-book-2e/proto_generate
  --go_opt=Mperson.proto=github.com/learning-go-book-2e/proto_generate/data
  person.proto
```

(If you look at the source code in GitHub, you'll see this should be a single line. It's wrapped to fit the constraints of a printed page.)

Run `go generate` by typing the following:

```
$ go generate ./...
```

After running `go generate`, you'll see a new directory called *data* that contains a file named *person.pb.go*. It contains the source code for the `Person` struct, and some methods and functions that are used by the `Marshal` and `Unmarshal` functions in the `google.golang.org/protobuf/proto` module. You call these functions in your `main` function:

```
func main() {
    p := &data.Person{
        Name:  "Bob Bobson",
        Id:    20,
        Email: "bob@bobson.com",
    }
    fmt.Println(p)
    protoBytes, _ := proto.Marshal(p)
    fmt.Println(protoBytes)
    var p2 data.Person
    proto.Unmarshal(protoBytes, &p2)
    fmt.Println(&p2)
}
```

Build and run the program as usual:

```
$ go build
$ ./proto_generate
name:"Bob Bobson"  id:20  email:"bob@bobson.com"
[10 10 66 111 98 32 66 111 98 115 111 110 16 20 26 14 98
  111 98 64 98 111 98 115 111 110 46 99 111 109]
name:"Bob Bobson"  id:20  email:"bob@bobson.com"
```

Another tool commonly used with `go generate` is `stringer`. As I discussed in "iota Is for Enumerations—Sometimes" on page 152, enumerations in Go lack many of the features that are found in other languages with enumerations. One of those features is automatically generating a printable name for each value in the enumeration. The `stringer` tool is used with `go generate` to add a `String` method to your enumeration's values so they can be printed.

Install `stringer` with `go install golang.org/x/tools/cmd/stringer@latest`. The *sample_code/stringer_demo* directory in the Chapter 11 repository provides a very simple example of how to use `stringer`. Here's the source in *main.go*:

```
type Direction int

const (
    _ Direction = iota
    North
    South
    East
    West
)

//go:generate stringer -type=Direction

func main() {
    fmt.Println(North.String())
}
```

Run `go generate ./...` and you'll see a new file generated called *direction_string.go*. Use `go build` to build the `string_demo` binary and when you run it, you'll get the output:

```
North
```

You can configure `stringer` and its output in multiple ways. Arjun Mahishi has written a great blog post describing how to use `stringer` and customize its output.

Working with go generate and Makefiles

Since the job of `go generate` is to run other tools, you might wonder if it's worth using when you have a perfectly good Makefile in your project. The advantage of `go generate` is that it creates a separation of responsibilities. Use `go generate` commands to mechanically create source code, and use the Makefile to validate and compile source code.

It is a best practice to commit the source code created by `go generate` to version control. (The sample projects in the Chapter 11 repository don't include generated source code so you can see `go generate` work.) This allows people browsing your source code to see everything that's invoked, even the generated parts. It also means they don't need to have tools like `protoc` installed in order to build your code.

Checking in your generated source code technically means that you don't *need* to run `go generate` unless it will produce different output, such as processing a modified protobuf definition or an updated enumeration. However, it's still a good idea to automate calling `go generate` before `go build`. Relying on a manual process is asking for trouble. Some generator tools, like `stringer`, include clever tricks to block compilation if you forget to rerun `go generate`, but that's not universal. You'll inevitably waste time during testing trying to understand why a change didn't show up before realizing that you forgot to invoke `go generate`. (I made this mistake multiple times before I learned my lesson.) Given this, it is best to add a `generate` step to your Makefile and make it a dependency of your `build` step.

However, I would disregard this advice in two situations. The first is if invoking `go generate` on identical input produces source files with minor differences, such as a timestamp. A well-written `go generate` tool should produce identical output every time it's run on the same input, but there are no guarantees that every tool you need to use is well written. You don't want to keep on checking in new versions of files that are functionally identical, as they will clutter your version control system and make your code reviews noisier.

The second situation is if `go generate` takes a very long time to complete. Fast builds are a feature of Go, because they allow developers to stay focused and get rapid feedback. If you are noticeably slowing down a build to generate identical files, the loss in developer productivity is not worth it. In both cases, all you can do is leave lots of comments to remind people to rebuild when things change and hope that everyone on your team is diligent.

Reading the Build Info Inside a Go Binary

As companies develop more of their own software, it is becoming increasingly common for them to want to understand exactly what they have deployed to their data centers and cloud environments, down to the version and the dependencies. You might wonder why you'd want to get this information from compiled code. After all, a company already has this information in version control.

Companies with mature development and deployment pipelines can capture this information right before deploying a program, allowing them to be sure that the information is accurate. However, many, if not most, companies don't track the exact version of internal software that's deployed. In some cases, software can be deployed for years without being replaced, and no one remembers much about it. If a vulnerability is reported in a version of a third-party library, you need to either find some way to scan your deployed software and figure out what versions of third-party libraries are deployed, or redeploy everything just to be safe. In the Java world, this exact problem happened when a serious vulnerability was discovered in the popular Log4j library.

Luckily, Go solves this problem for you. Every Go binary you create with `go build` automatically contains build information on what versions of what modules make up the binary, and also what build commands were used, what version control system was used, and what revision the code was at in your version control system. You can view this information with the `go version -m` command. The following shows the output for the `vulnerable` program when built on an Apple Silicon Mac:

```
$ go build
go: downloading gopkg.in/yaml.v2 v2.2.7
$ go version -m vulnerable
vulnerable: go1.20
    path    github.com/learning-go-book-2e/vulnerable
    mod     github.com/learning-go-book-2e/vulnerable    (devel)
    dep     gopkg.in/yaml.v2  v2.2.7  h1:VUgggvou5XRW9mHwD/yXxIYSMtY0zoKQf/v...
    build   -compiler=gc
    build   CGO_ENABLED=1
    build   CGO_CFLAGS=
    build   CGO_CPPFLAGS=
    build   CGO_CXXFLAGS=
    build   CGO_LDFLAGS=
    build   GOARCH=arm64
    build   GOOS=darwin
    build   vcs=git
    build   vcs.revision=623a65b94fd02ea6f18df53afaaea3510cd1e611
    build   vcs.time=2022-10-02T03:31:05Z
    build   vcs.modified=false
```

Because this information is embedded into every binary, `govulncheck` is capable of scanning Go programs to check for libraries with known vulnerabilities:

```
$ govulncheck -mode binary vulnerable
Using govulncheck@v1.0.0 with vulnerability data from
    https://vuln.go.dev (last modified 2023-07-27 20:09:46 +0000 UTC).
```

```
Scanning your binary for known vulnerabilities...

Vulnerability #1: GO-2020-0036
    Excessive resource consumption in YAML parsing in gopkg.in/yaml.v2
  More info: https://pkg.go.dev/vuln/GO-2020-0036
  Module: gopkg.in/yaml.v2
    Found in: gopkg.in/yaml.v2@v2.2.7
    Fixed in: gopkg.in/yaml.v2@v2.2.8
    Example traces found:
      #1: yaml.Unmarshal

Your code is affected by 1 vulnerability from 1 module.
```

Be aware that `govulncheck` can't track down exact lines of code when inspecting a binary. If `govulncheck` finds a problem in a binary, use `go version -m` to find out the exact deployed version, check the code out of version control, and run it again against the source code to pinpoint the issue.

If you want to build your own tools to read the build information, look at the `debug/buildinfo` package in the standard library.

Building Go Binaries for Other Platforms

One of the advantages of a VM-based language like Java, JavaScript, or Python is that you can take your code and get it to run on any computer where the virtual machine has been installed. This portability makes it easy for developers using these languages to build programs on a Windows or Mac computer and deploy it on a Linux server, even though the operating system and possibly the CPU architecture are different.

Go programs are compiled to native code, so the generated binary is compatible with only a single operating system and CPU architecture. However, that doesn't mean that Go developers need to maintain a menagerie of machines (virtual or otherwise) to release on multiple platforms. The `go build` command makes it easy to *cross-compile*, or create a binary for a different operating system and/or CPU. When `go build` is run, the target operating system is specified by the `GOOS` environment variable. Similarly, the `GOARCH` environment variable specifies the CPU architecture. If you don't set them explicitly, `go build` defaults to using the values for your current computer, which is why you've never had to worry about these variables before.

You can find the valid values and combinations for `GOOS` and `GOARCH` (sometimes pronounced "GOOSE" and "GORCH") in the installation documentation. Some of the supported operating systems and CPUs are a bit esoteric, and others might require some translation. For example, `darwin` refers to macOS (Darwin is the name of the macOS kernel), and `amd64` means 64-bit Intel-compatible CPUs.

Let's go back to the `vulnerable` program one last time. When using an Apple Silicon Mac (which has an ARM64 CPU), running `go build` defaults to `darwin` for `GOOS` and `arm64` for `GOARCH`. You can confirm this using the `file` command:

```
$ go build
$ file vulnerable
vulnerable: Mach-O 64-bit executable arm64
```

Here is how to build a binary for Linux on 64-bit Intel CPUs:

```
$ GOOS=linux GOARCH=amd64 go build
$ file vulnerable
vulnerable: ELF 64-bit LSB executable, x86-64, version 1 (SYSV),
    statically linked, Go BuildID=IDHVCE8XQPpWluGpMXpX/4VU3GpRZEifN
    8TzUrT_6/1c30VcDYNVPfSSN-zCkz/JsZSLAbWkxqIVhPkC5p5, with debug_info,
    not stripped
```

Using Build Tags

When writing programs that need to run on multiple operating systems or CPU architectures, you sometimes need different code for different platforms. You also might want to write a module that takes advantage of the latest Go features but is still backward compatible with older Go compilers.

You can create targeted code in two ways. The first is to use the name of the file to indicate when the file should be included in the build. You do this by adding the target *GOOS* and *GOARCH*, separated by _, to the filename before *.go*. For example, if you have a file that you want to be compiled only on Windows, you'd name the file *something_windows.go*, but if you wanted it to be compiled only when building for ARM64 Windows, name the file *something_windows_arm64.go*.

A *build tag* (also called a *build constraint*) is the other option you can use to specify when a file is compiled. Like embedding and generating, build tags take advantage of a magic comment. In this case, it's `//go:build`. This comment must be placed on the line before the package declaration in your file.

Build tags use boolean operators (`||`, `&&`, and `!`) and parentheses to specify exact build rules for architectures, operating systems, and Go versions. The build tag `//go:build (!darwin && !linux) || (darwin && !go1.12)`—which really appears in the Go standard library—specifies that the file should not be compiled on Linux or macOS, except it's OK to compile it on macOS if the Go version is 1.11 or earlier.

Some meta build constraints are also available. The constraint `unix` matches any Unix-ish platform, and `cgo` matches if `cgo` is supported by the current platform and is enabled. (I cover `cgo` in "Cgo Is for Integration, Not Performance" on page 433.)

The question becomes when you should use filenames to indicate where to run code and when you should use build tags. Because build tags allow binary operators, you can specify a more specific set of platforms with them. The Go standard library sometimes takes a belt-and-suspenders approach. The package `internal/cpu` in the standard library has platform-specific source code for CPU feature detection. The file *internal/cpu/cpu_arm64_darwin.go* has a name that indicates that it is meant only for computers using Apple CPUs. It also has a `//go:build arm64 && darwin && !ios` line in the file to indicate that it should be compiled only when building for Apple Silicon Macs and not for iPhones or iPads. The build tags are able to specify the target platform with more detail, but following the filename convention makes it easy for a person to find the right file for a given platform.

In addition to the built-in build tags that represent Go versions, operating systems and CPU architectures, you can also use any string at all as a custom build tag. You can then control compilation of that file with the `-tags` command-line flag. For example, if you put `//go:build gopher` on the line before the package declaration in a file, it will not be compiled unless you include a `-tags gopher` flag as part of the `go build`, `go run`, or `go test` command.

Custom build tags are surprisingly handy. If you have a source file that you don't want to build right now (perhaps it doesn't compile yet, or it's an experiment that's not ready to be included), it is idiomatic to skip over the file by putting `//go:build ignore` on the line before the package declaration. You will see another use for custom build tags when looking at integration tests in "Using Integration Tests and Build Tags" on page 405.

When writing your build tags, make sure there isn't any whitespace between the `//` and `go:build`. If there is, Go will not consider it a build tag.

Testing Versions of Go

Despite Go's strong backward-compatibility guarantees, bugs do happen. It's natural to want to make sure that a new release doesn't break your programs. You also might get a bug report from a user of your library saying that your code doesn't work as expected on an older version of Go. One option is to install a secondary Go environment. For example, if you wanted to try out version 1.19.2, you would use the following commands:

```
$ go install golang.org/dl/go1.19.2@latest
$ go1.19.2 download
```

You can then use the command `go1.19.2` instead of the `go` command to see if version 1.19.2 works for your programs:

```
$ go1.19.2 build
```

Once you have validated that your code works, you can uninstall the secondary environment. Go stores secondary Go environments in the *sdk* directory within your home directory. To uninstall, delete the environment from the *sdk* directory and the binary from the *go/bin* directory. Here's how to do that on macOS, Linux, and BSD:

```
$ rm -rf ~/sdk/go.19.2
$ rm ~/go/bin/go1.19.2
```

Using go help to Learn More About Go Tooling

You can learn more about Go's tooling and runtime environment with the `go help` command. It contains exhaustive information about all the commands mentioned here, as well as things like modules, import path syntax, and working with nonpublic source code. For example, you can get information on import path syntax by typing `go help importpath`.

Exercises

These exercises cover some of the tools that you've learned about in this chapter. You can find the solutions in the *exercise_solutions* directory in the Chapter 11 repository.

1. Go to the UN's Universal Declaration of Human Rights (UDHR) page and copy the text of the UDHR into a text file called *english_rights.txt*. Click the Other Languages link and copy the document text in a few additional languages into files named *LANGUAGE_rights.txt*. Create a program that embeds these files into package-level variables. Your program should take in one command-line parameter, the name of a language. It should then print out the UDHR in that language.
2. Use `go install` to install `staticcheck`. Run it against your program and fix any problems it finds.
3. Cross-compile your program for ARM64 on Windows. If you are using an ARM64 Windows computer, cross-compile for AMD64 on Linux.

Wrapping Up

In this chapter, you learned about the tools that Go provides to improve software engineering practices and third-party code-quality tools. In the next chapter, you're going to explore one of the signature features in Go: concurrency.

CHAPTER 12

Concurrency in Go

Concurrency is the computer science term for breaking up a single process into independent components and specifying how these components safely share data. Most languages provide concurrency via a library using operating system–level threads that share data by attempting to acquire locks. Go is different. Its main concurrency model, arguably Go's most famous feature, is based on Communicating Sequential Processes (CSP). This style for concurrency was described in 1978 in a paper by Tony Hoare, the man who invented the Quicksort algorithm. The patterns implemented with CSP are just as powerful as the standard ones but are far easier to understand.

In this chapter, you are going to quickly review the features that are the backbone of concurrency in Go: goroutines, channels, and the `select` keyword. Then you are going to look at some common Go concurrency patterns and learn about the situations where lower-level techniques are a better approach.

When to Use Concurrency

Let's start with a word of caution. Be sure that your program benefits from concurrency. When new Go developers start experimenting with concurrency, they tend to go through a series of stages:

1. This is *amazing*; I'm going to put everything in goroutines!
2. My program isn't any faster. I'm adding buffers to my channels.
3. My channels are blocking and I'm getting deadlocks. I'm going to use buffered channels with *really* big buffers.

4. My channels are still blocking. I'm going to use mutexes.
5. Forget it, I'm giving up on concurrency.

People are attracted to concurrency because they believe concurrent programs run faster. Unfortunately, that's not always the case. More concurrency doesn't automatically make things faster, and it can make code harder to understand. The key is understanding that *concurrency is not parallelism*. Concurrency is a tool to better structure the problem you are trying to solve.

Whether concurrent code runs in parallel (at the same time) depends on the hardware and whether the algorithm allows it. In 1967, Gene Amdahl, one of the pioneers of computer science, derived Amdahl's law. It is a formula for figuring out how much parallel processing can improve performance, given how much of the work must be performed sequentially. If you want to dive into the details on Amdahl's law, you can learn more in *The Art of Concurrency* by Clay Breshears (O'Reilly). For our purposes, all you need to understand is that more concurrency does not mean more speed.

Broadly speaking, all programs follow the same three-step process: they take data, transform it, and then output the result. Whether you should use concurrency in your program depends on how data flows through the steps in your program. Sometimes two steps can be concurrent because the data from one is not required for the other to proceed, and at other times two steps must happen in series because one depends on the other's output. Use concurrency when you want to combine data from multiple operations that can operate independently.

Another important thing to note is that concurrency isn't worth using if the process that's running concurrently doesn't take a lot of time. Concurrency isn't free; many common in-memory algorithms are so fast that the overhead of passing values via concurrency overwhelms any potential time savings you'd gain by running concurrent code in parallel. This is why concurrent operations are often used for I/O; reading or writing to a disk or network is thousands of times slower than all but the most complicated in-memory processes. If you are not sure if concurrency will help, first write your code serially and then write a benchmark to compare performance with a concurrent implementation. (See "Using Benchmarks" on page 393 for information on how to benchmark your code.)

Let's consider an example. Say you are writing a web service that calls three other web services. Your program sends data to two of those services, and then takes the results of those two calls and sends them to the third, returning the result. The entire process must take less than 50 milliseconds, or an error should be returned. This is a good use of concurrency, because there are parts of the code that need to perform I/O that can run without interacting with one another, there's a part where the results are combined, and there's a limit on how long the code needs to run. At the end of this chapter, you'll see how to implement this code.

Goroutines

The goroutine is the core concept in Go's concurrency model. To understand goroutines, let's define a couple of terms. The first is *process*. A process is an instance of a program that's being run by a computer's operating system. The operating system associates some resources, such as memory, with the process and makes sure that other processes can't access them. A process is composed of one or more *threads*. A thread is a unit of execution that is given some time to run by the operating system. Threads within a process share access to resources. A CPU can execute instructions from one or more threads at the same time, depending on the number of cores. One of the jobs of an operating system is to schedule threads on the CPU to make sure that every process (and every thread within a process) gets a chance to run.

Think of a goroutine as a lightweight thread, managed by the Go runtime. When a Go program starts, the Go runtime creates a number of threads and launches a single goroutine to run your program. All the goroutines created by your program, including the initial one, are assigned to these threads automatically by the Go runtime scheduler, just as the operating system schedules threads across CPU cores. This might seem like extra work, since the underlying operating system already includes a scheduler that manages threads and processes, but it has several benefits:

- Goroutine creation is faster than thread creation, because you aren't creating an operating system–level resource.
- Goroutine initial stack sizes are smaller than thread stack sizes and can grow as needed. This makes goroutines more memory efficient.
- Switching between goroutines is faster than switching between threads because it happens entirely within the process, avoiding operating system calls that are (relatively) slow.
- The goroutine scheduler is able to optimize its decisions because it is part of the Go process. The scheduler works with the network poller, detecting when a goroutine can be unscheduled because it is blocking on I/O. It also integrates with the garbage collector, making sure that work is properly balanced across all the operating system threads assigned to your Go process.

These advantages allow Go programs to spawn hundreds, thousands, even tens of thousands of simultaneous goroutines. If you try to launch thousands of threads in a language with native threading, your program will slow to a crawl.

If you are interested in learning more about how the scheduler does its work, watch the talk Kavya Joshi gave at GopherCon 2018 called "The Scheduler Saga".

A goroutine is launched by placing the `go` keyword before a function invocation. Just as with any other function, you can pass it parameters to initialize its state. However, any values returned by the function are ignored.

Any function can be launched as a goroutine. This is different from JavaScript, where a function runs asynchronously only if the author of the function declared it with the `async` keyword. However, it is customary in Go to launch goroutines with a closure that wraps business logic. The closure takes care of the concurrent bookkeeping. The following sample code demonstrates the concept:

```
func process(val int) int {
    // do something with val
}

func processConcurrently(inVals []int) []int {
    // create the channels
    in := make(chan int, 5)
    out := make(chan int, 5)
    // launch processing goroutines
    for i := 0; i < 5; i++ {
        go func() {
            for val := range in {
                out <- process(val)
            }
        }()
    }
    // load the data into the in channel in another goroutine
    // read the data from the out channel
    // return the data
}
```

In this code, the `processConcurrently` function creates a closure, which reads values out of a channel and passes them to the business logic in the `process` function. The `process` function is completely unaware that it is running in a goroutine. The result of `process` is then written back to a different channel by the closure. (I'll do a brief overview of channels in the next section.) This separation of responsibility makes your programs modular and testable, and keeps concurrency out of your APIs. The decision to use a thread-like model for concurrency means that Go programs avoid the "function coloring" problem described by Bob Nystrom in his famous blog post "What Color Is Your Function?"

You can find a complete example on The Go Playground or in the *sample_code/goroutine* directory in the Chapter 12 repository.

Channels

Goroutines communicate using *channels*. Like slices and maps, channels are a built-in type created using the `make` function:

```
ch := make(chan int)
```

Like maps, channels are reference types. When you pass a channel to a function, you are really passing a pointer to the channel. Also like maps and slices, the zero value for a channel is `nil`.

Reading, Writing, and Buffering

Use the `<-` operator to interact with a channel. You read from a channel by placing the `<-` operator to the left of the channel variable, and you write to a channel by placing it to the right:

```
a := <-ch // reads a value from ch and assigns it to a
ch <- b   // write the value in b to ch
```

Each value written to a channel can be read only once. If multiple goroutines are reading from the same channel, a value written to the channel will be read by only one of them.

A single goroutine rarely reads and writes to the same channel. When assigning a channel to a variable or field, or passing it to a function, use an arrow before the `chan` keyword (`ch <-chan int`) to indicate that the goroutine only *reads* from the channel. Use an arrow after the `chan` keyword (`ch chan<- int`) to indicate that the goroutine only *writes* to the channel. Doing so allows the Go compiler to ensure that a channel is only read from or written to by a function.

By default, channels are *unbuffered*. Every write to an open, unbuffered channel causes the writing goroutine to pause until another goroutine reads from the same channel. Likewise, a read from an open, unbuffered channel causes the reading goroutine to pause until another goroutine writes to the same channel. This means you cannot write to or read from an unbuffered channel without at least two concurrently running goroutines.

Go also has *buffered* channels. These channels buffer a limited number of writes without blocking. If the buffer fills before there are any reads from the channel, a subsequent write to the channel pauses the writing goroutine until the channel is read. Just as writing to a channel with a full buffer blocks, reading from a channel with an empty buffer also blocks.

A buffered channel is created by specifying the capacity of the buffer when creating the channel:

```
ch := make(chan int, 10)
```

The built-in functions `len` and `cap` return information about a buffered channel. Use `len` to find out how many values are currently in the buffer and use `cap` to find out the maximum buffer size. The capacity of the buffer cannot be changed.

Passing an unbuffered channel to both `len` and `cap` returns 0. This makes sense because, by definition, an unbuffered channel doesn't have a buffer to store values.

Most of the time, you should use unbuffered channels. In "Know When to Use Buffered and Unbuffered Channels" on page 301, I'll talk about the situations where buffered channels are useful.

Using for-range and Channels

You can also read from a channel by using a `for-range` loop:

```
for v := range ch {
    fmt.Println(v)
}
```

Unlike other `for-range` loops, there is only a single variable declared for the channel, which is the value. If the channel is open and a value is available on the channel, it is assigned to `v` and the body of the loop executes. If no value is available on the channel, the goroutine pauses until a value is available or the channel is closed. The loop continues until the channel is closed, or until a `break` or `return` statement is reached.

Closing a Channel

When you're done writing to a channel, you close it using the built-in `close` function:

```
close(ch)
```

Once a channel is closed, any attempts to write to it or close it again will panic. Interestingly, attempting to read from a closed channel always succeeds. If the channel is buffered and some values haven't been read yet, they will be returned in order. If the channel is unbuffered or the buffered channel has no more values, the zero value for the channel's type is returned.

This leads to a question that might sound familiar from your experience with maps: when your code reads from a channel, how do you tell the difference between a zero value that was written and a zero value that was returned because the channel is closed? Since Go tries to be a consistent language, there is a familiar answer—use the comma ok idiom to detect whether a channel has been closed:

```
v, ok := <-ch
```

If `ok` is set to `true`, the channel is open. If it is set to `false`, the channel is closed.

Anytime you are reading from a channel that might be closed, use the comma ok idiom to ensure that the channel is still open.

The responsibility for closing a channel lies with the goroutine that writes to the channel. Be aware that closing a channel is required only if a goroutine is waiting for the channel to close (such as one using a `for-range` loop to read from the channel). Since a channel is just another variable, Go's runtime can detect channels that are no longer referenced and garbage collect them.

Channels are one of the two things that set apart Go's concurrency model. They guide you into thinking about your code as a series of stages and making data dependencies clear, which makes it easier to reason about concurrency. Other languages rely on global shared state to communicate between threads. This mutable shared state makes it hard to understand how data flows through a program, which in turn makes it difficult to understand whether two threads are actually independent.

Understanding How Channels Behave

Channels have many states, each with a different behavior when reading, writing, or closing. Use Table 12-1 to keep them straight.

Table 12-1. How channels behave

	Unbuffered, open	Unbuffered, closed	Buffered, open	Buffered, closed	Nil
Read	Pause until something is written	Return zero value (use comma ok to see if closed)	Pause if buffer is empty	Return a remaining value in the buffer; if the buffer is empty, return zero value (use comma ok to see if closed)	Hang forever
Write	Pause until something is read	PANIC	Pause if buffer is full	PANIC	Hang forever
Close	Works	PANIC	Works, remaining values still there	PANIC	PANIC

You must avoid situations that cause Go programs to panic. As mentioned earlier, the standard pattern is to make the writing goroutine responsible for closing the channel when there's nothing left to write. When multiple goroutines are writing to the same channel, this becomes more complicated, as calling `close` twice on the same channel causes a panic. Furthermore, if you close a channel in one goroutine, a write to the channel in another goroutine triggers a panic as well. The way to address this is to use a `sync.WaitGroup`. You'll see an example in "Use WaitGroups" on page 306.

A `nil` channel can be dangerous as well, but it is useful in some cases. You'll learn more about them in "Turn Off a case in a select" on page 304.

select

The `select` statement is the other thing that sets apart Go's concurrency model. It is the control structure for concurrency in Go, and it elegantly solves a common problem: if you can perform two concurrent operations, which one do you do first? You can't favor one operation over others, or you'll never process some cases. This is called *starvation*.

The `select` keyword allows a goroutine to read from or write to one of a set of multiple channels. It looks a great deal like a blank `switch` statement:

```go
select {
case v := <-ch:
    fmt.Println(v)
case v := <-ch2:
    fmt.Println(v)
case ch3 <- x:
    fmt.Println("wrote", x)
case <-ch4:
    fmt.Println("got value on ch4, but ignored it")
}
```

Each `case` in a `select` is a read or a write to a channel. If a read or write is possible for a `case`, it is executed along with the body of the `case`. Like a `switch`, each `case` in a `select` creates its own block.

What happens if multiple cases have channels that can be read or written? The `select` algorithm is simple: it picks randomly from any of its cases that can go forward; order is unimportant. This is very different from a `switch` statement, which always chooses the first `case` that resolves to `true`. It also cleanly resolves the starvation problem, as no `case` is favored over another and all are checked at the same time.

Another advantage of `select` choosing at random is that it prevents one of the most common causes of deadlocks: acquiring locks in an inconsistent order. If you have two goroutines that both access the same two channels, they must be accessed in the same order in both goroutines, or they will *deadlock*. This means that neither one can proceed because they are waiting on each other. If every goroutine in your Go application is deadlocked, the Go runtime kills your program (see Example 12-1).

Example 12-1. Deadlocking goroutines

```go
func main() {
    ch1 := make(chan int)
    ch2 := make(chan int)
    go func() {
        inGoroutine := 1
        ch1 <- inGoroutine
        fromMain := <-ch2
        fmt.Println("goroutine:", inGoroutine, fromMain)
    }()
    inMain := 2
    ch2 <- inMain
    fromGoroutine := <-ch1
    fmt.Println("main:", inMain, fromGoroutine)
}
```

If you run this program on The Go Playground or in the *sample_code/deadlock* directory in the Chapter 12 repository, you'll see the following error:

```
fatal error: all goroutines are asleep - deadlock!
```

Remember that `main` is running on a goroutine that is launched at startup by the Go runtime. The goroutine that is explicitly launched cannot proceed until `ch1` is read, and the main goroutine cannot proceed until `ch2` is read.

If the channel read and the channel write in the main goroutine are wrapped in a `select`, deadlock is avoided (see Example 12-2).

Example 12-2. Using `select` to avoid deadlocks

```go
func main() {
    ch1 := make(chan int)
    ch2 := make(chan int)
    go func() {
        inGoroutine := 1
        ch1 <- inGoroutine
        fromMain := <-ch2
        fmt.Println("goroutine:", inGoroutine, fromMain)
    }()
    inMain := 2
    var fromGoroutine int
    select {
    case ch2 <- inMain:
    case fromGoroutine = <-ch1:
    }
    fmt.Println("main:", inMain, fromGoroutine)
}
```

If you run this program on The Go Playground or in the *sample_code/select* directory in the Chapter 12 repository, you'll get the output:

```
main: 2 1
```

Because a `select` checks whether any of its cases can proceed, the deadlock is avoided. The goroutine that is launched explicitly wrote the value 1 into `ch1`, so the read from `ch1` into `fromGoroutine` in the main goroutine is able to succeed.

Although this program doesn't deadlock, it still doesn't do the right thing. The `fmt.Println` statement in the launched goroutine never executes, because that goroutine is paused, waiting for a value to read from `ch2`. When the main goroutine exits, the program exits and kills any remaining goroutines, which does technically resolve the pause. However, you should make sure that all your goroutines exit properly so that you don't *leak* them. I talk about this in more detail in "Always Clean Up Your Goroutines" on page 299.

Making this program behave properly requires a few techniques that you'll learn about later in the chapter. You can find a working solution on The Go Playground.

Since `select` is responsible for communicating over a number of channels, it is often embedded within a `for` loop:

```
for {
    select {
    case <-done:
        return
    case v := <-ch:
        fmt.Println(v)
    }
}
```

This is so common that the combination is often referred to as a `for-select` loop. When using a `for-select` loop, you must include a way to exit the loop. You'll see one way to do this in "Use the Context to Terminate Goroutines" on page 300.

Just like `switch` statements, a `select` statement can have a `default` clause. Also just like `switch`, `default` is selected when there are no cases with channels that can be read or written. If you want to implement a nonblocking read or write on a channel, use a `select` with a `default`. The following code does not wait if there's no value to read in `ch`; it immediately executes the body of the `default`:

```
select {
case v := <-ch:
    fmt.Println("read from ch:", v)
default:
    fmt.Println("no value written to ch")
}
```

You'll take a look at a use for `default` in "Implement Backpressure" on page 302.

> Having a `default` case inside a `for-select` loop is almost always the wrong thing to do. It will be triggered every time through the loop when there's nothing to read or write for any of the cases. This makes your `for` loop run constantly, which uses a great deal of CPU.

Concurrency Practices and Patterns

Now that you've seen the basic tools that Go provides for concurrency, let's take a look at some concurrency best practices and patterns.

Keep Your APIs Concurrency-Free

Concurrency is an implementation detail, and good API design should hide implementation details as much as possible. This allows you to change how your code works without changing how your code is invoked.

Practically, this means that you should never expose channels or mutexes in your API's types, functions, and methods (I'll talk about mutexes in "When to Use Mutexes Instead of Channels" on page 313). If you expose a channel, you put the responsibility of channel management on the users of your API. The users then have to worry about concerns like whether a channel is buffered or closed or `nil`. They can also trigger deadlocks by accessing channels or mutexes in an unexpected order.

> This doesn't mean that you shouldn't ever have channels as function parameters or struct fields. It means that they shouldn't be exported.

This rule has some exceptions. If your API is a library with a concurrency helper function, channels are going to be part of its API.

Goroutines, for Loops, and Varying Variables

Most of the time, the closure that you use to launch a goroutine has no parameters. Instead, it captures values from the environment where it was declared. Before Go 1.22, there was one common situation where this didn't work: when trying to capture the index or value of a `for` loop. As mentioned in "The for-range value is a copy" on page 81 and "Using go.mod" on page 224, a backward-breaking change was introduced in Go 1.22 that changed the behavior of a `for` loop so that it creates new variables for the index and value on each iteration instead of reusing a single variable.

The following code demonstrates the reason this change was worthwhile. You can find it in the `goroutine_for_loop` repository in the Learning Go 2nd Edition organization on GitHub.

If you run the following code on Go 1.21 or earlier (or on Go 1.22 or later with the Go version set to 1.21 or earlier in the `go` directive in the *go.mod* file), you'll see a subtle bug:

```go
func main() {
    a := []int{2, 4, 6, 8, 10}
    ch := make(chan int, len(a))
    for _, v := range a {
        go func() {
            ch <- v * 2
        }()
    }
    for i := 0; i < len(a); i++ {
        fmt.Println(<-ch)
    }
}
```

One goroutine is launched for each value in `a`. It looks like a different value is passed in to each goroutine, but running the code shows something different:

```
20
20
20
20
20
```

The reason every goroutine wrote `20` to `ch` on earlier versions of Go is that the closure for every goroutine captured the same variable. The index and value variables in a `for` loop were reused on each iteration. The last value assigned to `v` was `10`. When the goroutines run, that's the value that they see.

Upgrading to Go 1.22 or later and changing the value of the `go` directive in *go.mod* to 1.22 or later changes the behavior of `for` loops so they create a new index and value variable on each iteration. This gives you the expected result, with a different value passed to each goroutine:

```
20
8
4
12
16
```

If you cannot upgrade to Go 1.22, you can resolve this issue in two ways. The first is to make a copy of the value by shadowing the value within the loop:

```
for _, v := range a {
    v := v
    go func() {
        ch <- v * 2
    }()
}
```

If you want to avoid shadowing and make the data flow more obvious, you can also pass the value as a parameter to the goroutine:

```
for _, v := range a {
    go func(val int) {
        ch <- val * 2
    }(v)
}
```

While Go 1.22 prevents this issue for the index and value variables in `for` loops, you still need to be careful with other variables that are captured by closures. Anytime a closure depends on a variable whose value might change, whether or not it is used as a goroutine, you must pass the value into the closure or make sure a unique copy of the variable is created for each closure that refers to the variable.

Anytime a closure uses a variable whose value might change, use a parameter to pass a copy of the variable's current value into the closure.

Always Clean Up Your Goroutines

Whenever you launch a goroutine function, you must make sure that it will eventually exit. Unlike variables, the Go runtime can't detect that a goroutine will never be used again. If a goroutine doesn't exit, all the memory allocated for variables on its stack remains allocated and any memory on the heap that is rooted in the goroutine's stack variables cannot be garbage collected. This is called a *goroutine leak*.

It may not be obvious that a goroutine isn't guaranteed to exit. For example, say you used a goroutine as a generator:

```go
func countTo(max int) <-chan int {
    ch := make(chan int)
    go func() {
        for i := 0; i < max; i++ {
            ch <- i
        }
        close(ch)
    }()
    return ch
}

func main() {
    for i := range countTo(10) {
        fmt.Println(i)
    }
}
```

This is just a short example; don't use a goroutine to generate a list of numbers. It's too simple of an operation, which violates one of our "when to use concurrency" guidelines.

In the common case, where you use all the values, the goroutine exits. However, if you exit the loop early, the goroutine blocks forever, waiting for a value to be read from the channel:

```go
func main() {
    for i := range countTo(10) {
        if i > 5 {
            break
        }
        fmt.Println(i)
    }
}
```

Use the Context to Terminate Goroutines

To solve the `countTo` goroutine leak, you need a way to tell the goroutine that it's time to stop processing. You solve this in Go by using a *context*. Here's a rewrite of `countTo` to demonstrate this technique. You can find the code in the *sample_code/context_cancel* directory in the Chapter 12 repository:

```go
func countTo(ctx context.Context, max int) <-chan int {
    ch := make(chan int)
    go func() {
        defer close(ch)
        for i := 0; i < max; i++ {
            select {
            case <-ctx.Done():
                return
            case ch <- i:
            }
        }
    }()
    return ch
}

func main() {
    ctx, cancel := context.WithCancel(context.Background())
    defer cancel()
    ch := countTo(ctx, 10)
    for i := range ch {
        if i > 5 {
            break
        }
        fmt.Println(i)
    }
}
```

The `countTo` function is modified to take a `context.Context` parameter in addition to `max`. The `for` loop in the goroutine is also changed. It is now a `for-select` loop with two cases. One tries to write to `ch`. The other case checks the channel returned by the `Done` method on the context. If it returns a value, you exit the `for-select` loop and the goroutine. Now, you have a way to prevent the goroutine from leaking when every value is read.

This leads to the question, how do you get the `Done` channel to return a value? It is triggered via *context cancellation*. In `main`, you create a context and a cancel function by using the `WithCancel` function in the `context` package. Next, you use `defer` to call `cancel` when the `main` function exits. This closes the channel returned by `Done`, and since a closed channel always returns a value, it ensures that the goroutine running `countTo` exits.

Using the context to terminate a goroutine is a very common pattern. It allows you to stop goroutines based on something from an earlier function in the call stack. In "Cancellation" on page 358, you'll learn in detail how to use the context to tell one or more goroutines that it is time to shut down.

Know When to Use Buffered and Unbuffered Channels

One of the most complicated techniques to master in Go concurrency is deciding when to use a buffered channel. By default, channels are unbuffered, and they are easy to understand: one goroutine writes and waits for another goroutine to pick up its work, like a baton in a relay race. Buffered channels are much more complicated. You have to pick a size, since buffered channels never have unlimited buffers. Proper use of a buffered channel means that you must handle the case where the buffer is full and your writing goroutine blocks waiting for a reading goroutine. So what is the proper use of a buffered channel?

The case for buffered channels is subtle. To sum it up in a single sentence: buffered channels are useful when you know how many goroutines you have launched, want to limit the number of goroutines you will launch, or want to limit the amount of work that is queued up.

Buffered channels work great when you either want to gather data back from a set of goroutines that you have launched or want to limit concurrent usage. They are also helpful for managing the amount of work a system has queued up, preventing your services from falling behind and becoming overwhelmed. Here are a couple of examples to show how they can be used.

In the first example, you are processing the first 10 results on a channel. To do this, you launch 10 goroutines, each of which writes its results to a buffered channel:

```go
func processChannel(ch chan int) []int {
    const conc = 10
    results := make(chan int, conc)
    for i := 0; i < conc; i++ {
        go func() {
            v := <- ch
            results <- process(v)
        }()
    }
    var out []int
    for i := 0; i < conc; i++ {
        out = append(out, <-results)
    }
    return out
}
```

You know exactly how many goroutines have been launched, and you want each goroutine to exit as soon as it finishes its work. This means you can create a buffered channel with one space for each launched goroutine, and have each goroutine write data to this goroutine without blocking. You can then loop over the buffered channel, reading out the values as they are written. When all the values have been read, you return the results, knowing that you aren't leaking any goroutines.

You can find this code in the *sample_code/buffered_channel_work* directory in the Chapter 12 repository.

Implement Backpressure

Another technique that can be implemented with a buffered channel is *backpressure*. It is counterintuitive, but systems perform better overall when their components limit the amount of work they are willing to perform. You can use a buffered channel and a `select` statement to limit the number of simultaneous requests in a system:

```go
type PressureGauge struct {
    ch chan struct{}
}

func New(limit int) *PressureGauge {
    return &PressureGauge{
        ch: make(chan struct{}, limit),
    }
}

func (pg *PressureGauge) Process(f func()) error {
    select {
    case pg.ch <- struct{}{}:
        f()
        <-pg.ch
        return nil
    default:
        return errors.New("no more capacity")
    }
}
```

In this code, you create a struct containing a buffered channel that can hold a number of "tokens" and a function to run. Every time a goroutine wants to use the function, it calls `Process`. This is one of the rare examples of the same goroutine both reading and writing the same channel. The `select` tries to write a token to the channel. If it can, the function runs, and then a token is read to the buffered channel. If it can't write a token, the `default` case runs, and an error is returned instead. Here's a quick example that uses this code with the built-in HTTP server (you'll learn more about working with HTTP in "The Server" on page 337):

```go
func doThingThatShouldBeLimited() string {
    time.Sleep(2 * time.Second)
    return "done"
}

func main() {
    pg := New(10)
    http.HandleFunc("/request", func(w http.ResponseWriter, r *http.Request) {
        err := pg.Process(func() {
            w.Write([]byte(doThingThatShouldBeLimited()))
        })
        if err != nil {
            w.WriteHeader(http.StatusTooManyRequests)
            w.Write([]byte("Too many requests"))
        }
    })
    http.ListenAndServe(":8080", nil)
}
```

You can find this code in the *sample_code/backpressure* directory in the Chapter 12 repository.

Turn Off a case in a select

When you need to combine data from multiple concurrent sources, the select keyword is great. However, you need to properly handle closed channels. If one of the cases in a select is reading a closed channel, it will always be successful, returning the zero value. Every time that case is selected, you need to check to make sure that the value is valid and skip the case. If reads are spaced out, your program is going to waste a lot of time reading junk values. Even if there is lots of activity on the nonclosed channels, your program will still spend some portion of its time reading from the closed channel, since select chooses a case at random.

When that happens, you rely on something that looks like an error: reading a nil channel. As you saw earlier, reading from or writing to a nil channel causes your code to hang forever. While that is bad if it is triggered by a bug, you can use a nil channel to disable a case in a select. When you detect that a channel has been closed, set the channel's variable to nil. The associated case will no longer run, because the read from the nil channel never returns a value. Here is a for-select loop that reads from two channels until both are closed:

```go
// in and in2 are channels
for count := 0; count < 2; {
    select {
    case v, ok := <-in:
        if !ok {
            in = nil // the case will never succeed again!
            count++
            continue
        }
        // process the v that was read from in
    case v, ok := <-in2:
        if !ok {
            in2 = nil // the case will never succeed again!
            count++
            continue
        }
        // process the v that was read from in2
    }
}
```

You can try out this code on The Go Playground or in the *sample_code/close_case* directory in the Chapter 12 repository.

Time Out Code

Most interactive programs have to return a response within a certain amount of time. One of the things that you can do with concurrency in Go is manage how much time a request (or a part of a request) has to run. Other languages introduce additional features on top of promises or futures to add this functionality, but Go's timeout idiom shows how you build complicated features from existing parts. Let's take a look:

```go
func timeLimit[T any](worker func() T, limit time.Duration) (T, error) {
    out := make(chan T, 1)
    ctx, cancel := context.WithTimeout(context.Background(), limit)
    defer cancel()
    go func() {
        out <- worker()
    }()
    select {
    case result := <-out:
        return result, nil
    case <-ctx.Done():
        var zero T
        return zero, errors.New("work timed out")
    }
}
```

Whenever you need to limit how long an operation takes in Go, you'll see a variation on this pattern. I talk about the context in Chapter 14 and cover using timeouts in detail in "Contexts with Deadlines" on page 363. For now, all you need to know is that reaching the timeout cancels the context. The `Done` method on the context returns a channel that returns a value when the context is canceled by either timing out or when the context's cancel method is called. You create a timed context by using the `WithTimeout` function in the `context` package and specify how long to wait by using constants from the `time` package (I'll talk more about the `time` package in "time" on page 324).

Once the context is set up, you run the worker in a goroutine and then use `select` to choose between two cases. The first case reads the value from the `out` channel when the work completes. The second case waits for the channel returned by the `Done` method to return a value, just as you saw in "Use the Context to Terminate Goroutines" on page 300. If it does, you return a timeout error. You write to a buffered channel of size 1 so that the channel write in the goroutine will complete even if `Done` is triggered first.

You can try out this code on The Go Playground or in the *sample_code/time_out* directory in the Chapter 12 repository.

If `timeLimit` exits before the goroutine finishes processing, the goroutine continues to run, eventually writing the returned value to the buffered channel and exiting. You just don't do anything with the result that is returned. If you want to stop work in a goroutine when you are no longer waiting for it to complete, use context cancellation, which I'll discuss in "Cancellation" on page 358.

Use WaitGroups

Sometimes one goroutine needs to wait for multiple goroutines to complete their work. If you are waiting for a single goroutine, you can use the context cancellation pattern that you saw earlier. But if you are waiting on several goroutines, you need to use a `WaitGroup`, which is found in the `sync` package in the standard library. Here is a simple example, which you can run on The Go Playground or in the *sample_code/waitgroup* directory in the Chapter 12 repository:

```go
func main() {
    var wg sync.WaitGroup
    wg.Add(3)
    go func() {
        defer wg.Done()
        doThing1()
    }()
    go func() {
        defer wg.Done()
        doThing2()
    }()
    go func() {
        defer wg.Done()
        doThing3()
    }()
    wg.Wait()
}
```

A `sync.WaitGroup` doesn't need to be initialized, just declared, as its zero value is useful. There are three methods on `sync.WaitGroup`: `Add`, which increments the counter of goroutines to wait for; `Done`, which decrements the counter and is called by a goroutine when it is finished; and `Wait`, which pauses its goroutine until the counter hits zero. `Add` is usually called once, with the number of goroutines that will be launched. `Done` is called within the goroutine. To ensure that it is called, even if the goroutine panics, you use a `defer`.

You'll notice that you don't explicitly pass the `sync.WaitGroup`. There are two reasons. The first is that you must ensure that every place that uses a `sync.WaitGroup` is using the same instance. If you pass the `sync.WaitGroup` to the goroutine function and don't use a pointer, then the function has a *copy* and the call to `Done` won't decrement the original `sync.WaitGroup`. By using a closure to capture the `sync.WaitGroup`, you are assured that every goroutine is referring to the same instance.

The second reason is design. Remember, you should keep concurrency out of your API. As you saw with channels earlier, the usual pattern is to launch a goroutine with a closure that wraps the business logic. The closure manages issues around concurrency, and the function provides the algorithm.

Let's take a look at a more realistic example. As I mentioned earlier, when you have multiple goroutines writing to the same channel, you need to make sure that the channel being written to is closed only once. A `sync.WaitGroup` is perfect for this. Let's see how it works in a function that processes the values in a channel concurrently, gathers the results into a slice, and returns the slice:

```go
func processAndGather[T, R any](in <-chan T, processor func(T) R, num int) []R {
    out := make(chan R, num)
    var wg sync.WaitGroup
    wg.Add(num)
    for i := 0; i < num; i++ {
        go func() {
            defer wg.Done()
            for v := range in {
                out <- processor(v)
            }
        }()
    }
    go func() {
        wg.Wait()
        close(out)
    }()
    var result []R
    for v := range out {
        result = append(result, v)
    }
    return result
}
```

In this example, you launch a monitoring goroutine that waits until all the processing goroutines exit. When they do, the monitoring goroutine calls `close` on the output channel. The `for-range` channel loop exits when `out` is closed and the buffer is empty. Finally, the function returns the processed values. You can try out this code in the *sample_code/waitgroup_close_once* directory in the Chapter 12 repository.

While `WaitGroups` are handy, they shouldn't be your first choice when coordinating goroutines. Use them only when you have something to clean up (like closing a channel they all write to) after all your worker goroutines exit.

golang.org/x and errgroup.Group

The Go authors maintain a set of utilities that supplements the standard library. Collectively known as the `golang.org/x` packages, they include a package called `errgroup` that contains a type, `errgroup.Group`. It builds on top of `WaitGroup` to create a set of goroutines that stop processing when one of them returns an error. Read the `errgroup.Group` documentation to learn more.

Run Code Exactly Once

As I covered in "Avoiding the init Function if Possible" on page 239, `init` should be reserved for initialization of effectively immutable package-level state. However, sometimes you want to *lazy load*, or call some initialization code exactly once after program launch time. This is usually because the initialization is relatively slow and may not even be needed every time your program runs. The `sync` package includes a handy type called `Once` that enables this functionality. Let's take a quick look at how it works. Say you have some code that takes a long time to initialize:

```
type SlowComplicatedParser interface {
    Parse(string) string
}

func initParser() SlowComplicatedParser {
    // do all sorts of setup and loading here
}
```

Here's how you use `sync.Once` to delay initialization of a `SlowComplicatedParser`:

```
var parser SlowComplicatedParser
var once sync.Once

func Parse(dataToParse string) string {
    once.Do(func() {
        parser = initParser()
    })
    return parser.Parse(dataToParse)
}
```

There are two package-level variables: `parser`, which is of type `SlowComplicatedParser`, and `once`, which is of type `sync.Once`. As with `sync.WaitGroup`, you do not have to configure an instance of `sync.Once`. This is an example of *making the zero value useful*, which is a common pattern in Go.

As with `sync.WaitGroup`, you must make sure not to make a copy of an instance of `sync.Once`, because each copy has its own state to indicate whether it has already been used. Declaring a `sync.Once` instance inside a function is usually the wrong thing to do, as a new instance will be created on every function call and there will be no memory of previous invocations.

In the example, you want to make sure that `parser` is initialized only once, so you set the value of `parser` from within a closure that's passed to the `Do` method on `once`. If `Parse` is called more than once, `once.Do` will not execute the closure again.

You can try out this code on The Go Playground or in the *sample_code/sync_once* directory in the Chapter 12 repository.

Go 1.21 added helper functions that make it easier to run a function exactly once: `sync.OnceFunc`, `sync.OnceValue`, and `sync.OnceValues`. The only difference between the three functions is the number of return values of the passed-in function (zero, one, or two, respectively). The `sync.OnceValue` and `sync.OnceValues` functions are generic, so they adapt to the type of the original function's return values.

Using these functions is straightforward. You pass the original function to the helper function and get back a function that calls the original function only once. The values returned by the original function are cached. Here's how you can use `sync.OnceValue` to rewrite the `Parse` function in the previous example:

```go
var initParserCached func() SlowComplicatedParser = sync.OnceValue(initParser)

func Parse(dataToParse string) string {
    parser := initParserCached()
    return parser.Parse(dataToParse)
}
```

The package-level `initParserCached` variable is assigned the function returned by `sync.OnceValue` when `initParser` is passed to it. The first time `initParserCached` is called, `initParser` is also called, and its return value is cached. Each subsequent time `initParserCached` is called, the cached value is returned. This means you can get rid of the `parser` package-level variable.

You can try out this code on The Go Playground or in the *sample_code/sync_value* directory in the Chapter 12 repository.

Put Your Concurrent Tools Together

Let's go back to the example from the first section in the chapter. You have a function that calls three web services. You send data to two of those services, and then take the results of those two calls and send them to the third, returning the result. The entire process must take less than 50 milliseconds, or an error is returned.

You'll start with the function you invoke:

```go
func GatherAndProcess(ctx context.Context, data Input) (COut, error) {
    ctx, cancel := context.WithTimeout(ctx, 50*time.Millisecond)
    defer cancel()

    ab := newABProcessor()
    ab.start(ctx, data)
    inputC, err := ab.wait(ctx)
    if err != nil {
        return COut{}, err
    }

    c := newCProcessor()
    c.start(ctx, inputC)
    out, err := c.wait(ctx)
    return out, err
}
```

The first thing to do is set up a `context.Context` that times out in 50 milliseconds, as you saw in "Time Out Code" on page 304.

After creating the context, use a `defer` to make sure the context's `cancel` function is called. As I'll discuss in "Cancellation" on page 358, you must call this function, or resources leak.

You are using `A` and `B` as the names of the two services that are called in parallel, so you'll make a new `abProcessor` to call them. You then start processing with a call to the `start` method, and then wait for your results with a call to the `wait` method.

When `wait` returns, you do a standard error check. If all is well, you call the third service, which you are calling `C`. The logic is the same as before. Processing is started with a call to the `start` method on the `cProcessor` and then you wait for the result with a call to the `wait` method on `cProcessor`. You then return the result of the `wait` method call.

This looks a lot like standard sequential code without concurrency. Let's look at the `abProcessor` and `cProcessor` to see how the concurrency happens:

```go
type abProcessor struct {
    outA chan aOut
    outB chan bOut
    errs chan error
}

func newABProcessor() *abProcessor {
    return &abProcessor{
        outA: make(chan aOut, 1),
        outB: make(chan bOut, 1),
        errs: make(chan error, 2),
    }
}
```

The `abProcessor` has three fields, all of which are channels. They are `outA`, `outB`, and `errs`. You'll see how you use all these channels next. Notice that every channel is buffered, so that the goroutines that write to them can exit after writing without waiting for a read to happen. The `errs` channel has a buffer size of `2`, because it could have up to two errors written to it.

Next is the implementation of the `start` method:

```go
func (p *abProcessor) start(ctx context.Context, data Input) {
    go func() {
        aOut, err := getResultA(ctx, data.A)
        if err != nil {
            p.errs <- err
            return
        }
        p.outA <- aOut
    }()
    go func() {
        bOut, err := getResultB(ctx, data.B)
        if err != nil {
            p.errs <- err
            return
        }
        p.outB <- bOut
    }()
}
```

The `start` method launches two goroutines. The first one calls `getResultA` to talk to the `A` service. If the call returns an error, you write to the `errs` channel. Otherwise, you write to the `outA` channel. Since these channels are buffered, the goroutine will not hang, no matter which channel is written to. Also notice that you are passing the context along to `getResultA`, which allows it to cancel processing if the timeout happens.

The second goroutine is just like the first, only it calls `getResultB` and writes to the `outB` channel on success.

Let's see what the `wait` method for `ABProcessor` looks like:

```
func (p *abProcessor) wait(ctx context.Context) (cIn, error) {
    var cData cIn
    for count := 0; count < 2; count++ {
        select {
        case a := <-p.outA:
            cData.a = a
        case b := <-p.outB:
            cData.b = b
        case err := <-p.errs:
            return cIn{}, err
        case <-ctx.Done():
            return cIn{}, ctx.Err()
        }
    }
    return cData, nil
}
```

The `wait` method on `abProcessor` is the most complicated method you need to implement. It populates a struct of type `cIn`, which holds the data returned from calling the `A` service and the `B` service. You define your output variable, `cData`, as type `cIn`. You then have a `for` loop that counts to two, since you need to read from two channels to finish successfully. Inside the loop, you have a `select` statement. If you read a value on `outA`, you set the `a` field on `cData`. If you read a value on `outB`, you set the b field on cData. If you read a value on the errs channel, you return immediately with the error. Finally, if the context times out, you return immediately with the error from the context's Err method.

Once you have read a value from both the p.outA channel and the p.outB channel, you exit the loop and return the input that you're going to use with the cProcessor.

The cProcessor looks like a simpler version of the abProcessor:

```
type cProcessor struct {
    outC chan COut
    errs chan error
}

func newCProcessor() *cProcessor {
    return &cProcessor{
        outC: make(chan COut, 1),
        errs: make(chan error, 1),
    }
}

func (p *cProcessor) start(ctx context.Context, inputC cIn) {
    go func() {
        cOut, err := getResultC(ctx, inputC)
        if err != nil {
            p.errs <- err
            return
        }
        p.outC <- cOut
    }()
}

func (p *cProcessor) wait(ctx context.Context) (COut, error) {
    select {
    case out := <-p.outC:
        return out, nil
    case err := <-p.errs:
        return COut{}, err
    case <-ctx.Done():
        return COut{}, ctx.Err()
    }
}
```

The cProcessor struct has one out channel and one error channel.

The start method on the cProcessor looks like the start method on the abProcessor. It launches a goroutine that calls getResultC with your input data, writes to the errs channel on an error, and writes to the outC channel on success.

Finally, the `wait` method on the `cProcessor` is a simple `select` statement that checks whether there's a value to read from the `outC` channel, the `errs` channel, or the context's `Done` channel.

By structuring code with goroutines, channels, and `select` statements, you separate the individual steps, allow independent parts to run and complete in any order, and cleanly exchange data between the dependent parts. In addition, you make sure that no part of the program hangs, and you properly handle timeouts set both within this function and from earlier functions in the call history. If you are not convinced that this is a better method for implementing concurrency, try to implement this in another language. You might be surprised at how difficult it is.

You can find the code for this concurrent pipeline in the *sample_code/pipeline* directory in the Chapter 12 repository.

When to Use Mutexes Instead of Channels

If you've had to coordinate access to data across threads in other programming languages, you have probably used a *mutex*. This is short for *mutual exclusion*, and the job of a mutex is to limit the concurrent execution of some code or access to a shared piece of data. This protected part is called the *critical section*.

There are good reasons Go's creators designed channels and `select` to manage concurrency. The main problem with mutexes is that they obscure the flow of data through a program. When a value is passed from goroutine to goroutine over a series of channels, the data flow is clear. Access to the value is localized to a single goroutine at a time. When a mutex is used to protect a value, there is nothing to indicate which goroutine currently has ownership of the value, because access to the value is shared by all the concurrent processes. That makes it hard to understand the order of processing. There is a saying in the Go community to describe this philosophy: "Share memory by communicating; do not communicate by sharing memory."

That said, sometimes it is clearer to use a mutex, and the Go standard library includes mutex implementations for these situations. The most common case is when your goroutines read or write a shared value, but don't process the value. Let's use an in-memory scoreboard for a multiplayer game as an example. You'll first see how to implement this using channels. Here's a function that you can launch as a goroutine to manage the scoreboard:

```go
func scoreboardManager(ctx context.Context, in <-chan func(map[string]int)) {
    scoreboard := map[string]int{}
    for {
        select {
        case <-ctx.Done():
            return
        case f := <-in:
            f(scoreboard)
        }
    }
}
```

This function declares a map and then listens on one channel for a function that reads or modifies the map and on a context's Done channel to know when to shut down. Let's create a type with a method to write a value to the map:

```
type ChannelScoreboardManager chan func(map[string]int)

func NewChannelScoreboardManager(ctx context.Context) ChannelScoreboardManager {
    ch := make(ChannelScoreboardManager)
    go scoreboardManager(ctx, ch)
    return ch
}

func (csm ChannelScoreboardManager) Update(name string, val int) {
    csm <- func(m map[string]int) {
        m[name] = val
    }
}
```

The update method is very straightforward: just pass a function that puts a value into the map. But how about reading from the scoreboard? You need to return a value back. That means creating a channel that's written to within the passed-in function:

```
func (csm ChannelScoreboardManager) Read(name string) (int, bool) {
    type Result struct {
        out int
        ok  bool
    }
    resultCh := make(chan Result)
    csm <- func(m map[string]int) {
        out, ok := m[name]
        resultCh <- Result{out, ok}
    }
    result := <-resultCh
    return result.out, result.ok
}
```

While this code works, it's cumbersome and allows only a single reader at a time. A better approach is to use a mutex. The standard library has two mutex implementations, both in the `sync` package. The first, `Mutex`, has two methods, `Lock` and `Unlock`. Calling `Lock` causes the current goroutine to pause as long as another goroutine is currently in the critical section. When the critical section is clear, the lock is *acquired* by the current goroutine, and the code in the critical section is executed. A call to the `Unlock` method on the `Mutex` marks the end of the critical section.

The second mutex implementation, called `RWMutex`, allows you to have both reader locks and writer locks. While only one writer can be in the critical section at a time, reader locks are shared; multiple readers can be in the critical section at once. The writer lock is managed with the `Lock` and `Unlock` methods, while the reader lock is managed with `RLock` and `RUnlock` methods.

Anytime you acquire a mutex lock, you must make sure that you release the lock. Use a `defer` statement to call `Unlock` immediately after calling `Lock` or `RLock`:

```go
type MutexScoreboardManager struct {
    l          sync.RWMutex
    scoreboard map[string]int
}

func NewMutexScoreboardManager() *MutexScoreboardManager {
    return &MutexScoreboardManager{
        scoreboard: map[string]int{},
    }
}

func (msm *MutexScoreboardManager) Update(name string, val int) {
    msm.l.Lock()
    defer msm.l.Unlock()
    msm.scoreboard[name] = val
}

func (msm *MutexScoreboardManager) Read(name string) (int, bool) {
    msm.l.RLock()
    defer msm.l.RUnlock()
    val, ok := msm.scoreboard[name]
    return val, ok
}
```

You can find the example in the *sample_code/mutex* directory in the Chapter 12 repository.

Now that you've seen an implementation using mutexes, carefully consider your options before using one. Katherine Cox-Buday's excellent book *Concurrency in Go* (O'Reilly) includes a decision tree to help you decide whether to use channels or mutexes:

- If you are coordinating goroutines or tracking a value as it is transformed by a series of goroutines, use channels.
- If you are sharing access to a field in a struct, use mutexes.
- If you discover a critical performance issue when using channels (see "Using Benchmarks" on page 393 to learn how to do this), and you cannot find any other way to fix the issue, modify your code to use a mutex.

Since your scoreboard is a field in a struct and there's no transfer of the scoreboard, using a mutex makes sense. This is a good use for a mutex only because the data is stored in-memory. When data is stored in external services, like an HTTP server or a database, don't use a mutex to guard access to the system.

Mutexes require you to do more bookkeeping. For example, you must correctly pair locks and unlocks, or your programs will likely deadlock. The example both acquires and releases the locks within the same method. Another issue is that mutexes in Go aren't *reentrant*. If a goroutine tries to acquire the same lock twice, it deadlocks, waiting for itself to release the lock. This is different from languages like Java, where locks are reentrant.

Nonreentrant locks make it tricky to acquire a lock in a function that calls itself recursively. You must release the lock before the recursive function call. In general, be careful when holding a lock while making a function call, because you don't know what locks are going to be acquired in those calls. If your function calls another function that tries to acquire the same mutex lock, the goroutine deadlocks.

Like `sync.WaitGroup` and `sync.Once`, mutexes must never be copied. If they are passed to a function or accessed as a field on a struct, it must be via a pointer. If a mutex is copied, its lock won't be shared.

Never try to access a variable from multiple goroutines unless you acquire a mutex for that variable first. It can cause odd errors that are hard to trace. See "Finding Concurrency Problems with the Data Race Detector" on page 406 to learn how to detect these problems.

sync.Map—This Is Not the Map You Are Looking For

When looking through the `sync` package, you'll find a type called `Map`. It provides a concurrency-safe version of Go's built-in `map`. Because of trade-offs in its implementation, `sync.Map` is appropriate only in very specific situations:

- When you have a shared map where key-value pairs are inserted once and read many times
- When goroutines share the map, but don't access each other's keys and values

Furthermore, because `sync.Map` was added to the standard library before the introduction of generics, `sync.Map` uses `any` as the type for its keys and values. This means the compiler cannot help you ensure that the right data types are used.

Given these limitations, in the rare situations where you need to share a map across multiple goroutines, use a built-in `map` protected by a `sync.RWMutex`.

Atomics—You Probably Don't Need These

In addition to mutexes, Go provides another way to keep data consistent across multiple threads. The `sync/atomic` package provides access to the *atomic variable* operations built into modern CPUs to add, swap, load, store, or compare and swap (CAS) a value that fits into a single register.

If you need to squeeze out every last bit of performance and are an expert on writing concurrent code, you'll be glad that Go includes atomic support. For everyone else, use goroutines and mutexes to manage your concurrency needs.

Where to Learn More About Concurrency

I've covered a few simple concurrency patterns here, but there are many more. In fact, you could write an entire book on how to properly implement various concurrency patterns in Go, and, luckily, Katherine Cox-Buday has. I've already mentioned *Concurrency in Go*, when discussing how to decide between mutexes or channels, but it's an excellent resource on all things involving Go and concurrency. Check out her book if you want to learn more.

Exercises

Using concurrency effectively is one of the most important skills for a Go developer. Work through these exercises to see if you have mastered them. The solutions are available in the *exercise_solutions* directory in the Chapter 12 repository.

1. Create a function that launches three goroutines that communicate using a channel. The first two goroutines each write 10 numbers to the channel. The third goroutine reads all the numbers from the channel and prints them out. The function should exit when all values have been printed out. Make sure that none of the goroutines leak. You can create additional goroutines if needed.
2. Create a function that launches two goroutines. Each goroutine writes 10 numbers to its own channel. Use a `for-select` loop to read from both channels, printing out the number and the goroutine that wrote the value. Make sure that your function exits after all values are read and that none of your goroutines leak.
3. Write a function that builds a `map[int]float64` where the keys are the numbers from 0 (inclusive) to 100,000 (exclusive) and the values are the square roots of those numbers (use the `math.Sqrt` function to calculate square roots). Use `sync.OnceValue` to generate a function that caches the `map` returned by this function and use the cached value to look up square roots for every 1,000th number from 0 to 100,000.

Wrapping Up

In this chapter, you've looked at concurrency and learned why Go's approach is simpler than more traditional concurrency mechanisms. In doing so, you've also learned when you should use concurrency as well as a few concurrency rules and patterns. In the next chapter, you're going to take a quick look at Go's standard library, which embraces a "batteries included" ethos for modern computing.

CHAPTER 13

The Standard Library

One of the best parts of developing with Go is being able to take advantage of its standard library. Like Python, it has a "batteries included" philosophy, providing many of the tools that you need to build an application. Since Go is a relatively new language, it ships with a library that is focused on problems faced in modern programming environments.

I can't cover all the standard library packages, and luckily, I don't have to, as there are many excellent sources of information on the standard library, starting with the documentation. Instead, I'll focus on several of the most important packages and how their design and use demonstrate the principles of idiomatic Go. Some packages (`errors`, `sync`, `context`, `testing`, `reflect`, and `unsafe`) are covered in their own chapters. In this chapter, you'll look at Go's built-in support for I/O, time, JSON, and HTTP.

io and Friends

For a program to be useful, it needs to read in and write out data. The heart of Go's input/output philosophy can be found in the `io` package. In particular, two interfaces defined in this package are probably the second and third most-used interfaces in Go: `io.Reader` and `io.Writer`.

What's number one? That'd be `error`, which you already looked at in Chapter 9.

Both io.Reader and io.Writer define a single method:

```
type Reader interface {
    Read(p []byte) (n int, err error)
}

type Writer interface {
    Write(p []byte) (n int, err error)
}
```

The Write method on the io.Writer interface takes in a slice of bytes, which are written to the interface implementation. It returns the number of bytes written and an error if something went wrong. The Read method on io.Reader is more interesting. Rather than return data through a return parameter, a slice is passed into the implementation and modified. Up to len(p) bytes will be written into the slice. The method returns the number of bytes written. This might seem a little strange. You might expect this:

```
type NotHowReaderIsDefined interface {
    Read() (p []byte, err error)
}
```

There's a very good reason io.Reader is defined the way it is. Let's write a function that's representative of how to work with an io.Reader to illustrate:

```
func countLetters(r io.Reader) (map[string]int, error) {
    buf := make([]byte, 2048)
    out := map[string]int{}
    for {
        n, err := r.Read(buf)
        for _, b := range buf[:n] {
            if (b >= 'A' && b <= 'Z') || (b >= 'a' && b <= 'z') {
                out[string(b)]++
            }
        }
        if err == io.EOF {
            return out, nil
        }
        if err != nil {
            return nil, err
        }
    }
}
```

There are three things to note. First, you create your buffer once and reuse it on every call to r.Read. This allows you to use a single memory allocation to read from a potentially large data source. If the Read method were written to return a []byte, it would require a new allocation on every single call. Each allocation would end up on the heap, which would make quite a lot of work for the garbage collector.

If you want to reduce the allocations further, you could create a pool of buffers when the program launches. You would then take a buffer out of the pool when the function starts, and return it when it ends. By passing in a slice to `io.Reader`, memory allocation is under the control of the developer.

Second, you use the `n` value returned from `r.Read` to know how many bytes were written to the buffer and iterate over a subslice of your `buf` slice, processing the data that was read.

Finally, you know that you're done reading from `r` when the error returned from `r.Read` is `io.EOF`. This error is a bit odd, in that it isn't really an error. It indicates that there's nothing left to read from the `io.Reader`. When `io.EOF` is returned, you are finished processing and return your result.

The `Read` method in `io.Reader` has one unusual aspect. In most cases when a function or method has an error return value, you check the error before you try to process the nonerror return values. You do the opposite for `Read` because bytes might have been copied into the buffer before an error was triggered by the end of the data stream or by an unexpected condition.

If you get to the end of an `io.Reader` unexpectedly, a different sentinel error is returned (`io.ErrUnexpectedEOF`). Note that it starts with the string `Err` to indicate that it is an unexpected state.

Because `io.Reader` and `io.Writer` are such simple interfaces, they can be implemented many ways. You can create an `io.Reader` from a string by using the `strings.NewReader` function:

```
s := "The quick brown fox jumped over the lazy dog"
sr := strings.NewReader(s)
counts, err := countLetters(sr)
if err != nil {
    return err
}
fmt.Println(counts)
```

As I discussed in "Interfaces Are Type-Safe Duck Typing" on page 158, implementations of `io.Reader` and `io.Writer` are often chained together in a decorator pattern. Because `countLetters` depends on an `io.Reader`, you can use the exact same `countLetters` function to count English letters in a gzip-compressed file. First you write a function that, when given a filename, returns a `*gzip.Reader`:

```
func buildGZipReader(fileName string) (*gzip.Reader, func(), error) {
    r, err := os.Open(fileName)
    if err != nil {
        return nil, nil, err
    }
    gr, err := gzip.NewReader(r)
    if err != nil {
        return nil, nil, err
    }
    return gr, func() {
        gr.Close()
        r.Close()
    }, nil
}
```

This function demonstrates the way to properly wrap types that implement `io.Reader`. You create an `*os.File` (which meets the `io.Reader` interface), and after making sure it's valid, you pass it to the `gzip.NewReader` function, which returns a `*gzip.Reader` instance. If it is valid, you return the `*gzip.Reader` and a closure that properly cleans up your resources when it is invoked.

Since `*gzip.Reader` implements `io.Reader`, you can use it with `countLetters` just as you used the `*strings.Reader` previously:

```
r, closer, err := buildGZipReader("my_data.txt.gz")
if err != nil {
    return err
}
defer closer()
counts, err := countLetters(r)
if err != nil {
    return err
}
fmt.Println(counts)
```

You can find the code for `countLetters` and `buildGZipReader` in the *sample_code/io_friends* directory in the Chapter 13 repository.

Because there are standard interfaces for reading and writing, there's a standard function in the `io` package for copying from an `io.Reader` to an `io.Writer`, `io.Copy`. There are other standard functions for adding new functionality to existing `io.Reader` and `io.Writer` instances. These include the following:

`io.MultiReader`
: Returns an `io.Reader` that reads from multiple `io.Reader` instances, one after another

`io.LimitReader`
: Returns an `io.Reader` that reads only up to a specified number of bytes from the supplied `io.Reader`

`io.MultiWriter`
: Returns an `io.Writer` that writes to multiple `io.Writer` instances at the same time

Other packages in the standard library provide their own types and functions to work with `io.Reader` and `io.Writer`. You've seen a few of them already, but there are many more. These cover compression algorithms, archives, cryptography, buffers, byte slices, and strings.

Other one-method interfaces are defined in `io`, such as `io.Closer` and `io.Seeker`:

```
type Closer interface {
        Close() error
}

type Seeker interface {
        Seek(offset int64, whence int) (int64, error)
}
```

The `io.Closer` interface is implemented by types like `os.File` that need to do cleanup when reading or writing is complete. Usually, `Close` is called via a `defer`:

```
f, err := os.Open(fileName)
if err != nil {
    return nil, err
}
defer f.Close()
// use f
```

If you are opening the resource in a loop, do not use `defer`, as it will not run until the function exits. Instead, you should call `Close` before the end of the loop iteration. If there are errors that can lead to an exit, you must call `Close` there too.

The `io.Seeker` interface is used for random access to a resource. The valid values for `whence` are the constants `io.SeekStart`, `io.SeekCurrent`, and `io.SeekEnd`. This should have been made clearer by using a custom type, but in a surprising design oversight, `whence` is of type `int`.

The `io` package defines interfaces that combine these four interfaces in various ways. They include `io.ReadCloser`, `io.ReadSeeker`, `io.ReadWriteCloser`, `io.ReadWriteSeeker`, `io.ReadWriter`, `io.WriteCloser`, and `io.WriteSeeker`. Use these interfaces to specify what your functions expect to do with the data. For example, rather than just using an `os.File` as a parameter, use the interfaces to specify exactly what your function will do with the parameter. Not only does it make your functions more general-purpose, it also makes your intent clearer. Furthermore, make your code compatible with these interfaces if you are writing your own data sources and sinks.

In general, strive to create interfaces as simple and decoupled as the interfaces defined in io. They demonstrate the power of simple abstractions.

In addition to the interfaces in the io package, there are several helper functions for common operations. For example, the io.ReadAll function reads all the data from an io.Reader into a byte slice. One of the more clever functions in io demonstrates a pattern for adding a method to a Go type. If you have a type that implements io.Reader but not io.Closer (such as strings.Reader) and need to pass it to a function that expects an io.ReadCloser, pass your io.Reader into io.NopCloser and get back a type that implements io.ReadCloser. If you look at the implementation, it's very simple:

```
type nopCloser struct {
    io.Reader
}

func (nopCloser) Close() error { return nil }

func NopCloser(r io.Reader) io.ReadCloser {
    return nopCloser{r}
}
```

Anytime you need to add additional methods to a type so that it can meet an interface, use this embedded type pattern.

The io.NopCloser function violates the general rule of not returning an interface from a function, but it's a simple adapter for an interface that is guaranteed to stay the same because it is part of the standard library.

Among other things, the os package contains functions for interacting with files. The functions os.ReadFile and os.WriteFile read an entire file into a slice of bytes and write a slice of bytes into a file, respectively. These functions (and io.ReadAll) are fine for small amounts of data, but they are not appropriate for large data sources. When working with larger data sources, use the Create, NewFile, Open, and OpenFile functions in the os package. They return an *os.File instance, which implements the io.Reader and io.Writer interfaces. You can use an *os.File instance with the Scanner type in the bufio package.

time

Like most languages, Go's standard library includes time support, which is found, unsurprisingly, in the time package. Two main types are used to represent time: time.Duration and time.Time.

A period of time is represented with a `time.Duration`, a type based on an `int64`. The smallest amount of time that Go can represent is one nanosecond, but the `time` package defines constants of type `time.Duration` to represent a nanosecond, microsecond, millisecond, second, minute, and hour. For example, you represent a duration of 2 hours and 30 minutes as follows:

```
d := 2 * time.Hour + 30 * time.Minute // d is of type time.Duration
```

These constants make the use of a `time.Duration` both readable and type-safe. They demonstrate a good use of a typed constant.

Go defines a sensible string format, a series of numbers, that can be parsed into a `time.Duration` with the `time.ParseDuration` function. This format is described in the standard library documentation:

> A duration string is a possibly signed sequence of decimal numbers, each with optional fraction and a unit suffix, such as "300ms", "-1.5h" or "2h45m". Valid time units are "ns", "us" (or "µs"), "ms", "s", "m", "h".
>
> —Go Standard Library Documentation

Several methods are defined on `time.Duration`. It meets the `fmt.Stringer` interface and returns a formatted duration string via the `String` method. It also has methods to get the value as a number of hours, minutes, seconds, milliseconds, microseconds, or nanoseconds. The `Truncate` and `Round` methods truncate or round a `time.Duration` to the units of the specified `time.Duration`.

A moment of time is represented with the `time.Time` type, complete with a time zone. You acquire a reference to the current time with the function `time.Now`. This returns a `time.Time` instance set to the current local time.

> The fact that a `time.Time` instance contains a time zone means that you should not use `==` to check whether two `time.Time` instances refer to the same moment in time. Instead, use the `Equal` method, which corrects for time zone.

The `time.Parse` function converts from a `string` to a `time.Time`, while the `Format` method converts a `time.Time` to a `string`. While Go usually adopts ideas that worked well in the past, it uses its own date and time formatting language. It relies on the idea of formatting the date and time January 2, 2006 at 3:04:05PM MST (Mountain Standard Time) to specify your format.

Why that date? Because each part of it represents one of the numbers from 1 to 7 in sequence, that is, 01/02 03:04:05PM ’06 -0700 (MST is 7 hours before UTC).

For example, the following code

```
t, err := time.Parse("2006-01-02 15:04:05 -0700", "2023-03-13 00:00:00 +0000")
if err != nil {
    return err
}
fmt.Println(t.Format("January 2, 2006 at 3:04:05PM MST"))
```

prints out this output:

```
March 13, 2023 at 12:00:00AM UTC
```

While the date and time used for formatting is intended to be a clever mnemonic, I find it hard to remember and have to look it up each time I want to use it. Luckily, the most commonly used date and time formats have been given their own constants in the `time` package.

Just as there are methods on `time.Duration` to extract portions of it, there are methods defined on `time.Time` to do the same, including `Day`, `Month`, `Year`, `Hour`, `Minute`, `Second`, `Weekday`, `Clock` (which returns the time portion of a `time.Time` as separate hour, minute, and second `int` values), and `Date` (which returns the year, month, and day as separate `int` values). You can compare one `time.Time` instance against another with the `After`, `Before`, and `Equal` methods.

The `Sub` method returns a `time.Duration` that represents the elapsed time between two `time.Time` instances, while the `Add` method returns a `time.Time` that is `time.Duration` later, and the `AddDate` method returns a new `time.Time` instance that's incremented by the specified number of years, months, and days. As with `time.Duration`, there are `Truncate` and `Round` methods defined as well. All these methods are defined on a value receiver, so they do not modify the `time.Time` instance.

Monotonic Time

Most operating systems keep track of two sorts of time: the *wall clock*, which corresponds to the current time, and the *monotonic clock*, which counts up from the time the computer was booted. The reason for tracking two clocks is that the wall clock doesn't uniformly increase. Daylight Saving Time, leap seconds, and Network Time Protocol (NTP) updates can make the wall clock move unexpectedly forward or backward. This can cause problems when setting a timer or finding the amount of time that's elapsed.

To address this potential problem, Go uses monotonic time to track elapsed time whenever a timer is set or a `time.Time` instance is created with `time.Now`. This support is invisible; timers use it automatically. The `Sub` method uses the monotonic clock to calculate the `time.Duration` if both `time.Time` instances have it set. If they don't (because one or both of the instances was not created with `time.Now`), the `Sub` method uses the time specified in the instances to calculate the `time.Duration` instead.

If you want to understand the sorts of problems that can occur when not handling monotonic time correctly, take a look at the Cloudflare blog post that detailed a bug caused by the lack of monotonic time support in an earlier version of Go.

Timers and Timeouts

As I covered in "Time Out Code" on page 304, the `time` package includes functions that return channels that output values after a specified time. The `time.After` function returns a channel that outputs once, while the channel returned by `time.Tick` returns a new value every time the specified `time.Duration` elapses. These are used with Go's concurrency support to enable timeouts or recurring tasks.

You can also trigger a single function to run after a specified `time.Duration` with the `time.AfterFunc` function. Don't use `time.Tick` outside trivial programs, because the underlying `time.Ticker` cannot be shut down (and therefore cannot be garbage collected). Use the `time.NewTicker` function instead, which returns a `*time.Ticker` that has the channel to listen to, as well as methods to reset and stop the ticker.

encoding/json

REST APIs have enshrined JSON as the standard way to communicate between services, and Go's standard library includes support for converting Go data types to and from JSON. The word *marshaling* means converting from a Go data type to an encoding, and *unmarshaling* means converting to a Go data type.

Using Struct Tags to Add Metadata

Let's say that you are building an order management system and have to read and write the following JSON:

```
{
    "id":"12345",
    "date_ordered":"2020-05-01T13:01:02Z",
    "customer_id":"3",
    "items":[{"id":"xyz123","name":"Thing 1"},{"id":"abc789","name":"Thing 2"}]
}
```

You define types to map this data:

```
type Order struct {
    ID            string        `json:"id"`
    DateOrdered   time.Time     `json:"date_ordered"`
    CustomerID    string        `json:"customer_id"`
    Items         []Item        `json:"items"`
}

type Item struct {
    ID   string `json:"id"`
    Name string `json:"name"`
}
```

You specify the rules for processing your JSON with *struct tags*, strings that are written after the fields in a struct. Even though struct tags are strings marked with backticks, they cannot extend past a single line. Struct tags are composed of one or more tag/value pairs, written as `tagName:"tagValue"` and separated by spaces. Because they are just strings, the compiler cannot validate that they are formatted correctly, but `go vet` does. Also, note that all these fields are exported. Like any other package, the code in the `encoding/json` package cannot access an unexported field on a struct in another package.

For JSON processing, use the tag `json` to specify the name of the JSON field that should be associated with the struct field. If no `json` tag is provided, the default behavior is to assume that the name of the JSON object field matches the name of the Go struct field. Despite this default behavior, it's best to use the struct tag to specify the name of the field explicitly, even if the field names are identical.

When unmarshaling from JSON into a struct field with no `json` tag, the name match is case-insensitive. When marshaling a struct field with no `json` tag back to JSON, the JSON field will always have an uppercase first letter, because the field is exported.

If a field should be ignored when marshaling or unmarshaling, use a dash (`-`) for the name. If the field should be left out of the output when it is empty, add `,omitempty` after the name. For example, in the `Order` struct, if you didn't want to include `CustomerID` in the output if it was set to an empty string, the struct tag would be `json:"customer_id,omitempty"`.

Unfortunately, the definition of "empty" doesn't exactly align with the zero value, as you might expect. The zero value of a struct doesn't count as empty, but a zero-length slice or map does.

Struct tags allow you to use metadata to control how your program behaves. Other languages, most notably Java, encourage developers to place annotations on various program elements to describe *how* they should be processed, without explicitly specifying *what* is going to do the processing. While declarative programming allows for more concise programs, automatic processing of metadata makes it difficult to understand how a program behaves. Anyone who has worked on a large Java project with annotations has had a moment of panic when something goes wrong and they don't understand which code is processing a particular annotation and what changes it made. Go favors explicit code over short code. Struct tags are never evaluated automatically; they are processed when a struct instance is passed into a function.

Unmarshaling and Marshaling

The `Unmarshal` function in the `encoding/json` package is used to convert a slice of bytes into a struct. If you have a string named `data`, this is the code to convert `data` to a struct of type `Order`:

```
var o Order
err := json.Unmarshal([]byte(data), &o)
if err != nil {
    return err
}
```

The `json.Unmarshal` function populates data into an input parameter, just like the implementations of the `io.Reader` interface. As I discussed in "Pointers Are a Last Resort" on page 129, this allows for efficient reuse of the same struct over and over, giving you control over memory usage.

You use the `Marshal` function in the `encoding/json` package to write an `Order` instance back as JSON, stored in a slice of bytes:

```
out, err := json.Marshal(o)
```

This leads to the question: how are you able to evaluate struct tags? You might also be wondering how `json.Marshal` and `json.Unmarshal` are able to read and write a struct of any type. After all, every other method that you've written has worked only with types that were known when the program was compiled (even the types listed in a type switch are enumerated ahead of time). The answer to both questions is reflection. You can find out more about reflection in Chapter 16.

JSON, Readers, and Writers

The `json.Marshal` and `json.Unmarshal` functions work on slices of bytes. As you just saw, most data sources and sinks in Go implement the `io.Reader` and `io.Writer` interfaces. While you could use `io.ReadAll` to copy the entire contents of an `io.Reader` into a byte slice so it can be read by `json.Unmarshal`, this is inefficient. Similarly, you could write to an in-memory byte slice buffer using `json.Marshal` and then write that byte slice to the network or disk, but it'd be better if you could write to an `io.Writer` directly.

The `encoding/json` package includes two types that allow you to handle these situations. The `json.Decoder` and `json.Encoder` types read from and write to anything that meets the `io.Reader` and `io.Writer` interfaces, respectively. Let's take a quick look at how they work.

Start with your data in `toFile`, which implements a simple struct:

```
type Person struct {
    Name string `json:"name"`
    Age  int    `json:"age"`
}
toFile := Person {
    Name: "Fred",
    Age:  40,
}
```

The `os.File` type implements both the `io.Reader` and `io.Writer` interfaces, so it can be used to demonstrate `json.Decoder` and `json.Encoder`. First, you write `toFile` to a temp file by passing the temp file to `json.NewEncoder`, which returns a `json.Encoder` for the temp file. You then pass `toFile` to the `Encode` method:

```
tmpFile, err := os.CreateTemp(os.TempDir(), "sample-")
if err != nil {
    panic(err)
}
defer os.Remove(tmpFile.Name())
err = json.NewEncoder(tmpFile).Encode(toFile)
if err != nil {
    panic(err)
}
err = tmpFile.Close()
if err != nil {
    panic(err)
}
```

Once `toFile` is written, you can read the JSON back in by passing a reference to the temp file to `json.NewDecoder` and then calling the `Decode` method on the returned `json.Decoder` with a variable of type `Person`:

```
tmpFile2, err := os.Open(tmpFile.Name())
if err != nil {
    panic(err)
}
var fromFile Person
err = json.NewDecoder(tmpFile2).Decode(&fromFile)
if err != nil {
    panic(err)
}
err = tmpFile2.Close()
if err != nil {
    panic(err)
}
fmt.Printf("%+v\n", fromFile)
```

You can see a complete example on The Go Playground or in the *sample_code/json* directory in the Chapter 13 repository.

Encoding and Decoding JSON Streams

What do you do when you have multiple JSON structs to read or write at once? Our friends `json.Decoder` and `json.Encoder` can be used for these situations too.

Assume you have the following data:

```
{"name": "Fred", "age": 40}
{"name": "Mary", "age": 21}
{"name": "Pat", "age": 30}
```

For the sake of this example, assume it's stored in a string called `streamData`, but it could be in a file or even an incoming HTTP request (you'll see how HTTP servers work in just a bit).

You're going to store this data into your `t` variable, one JSON object at a time.

Just as before, you initialize your `json.Decoder` with the data source, but this time you use a `for` loop and run until you get an error. If the error is `io.EOF`, you have successfully read all the data. If not, there was a problem with the JSON stream. This lets you read and process the data, one JSON object at a time:

```
var t struct {
    Name string `json:"name"`
    Age  int    `json:"age"`
}

dec := json.NewDecoder(strings.NewReader(streamData))
for {
    err := dec.Decode(&t)
    if err != nil {
        if errors.Is(err, io.EOF) {
            break
        }
        panic(err)
    }
    // process t
}
```

Writing out multiple values with the `json.Encoder` works just like using it to write out a single value. In this example, you are writing to a `bytes.Buffer`, but any type that meets the `io.Writer` interface will work:

```
var b bytes.Buffer
enc := json.NewEncoder(&b)
for _, input := range allInputs {
    t := process(input)
    err = enc.Encode(t)
    if err != nil {
        panic(err)
    }
}
out := b.String()
```

You can run this example on The Go Playground or find it in the *sample_code/encode_decode* directory in the Chapter 13 repository.

This example has multiple JSON objects in the data stream that aren't wrapped in an array, but you can also use the `json.Decoder` to read a single object from an array without loading the entire array into memory at once. This can greatly increase performance and reduce memory usage. An example is in the Go documentation.

Custom JSON Parsing

While the default functionality is often sufficient, sometimes you need to override it. While `time.Time` supports JSON fields in RFC 3339 format out of the box, you might have to deal with other time formats. You can handle this by creating a new type that implements two interfaces, `json.Marshaler` and `json.Unmarshaler`:

```
type RFC822ZTime struct {
    time.Time
}

func (rt RFC822ZTime) MarshalJSON() ([]byte, error) {
    out := rt.Time.Format(time.RFC822Z)
    return []byte(`"` + out + `"`), nil
}

func (rt *RFC822ZTime) UnmarshalJSON(b []byte) error {
    if string(b) == "null" {
        return nil
    }
    t, err := time.Parse(`"`+time.RFC822Z+`"`, string(b))
    if err != nil {
        return err
    }
    *rt = RFC822ZTime{t}
    return nil
}
```

You embedded a `time.Time` instance into a new struct called `RFC822ZTime` so that you still have access to the other methods on `time.Time`. As was discussed in "Pointer Receivers and Value Receivers" on page 145, the method that reads the time value is declared on a value receiver, while the method that modifies the time value is declared on a pointer receiver.

You then change the type of your `DateOrdered` field and can work with RFC 822 formatted times instead:

```
type Order struct {
    ID          string      `json:"id"`
    DateOrdered RFC822ZTime `json:"date_ordered"`
    CustomerID  string      `json:"customer_id"`
    Items       []Item      `json:"items"`
}
```

You can run this code on The Go Playground or find it in the *sample_code/custom_json* directory in the Chapter 13 repository.

This approach has a philosophical drawback: the date format of the JSON determines the types of the fields in your data structure. This is a drawback to the `encoding/json` approach. You could have `Order` implement `json.Marshaler` and `json.Unmarshaler`, but that requires you to write code to handle all the fields, even the ones that don't require custom support. The struct tag format does not provide a way to specify a function to parse a particular field. That leaves you with creating a custom type for the field.

Another option is described in a blog post by Ukiah Smith. It allows you to redefine only the fields that don't match the default marshaling behavior by taking advantage of how struct embedding (which was covered in "Use Embedding for Composition" on page 154) interacts with JSON marshaling and unmarshaling. If a field on an embedded struct has the same name as the containing struct, that field is ignored when marshaling or unmarshaling JSON.

In this example, the fields for `Order` look like this:

```
type Order struct {
    ID          string    `json:"id"`
    Items       []Item    `json:"items"`
    DateOrdered time.Time `json:"date_ordered"`
    CustomerID  string    `json:"customer_id"`
}
```

The `MarshalJSON` method looks like this:

```
func (o Order) MarshalJSON() ([]byte, error) {
    type Dup Order

    tmp := struct {
        DateOrdered string `json:"date_ordered"`
        Dup
    }{
        Dup: (Dup)(o),
    }
    tmp.DateOrdered = o.DateOrdered.Format(time.RFC822Z)
    b, err := json.Marshal(tmp)
    return b, err
}
```

In the `MarshalJSON` method for `Order`, you define a type `Dup` whose underlying type is `Order`. The reason for creating `Dup` is that a type based on another type has the same fields as the underlying type, but not the methods. If you didn't have `Dup`, there would be an infinite loop of calls to `MarshalJSON` when you call `json.Marshal`, eventually resulting in a stack overflow.

You define an anonymous struct that has the `DateOrdered` field and an embedded `Dup`. You then assign the `Order` instance to the embedded field in `tmp`, assign the `DateOrdered` field in `tmp` the time formatted as RFC822Z, and call `json.Marshal` on `tmp`. This produces the desired JSON output.

There is similar logic in `UnmarshalJSON`:

```
func (o *Order) UnmarshalJSON(b []byte) error {
    type Dup Order

    tmp := struct {
        DateOrdered string `json:"date_ordered"`
        *Dup
    }{
        Dup: (*Dup)(o),
    }

    err := json.Unmarshal(b, &tmp)
    if err != nil {
        return err
    }

    o.DateOrdered, err = time.Parse(time.RFC822Z, tmp.DateOrdered)
    if err != nil {
        return err
    }
    return nil
}
```

In `UnmarshalJSON`, the call to `json.Unmarshal` populates the fields in `o` (except `DateOrdered`) because it's embedded into `tmp`. You then populate `DateOrdered` in `o` by using `time.Parse` to process the `DateOrdered` field in `tmp`.

You can run this code on The Go Playground or find it in the *sample_code/custom_json2* directory in the Chapter 13 repository.

While this does keep `Order` from having a field tied to the JSON format, the `MarshalJSON` and `UnmarshalJSON` methods on `Order` are coupled to the format of the time field in the JSON. You cannot reuse `Order` to support JSON that has the time formatted another way.

To limit the amount of code that cares about what your JSON looks like, define two structs. Use one for converting to and from JSON and the other for data processing. Read in JSON to your JSON-aware type, and then copy it to the other. When you want to write out JSON, do the reverse. This does create some duplication, but it keeps your business logic from depending on wire protocols.

You can pass a `map[string]any` to `json.Marshal` and `json.Unmarshal` to translate back and forth between JSON and Go, but save that for the exploratory phase of your coding and replace it with a concrete type when you understand what you are processing. Go uses types for a reason; they document the expected data and the types of the expected data.

While JSON is probably the most commonly used encoder in the standard library, Go ships with others, including XML and Base64. If you have a data format that you want to encode and you can't find support for it in the standard library or a third-party module, you can write one yourself. You'll learn how to implement our own encoder in "Use Reflection to Write a Data Marshaler" on page 417.

> The standard library includes `encoding/gob`, which is a Go-specific binary representation that is a bit like serialization in Java. Just as Java serialization is the wire protocol for Enterprise Java Beans and Java RMI, the gob protocol is intended as the wire format for a Go-specific RPC (remote procedure call) implementation in the `net/rpc` package. Don't use either `encoding/gob` or `net/rpc`. If you want to do remote method invocation with Go, use a standard protocol like GRPC so that you aren't tied to a specific language. No matter how much you love Go, if you want your services to be useful, make them callable by developers using other languages.

net/http

Every language ships with a standard library, but the expectations of what a standard library should include have changed over time. As a language launched in the 2010s, Go's standard library includes something that other language distributions had considered the responsibility of a third party: a production-quality HTTP/2 client and server.

The Client

The `net/http` package defines a `Client` type to make HTTP requests and receive HTTP responses. A default client instance (cleverly named `DefaultClient`) is found in the `net/http` package, but you should avoid using it in production applications, because it defaults to having no timeout. Instead, instantiate your own. You need to create only a single `http.Client` for your entire program, as it properly handles multiple simultaneous requests across goroutines:

```
client := &http.Client{
    Timeout: 30 * time.Second,
}
```

When you want to make a request, you create a new `*http.Request` instance with the `http.NewRequestWithContext` function, passing it a context, the method, and URL that you are connecting to. If you are making a `PUT`, `POST`, or `PATCH` request, specify the body of the request with the last parameter as an `io.Reader`. If there is no body, use `nil`:

```
req, err := http.NewRequestWithContext(context.Background(),
    http.MethodGet, "https://jsonplaceholder.typicode.com/todos/1", nil)
if err != nil {
    panic(err)
}
```

I'll talk about what a context is in Chapter 14.

Once you have an `*http.Request` instance, you can set any headers via the `Headers` field of the instance. Call the `Do` method on the `http.Client` with your `http.Request`, and the result is returned in an `http.Response`:

```
req.Header.Add("X-My-Client", "Learning Go")
res, err := client.Do(req)
if err != nil {
    panic(err)
}
```

The response has several fields with information on the request. The numeric code of the response status is in the `StatusCode` field, the text of the response code is in the `Status` field, the response headers are in the `Header` field, and any returned content is in a `Body` field of type `io.ReadCloser`. This allows you to use it with `json.Decoder` to process REST API responses:

```go
defer res.Body.Close()
if res.StatusCode != http.StatusOK {
    panic(fmt.Sprintf("unexpected status: got %v", res.Status))
}
fmt.Println(res.Header.Get("Content-Type"))
var data struct {
    UserID    int    `json:"userId"`
    ID        int    `json:"id"`
    Title     string `json:"title"`
    Completed bool   `json:"completed"`
}
err = json.NewDecoder(res.Body).Decode(&data)
if err != nil {
    panic(err)
}
fmt.Printf("%+v\n", data)
```

You can find this code in the *sample_code/client* directory in the Chapter 13 repository.

There are functions in the `net/http` package to make `GET`, `HEAD`, and `POST` calls. Avoid using these functions because they use the default client, which means they don't set a request timeout.

The Server

The HTTP Server is built around the concept of an `http.Server` and the `http.Handler` interface. Just as the `http.Client` sends HTTP requests, the `http.Server` is responsible for listening for HTTP requests. It is a performant HTTP/2 server that supports TLS.

A request to a server is handled by an implementation of the `http.Handler` interface that's assigned to the `Handler` field. This interface defines a single method:

```go
type Handler interface {
    ServeHTTP(http.ResponseWriter, *http.Request)
}
```

The `*http.Request` should look familiar, as it's the exact same type that's used to send a request to an HTTP server. The `http.ResponseWriter` is an interface with three methods:

```
type ResponseWriter interface {
        Header() http.Header
        Write([]byte) (int, error)
        WriteHeader(statusCode int)
}
```

These methods must be called in a specific order. First, call `Header` to get an instance of `http.Header` and set any response headers you need. If you don't need to set any headers, you don't need to call it. Next, call `WriteHeader` with the HTTP status code for your response. (All the status codes are defined as constants in the `net/http` package. This would have been a good place to define a custom type, but that was not done; all status code constants are untyped integers.) If you are sending a response that has a 200 status code, you can skip `WriteHeader`. Finally, call the `Write` method to set the body for the response. Here's what a trivial handler looks like:

```
type HelloHandler struct{}

func (hh HelloHandler) ServeHTTP(w http.ResponseWriter, r *http.Request) {
    w.Write([]byte("Hello!\n"))
}
```

You instantiate a new `http.Server` just like any other struct:

```
s := http.Server{
    Addr:         ":8080",
    ReadTimeout:  30 * time.Second,
    WriteTimeout: 90 * time.Second,
    IdleTimeout:  120 * time.Second,
    Handler:      HelloHandler{},
}
err := s.ListenAndServe()
if err != nil {
    if err != http.ErrServerClosed {
        panic(err)
    }
}
```

The `Addr` field specifies the host and port the server listens on. If you don't specify them, your server defaults to listening on all hosts on the standard HTTP port, 80. You specify timeouts for the server's reads, writes, and idles by using `time.Duration` values. Be sure to set these to properly handle malicious or broken HTTP clients, as the default behavior is to not time out at all. Finally, you specify the `http.Handler` for your server with the `Handler` field.

You can find this code in the *sample_code/server* directory in the Chapter 13 repository.

A server that handles only a single request isn't terribly useful, so the Go standard library includes a request router, `*http.ServeMux`. You create an instance with the `http.NewServeMux` function. It meets the `http.Handler` interface, so it can be assigned to the `Handler` field in `http.Server`. It also includes two methods that allow it to dispatch requests. The first method is called `Handle` and takes in two parameters, a path and an `http.Handler`. If the path matches, the `http.Handler` is invoked.

While you could create implementations of `http.Handler`, the more common pattern is to use the `HandleFunc` method on `*http.ServeMux`:

```go
mux.HandleFunc("/hello", func(w http.ResponseWriter, r *http.Request) {
    w.Write([]byte("Hello!\n"))
})
```

This method takes in a function or closure and converts it to an `http.HandlerFunc`. You explored the `http.HandlerFunc` type in "Function Types Are a Bridge to Interfaces" on page 173. For simple handlers, a closure is sufficient. For more complicated handlers that depend on other business logic, use a method on a struct, as demonstrated in "Implicit Interfaces Make Dependency Injection Easier" on page 174.

Go 1.22 extends the path syntax to optionally allow HTTP verbs and path wildcard variables. The value of a wildcard variable is read using the `PathValue` method on `http.Request`:

```go
mux.HandleFunc("GET /hello/{name}", func(w http.ResponseWriter,
                                          r *http.Request) {
    name := r.PathValue("name")
    w.Write([]byte(fmt.Sprintf("Hello, %s!\n", name)))
})
```

> The package-level functions `http.Handle`, `http.HandleFunc`, `http.ListenAndServe`, and `http.ListenAndServeTLS` that work with a package-level instance of the `*http.ServeMux` called `http.DefaultServeMux`. Don't use them outside trivial test programs. The `http.Server` instance is created in the `http.ListenAndServe` and `http.ListenAndServeTLS` functions, so you are unable to configure server properties like timeouts. Furthermore, third-party libraries could have registered their own handlers with the `http.DefaultServeMux`, and there's no way to know without scanning through all your dependencies (both direct and indirect). Keep your application under control by avoiding shared state.

Because `*http.ServeMux` dispatches requests to `http.Handler` instances, and since `*http.ServeMux` implements `http.Handler`, you can create an `*http.ServeMux` instance with multiple related requests and register it with a parent `*http.ServeMux`:

```
person := http.NewServeMux()
person.HandleFunc("/greet", func(w http.ResponseWriter, r *http.Request) {
    w.Write([]byte("greetings!\n"))
})
dog := http.NewServeMux()
dog.HandleFunc("/greet", func(w http.ResponseWriter, r *http.Request) {
    w.Write([]byte("good puppy!\n"))
})
mux := http.NewServeMux()
mux.Handle("/person/", http.StripPrefix("/person", person))
mux.Handle("/dog/", http.StripPrefix("/dog", dog))
```

In this example, a request for `/person/greet` is handled by handlers attached to `person`, while `/dog/greet` is handled by handlers attached to `dog`. When you register `person` and `dog` with `mux`, you use the `http.StripPrefix` helper function to remove the part of the path that's already been processed by `mux`. You can find this code in the *sample_code/server_mux* directory in the Chapter 13 repository.

Middleware

One of the most common requirements of an HTTP server is to perform a set of actions across multiple handlers, such as checking whether a user is logged in, timing a request, or checking a request header. Go handles these cross-cutting concerns with the *middleware pattern*.

Rather than using a special type, the middleware pattern uses a function that takes in an `http.Handler` instance and returns an `http.Handler`. Usually, the returned `http.Handler` is a closure that is converted to an `http.HandlerFunc`. Here are two middleware generators, one that provides timing of requests and another that uses perhaps the worst access controls imaginable:

```
func RequestTimer(h http.Handler) http.Handler {
    return http.HandlerFunc(func(w http.ResponseWriter, r *http.Request) {
        start := time.Now()
        h.ServeHTTP(w, r)
        dur := time.Since(start)
        slog.Info("request time",
            "path", r.URL.Path,
            "duration", dur)
    })
}

var securityMsg = []byte("You didn't give the secret password\n")

func TerribleSecurityProvider(password string) func(http.Handler) http.Handler {
    return func(h http.Handler) http.Handler {
        return http.HandlerFunc(func(w http.ResponseWriter, r *http.Request) {
            if r.Header.Get("X-Secret-Password") != password {
                w.WriteHeader(http.StatusUnauthorized)
                w.Write(securityMsg)
                return
            }
            h.ServeHTTP(w, r)
        })
    }
}
```

These two middleware implementations demonstrate what middleware does. First, you do setup operations or checks. If the checks don't pass, you write the output in the middleware (usually with an error code) and return. If all is well, you call the handler's `ServeHTTP` method. When that returns, you run cleanup operations.

The `TerribleSecurityProvider` shows how to create configurable middleware. You pass in the configuration information (in this case, the password), and the function returns middleware that uses that configuration information. It is a bit of a mind bender, as it returns a closure that returns a closure.

You might be wondering how to pass values through the layers of middleware. This is done via the context, which you'll look at in Chapter 14.

You add middleware to your request handlers by chaining them:

```
terribleSecurity := TerribleSecurityProvider("GOPHER")

mux.Handle("/hello", terribleSecurity(RequestTimer(
    http.HandlerFunc(func(w http.ResponseWriter, r *http.Request) {
        w.Write([]byte("Hello!\n"))
    }))))
```

We get back your middleware from `TerribleSecurityProvider` and then wrap your handler in a series of function calls. This calls the `terribleSecurity` closure first, then calls the `RequestTimer`, which then calls your actual request handler.

Because `*http.ServeMux` implements the `http.Handler` interface, you can apply a set of middleware to all the handlers registered with a single request router:

```
terribleSecurity := TerribleSecurityProvider("GOPHER")
wrappedMux := terribleSecurity(RequestTimer(mux))
s := http.Server{
    Addr:    ":8080",
    Handler: wrappedMux,
}
```

You can find this code in the *sample_code/middleware* directory in the Chapter 13 repository.

Use third-party modules to enhance the server

Just because the server is production quality doesn't mean that you shouldn't use third-party modules to improve its functionality. If you don't like the function chains for middleware, you can use a third-party module called `alice`, which allows you to use the following syntax:

```
helloHandler := func(w http.ResponseWriter, r *http.Request) {
    w.Write([]byte("Hello!\n"))
}
chain := alice.New(terribleSecurity, RequestTimer).ThenFunc(helloHandler)
mux.Handle("/hello", chain)
```

While `*http.ServeMux` gained some much-requested features in Go 1.22, its routing and variable support are still basic. Nesting `*http.ServeMux` instances is also a bit clunky. If you find yourself needing more advanced features, such as routing based on a header value, specifying a path variable using a regular expression, or better handler nesting, many third-party request routers are available. Two of the most popular ones are gorilla mux and chi. Both are considered idiomatic because they work with `http.Handler` and `http.HandlerFunc` instances, demonstrating the Go philosophy of using composable libraries that fit together with the standard library. They also work with idiomatic middleware, and both projects provide optional middleware implementations of common concerns.

Several popular web frameworks also implement their own handler and middleware patterns. Two of the most popular are Echo and Gin. They simplify web development by incorporating features like automating the binding of data in requests or responses to JSON. They also provide adapter functions that enable you to use `http.Handler` implementations, providing a migration path.

ResponseController

In "Accept Interfaces, Return Structs" on page 162, you learned that modifying interfaces breaks backward compatibility. You also learned that you can evolve an interface over time by defining new interfaces and using type switches and type assertions to see whether the new interfaces are implemented. The drawback to creating these additional interfaces is that it is difficult to know that they exist, and using type switches to check for them is verbose.

You can find an example of this in the `http` package. When the package was designed, the choice was made to make `http.ResponseWriter` an interface. This meant that additional methods could not be added to it in future releases, or the Go Compatibility Guarantee would be broken. To represent new optional functionality for an `http.ResponseWriter` instance, the `http` package contains a couple of interfaces that may be implemented by `http.ResponseWriter` implementations: `http.Flusher` and http.Hijacker. The methods on these interfaces are used to control the output for a response.

In Go 1.20, a new concrete type was added to the http package, http.ResponseController. It demonstrates another way to expose methods that have been added to an existing API:

```
func handler(rw http.ResponseWriter, req *http.Request) {
    rc := http.NewResponseController(rw)
    for i := 0; i < 10; i++ {
        result := doStuff(i)
        _, err := rw.Write([]byte(result))
        if err != nil {
            slog.Error("error writing", "msg", err)
            return
        }
        err = rc.Flush()
        if err != nil && !errors.Is(err, http.ErrNotSupported) {
            slog.Error("error flushing", "msg", err)
            return
        }
    }
}
```

In this example, you want to return data to the client as it is calculated, if the http.ResponseWriter supports Flush. If not, you will return all the data after all of it has been calculated. The factory function http.NewResponseController takes in an http.ResponseWriter and returns a pointer to an http.ResponseController. This concrete type has methods for the optional functionality of an http.ResponseWriter. You check whether the optional method is implemented by the underlying http.ResponseWriter by comparing the returned error to http.ErrNotSupported using errors.Is. You can find this code in the *sample_code/response_controller* directory in the Chapter 13 repository.

Because http.ResponseController is a concrete type that wraps access to an http.ResponseWriter implementation, new methods can be added to it over time without breaking existing implementations. This makes new functionality discoverable and provides a way to check for the presence or absence of an optional method with a standard error check. This pattern is an interesting way to handle situations where an interface needs to evolve. In fact, http.ResponseController contains two methods that don't have corresponding interfaces: SetReadDeadline and SetWriteDeadline. Future optional methods on http.ResponseWriter will likely be added via this technique.

Structured Logging

Since its initial release, the Go standard library has included a simple logging package, `log`. While it's fine for small programs, it doesn't easily produce *structured* logs. Modern web services can have millions of simultaneous users, and at that scale you need software to process log output in order to understand what's going on. A structured log uses a documented format for each log entry, making it easier to write programs that process log output and discover patterns and anomalies.

JSON is commonly used for structured logs, but even whitespace separated key-value pairs are easier to process than unstructured logs that don't separate values into fields. While you certainly could write JSON by using the `log` package, it doesn't provide any support for simplifying structured log creation. The `log/slog` package resolves this problem.

Adding `log/slog` to the standard library demonstrated several good Go library design practices. The first good decision was to include structured logging in the standard library. Having a standard structured logger makes it easier to write modules that work together. Several third-party structured loggers have been released to address the shortcomings of `log`, including zap, logrus, go-kit log, and many others. The problem with a fragmented logging ecosystem is that you want control over where log output goes and what level of messages are logged. If your code depends on third-party modules that use different loggers, this becomes impossible. The usual advice to prevent logging fragmentation is to not log in a module intended as a library, but that's impossible to enforce and makes it harder to monitor what's going on in a third-party library. The `log/slog` package was new in Go 1.21, but the fact that it solves these inconsistencies makes it likely that within a few years, it will be used in the vast majority of Go programs.

The second good decision was to make structured logging its own package and not part of the `log` package. While both packages have similar purposes, they have very different design philosophies. Trying to add structured logging into an unstructured logging package would confuse the API. By making them separate packages, you know at a glance that `slog.Info` is a structured log and `log.Print` is unstructured, even if you don't remember whether `Info` is for structured or unstructured logging.

The next good decision was to make the `log/slog` API scalable. It starts simply, with a default logger available via functions:

```go
func main() {
    slog.Debug("debug log message")
    slog.Info("info log message")
    slog.Warn("warning log message")
    slog.Error("error log message")
}
```

These functions allow you to log simple messages at various logging levels. The output looks like the following:

```
2023/04/20 23:13:31 INFO info log message
2023/04/20 23:13:31 WARN warning log message
2023/04/20 23:13:31 ERROR error log message
```

There are two things to notice. First, the default logger suppresses debug messages by default. You'll see how to control the logging level when I discuss creating your own logger in a bit.

The second point is a bit more subtle. While this is plain-text output, it uses whitespace to make a structured log. The first column is the date in year/month/day format. The second column is the time in 24-hour time. The third column is the logging level. Finally, there is the message.

The power of structured logging comes from the ability to add fields with custom values. Update your logs with some custom fields:

```
userID := "fred"
loginCount := 20
slog.Info("user login",
    "id", userID,
    "login_count", loginCount)
```

You use the same function as before, but now you add optional arguments. Optional arguments come in pairs. The first part is the key, which should be a string. The second part is the value. This log line prints out the following:

```
2023/04/20 23:36:38 INFO user login id=fred login_count=20
```

After the message, you have key-value pairs, again space separated.

While this text format is far easier to parse than an unstructured log, you might want to use something like JSON instead. You also might want to customize where the log is written or the logging level. To do that, you create a structured logging instance:

```
options := &slog.HandlerOptions{Level: slog.LevelDebug}
handler := slog.NewJSONHandler(os.Stderr, options)
mySlog := slog.New(handler)
lastLogin := time.Date(2023, 01, 01, 11, 50, 00, 00, time.UTC)
mySlog.Debug("debug message",
    "id", userID,
    "last_login", lastLogin)
```

You are using the `slog.HandlerOptions` struct to define the minimum logging level for the new logger. You then use the `NewJSONHandler` method on `slog.HandlerOptions` to create a `slog.Handler` that writes logs using JSON to the specified `io.Writer`. In this case, you are using the standard error output. Finally, you use the `slog.New` function to create a `*slog.Logger` that wraps the slog.Handler. You then create a lastLogin value to log, along with a user ID. This gives the following output:

```
{"time":"2023-04-22T23:30:01.170243-04:00","level":"DEBUG",
 "msg":"debug message","id":"fred","last_login":"2023-01-01T11:50:00Z"}
```

If JSON and text aren't sufficient for your output needs, you can define your own implementation of the slog.Handler interface and pass it to slog.New.

Finally, the log/slog package takes performance into consideration. If you aren't careful, your program might end up spending more time writing logs than doing the work it was designed to perform. You can choose to write data out to log/slog in a number of ways. You have already seen the simplest (but slowest) method, using alternating keys and values on the Debug, Info, Warn, and Error methods. For improved performance with fewer allocations, use the LogAttrs method instead:

```
mySlog.LogAttrs(ctx, slog.LevelInfo, "faster logging",
                slog.String("id", userID),
                slog.Time("last_login", lastLogin))
```

The first parameter is a context.Context, next comes the logging level, and then zero or more slog.Attr instances. There are factory functions for the most commonly used types, and you can use slog.Any for the ones that don't have functions already supplied.

Because of the Go Compatibility Promise, the log package isn't going away. Existing programs that use it will continue to work, as will programs that use third-party structured loggers. If you have code that uses a log.Logger, the slog.NewLogLogger function provides a bridge to the original log package. It creates a log.Logger instance that uses a slog.Handler to write its output:

```
myLog := slog.NewLogLogger(mySlog.Handler(), slog.LevelDebug)
myLog.Println("using the mySlog Handler")
```

This produces the following output:

```
{"time":"2023-04-22T23:30:01.170269-04:00","level":"DEBUG",
 "msg":"using the mySlog Handler"}
```

You can find all the coding examples for log/slog in the *sample_code/structured_logging* directory in the Chapter 13 repository.

The log/slog API includes more features, including dynamic logging-level support, context support (the context is covered in Chapter 14), grouping values, and creating a common header of values. You can learn more by looking at its API documentation. Most importantly, look at how log/slog was put together so you can learn how to construct APIs of your own.

Exercises

Now that you've learned more about the standard library, work through these exercises to reinforce what you've learned. Solutions are in the *exercise_solutions* directory of the Chapter 13 repository.

1. Write a small web server that returns the current time in RFC 3339 format when you send it a `GET` command. You can use a third-party module if you'd like.
2. Write a small middleware component that uses JSON structured logging to log the IP address of each incoming request to your web server.
3. Add the ability to return the time as JSON. Use the `Accept` header to control whether JSON or text is returned (default to text). The JSON should be structured as follows:

```
{
    "day_of_week": "Monday",
    "day_of_month": 10,
    "month": "April",
    "year": 2023,
    "hour": 20,
    "minute": 15,
    "second": 20
}
```

Wrapping Up

In this chapter, you looked at some of the most commonly used packages in the standard library and saw how they embody best practices that should be emulated in your code. You've also seen other sound software engineering principles: how some decisions might have been made differently given experience, and how to respect backward compatibility so you can build applications on a solid foundation.

In the next chapter, you're going to look at the context, a package and pattern for passing state and timers through Go code.

CHAPTER 14

The Context

Servers need a way to handle metadata on individual requests. This metadata falls into two general categories: metadata that is required to correctly process the request, and metadata on when to stop processing the request. For example, an HTTP server might want to use a tracking ID to identify a chain of requests through a set of microservices. It also might want to set a timer that ends requests to other microservices if they take too long.

Many languages use *threadlocal* variables to store this kind of information, associating data to a specific operating system thread of execution. This doesn't work in Go because goroutines don't have unique identities that can be used to look up values. More importantly, threadlocals feel like magic; values go in one place and pop up somewhere else.

Go solves the request metadata problem with a construct called the *context*. Let's see how to use it correctly.

What Is the Context?

Rather than add a new feature to the language, a context is simply an instance that meets the `Context` interface defined in the `context` package. As you know, idiomatic Go encourages explicit data passing via function parameters. The same is true for the context. It is just another parameter to your function.

Just as Go has a convention that the last return value from a function is an `error`, Go has another convention that the context is explicitly passed through your program as the first parameter of a function. The usual name for the context parameter is `ctx`:

```go
func logic(ctx context.Context, info string) (string, error) {
    // do some interesting stuff here
    return "", nil
}
```

In addition to defining the `Context` interface, the `context` package contains several factory functions for creating and wrapping contexts. When you don't have an existing context, such as at the entry point to a command-line program, create an empty initial context with the function `context.Background`. This returns a variable of type `context.Context`. (Yes, this is an exception to the usual pattern of returning a concrete type from a function call.)

An empty context is a starting point; each time you add metadata to the context, you do so by *wrapping* the existing context by using one of the factory functions in the `context` package.

> Another function, `context.TODO`, also creates an empty `con`
> `text.Context`. It is intended for temporary use during development. If you aren't sure where the context is going to come from or how it's going to be used, use `context.TODO` to put a placeholder in your code. Production code shouldn't include `context.TODO`.

When writing an HTTP server, you use a slightly different pattern for acquiring and passing the context through layers of middleware to the top-level `http.Handler`. Unfortunately, context was added to the Go APIs long after the `net/http` package was created. Because of the compatibility promise, there was no way to change the `http.Handler` interface to add a `context.Context` parameter.

The compatibility promise does allow new methods to be added to existing types, and that's what the Go team did. Two context-related methods are on `http.Request`:

- `Context` returns the `context.Context` associated with the request.
- `WithContext` takes in a `context.Context` and returns a new `http.Request` with the old request's state combined with the supplied `context.Context`.

Here's the general pattern:

```go
func Middleware(handler http.Handler) http.Handler {
    return http.HandlerFunc(func(rw http.ResponseWriter, req *http.Request) {
        ctx := req.Context()
        // wrap the context with stuff -- you'll see how soon!
        req = req.WithContext(ctx)
        handler.ServeHTTP(rw, req)
    })
}
```

The first thing you do in your middleware is extract the existing context from the request by using the `Context` method. (If you want to skip ahead, you can see how to put values into the context in "Values" on page 352.) After you put values into the context, you create a new request based on the old request and the now-populated context by using the `WithContext` method. Finally, you call the `handler` and pass it your new request and the existing `http.ResponseWriter`.

When you implement the handler, extract the context from the request by using the `Context` method and call your business logic with the context as the first parameter, just as you saw previously:

```go
func handler(rw http.ResponseWriter, req *http.Request) {
    ctx := req.Context()
    err := req.ParseForm()
    if err != nil {
        rw.WriteHeader(http.StatusInternalServerError)
        rw.Write([]byte(err.Error()))
        return
    }
    data := req.FormValue("data")
    result, err := logic(ctx, data)
    if err != nil {
        rw.WriteHeader(http.StatusInternalServerError)
        rw.Write([]byte(err.Error()))
        return
    }
    rw.Write([]byte(result))
}
```

When making an HTTP call from your application to another HTTP service, use the `NewRequestWithContext` function in the `net/http` package to construct a request that includes existing context information:

```go
type ServiceCaller struct {
    client *http.Client
}

func (sc ServiceCaller) callAnotherService(ctx context.Context, data string)
                                        (string, error) {
    req, err := http.NewRequestWithContext(ctx, http.MethodGet,
                "http://example.com?data="+data, nil)
    if err != nil {
        return "", err
    }
    resp, err := sc.client.Do(req)
    if err != nil {
        return "", err
    }
    defer resp.Body.Close()
    if resp.StatusCode != http.StatusOK {
        return "", fmt.Errorf("Unexpected status code %d",
                                 resp.StatusCode)
    }
    // do the rest of the stuff to process the response
    id, err := processResponse(resp.Body)
    return id, err
}
```

You can find these code samples in the *sample_code/context_patterns* directory in the Chapter 14 repository.

Now that you know how to acquire and pass a context, let's start making them useful. You'll begin with passing values.

Values

By default, you should prefer to pass data through explicit parameters. As has been mentioned before, idiomatic Go favors the explicit over the implicit, and this includes explicit data passing. If a function depends on some data, it should be clear what data it needs and where that data came from.

However, in some cases you cannot pass data explicitly. The most common situation is an HTTP request handler and its associated middleware. As you have seen, all HTTP request handlers have two parameters, one for the request and one for the response. If you want to make a value available to your handler in middleware, you need to store it in the context. Possible situations include extracting a user from a JWT (JSON Web Token) or creating a per-request GUID that is passed through multiple layers of middleware and into your handler and business logic.

There is a factory method for putting values into the context, `context.WithValue`. It takes in three values: a context, a key to look up the value, and the value itself. The key and the value parameters are declared to be of type `any`. The `context.WithValue` function returns a context, but it is not the same context that was passed into the function. Instead, it is a *child* context that contains the key-value pair and *wraps* the passed-in *parent* `context.Context`.

You'll see this wrapping pattern several times. A context is treated as an immutable instance. Whenever you add information to a context, you do so by wrapping an existing parent context with a child context. This allows you to use contexts to pass information into deeper layers of the code. The context is never used to pass information out of deeper layers to higher layers.

The `Value` method on `context.Context` checks whether a value is in a context or any of its parent contexts. This method takes in a key and returns the value associated with the key. Again, both the key parameter and the value result are declared to be of type any. If no value is found for the supplied key, nil is returned. Use the comma ok idiom to type-assert the returned value to the correct type:

```
ctx := context.Background()
if myVal, ok := ctx.Value(myKey).(int); !ok {
    fmt.Println("no value")
} else {
    fmt.Println("value:", myVal)
}
```

If you are familiar with data structures, you might recognize that searching for values stored in the context chain is a *linear* search. This has no serious performance implications when there are only a few values, but it would perform poorly if you stored dozens of values in the context during a request. That said, if your program is creating a context chain with dozens of values, your program probably needs some refactoring.

The value stored in the context can be of any type, but picking the correct key is important. Like the key for a map, the key for a context value must be comparable. Don't just use a string like "id". If you use string or another predefined or exported type for the type of the key, different packages could create identical keys, resulting in collisions. This causes problems that are hard to debug, such as one package writing data to the context that masks the data written by another package, or reading data from the context that was written by another package.

Two patterns are used to guarantee that a key is unique and comparable. The first creates a new, unexported type for the key, based on an int:

```
type userKey int
```

After declaring your unexported key type, you then declare an unexported constant of that type:

```
const (
    _ userKey = iota
    key
)
```

With both the type and the typed constant of the key being unexported, no code from outside your package can put data into the context that would cause a collision. If your package needs to put multiple values into the context, define a different key of the same type for each value, using the iota pattern you looked at in "iota Is for Enumerations—Sometimes" on page 152. Since you care about the constant's value only as a way to differentiate multiple keys, this is a perfect use for iota.

Next, build an API to place a value into the context and to read the value from the context. Make these functions public only if code outside your package should be able to read and write your context values. The name of the function that creates a context with the value should start with `ContextWith`. The function that returns the value from the context should have a name that ends with `FromContext`. Here are the implementations of functions to set and read the user from the context:

```go
func ContextWithUser(ctx context.Context, user string) context.Context {
    return context.WithValue(ctx, key, user)
}

func UserFromContext(ctx context.Context) (string, bool) {
    user, ok := ctx.Value(key).(string)
    return user, ok
}
```

Another option is to define the unexported key type by using an empty struct:

```go
type userKey struct{}
```

The functions for managing access to the context value are then changed:

```go
func ContextWithUser(ctx context.Context, user string) context.Context {
    return context.WithValue(ctx, userKey{}, user)
}

func UserFromContext(ctx context.Context) (string, bool) {
    user, ok := ctx.Value(userKey{}).(string)
    return user, ok
}
```

How do you know which key style to use? If you have a set of related keys for storing different values in the context, use the `int` and `iota` technique. If you have only a single key, either is fine. The important thing is that you want to make it impossible for context keys to collide.

Now that you've written your user-management code, let's see how to use it. You're going to write middleware that extracts a user ID from a cookie:

```go
// a real implementation would be signed to make sure
// the user didn't spoof their identity
func extractUser(req *http.Request) (string, error) {
    userCookie, err := req.Cookie("identity")
    if err != nil {
        return "", err
    }
    return userCookie.Value, nil
}

func Middleware(h http.Handler) http.Handler {
    return http.HandlerFunc(func(rw http.ResponseWriter, req *http.Request) {
        user, err := extractUser(req)
        if err != nil {
            rw.WriteHeader(http.StatusUnauthorized)
            rw.Write([]byte("unauthorized"))
            return
        }
        ctx := req.Context()
        ctx = ContextWithUser(ctx, user)
        req = req.WithContext(ctx)
        h.ServeHTTP(rw, req)
    })
}
```

In the middleware, you first get your user value. Next, you extract the context from the request with the `Context` method and create a new context that contains the user with your `ContextWithUser` function. It is idiomatic to reuse the `ctx` variable name when you wrap a context. You then make a new request from the old request and the new context by using the `WithContext` method. Finally, you call the next function in your handler chain with our new request and the supplied `http.ResponseWriter`.

In most cases, you want to extract the value from the context in your request handler and pass it in to your business logic explicitly. Go functions have explicit parameters, and you shouldn't use the context as a way to sneak values past the API:

```
func (c Controller) DoLogic(rw http.ResponseWriter, req *http.Request) {
    ctx := req.Context()
    user, ok := identity.UserFromContext(ctx)
    if !ok {
        rw.WriteHeader(http.StatusInternalServerError)
        return
    }
    data := req.URL.Query().Get("data")
    result, err := c.Logic.BusinessLogic(ctx, user, data)
    if err != nil {
        rw.WriteHeader(http.StatusInternalServerError)
        rw.Write([]byte(err.Error()))
        return
    }
    rw.Write([]byte(result))
}
```

Your handler gets the context by using the `Context` method on the request, extracts the user from the context by using the `UserFromContext` function, and then calls the business logic. This code shows the value of separation of concerns; how the user is loaded is unknown to the `Controller`. A real user-management system could be implemented in middleware and swapped in without changing any of the controller's code.

The complete code for this example is in the *sample_code/context_user* directory in the Chapter 14 repository.

In some situations, it's better to keep a value in the context. The tracking GUID that was mentioned earlier is one. This information is meant for management of your application; it is not part of your business state. Passing it explicitly through your code adds additional parameters and prevents integration with third-party libraries that do not know about your metainformation. By leaving a tracking GUID in the context, it passes invisibly through business logic that doesn't need to know about tracking and is available when your program writes a log message or connects to another server.

Here is a simple context-aware GUID implementation that tracks from service to service and creates logs with the GUID included:

```go
package tracker

import (
    "context"
    "fmt"
    "net/http"

    "github.com/google/uuid"
)

type guidKey int

const key guidKey = 1

func contextWithGUID(ctx context.Context, guid string) context.Context {
    return context.WithValue(ctx, key, guid)
}

func guidFromContext(ctx context.Context) (string, bool) {
    g, ok := ctx.Value(key).(string)
    return g, ok
}

func Middleware(h http.Handler) http.Handler {
    return http.HandlerFunc(func(rw http.ResponseWriter, req *http.Request) {
        ctx := req.Context()
        if guid := req.Header.Get("X-GUID"); guid != "" {
            ctx = contextWithGUID(ctx, guid)
        } else {
            ctx = contextWithGUID(ctx, uuid.New().String())
        }
        req = req.WithContext(ctx)
        h.ServeHTTP(rw, req)
    })
}

type Logger struct{}

func (Logger) Log(ctx context.Context, message string) {
    if guid, ok := guidFromContext(ctx); ok {
        message = fmt.Sprintf("GUID: %s - %s", guid, message)
    }
    // do logging
    fmt.Println(message)
}

func Request(req *http.Request) *http.Request {
    ctx := req.Context()
    if guid, ok := guidFromContext(ctx); ok {
        req.Header.Add("X-GUID", guid)
    }
    return req
}
```

The `Middleware` function either extracts the GUID from the incoming request or generates a new GUID. In both cases, it places the GUID into the context, creates a new request with the updated context, and continues the call chain.

Next you see how this GUID is used. The `Logger` struct provides a generic logging method that takes in a context and a string. If there's a GUID in the context, it appends it to the beginning of the log message and outputs it. The `Request` function is used when this service makes a call to another service. It takes in an `*http.Request`, adds a header with the GUID if it exists in the context, and returns the `*http.Request`.

Once you have this package, you can use the dependency injection techniques that I discussed in "Implicit Interfaces Make Dependency Injection Easier" on page 174 to create business logic that is completely unaware of any tracking information. First, you declare an interface to represent your logger, a function type to represent a request decorator, and a business logic struct that depends on them:

```
type Logger interface {
    Log(context.Context, string)
}

type RequestDecorator func(*http.Request) *http.Request

type LogicImpl struct {
    RequestDecorator RequestDecorator
    Logger           Logger
    Remote           string
}
```

Next, you implement your business logic:

```
func (l LogicImpl) Process(ctx context.Context, data string) (string, error) {
    l.Logger.Log(ctx, "starting Process with "+data)
    req, err := http.NewRequestWithContext(ctx,
        http.MethodGet, l.Remote+"/second?query="+data, nil)
    if err != nil {
        l.Logger.Log(ctx, "error building remote request:"+err.Error())
        return "", err
    }
    req = l.RequestDecorator(req)
    resp, err := http.DefaultClient.Do(req)
    // process the response...
}
```

The GUID is passed through to the logger and the request decorator without the business logic being aware of it, separating the data needed for program logic from the data needed for program management. The only place that's aware of the association is the code in `main` that wires up your dependencies:

```
controller := Controller{
    Logic: LogicImpl{
        RequestDecorator: tracker.Request,
        Logger:           tracker.Logger{},
        Remote:           "http://localhost:4000",
    },
}
```

You can find the complete code for the GUID tracker in the *sample_code/context_guid* directory in the Chapter 14 repository.

Use the context to pass values through standard APIs. Copy values from the context into explicit parameters when they are needed for processing business logic. System maintenance information can be accessed directly from the context.

Cancellation

While context values are useful for passing metadata and working around the limitations of Go's HTTP API, the context has a second use. The context also allows you to control the responsiveness of your application and coordinate concurrent goroutines. Let's see how.

I discussed this briefly in "Use the Context to Terminate Goroutines" on page 300. Imagine that you have a request that launches several goroutines, each one calling a different HTTP service. If one service returns an error that prevents you from returning a valid result, there is no point in continuing to process the other goroutines. In Go, this is called *cancellation*, and the context provides the mechanism for its implementation.

To create a cancellable context, use the `context.WithCancel` function. It takes in a `context.Context` as a parameter and returns a `context.Context` and a `context.CancelFunc`. Just like `context.WithValue`, the returned `context.Context` is a child context of the context that was passed into the function. A `context.CancelFunc` is a function that takes no parameters and *cancels* the context, telling all the code that's listening for potential cancellation that it's time to stop processing.

Anytime you create a context that has an associated cancel function, you *must* call that cancel function when you are done processing, whether or not your processing ends in an error. If you do not, your program will leak resources (memory and goroutines) and eventually slow down or crash. No error occurs if you call the cancel function more than once; any invocation after the first does nothing.

The easiest way to make sure you call the cancel function is to use `defer` to invoke it right after the cancel function is returned:

```go
ctx, cancelFunc := context.WithCancel(context.Background())
defer cancelFunc()
```

This leads to the question, how do you detect cancellation? The `context.Context` interface has a method called `Done`. It returns a channel of type `struct{}`. (The reason this is the chosen return type is that an empty struct uses no memory.) This channel is closed when the `cancel` function is invoked. Remember, a closed channel always immediately returns its zero value when you attempt to read it.

> If you call `Done` on a context that isn't cancellable, it returns `nil`. As was covered in "Turn Off a case in a select" on page 304, a read from a `nil` channel never returns. If this is not done inside a `case` in a `select` statement, your program will hang.

Let's take a look at how this works. Let's say you have a program that's gathering data from a number of HTTP endpoints. If any one of them fails, you want to end processing across all of them. Context cancellation allows you to do that.

> In this example, you are going to take advantage of a great service called httpbin.org. You send it HTTP or HTTPS requests to test how your application responds to a variety of situations. You'll use two of its endpoints: one that delays response for a specified number of seconds, and one that will return one of the status codes that you send it.

First, create your cancellable context, a channel to get back data from your goroutines, and a `sync.WaitGroup` to allow you to wait until all goroutines have completed:

```go
ctx, cancelFunc := context.WithCancel(context.Background())
defer cancelFunc()
ch := make(chan string)
var wg sync.WaitGroup
wg.Add(2)
```

Next, you launch two goroutines, one that calls a URL that randomly returns a bad status, and the other that sends a canned JSON response after a delay. First the random status goroutine:

```
go func() {
    defer wg.Done()
    for {
        // return one of these status code at random
        resp, err := makeRequest(ctx,
            "http://httpbin.org/status/200,200,200,500")
        if err != nil {
            fmt.Println("error in status goroutine:", err)
            cancelFunc()
            return
        }
        if resp.StatusCode == http.StatusInternalServerError {
            fmt.Println("bad status, exiting")
            cancelFunc()
            return
        }
        select {
        case ch <- "success from status":
        case <-ctx.Done():
        }
        time.Sleep(1 * time.Second)
    }
}()
```

The makeRequest function is a helper to make an HTTP request using the supplied context and URL. If you get back an OK status, you write a message to the channel and sleep for a second. When an error occurs or you get back a bad status code, you call cancelFunc and exit the goroutine.

The delay goroutine is similar:

```
go func() {
    defer wg.Done()
    for {
        // return after a 1 second delay
        resp, err := makeRequest(ctx, "http://httpbin.org/delay/1")
        if err != nil {
            fmt.Println("error in delay goroutine:", err)
            cancelFunc()
            return
        }
        select {
        case ch <- "success from delay: " + resp.Header.Get("date"):
        case <-ctx.Done():
        }
    }
}()
```

Finally, you use the for/select pattern to read data from the channel written to by the goroutines and wait for cancellation to happen:

```
loop:
    for {
        select {
        case s := <-ch:
            fmt.Println("in main:", s)
        case <-ctx.Done():
            fmt.Println("in main: cancelled!")
            break loop
        }
    }
    wg.Wait()
```

In your `select` statement, you have two cases. One reads from the message channel, and the other waits for the done channel to be closed. When it closes, you exit the loop and wait for the goroutines to exit. You can find this program in the *sample_code/cancel_http* directory in the Chapter 14 repository.

Here's what happens when you run the code (the results are random, so go ahead and run it a few times to see different results):

```
in main: success from status
in main: success from delay: Thu, 16 Feb 2023 03:53:57 GMT
in main: success from status
in main: success from delay: Thu, 16 Feb 2023 03:53:58 GMT
bad status, exiting
in main: cancelled!
error in delay goroutine: Get "http://httpbin.org/delay/1": context canceled
```

There are some interesting things to note. First, you are calling `cancelFunc` multiple times. As mentioned earlier, this is perfectly fine and causes no problems. Next, notice that you got an error from the delay goroutine after cancellation was triggered. This is because the built-in HTTP client in the Go standard library respects cancellation. You created the request using the cancellable context, and when it was cancelled, the request ended. This triggers the error path in the goroutine and makes sure that it does not leak.

You might wonder about the error that caused the cancellation and how you can report it. An alternate version of `WithCancel`, called `WithCancelCause`, returns a cancellation function that takes in an error as a parameter. The `Cause` function in the `context` package returns the error that was passed into the first invocation of the cancellation function.

Cause is a function in the context package instead of a method on context.Context because the ability to return errors via cancellation was added to the context package in Go 1.20, long after the context was initially introduced. If a new method was added to the context.Context interface, this would have broken any third-party code that implemented it. Another option would be to define a new interface that included this method, but existing code already passes context.Context everywhere, and converting to a new interface with a Cause method would require type assertions or type switches. Adding a function is the simplest approach. There are several ways to evolve your APIs over time. You should pick the one that has the least impact on your users.

Let's rewrite the program to capture the error. First, you change your context creation:

```
ctx, cancelFunc := context.WithCancelCause(context.Background())
defer cancelFunc(nil)
```

Next, you are going to make slight modifications to your two goroutines. The body of the for loop in the status goroutine now looks like this:

```
resp, err := makeRequest(ctx, "http://httpbin.org/status/200,200,200,500")
if err != nil {
    cancelFunc(fmt.Errorf("in status goroutine: %w", err))
    return
}
if resp.StatusCode == http.StatusInternalServerError {
    cancelFunc(errors.New("bad status"))
    return
}
ch <- "success from status"
time.Sleep(1 * time.Second)
```

You've removed the fmt.Println statements and pass errors to cancelFunc. The body of the for loop in the delay goroutine now looks like this:

```
resp, err := makeRequest(ctx, "http://httpbin.org/delay/1")
if err != nil {
    fmt.Println("in delay goroutine:", err)
    cancelFunc(fmt.Errorf("in delay goroutine: %w", err))
    return
}
ch <- "success from delay: " + resp.Header.Get("date")
```

The fmt.Println is still there so you can show that the error is still generated and passed to cancelFunc.

Finally, you use `context.Cause` to print out the error both on initial cancellation and after you finish waiting for your goroutines to complete:

```
loop:
    for {
        select {
        case s := <-ch:
            fmt.Println("in main:", s)
        case <-ctx.Done():
            fmt.Println("in main: cancelled with error", context.Cause(ctx))
            break loop
        }
    }
    wg.Wait()
    fmt.Println("context cause:", context.Cause(ctx))
```

You can find this code in the *sample_code/cancel_error_http* directory in the Chapter 14 repository.

Running your new program produces this output:

```
in main: success from status
in main: success from delay: Thu, 16 Feb 2023 04:11:49 GMT
in main: cancelled with error bad status
in delay goroutine: Get "http://httpbin.org/delay/1": context canceled
context cause: bad status
```

You see that the error from the status goroutine is printed out both when cancellation is initially detected in the `switch` statement and after you finish waiting for the delay goroutine to complete. Notice that the delay goroutine called `cancelFunc` with an error, but that error doesn't overwrite the initial cancellation error.

Manual cancellation is very useful when your code reaches a logical state that ends processing. Sometimes you want to cancel because a task is taking too long. In that case, you use a timer.

Contexts with Deadlines

One of the most important jobs for a server is managing requests. A novice programmer often thinks that a server should take as many requests as it possibly can and work on them for as long as it can until it returns a result for each client.

The problem is that this approach does not scale. A server is a shared resource. Like all shared resources, each user wants to get as much as they can out of it and isn't terribly concerned with the needs of other users. It's the responsibility of the shared resource to manage itself so that it provides a fair amount of time to all its users.

Generally, a server can do four things to manage its load:

- Limit simultaneous requests
- Limit the number of queued requests waiting to run
- Limit the amount of time a request can run
- Limit the resources a request can use (such as memory or disk space)

Go provides tools to handle the first three. You saw how to handle the first two when learning about concurrency in Chapter 12. By limiting the number of goroutines, a server manages simultaneous load. The size of the waiting queue is handled via buffered channels.

The context provides a way to control how long a request runs. When building an application, you should have an idea of your performance envelope: how long you have for your request to complete before the user has an unsatisfactory experience. If you know the maximum amount of time that a request can run, you can enforce it using the context.

> While `GOMEMLIMIT` provides a soft way to limit the amount of memory a Go program uses, if you want to enforce constraints on memory or disk space that a single request uses, you'll have to write the code to manage that yourself. Discussion of this topic is beyond the scope of this book.

You can use one of two functions to create a time-limited context. The first is `context.WithTimeout`. It takes two parameters: an existing context and `time.Duration` that specifies the duration until the context automatically cancels. It returns a context that automatically triggers a cancellation after the specified duration as well as a cancellation function that is invoked to cancel the context immediately.

The second function is `context.WithDeadline`. This function takes in an existing context and a `time.Time` that specifies the time when the context is automatically canceled. Like `context.WithTimeout`, it returns a context that automatically triggers a cancellation after the specified time has elapsed as well as a cancellation function.

> If you pass a time in the past to `context.WithDeadline`, the context is created already canceled.

Just as with the cancellation function returned from `context.WithCancel` and `context.WithCancelCause`, you must make sure that that the cancellation function returned by context.WithTimeout and context.WithDeadline is invoked at least once.

If you want to find out when a context will automatically cancel, use the Deadline method on context.Context. It returns a time.Time that indicates the time and a bool that indicates if a timeout was set. This mirrors the comma ok idiom you use when reading from maps or channels.

When you set a time limit for the overall duration of the request, you might want to subdivide that time. And if you call another service from your service, you might want to limit how long you allow the network call to run, reserving some time for the rest of your processing or for other network calls. You control how long an individual call takes by creating a child context that wraps a parent context by using context.WithTimeout or context.WithDeadline.

Any timeout that you set on the child context is bounded by the timeout set on the parent context; if a parent context times out in 2 seconds, you can declare that a child context times out in 3 seconds, but when the parent context times out after 2 seconds, so will the child.

You can see this with a simple program:

```go
ctx := context.Background()
parent, cancel := context.WithTimeout(ctx, 2*time.Second)
defer cancel()
child, cancel2 := context.WithTimeout(parent, 3*time.Second)
defer cancel2()
start := time.Now()
<-child.Done()
end := time.Now()
fmt.Println(end.Sub(start).Truncate(time.Second))
```

In this sample, you specify a 2-second timeout on the parent context and a 3-second timeout on the child context. You then wait for the child context to complete by waiting on the channel returned from the Done method on the child context.Context. I'll talk more about the Done method in the next section.

You can find this code in the *sample_code/nested_timers* directory in the Chapter 14 repository or run this code on The Go Playground. You'll see the following result:

```
2s
```

Since contexts with timers can cancel because of a timeout or an explicit call to the cancellation function, the context API provides a way to tell what caused cancellation. The Err method returns nil if the context is still active, or it returns one of two sentinel errors if the context has been canceled: context.Canceled or context.DeadlineExceeded. The first is returned after explicit cancellation, and the second is returned when a timeout triggered cancellation.

Let's see them in use. You're going to make one more change to your httpbin program. This time, you're adding a timeout to the context that's used to control how long the goroutines run:

```
ctx, cancelFuncParent := context.WithTimeout(context.Background(), 3*time.Second)
defer cancelFuncParent()
ctx, cancelFunc := context.WithCancelCause(ctx)
defer cancelFunc(nil)
```

If you want the option of returning the error for the cancellation cause, you need to wrap a context created by `WithTimeout` or `WithDeadline` in a context created by `WithCancelCause`. You must `defer` both cancellation functions to keep resources from being leaked. If you want to return a custom sentinel error when a context times out, use the `context.WithTimeoutCause` or `context.WithDeadlineCause` functions instead.

Now your program will exit if a 500 status code is returned or if you don't get a 500 status code within 3 seconds. The only other change you are making to the program is to print out the value returned by `Err` when cancellation happens:

```
fmt.Println("in main: cancelled with cause:", context.Cause(ctx),
    "err:", ctx.Err())
```

You can find the code in the *sample_code/timeout_error_http* directory in the Chapter 14 repository.

The results are random, so run the program multiple times to see different results. If you run the program and hit the timeout, you'll get output like this:

```
in main: success from status
in main: success from delay: Sun, 19 Feb 2023 04:36:44 GMT
in main: success from status
in main: success from status
in main: success from delay: Sun, 19 Feb 2023 04:36:45 GMT
in main: cancelled with cause: context deadline exceeded
    err: context deadline exceeded
in delay goroutine: Get "http://httpbin.org/delay/1":
    context deadline exceeded
context cause: context deadline exceeded
```

Notice that the error returned by `context.Cause` is the same error that's returned by the `Err` method: `context.DeadlineExceeded`.

If the status error happens within 3 seconds, you'll get output like this:

```
in main: success from status
in main: success from status
in main: success from delay: Sun, 19 Feb 2023 04:37:14 GMT
in main: cancelled with cause: bad status err: context canceled
in delay goroutine: Get "http://httpbin.org/delay/1": context canceled
context cause: bad status
```

Now the error returned by `context.Cause` is `bad status`, but `Err` returns a `context.Canceled` error.

Context Cancellation in Your Own Code

Most of the time, you don't need to worry about timeouts or cancellation within your own code; it simply doesn't run for long enough. Whenever you call another HTTP service or the database, you should pass along the context; those libraries properly handle cancellation via the context.

You should think about handling cancellation for two situations. The first is when you have a function that reads or writes channels by using a `select` statement. As shown in "Cancellation" on page 358, include a `case` that checks the channel returned by the `Done` method on the context. This allows your function to exit upon context cancellation, even if the goroutines do not handle cancellation properly.

The second situation is when you write code that runs long enough that it should be interrupted by a context cancellation. In that case, check the status of the context periodically using `context.Cause`. The `context.Cause` function returns an error if the context has been cancelled.

Here's the pattern for supporting context cancellation in your code:

```go
func longRunningComputation(ctx context.Context, data string) (string, error) {
    for {
        // do some processing
        // insert this if statement periodically
        // to check if the context has been cancelled
        if err := context.Cause(ctx); err != nil {
            // return a partial value if it makes sense,
            // or a default one if it doesn't
            return "", err
        }
        // do some more processing and loop again
    }
}
```

Here's an example loop from a function that calculates π by using the inefficient Leibniz algorithm. Using context cancellation allows you to control how long it can run:

```go
i := 0
for {
    if err := context.Cause(ctx); err != nil {
        fmt.Println("cancelled after", i, "iterations")
        return sum.Text('g', 100), err
    }
```

```
        var diff big.Float
        diff.SetInt64(4)
        diff.Quo(&diff, &d)
        if i%2 == 0 {
            sum.Add(&sum, &diff)
        } else {
            sum.Sub(&sum, &diff)
        }
        d.Add(&d, two)
        i++
    }
```

You can see the complete sample program that demonstrates this pattern in the *sample_code/own_cancellation* directory in the Chapter 14 repository.

Exercises

Now that you've seen how to use the context, try to implement these exercises. All the answers are found in the Chapter 14 repository.

1. Create a middleware-generating function that creates a context with a timeout. The function should have one parameter, which is the number of milliseconds that a request is allowed to run. It should return a `func(http.Handler) http.Handler`.

2. Write a program that adds randomly generated numbers between 0 (inclusive) and 100,000,000 (exclusive) together until one of two things happen: the number 1234 is generated or 2 seconds has passed. Print out the sum, the number of iterations, and the reason for ending (timeout or number reached).

3. Assume you have a simple logging function that looks like this:

   ```
   func Log(ctx context.Context, level Level, message string) {
       var inLevel Level
       // TODO get a logging level out of the context and assign it to inLevel
       if level == Debug && inLevel == Debug {
           fmt.Println(message)
       }
       if level == Info && (inLevel == Debug || inLevel == Info) {
           fmt.Println(message)
       }
   }
   ```

   Define a type called `Level` whose underlying type is `string`. Define two constants of this type, `Debug` and `Info`, and set them to `"debug"` and `"info"`, respectively.

   Create functions to store the log level in the context and to extract it.

   Create a middleware function to get the logging level from a query parameter called `log_level`. The valid values for `log_level` are `debug` and `info`.

Finally, fill in the `TODO` in `Log` to properly extract the log level from the context. If the log level is not assigned or is not a valid value, nothing should be printed.

Wrapping Up

In this chapter, you learned how to manage request metadata by using the context. You can now set timeouts, perform explicit cancellation, pass values through the context, and know when you should do each of these things. In the next chapter, you're going to see Go's built-in testing framework and learn how to use it to find bugs and diagnose performance problems in your programs.

CHAPTER 15

Writing Tests

Since the 2000s, the widespread adoption of automated testing has probably done more to improve code quality than any other software engineering technique. As a language and ecosystem focused on improving software quality, it's not surprising that Go includes testing support as part of its standard library. Go makes it so easy to test your code, there's no excuse to not do it.

In this chapter, you'll see how to test Go code, group tests into unit and integration tests, examine code coverage, write benchmarks, and learn how to check code for concurrency issues by using the Go data race detector. Along the way, I'll discuss how to write code that is testable and why this improves our code quality.

Understanding the Basics of Testing

Go's testing support has two parts: libraries and tooling. The `testing` package in the standard library provides the types and functions to write tests, while the `go test` tool that's bundled with Go runs your tests and generates reports. Unlike many other languages, Go places its tests in the same directory and the same package as the production code. Since tests are located in the same package, they are able to access and test unexported functions and variables. You'll see in a bit how to write tests that ensure that you are testing only a public API.

Complete code samples for this chapter are found in the Chapter 15 repository.

Let's write a simple function and then a test to make sure the function works. In the *sample_code/adder* directory, in the file *adder.go*, you have the following:

```go
func addNumbers(x, y int) int {
    return x + x
}
```

The corresponding test is in *adder_test.go*:

```go
func Test_addNumbers(t *testing.T) {
    result := addNumbers(2,3)
    if result != 5 {
        t.Error("incorrect result: expected 5, got", result)
    }
}
```

Every test is written in a file whose name ends with *_test.go*. If you are writing tests against *foo.go*, place your tests in a file named *foo_test.go*.

Test functions start with the word `Test` and take in a single parameter of type `*testing.T`. By convention, this parameter is named `t`. Test functions do not return any values. The name of the test (apart from starting with the word "Test") is meant to document what you are testing, so pick something that explains what you are testing. When writing unit tests for individual functions, the convention is to name the unit test `Test` followed by the name of the function. When testing unexported functions, some people use an underscore between the word `Test` and the name of the function.

Also note that you use standard Go code to call the code being tested and to validate that the responses are as expected. When there's an incorrect result, you report the error with the `t.Error` method, which works like the `fmt.Print` function. You'll see other error-reporting methods in a bit.

You've just seen the library portion of Go's test support. Now let's take a look at the tooling. Just as `go build` builds a binary and `go run` runs a program, the command `go test` runs the test functions in the current directory:

```
$ go test
--- FAIL: Test_addNumbers (0.00s)
    adder_test.go:8: incorrect result: expected 5, got 4
FAIL
exit status 1
FAIL    test_examples/adder     0.006s
```

It looks like you found a bug in your code. Taking a second look at `addNumbers`, you see that you are adding `x` to `x`, not `x` to `y`. Let's change the code and rerun the test to verify that the bug is fixed:

```
$ go test
PASS
ok      test_examples/adder     0.006s
```

The `go test` command allows you to specify which packages to test. Using `./...` for the package name specifies that you want to run tests in the current directory and all subdirectories of the current directory. Include a `-v` flag to get verbose testing output.

Reporting Test Failures

There are several methods on `*testing.T` for reporting test failures. You've already seen `Error`, which builds a failure description string out of a comma-separated list of values.

If you'd rather use a `Printf`-style formatting string to generate your message, use the `Errorf` method instead:

```
t.Errorf("incorrect result: expected %d, got %d", 5, result)
```

While `Error` and `Errorf` mark a test as failed, the test function continues running. If you think a test function should stop processing as soon as a failure is found, use the `Fatal` and `Fatalf` methods. The `Fatal` method works like `Error`, and the `Fatalf` method works like `Errorf`. The difference is that the test function exits immediately after the test failure message is generated. Note that this doesn't exit *all* tests; any remaining test functions will execute after the current test function exits.

When should you use `Fatal`/`Fatalf` and when should you use `Error`/`Errorf`? If the failure of a check in a test means that further checks in the same test function will always fail or cause the test to panic, use `Fatal` or `Fatalf`. If you are testing several independent items (such as validating fields in a struct), then use `Error` or `Errorf` so you can report many problems at once. This makes it easier to fix multiple problems without rerunning your tests over and over.

Setting Up and Tearing Down

Sometimes you have some common state that you want to set up before any tests run and remove when testing is complete. Use a `TestMain` function to manage this state and run your tests:

```
var testTime time.Time

func TestMain(m *testing.M) {
    fmt.Println("Set up stuff for tests here")
    testTime = time.Now()
    exitVal := m.Run()
    fmt.Println("Clean up stuff after tests here")
    os.Exit(exitVal)
}

func TestFirst(t *testing.T) {
    fmt.Println("TestFirst uses stuff set up in TestMain", testTime)
}
```

```
func TestSecond(t *testing.T) {
    fmt.Println("TestSecond also uses stuff set up in TestMain", testTime)
}
```

Both `TestFirst` and `TestSecond` refer to the package-level variable `testTime`. Assume that it needs to be initialized in order for the tests to run properly. You declare a function called `TestMain` with a parameter of type `*testing.M`. If there's a function named `TestMain` in a package, `go test` calls it instead of the test functions. It is the responsibility of the `TestMain` function to set up any state that's necessary to make the tests in the package run correctly.

Once the state is configured, the `TestMain` function calls the `Run` method on `*testing.M`. This runs the test functions in the package. The `Run` method returns the exit code; `0` indicates that all tests passed. Finally, the `TestMain` function must call `os.Exit` with the exit code returned from `Run`.

Running `go test` on this produces the output:

```
$ go test
Set up stuff for tests here
TestFirst uses stuff set up in TestMain 2020-09-01 21:42:36.231508 -0400 EDT
    m=+0.000244286
TestSecond also uses stuff set up in TestMain 2020-09-01 21:42:36.231508 -0400
    EDT m=+0.000244286
PASS
Clean up stuff after tests here
ok      test_examples/testmain  0.006s
```

Be aware that `TestMain` is invoked once, not before and after each individual test. Also be aware that you can have only one `TestMain` per package.

`TestMain` is useful in two common situations:

- When you need to set up data in an external repository, such as a database
- When the code being tested depends on package-level variables that need to be initialized

As mentioned before (and will be again!), you should avoid package-level variables in your programs. They make it hard to understand how data flows through your program. If you are using `TestMain` for this reason, consider refactoring your code.

The `Cleanup` method on `*testing.T` is used to clean up temporary resources created for a single test. This method has a single parameter, a function with no input parameters or return values. The function runs when the test completes. For simple tests, you can achieve the same result by using a `defer` statement, but `Cleanup` is useful when tests rely on helper functions to set up sample data, as you see in Example 15-1. It's fine to call `Cleanup` multiple times. Just like `defer`, the functions are invoked in last-added, first-called order.

Example 15-1. Using `t.Cleanup`

```
// createFile is a helper function called from multiple tests
func createFile(t *testing.T) (_ string, err error) {
    f, err := os.Create("tempFile")
    if err != nil {
        return "", err
    }
    defer func() {
        err = errors.Join(err, f.Close())
    }()
    // write some data to f
    t.Cleanup(func() {
        os.Remove(f.Name())
    })
    return f.Name(), nil
}

func TestFileProcessing(t *testing.T) {
    fName, err := createFile(t)
    if err != nil {
        t.Fatal(err)
    }
    // do testing, don't worry about cleanup
}
```

If your test uses temporary files, you can avoid writing cleanup code by taking advantage of the `TempDir` method on `*testing.T`. This method creates a new temporary directory every time it is invoked and returns the full path of the directory. It also registers a handler with `Cleanup` to delete the directory and its contents when the test has completed. You can use it to rewrite the previous example:

```
// createFile is a helper function called from multiple tests
func createFile(tempDir string) (_ string, err error) {
    f, err := os.CreateTemp(tempDir, "tempFile")
    if err != nil {
        return "", err
    }
    defer func() {
        err = errors.Join(err, f.Close())
    }()
    // write some data to f
    return f.Name(), nil
}
```

```
func TestFileProcessing(t *testing.T) {
    tempDir := t.TempDir()
    fName, err := createFile(tempDir)
    if err != nil {
        t.Fatal(err)
    }
    // do testing, don't worry about cleanup
}
```

Testing with Environment Variables

It's a common (and very good) practice to configure applications with environment variables. To help you test your environment-variable–parsing code, Go provides a helper method on `testing.T`. Call `t.Setenv()` to register a value for an environment variable for your test. Behind the scenes, it calls `Cleanup` to revert the environment variable to its previous state when the test exits:

```
// assume ProcessEnvVars is a function that processes environment variables
// and returns a struct with an OutputFormat field
func TestEnvVarProcess(t *testing.T) {
    t.Setenv("OUTPUT_FORMAT", "JSON")
    cfg := ProcessEnvVars()
    if cfg.OutputFormat != "JSON" {
        t.Error("OutputFormat not set correctly")
    }
    // value of OUTPUT_FORMAT is reset when the test function exits
}
```

While it is good to use environment variables to configure your application, it is also good to make sure that most of your code is entirely unaware of them. Be sure to copy the values of environment variables into configuration structs before your program starts its work, in your `main` function or soon afterward. Doing so makes it easier to reuse and test code, since *how* the code is configured has been abstracted away from *what* the code is doing.

Rather than writing this code yourself, you should strongly consider using a third-party configuration library, like Viper or envconfig. Also, look at GoDotEnv as a way to store environment variables in *.env* files for development or continuous integration machines.

Storing Sample Test Data

As `go test` walks your source code tree, it uses the current package directory as the current working directory. If you want to use sample data to test functions in a package, create a subdirectory named *testdata* to hold your files. Go reserves this directory name as a place to hold test files. When reading from *testdata*, always use a relative file reference. Since `go test` changes the current working directory to the current package, each package accesses its own *testdata* via a relative file path.

The `text` package in the *sample_code* directory of the Chapter 15 repository demonstrates how to use *testdata*.

Caching Test Results

Just as you learned in Chapter 10 that Go caches compiled packages if they haven't changed, Go also caches test results when running tests across multiple packages if they have passed and their code hasn't changed. The tests are recompiled and rerun if you change any file in the package or in the *testdata* directory. You can also force tests to always run if you pass the flag `-count=1` to `go test`.

Testing Your Public API

The tests that you've written are in the same package as the production code. This allows you to test both exported and unexported functions.

If you want to test just the public API of your package, Go has a convention for specifying this. You still keep your test source code in the same directory as the production source code, but you use `packagename_test` for the package name. Let's redo the initial test case, using an exported function instead. You can find the code in the *sample_code/pubadder* directory in the Chapter 15 repository. If you have the following function in the `pubadder` package

```go
func AddNumbers(x, y int) int {
    return x + y
}
```

then you can test it as public API by using the following code in a file in the `pubadder` package named *adder_public_test.go*:

```go
package pubadder_test

import (
    "github.com/learning-go-book-2e/ch15/sample_code/pubadder"
    "testing"
)

func TestAddNumbers(t *testing.T) {
    result := pubadder.AddNumbers(2, 3)
    if result != 5 {
        t.Error("incorrect result: expected 5, got", result)
    }
}
```

Notice that the package name for the test file is `pubadder_test`. You have to import `github.com/learning-go-book-2e/ch15/sample_code/pubadder` even though the files are in the same directory. To follow the convention for naming tests, the test function name matches the name of the `AddNumbers` function. Also note that you use `pubadder.AddNumbers`, since you are calling an exported function in a different package.

If you are typing this code in by hand, you'll need to create a module with a *go.mod* file that has the module declaration:

```
module github.com/learning-go-book-2e/ch15
```

and that puts the source code in the *sample_code/pubadder* directory within the module.

Just as you can call exported functions from within a package, you can test your public API from a test that is in the same package as your source code. The advantage of using the `_test` suffix in the package name is that it lets you treat your tested package as a "black box." You are forced to interact with it only via its exported functions, methods, types, constants, and variables. Also be aware that you can have test source files with both package names intermixed in the same source directory.

Using go-cmp to Compare Test Results

Writing a thorough comparison of a compound type's two instances can be verbose. While you can use `reflect.DeepEqual` to compare structs, maps, and slices, there's a better way. Google released a third-party module called `go-cmp` that does the comparison for you and returns a detailed description of what does not match. Let's see how it works by defining a simple `struct` and a factory function that populates it. You can find this code in the *sample_code/cmp* directory in the Chapter 15 repository:

```go
type Person struct {
    Name      string
    Age       int
    DateAdded time.Time
}

func CreatePerson(name string, age int) Person {
    return Person{
        Name:      name,
        Age:       age,
        DateAdded: time.Now(),
    }
}
```

In your test file, you need to import `github.com/google/go-cmp/cmp`, and your test function looks like this:

```
func TestCreatePerson(t *testing.T) {
    expected := Person{
        Name: "Dennis",
        Age:  37,
    }
    result := CreatePerson("Dennis", 37)
    if diff := cmp.Diff(expected, result); diff != "" {
        t.Error(diff)
    }
}
```

The `cmp.Diff` function takes in the expected output and the output that was returned by the function that you're testing. It returns a string that describes any mismatches between the two inputs. If the inputs match, it returns an empty string. You assign the output of the `cmp.Diff` function to a variable called `diff` and then check whether `diff` is an empty string. If it is not, an error occurred.

When you build and run the test, you'll see the output that `go-cmp` generates when two struct instances don't match:

```
$ go test
--- FAIL: TestCreatePerson (0.00s)
    ch13_cmp_test.go:16:   ch13_cmp.Person{
              Name:      "Dennis",
              Age:       37,
        -     DateAdded: s"0001-01-01 00:00:00 +0000 UTC",
        +     DateAdded: s"2020-03-01 22:53:58.087229 -0500 EST m=+0.001242842",
          }

FAIL
FAIL    ch13_cmp    0.006s
```

The lines with a `-` and `+` indicate the fields whose values differ. The test failed because the dates didn't match. This is a problem because you can't control what date is assigned by the `CreatePerson` function. You have to ignore the `DateAdded` field. You do that by specifying a comparator function. Declare the function as a local variable in your test:

```
comparer := cmp.Comparer(func(x, y Person) bool {
    return x.Name == y.Name && x.Age == y.Age
})
```

Pass a function to the `cmp.Comparer` function to create a customer comparator. The function that's passed in must have two parameters of the same type and return a `bool`. It also must be symmetric (the order of the parameters doesn't matter), deterministic (it always returns the same value for the same inputs), and pure (it must not modify its parameters). In your implementation, you are comparing the `Name` and `Age` fields and ignoring the `DateAdded` field.

Then change your call to `cmp.Diff` to include `comparer`:

```
if diff := cmp.Diff(expected, result, comparer); diff != "" {
    t.Error(diff)
}
```

This is only a quick preview of the most useful features in `go-cmp`. Check its documentation to learn more about how to control what is compared and the output format.

Running Table Tests

Most of the time, it takes more than a single test case to validate that a function is working correctly. You could write multiple test functions to validate your function or multiple tests within the same function, but you'll find that a great deal of the testing logic is repetitive. You set up supporting data and functions, specify inputs, check the outputs, and compare to see if they match your expectations.

Rather than writing this over and over, you can take advantage of a pattern called *table tests*. Let's take a look at a sample. You can find this code in the *sample_code/table* directory in the Chapter 15 repository. Assume you have the following function in the `table` package:

```
func DoMath(num1, num2 int, op string) (int, error) {
    switch op {
    case "+":
        return num1 + num2, nil
    case "-":
        return num1 - num2, nil
    case "*":
        return num1 + num2, nil
    case "/":
        if num2 == 0 {
            return 0, errors.New("division by zero")
        }
        return num1 / num2, nil
    default:
        return 0, fmt.Errorf("unknown operator %s", op)
    }
}
```

To test this function, you need to check the different branches, trying out inputs that return valid results, as well as inputs that trigger errors. You could write code like this, but it's very repetitive:

```
func TestDoMath(t *testing.T) {
    result, err := DoMath(2, 2, "+")
    if result != 4 {
        t.Error("Should have been 4, got", result)
    }
    if err != nil {
        t.Error("Should have been nil error, got", err)
    }
    result2, err2 := DoMath(2, 2, "-")
    if result2 != 0 {
        t.Error("Should have been 0, got", result2)
    }
    if err2 != nil {
        t.Error("Should have been nil error, got", err2)
    }
    // and so on...
}
```

Let's replace this repetition with a table test. First, you declare a slice of anonymous structs. The struct contains fields for the name of the test, the input parameters, and the return values. Each entry in the slice represents another test:

```
data := []struct {
    name     string
    num1     int
    num2     int
    op       string
    expected int
    errMsg   string
}{
    {"addition", 2, 2, "+", 4, ""},
    {"subtraction", 2, 2, "-", 0, ""},
    {"multiplication", 2, 2, "*", 4, ""},
    {"division", 2, 2, "/", 1, ""},
    {"bad_division", 2, 0, "/", 0, `division by zero`},
}
```

Next, loop over each test case in `data`, invoking the `Run` method each time. This is the line that does the magic. You pass two parameters to `Run`, a name for the subtest and a function with a single parameter of type `*testing.T`. Inside the function, you call `DoMath` by using the fields of the current entry in `data`, using the same logic over and over. When you run these tests, you'll see that not only do they pass, but when you use the `-v` flag, each subtest also now has a name:

```
for _, d := range data {
    t.Run(d.name, func(t *testing.T) {
        result, err := DoMath(d.num1, d.num2, d.op)
        if result != d.expected {
            t.Errorf("Expected %d, got %d", d.expected, result)
        }
        var errMsg string
        if err != nil {
            errMsg = err.Error()
        }
        if errMsg != d.errMsg {
            t.Errorf("Expected error message `%s`, got `%s`",
                d.errMsg, errMsg)
        }
    })
}
```

Comparing error messages can be fragile, because there may not be any compatibility guarantees on the message text. The function that you are testing uses `errors.New` and `fmt.Errorf` to make errors, so the only option is to compare the messages. If an error has a custom type or a named sentinel error, use `errors.Is` or `errors.As` to check that the correct error is returned.

Running Tests Concurrently

By default, unit tests are run sequentially. Since each unit test is supposed to be independent from every other unit test, they make ideal candidates for concurrency. To make a unit test run concurrently with other tests, call the `Parallel` method on `*testing.T` as the first line in your test:

```
func TestMyCode(t *testing.T) {
    t.Parallel()
    // rest of test goes here
}
```

Parallel tests run concurrently with other tests marked as parallel.

The advantage of parallel tests is that it can speed up long-running test suites. There are some disadvantages, though. If you have multiple tests that rely on the same shared mutable state, do not mark them as parallel, because you will get inconsistent results. (But after all of my warnings, you don't have any shared mutable state in your application, right?) Also be aware that your test will panic if you mark it as parallel and use the `Setenv` method in your test function.

Be careful when running table tests in parallel. When table tests run in parallel, it's just as you saw in "Goroutines, for Loops, and Varying Variables" on page 298, where you launched multiple goroutines within a `for` loop. If you run this example using Go 1.21 or earlier (or on Go 1.22 or later with the Go version set to 1.21 or earlier in the `go` directive in the *go.mod* file), a reference to the variable `d` is shared by all the parallel tests, so they all see the same value:

```
func TestParallelTable(t *testing.T) {
    data := []struct {
        name   string
        input  int
        output int
    }{
        {"a", 10, 20},
        {"b", 30, 40},
        {"c", 50, 60},
    }
    for _, d := range data {
        t.Run(d.name, func(t *testing.T) {
            t.Parallel()
            fmt.Println(d.input, d.output)
            out := toTest(d.input)
            if out != d.output {
                t.Error("didn't match", out, d.output)
            }
        })
    }
}
```

You can run this code on The Go Playground or in the *sample_code/parallel* directory in the Chapter 15 repository. Take a look at the output and you'll see that you test the last value in the table test three times:

```
=== CONT  TestParallelTable/a
50 60
=== CONT  TestParallelTable/c
50 60
=== CONT  TestParallelTable/b
50 60
```

This problem is common enough that Go 1.20 added a `go vet` check for this problem. When you run `go vet` on this code, you get the message `loop variable d captured by func literal` on each line where `d` is captured.

The `for` loop changes in Go 1.22 or later resolve this issue. If you cannot use Go 1.22, you can avoid this bug by shadowing `d` within the `for` loop before invoking `t.Run`:

```
    for _, d := range data {
        d := d // THIS IS THE LINE THAT SHADOWS d!
        t.Run(d.name, func(t *testing.T) {
            t.Parallel()
            fmt.Println(d.input, d.output)
            out := toTest(d.input)
            if out != d.output {
                t.Error("didn't match", out, d.output)
            }
        })
    }
```

Now that you have a way to run lots of tests, you'll learn about code coverage to find out what your tests are testing.

Checking Your Code Coverage

Code coverage is a very useful tool for knowing whether you've missed any obvious cases. However, reaching 100% code coverage doesn't guarantee that there aren't bugs in your code for some inputs. First you'll see how `go test` displays code coverage and then you'll look at the limitations of relying on code coverage alone.

Adding the `-cover` flag to the `go test` command calculates coverage information and includes a summary in the test output. If you include a second flag `-coverprofile`, you can save the coverage information to a file. Let's go back to the *sample_code/table* directory in the Chapter 15 repository and gather code coverage information:

```
$ go test -v -cover -coverprofile=c.out
```

If you run your table test with code coverage, the test output now includes a line that indicates the amount of test code coverage, 87.5%. That's good to know, but it'd be more useful if you could see what you missed. The `cover` tool included with Go generates an HTML representation of your source code with that information:

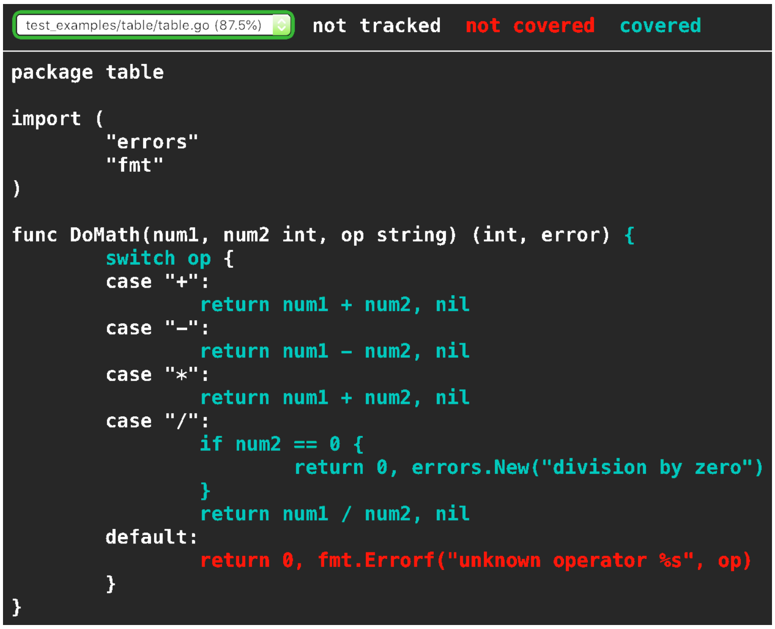
```
$ go tool cover -html=c.out
```

When you run it, your web browser should open and show you a page that looks like Figure 15-1.

Every file that's tested appears in the combo box in the upper left. The source code is in one of three colors. Gray is used for lines of code that aren't testable, green is used for code that's been covered by a test, and red is used for code that hasn't been tested. (The reliance on color is unfortunate for readers of the print edition and those who have red-green color blindness. If you are unable to see the colors, the lighter gray is the covered lines.) From looking at this, you can see that you didn't write a test to cover the default case, when a bad operator is passed to your function. Add that case to your slice of test cases:

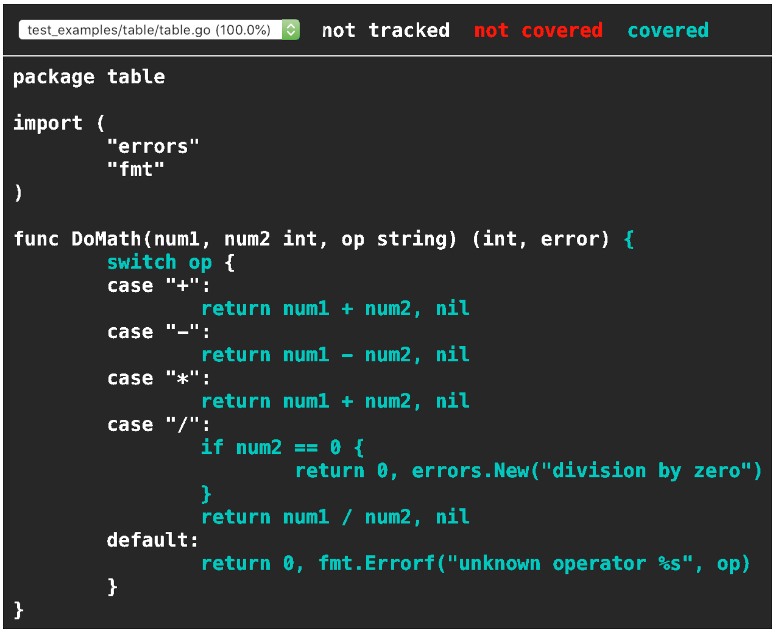
```
{"bad_op", 2, 2, "?", 0, `unknown operator ?`},
```

When you rerun `go test -v -cover -coverprofile=c.out` and `go tool cover -html=c.out`, you see in Figure 15-2 that the final line is covered and you have 100% test code coverage.



```
package table

import (
	"errors"
	"fmt"
)

func DoMath(num1, num2 int, op string) (int, error) {
	switch op {
	case "+":
		return num1 + num2, nil
	case "-":
		return num1 - num2, nil
	case "*":
		return num1 + num2, nil
	case "/":
		if num2 == 0 {
			return 0, errors.New("division by zero")
		}
		return num1 / num2, nil
	default:
		return 0, fmt.Errorf("unknown operator %s", op)
	}
}
```

Figure 15-1. Initial code coverage



```
package table

import (
	"errors"
	"fmt"
)

func DoMath(num1, num2 int, op string) (int, error) {
	switch op {
	case "+":
		return num1 + num2, nil
	case "-":
		return num1 - num2, nil
	case "*":
		return num1 + num2, nil
	case "/":
		if num2 == 0 {
			return 0, errors.New("division by zero")
		}
		return num1 / num2, nil
	default:
		return 0, fmt.Errorf("unknown operator %s", op)
	}
}
```

Figure 15-2. Final code coverage

Code coverage is a great thing, but it's not enough. There's actually a bug in your code, even though you have 100% coverage. Have you noticed it? If not, add another test case and rerun your tests:

```
{"another_mult", 2, 3, "*", 6, ""},
```

You should see the error:

```
table_test.go:57: Expected 6, got 5
```

Your case for multiplication has a typo. It adds the numbers together instead of multiplying them. (Beware the dangers of copy-and-paste coding!) Fix the code, rerun `go test -v -cover -coverprofile=c.out` and `go tool cover -html=c.out`, and you'll see that the tests pass again.

Code coverage is necessary but not sufficient. You can have 100% code coverage and still have bugs in your code!

Fuzzing

One of the most important lessons that every developer eventually learns is that all data is suspect. No matter how well specified a data format is, you will eventually have to process input that doesn't match what you expect. This doesn't happen for only malicious reasons. Data can be corrupted in transit, in storage, and even in memory. Programs that process data might have bugs, and specifications for data formats always have corner cases that can be interpreted differently by different developers.

Even when developers do the work of writing good unit tests, it's impossible to think of everything. As you've seen, even 100% unit test code coverage is no guarantee that your code is bug free. You need to supplement unit tests with generated data that could break your program in ways you didn't anticipate. That's where fuzzing helps.

Fuzzing is a technique for generating random data and submitting it to code to see whether it properly handles unexpected input. The developer can provide a *seed corpus* or set of known good data, and the fuzzer uses that as a basis for generating bad input. Let's see how to use the fuzzing support in Go's testing tools to discover additional test cases.

Assume that you are writing a program to processes data files. You can find the code for this example on GitHub. You are sending a list of strings but want to efficiently allocate memory, so the number of strings in a file is sent as the first line, while the remaining lines are the lines of text. Here's the sample function for processing this data:

```go
func ParseData(r io.Reader) ([]string, error) {
    s := bufio.NewScanner(r)
    if !s.Scan() {
        return nil, errors.New("empty")
    }
    countStr := s.Text()
    count, err := strconv.Atoi(countStr)
    if err != nil {
        return nil, err
    }
    out := make([]string, 0, count)
    for i := 0; i < count; i++ {
        hasLine := s.Scan()
        if !hasLine {
            return nil, errors.New("too few lines")
        }
        line := s.Text()
        out = append(out, line)
    }
    return out, nil
}
```

You use a `bufio.Scanner` to read line-by-line from an `io.Reader`. If there's no data to be read, an error is returned. You then read the first line and attempt to convert it to an int named `count`. If you can't, an error is returned. Next, you allocate the memory for your slice of strings, and read `count` number of lines from the scanner. If there aren't enough lines, an error is returned. If all goes well, you return the lines you read.

A unit test has already been written to validate the code:

```go
func TestParseData(t *testing.T) {
    data := []struct {
        name   string
        in     []byte
        out    []string
        errMsg string
    }{
        {
            name:   "simple",
            in:     []byte("3\nhello\ngoodbye\ngreetings\n"),
            out:    []string{"hello", "goodbye", "greetings"},
            errMsg: "",
        },
        {
            name:   "empty_error",
            in:     []byte(""),
            out:    nil,
            errMsg: "empty",
        },
        {
            name:   "zero",
            in:     []byte("0\n"),
            out:    []string{},
            errMsg: "",
        },
        {
            name:   "number_error",
            in:     []byte("asdf\nhello\ngoodbye\ngreetings\n"),
            out:    nil,
            errMsg: `strconv.Atoi: parsing "asdf": invalid syntax`,
        },
        {
            name:   "line_count_error",
            in:     []byte("4\nhello\ngoodbye\ngreetings\n"),
            out:    nil,
            errMsg: "too few lines",
        },
    }
    for _, d := range data {
        t.Run(d.name, func(t *testing.T) {
            r := bytes.NewReader(d.in)
            out, err := ParseData(r)
            var errMsg string
            if err != nil {
                errMsg = err.Error()
            }
            if diff := cmp.Diff(d.out, out); diff != "" {
                t.Error(diff)
            }
            if diff := cmp.Diff(d.errMsg, errMsg); diff != "" {
                t.Error(diff)
            }
        })
    }
}
```

The unit test has 100% line coverage for `ParseData`, handling all its error cases. You might think the code is ready for production, but let's see if fuzzing can help you discover errors that you hadn't considered.

Be aware that fuzzing uses a lot of resources. A fuzz test can allocate (or attempt to allocate) many gigabytes of memory and might write several gigabytes of data to your local disk. If you are running something else on the same machine at the same time as a fuzz test, don't be surprised if it slows down.

You start by writing a fuzz test:

```
func FuzzParseData(f *testing.F) {
    testcases := [][]byte{
        []byte("3\nhello\ngoodbye\ngreetings\n"),
        []byte("0\n"),
    }
    for _, tc := range testcases {
        f.Add(tc)
    }
    f.Fuzz(func(t *testing.T, in []byte) {
        r := bytes.NewReader(in)
        out, err := ParseData(r)
        if err != nil {
            t.Skip("handled error")
        }
        roundTrip := ToData(out)
        rtr := bytes.NewReader(roundTrip)
        out2, err := ParseData(rtr)
        if diff := cmp.Diff(out, out2); diff != "" {
            t.Error(diff)
        }
    })
}
```

A fuzz test looks similar to a standard unit test. The function name starts with `Fuzz`, the only parameter is of type `*testing.F`, and it has no return values.

Next, you set up a seed corpus, which is composed of one or more sets of sample data. The data can run successfully, error out, or even panic. The important things are that you know how your program behaves when this data is provided and that this behavior is accounted for by your fuzz test. These samples are mutated by the fuzzer to generate bad inputs. This example uses only a single field of data for each entry (a slice of bytes), but you can have as many fields as needed. The fields in a corpus entry are currently limited to only certain types:

- Any integer type (including unsigned types, `rune`, and `byte`)
- Any floating-point type
- `bool`
- `string`
- `[]byte`

Each entry in the corpus is passed to the `Add` method on the `*testing.F` instance. In the example, you have a slice of bytes for each entry:

```
f.Add(tc)
```

If the function being fuzzed needed an `int` and a `string`, the call to `Add` would look like this:

```
f.Add(1, "some text")
```

It's a runtime error to pass a value of an invalid type to `Add`.

Next you call the `Fuzz` method on your `*testing.F` instance. This looks a bit like a call to `Run` when writing a table test in a standard unit test. `Fuzz` takes in a single parameter, a function whose first parameter is of type `*testing.T` and whose remaining parameters exactly match the types, order, and count of the values that were passed in to `Add`. This also specifies the type of data generated by the fuzzing engine during fuzzing. There's no way for the Go compiler to enforce this constraint, so it's a runtime error if the convention is not followed.

Finally, let's look at the body of the fuzz target. Remember, fuzzing is used to find cases where bad input is not handled correctly. Since the input is randomly generated, you can't write tests that have knowledge of what the output should be. Instead, you have to use test conditions that will be true for all inputs. In the case of `ParseData`, you can check for two things:

- Does the code return an error for bad input, or does it panic?
- If you convert the slice of strings back to a slice of bytes and re-parse it, do you get the same result?

Let's see what happens when you run the fuzz test:

```
$ go test -fuzz=FuzzParseData
fuzz: elapsed: 0s, gathering baseline coverage: 0/243 completed
fuzz: elapsed: 0s, gathering baseline coverage: 243/243 completed,
    now fuzzing with 8 workers
fuzz: minimizing 289-byte failing input file
fuzz: elapsed: 3s, minimizing
fuzz: elapsed: 6s, minimizing
fuzz: elapsed: 9s, minimizing
fuzz: elapsed: 10s, minimizing
--- FAIL: FuzzParseData (10.48s)
    fuzzing process hung or terminated unexpectedly while minimizing: EOF
    Failing input written to testdata/fuzz/FuzzParseData/
        fedbaf01dc50bf41b40d7449657cdc9af9868b1be0421c98b2910071de9be3df
    To re-run:
    go test -run=FuzzParseData/
        fedbaf01dc50bf41b40d7449657cdc9af9868b1be0421c98b2910071de9be3df
FAIL
exit status 1
FAIL    file_parser     10.594s
```

If you don't specify the `-fuzz` flag, your fuzz tests will be treated like unit tests and will be run against the seed corpus. Only a single fuzz test can be fuzzed at a time.

If you want to get the full experience, delete the contents of the *testdata/fuzz/FuzzParseData* directory. This will cause the fuzzer to generate new seed corpus entries. Since the fuzzer generates random input, your samples might be different from the ones shown. The different entries will likely produce similar errors, though maybe not in the same order.

The fuzz test runs for several seconds and then fails. In this case, the `go` command reports that it has crashed. You don't want programs that crash, so let's look at the input that was generated. Every time a test case fails, the fuzzer writes it to the *testdata/fuzz/TESTNAME* subdirectory in the same package as the failed test, adding a new entry to the seed corpus. The new seed corpus entry in the file now becomes a new unit test, one that was automatically generated by the fuzzer. It is run anytime `go test` runs the `FuzzParseData` function, and acts as a regression test once you fix your bug.

Here are the contents of the file:

```
go test fuzz v1
[]byte("300000000000")
```

The first line is a header to indicate that this is test data for a fuzz test. The subsequent lines have the data that caused the failure.

The failure message tells you how to isolate this failing case when you rerun the test:

```
$ go test -run=FuzzParseData/
    fedbaf01dc50bf41b40d7449657cdc9af9868b1be0421c98b2910071de9be3df
signal: killed
FAIL    file_parser     15.046s
```

The problem is that you are trying to allocate a slice with the capacity to hold 300,000,000,000 strings. That requires quite a bit more RAM than my computer (and probably yours) has. You need to limit the number of expected text elements to a reasonable number. Set the maximum number of rows to 1,000 by adding the following code to `ParseData` after you parse the number of expected rows:

```
    if count > 1000 {
        return nil, errors.New("too many")
    }
```

Run the fuzzer again to see whether it finds any more errors:

```
$ go test -fuzz=FuzzParseData
fuzz: elapsed: 0s, gathering baseline coverage: 0/245 completed
fuzz: elapsed: 0s, gathering baseline coverage: 245/245 completed,
    now fuzzing with 8 workers
fuzz: minimizing 29-byte failing input file
fuzz: elapsed: 2s, minimizing
--- FAIL: FuzzParseData (2.20s)
```

```
    --- FAIL: FuzzParseData (0.00s)
        testing.go:1356: panic: runtime error: makeslice: cap out of range
            goroutine 23027 [running]:
            runtime/debug.Stack()
                /usr/local/go/src/runtime/debug/stack.go:24 +0x104
            testing.tRunner.func1()
                /usr/local/go/src/testing/testing.go:1356 +0x258
            panic({0x1003f9920, 0x10042a260})
                /usr/local/go/src/runtime/panic.go:884 +0x204
            file_parser.ParseData({0x10042a7c8, 0x14006c39bc0})
                file_parser/file_parser.go:24 +0x254
[...]
    Failing input written to testdata/fuzz/FuzzParseData/
        03f81b404ad91d092a482ad1ccb4a457800599ab826ec8dae47b49c01c38f7b1
    To re-run:
    go test -run=FuzzParseData/
        03f81b404ad91d092a482ad1ccb4a457800599ab826ec8dae47b49c01c38f7b1
FAIL
exit status 1
FAIL    file_parser     2.434s
```

This time you get a fuzz result that produces a panic. Looking at the file generated by `go fuzz`, you see this:

```
go test fuzz v1
[]byte("-1")
```

The line that's generating the panic is shown here:

```
    out := make([]string, 0, count)
```

You are trying to create a slice with negative capacity, which panics. Add another condition to your code to look for negative numbers:

```
    if count < 0 {
        return nil, errors.New("no negative numbers")
    }
```

Run your fuzzer again, and it generates another error:

```
$ go test -fuzz=FuzzParseData
fuzz: elapsed: 0s, gathering baseline coverage: 0/246 completed
fuzz: elapsed: 0s, gathering baseline coverage: 246/246 completed,
    now fuzzing with 8 workers
fuzz: elapsed: 3s, execs: 288734 (96241/sec), new interesting: 0 (total: 246)
fuzz: elapsed: 6s, execs: 418803 (43354/sec), new interesting: 0 (total: 246)
fuzz: minimizing 34-byte failing input file
fuzz: elapsed: 7s, minimizing
--- FAIL: FuzzParseData (7.43s)
    --- FAIL: FuzzParseData (0.00s)
        file_parser_test.go:89:   []string{
            -   "\r",
            +   "",
              }
    Failing input written to testdata/fuzz/FuzzParseData/
        b605c41104bf41a21309a13e90cfc6f30ecf133a2382759f2abc34d41b45ae79
    To re-run:
    go test -run=FuzzParseData/
        b605c41104bf41a21309a13e90cfc6f30ecf133a2382759f2abc34d41b45ae79
FAIL
exit status 1
FAIL    file_parser     7.558s
```

Looking at the file it created, you are generating blank lines with only `\r` (return) characters. Blank lines are not what you expect in your input, so add some code to the loop that reads lines of text from the `Scanner`. You'll check whether a line consists only of whitespace characters. If it does, return an error:

```go
        line = strings.TrimSpace(line)
        if len(line) == 0 {
            return nil, errors.New("blank line")
        }
```

Run your fuzzer yet again:

```
$ go test -fuzz=FuzzParseData
fuzz: elapsed: 0s, gathering baseline coverage: 0/247 completed
fuzz: elapsed: 0s, gathering baseline coverage: 247/247 completed,
    now fuzzing with 8 workers
fuzz: elapsed: 3s, execs: 391018 (130318/sec), new interesting: 2 (total: 249)
fuzz: elapsed: 6s, execs: 556939 (55303/sec), new interesting: 2 (total: 249)
fuzz: elapsed: 9s, execs: 622126 (21734/sec), new interesting: 2 (total: 249)
[...]
fuzz: elapsed: 2m0s, execs: 2829569 (0/sec), new interesting: 16 (total: 263)
fuzz: elapsed: 2m3s, execs: 2829569 (0/sec), new interesting: 16 (total: 263)
^Cfuzz: elapsed: 2m4s, execs: 2829569 (0/sec), new interesting: 16 (total: 263)
PASS
ok      file_parser     123.662s
```

After a few minutes, no more errors are found, so hit Ctrl-C to end fuzzing.

Just because the fuzzer didn't find additional issues doesn't mean that the code is now bug free. However, fuzzing allowed you to automatically find some significant oversights in the original code. Writing fuzz tests takes practice, as they require a slightly different mindset than writing unit tests. Once you get the hang of them, they become an essential tool for validating how your code handles unexpected user input.

Using Benchmarks

Determining how fast (or slow) code runs is surprisingly difficult. Rather than trying to figure it out yourself, you should use the benchmarking support that's built into Go's testing framework. Let's explore it with a function in the *sample_code/bench* directory in the Chapter 15 repository:

```
func FileLen(f string, bufsize int) (int, error) {
    file, err := os.Open(f)
    if err != nil {
        return 0, err
    }
    defer file.Close()
    count := 0
    for {
        buf := make([]byte, bufsize)
        num, err := file.Read(buf)
        count += num
        if err != nil {
            break
        }
    }
    return count, nil
}
```

This function counts the number of characters in a file. It takes in two parameters, the name of the file and the size of the buffer that you are using to read the file (you'll see the reason for the second parameter in a moment).

Before seeing how fast it is, you should test your library to make sure that it works (it does). Here's a simple test:

```
func TestFileLen(t *testing.T) {
    result, err := FileLen("testdata/data.txt", 1)
    if err != nil {
        t.Fatal(err)
    }
    if result != 65204 {
        t.Error("Expected 65204, got", result)
    }
}
```

Now you can see how long it takes your file-length function to run. Your goal is to find out what size buffer you should use to read from the file.

Before you spend time going down an optimization rabbit hole, be sure that you need to optimize. If your program is already fast enough to meet your responsiveness requirements and is using an acceptable amount of memory, your time is better spent on adding features and fixing bugs. Your business requirements determine what "fast enough" and "acceptable amount of memory" mean.

In Go, *benchmarks* are functions in your test files that start with the word `Benchmark` and take in a single parameter of type `*testing.B`. This type includes all the functionality of a `*testing.T` as well as additional support for benchmarking. Let's start by looking at a benchmark that uses a buffer size of 1 byte:

```
var blackhole int

func BenchmarkFileLen1(b *testing.B) {
    for i := 0; i < b.N; i++ {
        result, err := FileLen("testdata/data.txt", 1)
        if err != nil {
            b.Fatal(err)
        }
        blackhole = result
    }
}
```

The `blackhole` package-level variable is interesting. You write the results from `FileLen` to this package-level variable to make sure that the compiler doesn't get too clever and decide to optimize away the call to `FileLen`, ruining your benchmark.

Every Go benchmark must have a loop that iterates from 0 to `b.N`. The testing framework calls your benchmark functions over and over with larger and larger values for `N` until it is sure that the timing results are accurate. You'll see this in the output in a moment.

You run a benchmark by passing the `-bench` flag to `go test`. This flag expects a regular expression to describe the name of the benchmarks to run. Use `-bench=.` to run all benchmarks. A second flag, `-benchmem`, includes memory allocation information in the benchmark output. All tests are run before the benchmarks, so you can benchmark code only when tests pass.

Here's the output for the benchmark on my computer:

```
BenchmarkFileLen1-12  25  47201025 ns/op  65342 B/op  65208 allocs/op
```

Running a benchmark with memory allocation information produces output with five columns. Here's what each one means:

BenchmarkFileLen1-12
: The name of the benchmark, a hyphen, and the value of `GOMAXPROCS` for the benchmark.

25
: The number of times that the test ran to produce a stable result.

47201025 ns/op
: The amount of time it took to run a single pass of this benchmark, in nanoseconds (there are 1,000,000,000 nanoseconds in a second).

65342 B/op
: The number of bytes allocated during a single pass of the benchmark.

65208 allocs/op
: The number of times bytes had to be allocated from the heap during a single pass of the benchmark. This will always be less than or equal to the number of bytes allocated.

Now that you have results for a buffer of 1 byte, let's see what the results look like when you use buffers of different sizes:

```
func BenchmarkFileLen(b *testing.B) {
    for _, v := range []int{1, 10, 100, 1000, 10000, 100000} {
        b.Run(fmt.Sprintf("FileLen-%d", v), func(b *testing.B) {
            for i := 0; i < b.N; i++ {
                result, err := FileLen("testdata/data.txt", v)
                if err != nil {
                    b.Fatal(err)
                }
                blackhole = result
            }
        })
    }
}
```

Just as you launched table tests using `t.Run`, you're using `b.Run` to launch benchmarks that vary based only on input. Here are the results of this benchmark on my computer:

```
BenchmarkFileLen/FileLen-1-12          25  47828842 ns/op   65342 B/op  65208 allocs/op
BenchmarkFileLen/FileLen-10-12        230   5136839 ns/op  104488 B/op   6525 allocs/op
BenchmarkFileLen/FileLen-100-12      2246    509619 ns/op   73384 B/op    657 allocs/op
BenchmarkFileLen/FileLen-1000-12    16491     71281 ns/op   68744 B/op     70 allocs/op
BenchmarkFileLen/FileLen-10000-12   42468     26600 ns/op   82056 B/op     11 allocs/op
BenchmarkFileLen/FileLen-100000-12  36700     30473 ns/op  213128 B/op      5 allocs/op
```

These results aren't surprising; as you increase the size of the buffer, you make fewer allocations and your code runs faster, until the buffer is bigger than the file. When the buffer is bigger than the size of the file, extra allocations slow the output. If you expect files of roughly this size, a buffer of 10,000 bytes would work best.

But you can make a change that improves the numbers more. You are reallocating the buffer every time you get the next set of bytes from the file. That's unnecessary. If you move the byte slice allocation before the loop and rerun your benchmark, you see an improvement:

```
BenchmarkFileLen/FileLen-1-12          25  46167597 ns/op     137 B/op  4 allocs/op
BenchmarkFileLen/FileLen-10-12        261   4592019 ns/op     152 B/op  4 allocs/op
BenchmarkFileLen/FileLen-100-12      2518    478838 ns/op     248 B/op  4 allocs/op
BenchmarkFileLen/FileLen-1000-12    20059     60150 ns/op    1160 B/op  4 allocs/op
BenchmarkFileLen/FileLen-10000-12   62992     19000 ns/op   10376 B/op  4 allocs/op
BenchmarkFileLen/FileLen-100000-12  51928     21275 ns/op  106632 B/op  4 allocs/op
```

The number of allocations are now consistent and small, just four allocations for every buffer size. What is interesting is that you now can make trade-offs. If you are tight on memory, you can use a smaller buffer size and save memory at the expense of performance.

Profiling Your Go Code

If benchmarking reveals that you have a performance or memory problem, the next step is figuring out exactly what the problem is. Go includes profiling tools that gather CPU and memory usage data from a running program as well as tools that help you visualize and interpret the generated data. You can even expose a web service endpoint to gather profiling information remotely from a running Go service.

Discussing the profiler is a topic that's beyond the scope of this book. Many great resources are available online. A good starting point is the blog post "Profiling Go Programs with pprof" by Julia Evans.

Using Stubs in Go

So far, you've written tests for functions that didn't depend on other code. This is not typical, as most code is filled with dependencies. As you saw in Chapter 7, Go allows you to abstract function calls in two ways: defining a function type and defining an interface. These abstractions help you write not only modular production code but also unit tests.

> When your code depends on abstractions, it's easier to write unit tests!

Let's take a look at an example in the *sample_code/solver* directory in the Chapter 15 repository. You define a type called `Processor`:

```go
type Processor struct {
    Solver MathSolver
}
```

It has a field of type `MathSolver`:

```go
type MathSolver interface {
    Resolve(ctx context.Context, expression string) (float64, error)
}
```

You'll implement and test `MathSolver` in a bit.

`Processor` also has a method that reads an expression from an `io.Reader` and returns the calculated value:

```
func (p Processor) ProcessExpression(ctx context.Context, r io.Reader)
                                    (float64, error) {
    curExpression, err := readToNewLine(r)
    if err != nil {
        return 0, err
    }
    if len(curExpression) == 0 {
        return 0, errors.New("no expression to read")
    }
    answer, err := p.Solver.Resolve(ctx, curExpression)
    return answer, err
}
```

Let's write the code to test `ProcessExpression`. First, you need a simple implementation of the `Resolve` method to write your test:

```
type MathSolverStub struct{}

func (ms MathSolverStub) Resolve(ctx context.Context, expr string)
                                (float64, error) {
    switch expr {
    case "2 + 2 * 10":
        return 22, nil
    case "( 2 + 2 ) * 10":
        return 40, nil
    case "( 2 + 2 * 10":
        return 0, errors.New("invalid expression: ( 2 + 2 * 10")
    }
    return 0, nil
}
```

Next, you write a unit test that uses this stub (production code should test the error messages too, but for the sake of brevity, you'll leave those out):

```
func TestProcessorProcessExpression(t *testing.T) {
    p := Processor{MathSolverStub{}}
    in := strings.NewReader(`2 + 2 * 10
( 2 + 2 ) * 10
( 2 + 2 * 10`)
    data := []float64{22, 40, 0}
    hasErr := []bool{false, false, true}
    for i, d := range data {
        result, err := p.ProcessExpression(context.Background(), in)
        if err != nil && !hasErr[i] {
            t.Error(err)
        }
        if result != d {
            t.Errorf("Expected result %f, got %f", d, result)
        }
    }
}
```

You can then run your test and see that everything works.

While most Go interfaces specify only one or two methods, this isn't always the case. You sometimes find yourself with an interface that has many methods. Let's take a look at the code in the *sample_code/stub* directory in the Chapter 15 repository. Assume you have an interface that looks like this:

```go
type Entities interface {
    GetUser(id string) (User, error)
    GetPets(userID string) ([]Pet, error)
    GetChildren(userID string) ([]Person, error)
    GetFriends(userID string) ([]Person, error)
    SaveUser(user User) error
}
```

There are two patterns for testing code that depends on large interfaces. The first is to embed the interface in a struct. Embedding an interface in a struct automatically defines all the interface's methods on the struct. It doesn't provide any implementations of those methods, so you need to implement the methods that you care about for the current test. Let's assume that `Logic` is a struct that has a field of type `Entities`:

```go
type Logic struct {
    Entities Entities
}
```

Assume you want to test this method:

```go
func (l Logic) GetPetNames(userId string) ([]string, error) {
    pets, err := l.Entities.GetPets(userId)
    if err != nil {
        return nil, err
    }
    out := make([]string, len(pets))
    for _, p := range pets {
        out = append(out, p.Name)
    }
    return out, nil
}
```

This method uses only one of the methods declared on `Entities`: `GetPets`. Rather than creating a stub that implements every single method on `Entities` just to test `GetPets`, you can write a stub struct that implements only the method you need to test this method:

```go
type GetPetNamesStub struct {
    Entities
}
```

```go
func (ps GetPetNamesStub) GetPets(userID string) ([]Pet, error) {
    switch userID {
    case "1":
        return []Pet{{Name: "Bubbles"}}, nil
    case "2":
        return []Pet{{Name: "Stampy"}, {Name: "Snowball II"}}, nil
    default:
        return nil, fmt.Errorf("invalid id: %s", userID)
    }
}
```

You then write your unit test, with your stub injected into `Logic`:

```go
func TestLogicGetPetNames(t *testing.T) {
    data := []struct {
        name     string
        userID   string
        petNames []string
    }{
        {"case1", "1", []string{"Bubbles"}},
        {"case2", "2", []string{"Stampy", "Snowball II"}},
        {"case3", "3", nil},
    }
    l := Logic{GetPetNamesStub{}}
    for _, d := range data {
        t.Run(d.name, func(t *testing.T) {
            petNames, err := l.GetPetNames(d.userID)
            if err != nil {
                t.Error(err)
            }
            if diff := cmp.Diff(d.petNames, petNames); diff != "" {
                t.Error(diff)
            }
        })
    }
}
```

(By the way, the `GetPetNames` method has a bug. Did you see it? Even simple methods can sometimes have bugs.)

If you embed an interface in a stub struct, make sure you provide an implementation for every method that's called during your test! If you call an unimplemented method, your tests will panic.

If you need to implement only one or two methods in an interface for a single test, this technique works well. The drawback comes when you need to call the same method in different tests with different inputs and outputs. When that happens, you need to either include every possible result for every test within the same implementation or reimplement the struct for each test. This quickly becomes difficult to understand and maintain. A better solution is to create a stub struct that proxies method calls to function fields. For each method defined on `Entities`, you define a function field with a matching signature on your stub struct:

```
type EntitiesStub struct {
    getUser     func(id string) (User, error)
    getPets     func(userID string) ([]Pet, error)
    getChildren func(userID string) ([]Person, error)
    getFriends  func(userID string) ([]Person, error)
    saveUser    func(user User) error
}
```

You then make `EntitiesStub` meet the `Entities` interface by defining the methods. In each method, you invoke the associated function field. For example:

```
func (es EntitiesStub) GetUser(id string) (User, error) {
    return es.getUser(id)
}

func (es EntitiesStub) GetPets(userID string) ([]Pet, error) {
    return es.getPets(userID)
}
```

Once you create this stub, you can supply different implementations of different methods in different test cases via the fields in the data struct for a table test:

```
func TestLogicGetPetNames(t *testing.T) {
    data := []struct {
        name     string
        getPets  func(userID string) ([]Pet, error)
        userID   string
        petNames []string
        errMsg   string
    }{
        {"case1", func(userID string) ([]Pet, error) {
            return []Pet{{Name: "Bubbles"}}, nil
        }, "1", []string{"Bubbles"}, ""},
        {"case2", func(userID string) ([]Pet, error) {
            return nil, errors.New("invalid id: 3")
        }, "3", nil, "invalid id: 3"},
    }
    l := Logic{}
    for _, d := range data {
        t.Run(d.name, func(t *testing.T) {
            l.Entities = EntitiesStub{getPets: d.getPets}
            petNames, err := l.GetPetNames(d.userID)
            if diff := cmp.Diff(d.petNames, petNames); diff != "" {
                t.Error(diff)
            }
            var errMsg string
            if err != nil {
                errMsg = err.Error()
            }
            if errMsg != d.errMsg {
                t.Errorf("Expected error `%s`, got `%s`", d.errMsg, errMsg)
            }
        })
    }
}
```

You add a field of function type to `data`'s anonymous struct. In each test case, you specify a function that returns the data that `GetPets` would return. When you write your test stubs this way, it's clear what the stubs should return for each test case. As each test runs, you instantiate a new `EntitiesStub` and assign the `getPets` function field in your test data to the `getPets` function field in `EntitiesStub`.

Mocks and Stubs

The terms *mock* and *stub* are often used interchangeably, but they are actually two different concepts. Martin Fowler, a respected voice on all things related to software development, wrote a blog post on mocks that, among other things, covers the difference between mocks and stubs. In short, a *stub* returns a canned value for a given input, whereas a *mock* validates that a set of calls happen in the expected order with the expected inputs.

You used stubs in the examples to return canned values to a given response. You can write your own mocks by hand, or you can use a third-party library to generate them. The two most popular options are the gomock library from Google and the testify library from Stretchr, Inc.

Using httptest

It can be difficult to write tests for a function that calls an HTTP service. Traditionally, this became an integration test, requiring you to stand up a test instance of the service that the function calls. The Go standard library includes the `net/http/httptest` package to make it easier to stub HTTP services. Let's go back to the *sample_code/solver* directory in the Chapter 15 repository and provide an implementation of `MathSolver` that calls an HTTP service to evaluate expressions:

```
type RemoteSolver struct {
    MathServerURL string
    Client        *http.Client
}

func (rs RemoteSolver) Resolve(ctx context.Context, expression string)
                               (float64, error) {
    req, err := http.NewRequestWithContext(ctx, http.MethodGet,
        rs.MathServerURL+"?expression="+url.QueryEscape(expression),
        nil)
    if err != nil {
        return 0, err
    }
    resp, err := rs.Client.Do(req)
    if err != nil {
        return 0, err
    }
    defer resp.Body.Close()
    contents, err := io.ReadAll(resp.Body)
    if err != nil {
        return 0, err
    }
    if resp.StatusCode != http.StatusOK {
        return 0, errors.New(string(contents))
    }
    result, err := strconv.ParseFloat(string(contents), 64)
    if err != nil {
        return 0, err
    }
    return result, nil
}
```

Now let's see how to use the `httptest` library to test this code without standing up a server. The code is in the `TestRemoteSolver_Resolve` function in *sample_code/solver/remote_solver_test.go* in the Chapter 15 repository, but here are the highlights. First, you want to make sure that the data that's passed into the function arrives on the server. So in your test function, you define a type called `info` to hold your input and output and a variable called `io` that is assigned the current input and output:

```
type info struct {
    expression string
    code       int
    body       string
}
var io info
```

Next, you set up your fake remote server and use it to configure an instance of `RemoteSolver`:

```
server := httptest.NewServer(
    http.HandlerFunc(func(rw http.ResponseWriter, req *http.Request) {
        expression := req.URL.Query().Get("expression")
        if expression != io.expression {
            rw.WriteHeader(http.StatusBadRequest)
            fmt.Fprintf(rw, "expected expression '%s', got '%s'",
                io.expression, expression)
            return
        }
        rw.WriteHeader(io.code)
        rw.Write([]byte(io.body))
    }))
defer server.Close()
```

```
rs := RemoteSolver{
    MathServerURL: server.URL,
    Client:        server.Client(),
}
```

The `httptest.NewServer` function creates and starts an HTTP server on a random unused port. You need to provide an `http.Handler` implementation to process the request. Since this is a server, you must close it when the test completes. The `server` instance has its URL specified in the `URL` field of the `server` instance and a preconfigured `http.Client` for communicating with the test server. You pass these into `RemoteSolver`.

The rest of the function works like every other table test that you've seen:

```
data := []struct {
    name   string
    io     info
    result float64
}{
    {"case1", info{"2 + 2 * 10", http.StatusOK, "22"}, 22},
    // remaining cases
}
for _, d := range data {
    t.Run(d.name, func(t *testing.T) {
        io = d.io
        result, err := rs.Resolve(context.Background(), d.io.expression)
        if result != d.result {
            t.Errorf("io `%f`, got `%f`", d.result, result)
        }
        var errMsg string
        if err != nil {
            errMsg = err.Error()
        }
        if errMsg != d.errMsg {
            t.Errorf("io error `%s`, got `%s`", d.errMsg, errMsg)
        }
    })
}
```

The interesting thing to note is that the variable `io` has been captured by two closures: the one for the stub server and the one for running each test. You write to it in one closure and read it in the other. This is a bad idea in production code, but it works well in test code within a single function.

Using Integration Tests and Build Tags

Even though `httptest` provides a way to avoid testing against external services, you should still write *integration tests*, automated tests that connect to other services. These validate that your understanding of the service's API is correct. The challenge is figuring out how to group your automated tests; you want to run integration tests only when the support environment is present. Also, integration tests tend to be slower than unit tests, so they are usually run less frequently.

In "Using Build Tags" on page 284, I covered build tags, which are used by the Go compiler to control when a file is compiled. While they are primarily intended to allow developers to write code that's intended only for a specific operating system, CPU, or Go version, you can take advantage of the ability to specify custom build tags to control when integration tests are compiled and run.

Let's try this out with the math-solving project. Use Docker to download a server implementation with `docker pull jonbodner/math-server` and then run the server locally on port 8080 with `docker run -p 8080:8080 jonbodner/math-server`.

If you don't have Docker installed or if you want to build the code for yourself, you can find it on GitHub.

You need to write an integration test to make sure that your `Resolve` method properly communicates with the math server. The *sample_code/solver/remote_solver_integration_test.go* file in the Chapter 15 repository has a complete test in the `TestRemoteSolver_ResolveIntegration` function. The test looks like every other table test that you've written. The interesting thing is the first line of the file, separated from the package declaration by a newline:

```
//go:build integration
```

To run your integration test alongside the other tests you've written, use this:

```
$ go test -tags integration -v ./...
```

You should be aware that some people in the Go community prefer to use environment variables rather than build tags to create groups of integration tests. Peter Bourgon describes the concept in a blog post with the unsubtle title "Don't Use Build Tags for Integration Tests". His argument is that it's hard to find out what build tags to set in order to run integration tests. An explicit check for an environment variable in each integration test, combined with a detailed message in a `t.Skip` method call, makes it clear that tests aren't being run and how to run them. In the end, it's a trade-off between verbosity and discoverability. Feel free to use either technique.

Using the -short Flag

Yet another way to group tests is to use `go test` with the `-short` flag. If you want to skip over tests that take a long time, label your slow tests by placing the following code at the start of the test function:

```go
if testing.Short() {
    t.Skip("skipping test in short mode.")
}
```

When you want to run only short tests, pass the `-short` flag to `go test`.

There are a few problems with the `-short` flag. If you use it, there are only two levels of testing: short tests and all tests. By using build tags, you can group your integration tests, specifying which service they need in order to run. Another argument against using the `-short` flag to indicate integration tests is philosophical. Build tags indicate a dependency, while the `-short` flag is meant to indicate only that you don't want to run tests that take a long time. Those are different concepts. Finally, I find the `-short` flag unintuitive. You should run short tests all the time. It makes more sense to require a flag to *include* long-running tests, not to *exclude* them.

Finding Concurrency Problems with the Data Race Detector

Even with Go's built-in support for concurrency, bugs still happen. It's easy to accidentally reference a variable from two different goroutines without acquiring a lock. The computer science term for this is a *data race*. To help find these sorts of bugs, Go includes a *race checker*. It isn't guaranteed to find every single data race in your code, but if it finds one, you should put proper locks around what it finds.

Look at a simple example in the file *sample_code/race/race.go* in the Chapter 15 repository:

```go
func getCounter() int {
    var counter int
    var wg sync.WaitGroup
    wg.Add(5)
    for i := 0; i < 5; i++ {
        go func() {
            for i := 0; i < 1000; i++ {
                counter++
            }
            wg.Done()
        }()
    }
    wg.Wait()
    return counter
}
```

This code launches five goroutines, has each of them update a shared `counter` variable 1,000 times, and then returns the result. You'd expect it to be 5,000, so let's verify this with a unit test in *sample_code/race/race_test.go*:

```
func TestGetCounter(t *testing.T) {
    counter := getCounter()
    if counter != 5000 {
        t.Error("unexpected counter:", counter)
    }
}
```

If you run `go test` a few times, you'll see that sometimes it passes, but most of the time it fails with an error message like this:

```
unexpected counter: 3673
```

The problem is that there's a data race in the code. In a program this simple, the cause is obvious: multiple goroutines are trying to update `counter` simultaneously, and some of their updates are lost. In more complicated programs, these sorts of races are harder to see. Let's see what the data race detector does. Use the flag `-race` with `go test` to enable it:

```
$ go test -race
==================
WARNING: DATA RACE
Read at 0x00c000128070 by goroutine 10:
  test_examples/race.getCounter.func1()
      test_examples/race/race.go:12 +0x45

Previous write at 0x00c000128070 by goroutine 8:
  test_examples/race.getCounter.func1()
      test_examples/race/race.go:12 +0x5b
```

The traces make it clear that the line `counter++` is the source of your problems.

Some people try to fix race conditions by inserting "sleeps" into their code, trying to space out access to the variable that's being accessed by multiple goroutines. *This is a bad idea*. Doing so might eliminate the problem in some cases, but the code is still wrong and will fail in some situations.

You can also use the `-race` flag when you build your programs. This creates a binary that includes the data race detector and that reports any races it finds to the console. This allows you to find data races in code that doesn't have tests.

If the data race detector is so useful, why isn't it enabled all the time for testing and production? A binary with `-race` enabled runs approximately 10 times slower than a normal binary. That isn't a problem for test suites that take a second to run, but for large test suites that take several minutes, a 10× slowdown reduces productivity.

For more information on the data race detector, check out its official documentation.

Exercises

Now that you've learned about writing tests and using the code-quality tools included with Go, complete these exercises to apply that knowledge to a sample application.

1. Download the Simple Web App program. Write unit tests for the program and get as close to 100% code coverage as you can. If you find any bugs, fix them.
2. Use the race detector to find a concurrency problem in the program and fix it.
3. Write a fuzz test against the `parser` function and fix any problems that you find.

Wrapping Up

In this chapter, you've learned how to write tests and improve code quality by using Go's built-in support for testing, code coverage, benchmarking, fuzzing, and data race checking. In the next chapter, you're going to explore some Go features that allow you to break the rules: the `unsafe` package, reflection, and `cgo`.

CHAPTER 16

Here Be Dragons: Reflect, Unsafe, and Cgo

The edges of the known world are scary. Ancient maps would fill in the unexplored areas with pictures of dragons and lions. In the previous sections, I have emphasized that Go is a safe language, with typed variables to make clear what sort of data you are using and garbage collection to manage memory. Even the pointers are tame; you can't abuse them in the way that C and C++ do.

All those things are true, and for the vast majority of the Go code that you'll write, you can be assured that the Go runtime will protect you. But there are escape hatches. Sometimes your Go programs need to venture out into less defined areas. In this chapter, you're going to look at how to handle situations that can't be solved with normal Go code. For example, when the type of the data can't be determined at compile time, you can use the reflection support in the `reflect` package to interact with and even construct data. When you need to take advantage of the memory layout of data types in Go, you can use the `unsafe` package. And if there is functionality that can be provided only by libraries written in C, you can call into C code with `cgo`.

You might be wondering why these advanced concepts appear in a book targeted at those new to Go. There are two reasons. First, developers searching for a solution to a problem sometimes discover (and copy and paste) techniques they don't fully understand. It's best to know a bit about advanced techniques that can cause problems before you add them to your codebase. Second, these tools are fun. Because they allow you to do things that aren't normally possible with Go, it feels a bit exciting to play with them and see what you can do.

Reflection Lets You Work with Types at Runtime

One of the things that people who use Go like about it is that it is a statically typed language. Most of the time, declaring variables, types, and functions in Go is pretty straightforward. When you need a type, a variable, or a function, you define it:

```
type Foo struct {
  A int
  B string
}

var x Foo

func DoSomething(f Foo) {
  fmt.Println(f.A, f.B)
}
```

You use types to represent the data structures you know you need when you write your programs. Since types are a core part of Go, the compiler uses them to make sure that your code is correct. But sometimes, relying on only compilation-time information is a limitation. You might need to work with variables at runtime using information that didn't exist when the program was written. Maybe you're trying to map data from a file or network request into a variable. In those situations, you need to use *reflection*. Reflection allows you to examine types at runtime. It also provides the ability to examine, modify, and create variables, functions, and structs at runtime.

This leads to the question of when this functionality is needed. If you look at the Go standard library, you can get an idea. Its uses fall into one of a few general categories:

- Reading and writing from a database. The `database/sql` package uses reflection to send records to databases and read data back.
- Go's built-in templating libraries, `text/template` and `html/template`, use reflection to process the values that are passed to the templates.
- The `fmt` package uses reflection heavily, as all those calls to `fmt.Println` and friends rely on reflection to detect the type of the provided parameters.
- The `errors` package uses reflection to implement `errors.Is` and `errors.As`.
- The `sort` package uses reflection to implement functions that sort and evaluate slices of any type: `sort.Slice`, `sort.SliceStable`, and `sort.SliceIsSorted`.
- The last main usage of reflection in the Go standard library is for marshaling and unmarshaling data into JSON and XML, along with the other data formats defined in the various `encoding` packages. Struct tags (which I will talk about soon) are accessed via reflection, and the fields in structs are read and written using reflection as well.

Most of these examples have one thing in common: they involve accessing and formatting data that is being imported into or exported out of a Go program. You'll often see reflection used at the boundaries between your program and the outside world.

As you take a look at the techniques you can implement with reflection, keep in mind that this power has a price. Using reflection is quite a bit slower than performing the identical operation without it. I'll talk more about this in "Use Reflection Only if It's Worthwhile" on page 424. Even more importantly, code that uses reflection is both more fragile and more verbose. Many functions and methods in the `reflect` package panic when passed the wrong type of data. Be sure to leave comments in your code to explain what you are doing so that it's clear to future reviewers (including yourself).

Another use of the `reflect` package in the Go standard library is testing. In "Slices" on page 39, I mentioned a function that you can find in the `reflect` package called `DeepEqual`. It's in the `reflect` package because it takes advantage of reflection to do its work. The `reflect.DeepEqual` function checks whether two values are "deeply equal" to each other. This is a more thorough comparison than what you get if you use `==` to compare two things, and it's used in the standard library as a way to validate test results. It can also compare things that can't be compared using `==`, like slices and maps. Most of the time, you don't need `DeepEqual`. Since the release of Go 1.21, it's faster to use `slices.Equal` and `maps.Equal` to check for equality in slices and maps.

Types, Kinds, and Values

Now that you know what reflection is and when you might need it, let's see how it works. The `reflect` package in the standard library is the home for the types and functions that implement reflection in Go. Reflection is built around three core concepts: types, kinds, and values.

Types and kinds

A *type* is exactly what it sounds like. It defines the properties of a variable, what it can hold, and how you can interact with it. With reflection, you are able to query a type to find out about these properties using code.

You get the reflection representation of the type of a variable with the `TypeOf` function in the `reflect` package:

```
vType := reflect.TypeOf(v)
```

The `reflect.TypeOf` function returns a value of type `reflect.Type`, which represents the type of the variable passed into the `TypeOf` function. The `reflect.Type`

type defines methods with information about a variable's type. I can't cover all the methods, but here are a few.

The `Name` method returns, not surprisingly, the name of the type. Here is a quick example:

```
var x int
xt := reflect.TypeOf(x)
fmt.Println(xt.Name())     // returns int
f := Foo{}
ft := reflect.TypeOf(f)
fmt.Println(ft.Name())     // returns Foo
xpt := reflect.TypeOf(&x)
fmt.Println(xpt.Name())    // returns an empty string
```

You start with a variable `x` of type `int`. You pass it to `reflect.TypeOf` and get back a `reflect.Type` instance. For primitive types like `int`, `Name` returns the name of the type, in this case the string "int" for your `int`. For a struct, the name of the struct is returned. Some types, like a slice or a pointer, don't have names; in those cases, `Name` returns an empty string.

The `Kind` method on `reflect.Type` returns a value of type `reflect.Kind`, which is a constant that says what the type is made of—a slice, a map, a pointer, a struct, an interface, a string, an array, a function, an int, or some other primitive type. The difference between the kind and the type can be tricky to understand. Remember this rule: if you define a struct named Foo, the kind is `reflect.Struct` and the type is "Foo."

The kind is very important. One thing to be aware of when using reflection is that almost everything in the `reflect` package assumes that you know what you are doing. Some of the methods defined on `reflect.Type` and other types in the `reflect` package make sense for only certain kinds. For example, there's a method on `reflect.Type` called `NumIn`. If your `reflect.Type` instance represents a function, it returns the number of input parameters for the function. If your `reflect.Type` instance isn't a function, calling `NumIn` will panic your program.

> In general, if you call a method that doesn't make sense for the kind of the type, the method call panics. Always remember to use the kind of the reflected type to know which methods will work and which ones will panic.

Another important method on `reflect.Type` is `Elem`. Some types in Go have references to other types and `Elem` is how to find out the contained type. For example, let's use `reflect.TypeOf` on a pointer to an `int`:

```
var x int
xpt := reflect.TypeOf(&x)
fmt.Println(xpt.Name())        // returns an empty string
fmt.Println(xpt.Kind())        // returns reflect.Pointer
fmt.Println(xpt.Elem().Name()) // returns "int"
fmt.Println(xpt.Elem().Kind()) // returns reflect.Int
```

That gives you a `reflect.Type` instance with a blank name and a kind of `reflect.Pointer`. When the `reflect.Type` represents a pointer, `Elem` returns the `reflect.Type` for the type the pointer points to. In this case, the `Name` method returns "int," and `Kind` returns `reflect.Int`. The `Elem` method also works for slices, maps, channels, and arrays.

There are methods on `reflect.Type` for reflecting on structs. Use the `NumField` method to get the number of fields in the struct, and get the fields in a struct by index with the `Field` method. That returns each field's structure described in a `reflect.StructField`, which has the name, order, type, and struct tags on a field. Let's look at a quick example, which you can run on The Go Playground or in the *sample_code/struct_tag* directory in the Chapter 16 repository:

```
type Foo struct {
    A int    `myTag:"value"`
    B string `myTag:"value2"`
}

var f Foo
ft := reflect.TypeOf(f)
for i := 0; i < ft.NumField(); i++ {
    curField := ft.Field(i)
    fmt.Println(curField.Name, curField.Type.Name(),
        curField.Tag.Get("myTag"))
}
```

You create an instance of type `Foo` and use `reflect.TypeOf` to get the `reflect.Type` for `f`. Next you use the `NumField` method to set up a `for` loop to get the index of each field in `f`. Then you use the `Field` method to get the `reflect.StructField` struct that represents the field, and then you can use the fields on `reflect.StructField` to get more information about the field. This code prints out the following:

```
A int value
B string value2
```

There are many more methods in `reflect.Type`, but they all follow the same pattern, allowing you to access the information that describes the type of a variable. You can look at the `reflect.Type` documentation in the standard library for more information.

Values

In addition to examining the types of variables, you can also use reflection to read a variable's value, set its value, or create a new value from scratch.

You use the `reflect.ValueOf` function to create a `reflect.Value` instance that represents the value of a variable:

```
vValue := reflect.ValueOf(v)
```

Since every variable in Go has a type, `reflect.Value` has a method called `Type` that returns the `reflect.Type` of the `reflect.Value`. There's also a `Kind` method, just as there is on `reflect.Type`.

Just as `reflect.Type` has methods for finding out information about the type of a variable, `reflect.Value` has methods for finding out information about the value of a variable. I'm not going to cover all of them, but let's take a look at how to use a `reflect.Value` to get the value of the variable.

I'll start by demonstrating how to read your values back out of a `reflect.Value`. The `Interface` method returns the value of the variable as `any`. When you put the value returned by `Interface` into a variable, you have to use a type assertion to get back to a usable type:

```
s := []string{"a", "b", "c"}
sv := reflect.ValueOf(s)        // sv is of type reflect.Value
s2 := sv.Interface().([]string) // s2 is of type []string
```

While `Interface` can be called for `reflect.Value` instances that contain values of any kind, you can use special case methods if the kind of the variable is one of the built-in, primitive types: `Bool`, `Complex`, `Int`, `Uint`, `Float`, and `String`. There's also a `Bytes` method that works if the type of the variable is a slice of bytes. If you use a method that doesn't match the type of the `reflect.Value`, your code will panic. If you are unsure about the type of the `Value`, methods can preemptively check: the `CanComplex`, `CanFloat`, `CanInt`, and `CanUint` methods validate that the `Value` is of one of the numeric types, and `CanConvert` checks for other types.

You can use reflection to set the value of a variable as well, but it's a three-step process.

First, you pass a pointer to the variable into `reflect.ValueOf`. This returns a `reflect.Value` that represents the pointer:

```
i := 10
iv := reflect.ValueOf(&i)
```

Next, you need to get to the actual value to set it. You use the `Elem` method on `reflect.Value` to get to the value pointed to by the pointer that was passed into `reflect.ValueOf`. Just as `Elem` on `reflect.Type` returns the type that's pointed to by a containing type, `Elem` on `reflect.Value` returns the value that's pointed to by a pointer or the value that's stored in an interface:

```
ivv := iv.Elem()
```

Finally, you get to the actual method that's used to set the value. Just as there are special-case methods for reading primitive types, there are special-case methods for setting primitive types: `SetBool`, `SetInt`, `SetFloat`, `SetString`, and `SetUint`. In the example, calling `ivv.SetInt(20)` changes the value of `i`. If you print out `i` now, you will get 20:

```
ivv.SetInt(20)
fmt.Println(i) // prints 20
```

For all other types, you need to use the `Set` method, which takes a variable of type `reflect.Value`. The value that you are setting it to doesn't need to be a pointer, because you are just reading this value, not changing it. And just as you can use `Interface()` to read primitive types, you can use `Set` to write primitive types.

The reason you need to pass a pointer to `reflect.ValueOf` to change the value of the input parameter is that it is just like any other function in Go. As I discussed in "Pointers Indicate Mutable Parameters" on page 125, you use a parameter of a pointer type to indicate that you want to modify the value of the parameter. When you modify the value, you dereference the pointer and then set the value. The following two functions follow the same process:

```
func changeInt(i *int) {
    *i = 20
}

func changeIntReflect(i *int) {
    iv := reflect.ValueOf(i)
    iv.Elem().SetInt(20)
}
```

Attempting to set a `reflect.Value` to a value of the wrong type will produce a panic.

If you don't pass a pointer to a variable to `reflect.ValueOf`, you can still read the value of the variable using reflection. But if you try to use any of the methods that can change the value of a variable, the method calls will (not surprisingly) panic. The `CanSet` method on `reflect.Value` will tell you if calling `Set` will produce a panic.

Make New Values

Before you learn how to best use reflection, there's one more thing to cover: how to create a value. The `reflect.New` function is the reflection analogue of the `new` function. It takes in a reflect.Type and returns a reflect.Value that's a pointer to a reflect.Value of the specified type. Since it's a pointer, you can modify it and then assign the modified value to a variable by using the Interface method.

Just as reflect.New creates a pointer to a scalar type, you can also use reflection to do the same thing as the make keyword with the following functions:

```
func MakeChan(typ Type, buffer int) Value

func MakeMap(typ Type) Value

func MakeMapWithSize(typ Type, n int) Value

func MakeSlice(typ Type, len, cap int) Value
```

Each of these functions takes in a reflect.Type that represents the compound type, not the contained type.

You must always start from a value when constructing a reflect.Type. However, a trick lets you create a variable to represent a reflect.Type if you don't have a value handy:

```
var stringType = reflect.TypeOf((*string)(nil)).Elem()

var stringSliceType = reflect.TypeOf([]string(nil))
```

The variable stringType contains a reflect.Type that represents a string, and the variable stringSliceType contains a reflect.Type that represents a []string. That first line can take a bit of effort to decode. What you are doing is converting nil to a pointer to string, using reflect.TypeOf to make a reflect.Type of that pointer type, and then calling Elem on that pointer's reflect.Type to get the underlying type. You have to put *string in parentheses because of the Go order of operations; without the parentheses, the compiler thinks that you are converting nil to string, which is illegal.

For the stringSliceType, it's a bit simpler since nil is a valid value for a slice. All you have to do is type conversion of nil to a []string and pass that to reflect.Type.

Now that you have these types, you can see how to use reflect.New and reflect.MakeSlice:

```
ssv := reflect.MakeSlice(stringSliceType, 0, 10)

sv := reflect.New(stringType).Elem()
sv.SetString("hello")

ssv = reflect.Append(ssv, sv)
```

```
ss := ssv.Interface().([]string)
fmt.Println(ss) // prints [hello]
```

You can try out this code for yourself on The Go Playground or in the *sample_code/reflect_string_slice* directory in the Chapter 16 repository.

Use Reflection to Check If an Interface's Value Is nil

As I talked about in "Interfaces and nil" on page 164, if a `nil` variable of a concrete type is assigned to a variable of an interface type, the variable of the interface type is not `nil`. This is because a type is associated with the interface variable. If you want to check whether the value associated with an interface is `nil`, you can do so with reflection by using two methods—`IsValid` and `IsNil`:

```
func hasNoValue(i any) bool {
    iv := reflect.ValueOf(i)
    if !iv.IsValid() {
        return true
    }
    switch iv.Kind() {
    case reflect.Pointer, reflect.Slice, reflect.Map, reflect.Func,
         reflect.Interface:
        return iv.IsNil()
    default:
        return false
    }
}
```

The `IsValid` method returns `true` if `reflect.Value` holds anything other than a `nil` interface. You need to check this first because calling any other method on `reflect.Value` will (unsurprisingly) panic if `IsValid` is `false`. The `IsNil` method returns `true` if the value of the `reflect.Value` is `nil`, but it can be called only if the `reflect.Kind` is something that *can* be `nil`. If you call it on a type whose zero value isn't `nil`, it (you guessed it) panics.

You can see this function in use on The Go Playground or in the *sample_code/no_value* directory in the Chapter 16 repository.

Even though it is possible to detect an interface with a `nil` value, strive to write your code so that it performs correctly even when the value associated with an interface is `nil`. Reserve this code for situations where you have no other options.

Use Reflection to Write a Data Marshaler

As mentioned earlier, reflection is what the standard library uses to implement marshaling and unmarshaling. Let's see how it's done by building a data marshaler for ourselves. Go provides the `csv.NewReader` and `csv.NewWriter` functions to read a CSV file into a slice of slice of strings and to write a slice of slice of strings out to a

CSV file, but nothing in the standard library can automatically map that data to the fields in a struct. The following code is going to add that missing functionality.

The examples here have been cut down a bit to fit, reducing the number of supported types. You can find the complete code on The Go Playground or in the *sample_code/csv* directory in the Chapter 16 repository.

You'll start by defining your API. As with other marshalers, you'll define a struct tag that specifies the name of a field in the data to map it to a field in a struct:

```go
type MyData struct {
    Name   string `csv:"name"`
    Age    int    `csv:"age"`
    HasPet bool   `csv:"has_pet"`
}
```

The public API consists of two functions:

```go
// Unmarshal maps all of the rows of data in a slice of slice of strings
// into a slice of structs.
// The first row is assumed to be the header with the column names.
func Unmarshal(data [][]string, v any) error

// Marshal maps all of the structs in a slice of structs to a slice of slice
// of strings.
// The first row written is the header with the column names.
func Marshal(v any) ([][]string, error)
```

You'll start with `Marshal`, writing the function and then looking at the two helper functions it uses:

```go
func Marshal(v any) ([][]string, error) {
    sliceVal := reflect.ValueOf(v)
    if sliceVal.Kind() != reflect.Slice {
        return nil, errors.New("must be a slice of structs")
    }
    structType := sliceVal.Type().Elem()
    if structType.Kind() != reflect.Struct {
        return nil, errors.New("must be a slice of structs")
    }
    var out [][]string
    header := marshalHeader(structType)
    out = append(out, header)
    for i := 0; i < sliceVal.Len(); i++ {
        row, err := marshalOne(sliceVal.Index(i))
        if err != nil {
            return nil, err
        }
        out = append(out, row)
    }
    return out, nil
}
```

Since you can marshal a struct of any type, you need to use a parameter of type `any`. This isn't a pointer to a slice of structs, because you are only reading from your slice, not modifying it.

The first row of your CSV is going to be the header with the column names, so you get those column names from the struct tags on fields in the struct's type. You use the `Type` method to get the `reflect.Type` of the slice from the `reflect.Value`, and then call the `Elem` method to get the `reflect.Type` of the elements of the slice. You then pass this to `marshalHeader` and append the response to your output.

Next, you iterate through each element in the struct slice using reflection, passing the `reflect.Value` of each element to `marshalOne`, appending the result to your output. When you finish iterating, you return your slice of slice of `string`.

Look at the implementation of your first helper function, `marshalHeader`:

```
func marshalHeader(vt reflect.Type) []string {
    var row []string
    for i := 0; i < vt.NumField(); i++ {
        field := vt.Field(i)
        if curTag, ok := field.Tag.Lookup("csv"); ok {
            row = append(row, curTag)
        }
    }
    return row
}
```

This function simply loops over the fields of the `reflect.Type`, reads the `csv` tag on each field, appends it into a `string` slice, and returns the slice.

The second helper function is `marshalOne`:

```
func marshalOne(vv reflect.Value) ([]string, error) {
    var row []string
    vt := vv.Type()
    for i := 0; i < vv.NumField(); i++ {
        fieldVal := vv.Field(i)
        if _, ok := vt.Field(i).Tag.Lookup("csv"); !ok {
            continue
        }
        switch fieldVal.Kind() {
        case reflect.Int:
            row = append(row, strconv.FormatInt(fieldVal.Int(), 10))
        case reflect.String:
            row = append(row, fieldVal.String())
        case reflect.Bool:
            row = append(row, strconv.FormatBool(fieldVal.Bool()))
        default:
            return nil, fmt.Errorf("cannot handle field of kind %v",
                                    fieldVal.Kind())
        }
    }
    return row, nil
}
```

This function takes in a `reflect.Value` and returns a `string` slice. You create the `string` slice, and for each field in the struct, you switch on its `reflect.Kind` to determine how to convert it to a `string`, and append it to the output.

Your simple marshaler is now complete. Let's see what you have to do to unmarshal:

```go
func Unmarshal(data [][]string, v any) error {
    sliceValPointer := reflect.ValueOf(v)
    if sliceValPointer.Kind() != reflect.Pointer {
        return errors.New("must be a pointer to a slice of structs")
    }
    sliceVal := sliceValPointer.Elem()
    if sliceVal.Kind() != reflect.Slice {
        return errors.New("must be a pointer to a slice of structs")
    }
    structType := sliceVal.Type().Elem()
    if structType.Kind() != reflect.Struct {
        return errors.New("must be a pointer to a slice of structs")
    }

    // assume the first row is a header
    header := data[0]
    namePos := make(map[string]int, len(header))
    for i, name := range header {
        namePos[name] = i
    }

    for _, row := range data[1:] {
        newVal := reflect.New(structType).Elem()
        err := unmarshalOne(row, namePos, newVal)
        if err != nil {
            return err
        }
        sliceVal.Set(reflect.Append(sliceVal, newVal))
    }
    return nil
}
```

Since you are copying data into a slice of any kind of struct, you need to use a parameter of type `any`. Furthermore, because you are modifying the value stored in this parameter, you *must* pass in a pointer to a slice of structs. The `Unmarshal` function converts that slice of structs pointer to a `reflect.Value`, then gets the underlying slice, and then gets the type of the structs in the underlying slice.

As I said earlier, the code assumes that the first row of data is a header with the names of the columns. You use this information to build up a map, so you can associate the csv struct tag value with the correct data element.

You then loop through all the remaining string slices, creating a new reflect.Value using the reflect.Type of the struct, call unmarshalOne to copy the data in the current string slice into the struct, and then add the struct to your slice. After iterating through all the rows of data, you return.

All that remains is looking at the implementation of unmarshalOne:

```go
func unmarshalOne(row []string, namePos map[string]int, vv reflect.Value) error {
    vt := vv.Type()
    for i := 0; i < vv.NumField(); i++ {
        typeField := vt.Field(i)
        pos, ok := namePos[typeField.Tag.Get("csv")]
        if !ok {
            continue
        }
        val := row[pos]
        field := vv.Field(i)
        switch field.Kind() {
        case reflect.Int:
            i, err := strconv.ParseInt(val, 10, 64)
            if err != nil {
                return err
            }
            field.SetInt(i)
        case reflect.String:
            field.SetString(val)
        case reflect.Bool:
            b, err := strconv.ParseBool(val)
            if err != nil {
                return err
            }
            field.SetBool(b)
        default:
            return fmt.Errorf("cannot handle field of kind %v",
                              field.Kind())
        }
    }
    return nil
}
```

This function iterates over each field in the newly created reflect.Value, uses the csv struct tag on the current field to find its name, looks up the element in the data slice by using the namePos map, converts the value from a string to the correct type, and sets the value on the current field. After all fields have been populated, the function returns.

Now that you have written your marshaler and unmarshaler, you can integrate with the existing CSV support in the Go standard library:

```
data := `name,age,has_pet
Jon,"100",true
"Fred ""The Hammer"" Smith",42,false
Martha,37,"true"
`
r := csv.NewReader(strings.NewReader(data))
allData, err := r.ReadAll()
if err != nil {
    panic(err)
}
var entries []MyData
Unmarshal(allData, &entries)
fmt.Println(entries)

//now to turn entries into output
out, err := Marshal(entries)
if err != nil {
    panic(err)
}
sb := &strings.Builder{}
w := csv.NewWriter(sb)
w.WriteAll(out)
fmt.Println(sb)
```

Build Functions with Reflection to Automate Repetitive Tasks

Another thing that Go lets you do with reflection is create a function. You can use this technique to wrap existing functions with common functionality without writing repetitive code. For example, here's a factory function that adds timing to any function that's passed into it:

```
func MakeTimedFunction(f any) any {
    ft := reflect.TypeOf(f)
    fv := reflect.ValueOf(f)
    wrapperF := reflect.MakeFunc(ft, func(in []reflect.Value) []reflect.Value {
        start := time.Now()
        out := fv.Call(in)
        end := time.Now()
        fmt.Println(end.Sub(start))
        return out
    })
    return wrapperF.Interface()
}
```

This function takes in any function, so the parameter is of type `any`. It then passes the `reflect.Type` that represents the function into `reflect.MakeFunc`, along with a closure that captures the start time, calls the original function using reflection, captures the end time, prints out the difference, and returns the value calculated by the original function. The value returned from `reflect.MakeFunc` is a `reflect.Value`, and you call its `Interface` method to get the value to return. Here's how you use it:

```
func timeMe(a int) int {
    time.Sleep(time.Duration(a) * time.Second)
    result := a * 2
    return result
}

func main() {
    timed:= MakeTimedFunction(timeMe).(func(int) int)
    fmt.Println(timed(2))
}
```

You can run a more complete version of this program on The Go Playground or in the *sample_code/timed_function* directory in the Chapter 16 repository.

While generating functions is clever, be careful when using this feature. Make sure that it's clear when you are using a generated function and what functionality it is adding. Otherwise, you will be making it harder to understand the flow of data through your program. Furthermore, as I'll discuss in "Use Reflection Only if It's Worthwhile" on page 424, reflection makes your programs slower, so using it to generate and invoke functions seriously impacts performance unless the code you are generating is already performing a slow operation, like a network call. Remember, reflection works best when it's used to map data in and out of the edge of your programs.

One project that follows these rules for generated functions is my SQL mapping library Proteus. It creates a type-safe database API by generating a function from a SQL query and a function field or variable. You can learn more about Proteus in my GopherCon 2017 talk, "Runtime Generated, Typesafe, and Declarative: Pick Any Three," and you can find the source code on GitHub.

You Can Build Structs with Reflection, but Don't

You can make one more thing with reflection, and it's weird. The `reflect.StructOf` function takes in a slice of `reflect.StructField` and returns a `reflect.Type` that represents a new struct type. These structs can be assigned only to variables of type `any`, and their fields can only be read and written using reflection.

For the most part, this is a feature of academic interest only. To see a demo of how `reflect.StructOf` works, look at the memoizer function on The Go Playground or in the *sample_code/memoizer* directory in the Chapter 16 repository. It uses dynamically generated structs as the keys to a map that caches the output of a function.

Reflection Can't Make Methods

You've seen all the things that you can do with reflection, but there's one thing you can't make. While you can use reflection to create new functions and new struct types, there's no way to use reflection to add methods to a type. This means you cannot use reflection to create a new type that implements an interface.

Use Reflection Only if It's Worthwhile

Although reflection is essential when converting data at the boundaries of Go, be careful using it in other situations. Reflection isn't free. To demonstrate, let's implement `Filter` by using reflection. You looked at a generic implementation in "Generic Functions Abstract Algorithms" on page 187, but let's see what a reflection-based version looks like:

```go
func Filter(slice any, filter any) any {
    sv := reflect.ValueOf(slice)
    fv := reflect.ValueOf(filter)

    sliceLen := sv.Len()
    out := reflect.MakeSlice(sv.Type(), 0, sliceLen)
    for i := 0; i < sliceLen; i++ {
        curVal := sv.Index(i)
        values := fv.Call([]reflect.Value{curVal})
        if values[0].Bool() {
            out = reflect.Append(out, curVal)
        }
    }
    return out.Interface()
}
```

You use it like this:

```go
names := []string{"Andrew", "Bob", "Clara", "Hortense"}
longNames := Filter(names, func(s string) bool {
    return len(s) > 3
}).([]string)
fmt.Println(longNames)

ages := []int{20, 50, 13}
adults := Filter(ages, func(age int) bool {
    return age >= 18
}).([]int)
fmt.Println(adults)
```

This prints out the following:

```
[Andrew Clara Hortense]
[20 50]
```

Your reflection-using filter function isn't difficult to understand, but it's certainly longer than a custom-written or generic function. Let's see how it performs on an Apple Silicon M1 with 16 GB of RAM on Go 1.20 when filtering 1,000 element slices of strings and `int`s, compared to custom-written functions:

```
BenchmarkFilterReflectString-8     5870  203962 ns/op  46616 B/op  2219 allocs/op
BenchmarkFilterGenericString-8   294355    3920 ns/op  16384 B/op     1 allocs/op
BenchmarkFilterString-8          302636    3885 ns/op  16384 B/op     1 allocs/op
BenchmarkFilterReflectInt-8        5756  204530 ns/op  45240 B/op  2503 allocs/op
BenchmarkFilterGenericInt-8      439100    2698 ns/op   8192 B/op     1 allocs/op
BenchmarkFilterInt-8             443745    2677 ns/op   8192 B/op     1 allocs/op
```

You can find this code in the *sample_code/reflection_filter* directory in the Chapter 16 repository so you can run it yourself.

This benchmark demonstrates the value of using generics when you can. Reflection is over 50 times slower than a custom or generic function for string filtering and roughly 75 times slower for `int`s. It uses significantly more memory and performs thousands of allocations, which creates additional work for the garbage collector. The generic version provides the same performance as the custom-written functions without having to write multiple versions.

A more serious downside to the reflection implementation is that the compiler can't stop you from passing in a wrong type for either the `slice` or the `filter` parameter. You might not mind a few thousand nanoseconds of CPU time, but if someone passes in a function or slice of the wrong type to `Filter`, your program will crash in production. The maintenance cost might be too high to accept.

Some things can't be written using generics, and you'll need to fall back to reflection. CSV marshaling and unmarshaling requires reflection, as does the memoizing program. In both cases, you need to work with an unknown number of values of different (and unknown) types. But do make sure that reflection is essential before employing it.

unsafe Is Unsafe

Just as the `reflect` package allows you to manipulate types and values, the `unsafe` package allows you to manipulate memory. The `unsafe` package is very small and very odd. It defines several functions and one type, none of which act like the types and functions found in other packages.

Given Go's focus on memory safety, you might wonder why `unsafe` even exists. Just as you used `reflect` to translate text data between the outside world and Go code, you use `unsafe` to translate binary data. There are two main reasons for using `unsafe`. A 2020 paper by Diego Elias Costa et al. called "Breaking Type-Safety in Go: An

Empirical Study on the Usage of the unsafe Package" surveyed 2,438 popular Go open source projects and found the following:

- 24% of the studied Go projects use `unsafe` at least once in their codebase.
- The majority of `unsafe` usages were motivated by integration with operating systems and C code.
- Developers frequently use `unsafe` to write more efficient Go code.

The plurality of the uses of `unsafe` are for system interoperability. The Go standard library uses `unsafe` to read data from and write data to the operating system. You can see examples in the `syscall` package in the standard library or in the higher-level `sys` package. You can learn more about how to use `unsafe` to communicate with the operating system in a great blog post written by Matt Layher.

The `unsafe.Pointer` type is a special type that exists for a single purpose: a pointer of any type can be converted to or from `unsafe.Pointer`. In addition to pointers, `unsafe.Pointer` can also be converted to or from a special integer type, called `uintptr`. As with any other integer type, you can do math with it. This allows you to walk into an instance of a type, extracting individual bytes. You can also perform pointer arithmetic, just as you can with pointers in C and C++. This byte manipulation changes the value of the variable.

There are two common patterns in `unsafe` code. The first is a conversion between two types of variables that are normally not convertible. This is performed using a series of type conversions with `unsafe.Pointer` in the middle. The second is reading or modifying the bytes in a variable by converting a variable to an `unsafe.Pointer`, converting the `unsafe.Pointer` to a pointer, and then copying or manipulating the underlying bytes. Both of these techniques require you to know the size (and possibly the location) of the data being manipulated. The `Sizeof` and `Offsetof` functions in the `unsafe` package provide this information.

Using Sizeof and Offsetof

Some of the functions in `unsafe` reveal how the bytes in various types are laid out in memory. The first one you'll look at is `Sizeof`. As the name implies, it returns the size in bytes of whatever is passed into it.

While the sizes for numeric types are fairly obvious (an `int16` is 16 bits or 2 bytes, a `byte` is 1 byte, and so on), other types are a bit more complicated. For a pointer, you get the size of the memory to store the pointer (usually 8 bytes on a 64-bit system), not the size of the data that the pointer points to. This is why `Sizeof` considers any slice to be 24 bytes long on a 64-bit system; it's implemented as two `int` fields (for length and capacity) and a pointer to the data for the slice. Any `string` is 16 bytes long on a 64-bit system (an `int` for length and a pointer to the contents of the string). Any `map` on a 64-bit system is 8 bytes, since within the Go runtime, a `map` is implemented as a pointer to a rather complicated data structure.

Arrays are value types, so their size is calculated by multiplying the length of the array by the size of each element in the array.

For a struct, the size is the sum of the sizes of the fields, plus some adjustments for *alignment*. Computers like to read and write data in regular-sized chunks and they really don't want a value to start in one chunk and end in another. To make this happen, the compiler adds padding between fields so they line up properly. The compiler also wants the entire struct to be properly aligned. On a 64-bit system, it will add padding at the end of the struct to bring its size up to a multiple of 8 bytes.

Another function in `unsafe`, `Offsetof`, tells you the position of a field within a struct. Let's use `Sizeof` and `Offsetof` to look at the effects of field order on the size of a struct. Say you have two structs:

```go
type BoolInt struct {
    b bool
    i int64
}

type IntBool struct {
    i int64
    b bool
}
```

Running this code

```go
fmt.Println(unsafe.Sizeof(BoolInt{}),
    unsafe.Offsetof(BoolInt{}.b),
    unsafe.Offsetof(BoolInt{}.i))

fmt.Println(unsafe.Sizeof(IntBool{}),
    unsafe.Offsetof(IntBool{}.i),
    unsafe.Offsetof(IntBool{}.b))
```

produces the following output:

```
16 0 8
16 0 8
```

The size of both types is 16 bytes. When the `bool` comes first, the compiler puts 7 bytes of padding between `b` and `i`. When the `int64` comes first, the compiler puts 7 bytes of padding after `b` to make the struct's size a multiple of 8 bytes.

You can see the effect of field order when there are more fields:

```
type BoolIntBool struct {
    b  bool
    i  int64
    b2 bool
}

type BoolBoolInt struct {
    b  bool
    b2 bool
    i  int64
}

type IntBoolBool struct {
    i  int64
    b  bool
    b2 bool
}
```

Printing out the sizes and offsets for these types produces the following output:

```
24 0 8 16
16 0 1 8
16 0 8 9
```

Putting the `int64` field between the two `bool` fields produces a struct that's 24 bytes long, since both `bool` fields need to be padded to 8 bytes. Meanwhile, grouping the `bool` fields together produces a struct that's 16 bytes long, the same as the structs with only two fields. You can validate this on The Go Playground or in the *sample_code/sizeof_offsetof* directory in the Chapter 16 repository.

Although only of academic interest most of the time, this information is useful in two situations. The first is in programs that manage large amounts of data. You can sometimes achieve significant savings in memory usage simply by reordering the fields in heavily used structs in order to minimize the amount of padding needed for alignment.

The second situation occurs when you want to map a sequence of bytes directly into a struct. You'll look at that next.

Using unsafe to Convert External Binary Data

As was mentioned earlier, one of the main reasons people use `unsafe` is for performance, especially when reading data from a network. If you want to map the data into or out of a Go data structure, `unsafe.Pointer` gives you a very fast way to do so. You can explore this with a contrived example. Imagine a *wire protocol* (a specification indicating which bytes are written in which order when communicating over a network) with the following structure:

- Value: 4 bytes, representing an unsigned, big-endian 32-bit int
- Label: 10 bytes, ASCII name for the value
- Active: 1 byte, boolean flag to indicate whether the field is active
- Padding: 1 byte, because you want everything to fit into 16 bytes

Data sent over a network is usually sent in big-endian format (most significant bytes first), often called *network byte order*. Since most CPUs in use today are little-endian (or bi-endian running in little-endian mode), you need to be careful when reading or writing data to a network.

The code for this example is in the *sample_code/unsafe_data* directory in the Chapter 16 repository.

You define a data structure whose in-memory layout matches the wire protocol:

```go
type Data struct {
    Value  uint32   // 4 bytes
    Label  [10]byte // 10 bytes
    Active bool     // 1 byte
    // Go pads this with 1 byte to make it align
}
```

You use `unsafe.Sizeof` to define a constant that represents its size:

```go
const dataSize = unsafe.Sizeof(Data{}) // sets dataSize to 16
```

(One of the weird things about `unsafe.Sizeof` and `Offsetof` is that you can use them in `const` expressions. The size and layout of a data structure in memory is known at compile time, so the results of these functions are calculated at compile time, just like a constant expression.)

Say you just read the following bytes off the network:

```
[0 132 95 237 80 104 111 110 101 0 0 0 0 0 1 0]
```

You're going to read these bytes into an array of length 16 and then convert that array into the `struct` described previously.

With safe Go code, you could map it like this:

```go
func DataFromBytes(b [dataSize]byte) Data {
    d := Data{}
    d.Value = binary.BigEndian.Uint32(b[:4])
    copy(d.Label[:], b[4:14])
    d.Active = b[14] != 0
    return d
}
```

Or, you could use `unsafe.Pointer` instead:

```go
func DataFromBytesUnsafe(b [dataSize]byte) Data {
    data := *(*Data)(unsafe.Pointer(&b))
    if isLE {
        data.Value = bits.ReverseBytes32(data.Value)
    }
    return data
}
```

The first line is a little confusing, but you can take it apart and understand what's going on. First, you take the address of the byte array and convert it to an `unsafe.Pointer`. Then you convert the `unsafe.Pointer` to a `(*Data)` (you have to put `(*Data)` in parentheses because of Go's order of operations). You want to return the struct, not a pointer to it, so you dereference the pointer. Next, you check your flag to see if you are on a little-endian platform. If so, you reverse the bytes in the `Value` field. Finally, you return the value.

Why did you use an array instead of a slice for the parameter? Remember, arrays, like structs, are value types; the bytes are allocated directly. That means you can map the values in `b` directly into the `data` struct. A slice is composed of three parts: a length, a capacity, and a pointer to the actual values. You'll see how to map a slice into a struct using `unsafe` in a bit.

How do you know if you are on a little-endian platform? Here's the code you're using:

```go
var isLE bool

func init() {
    var x uint16 = 0xFF00
    xb := *(*[2]byte)(unsafe.Pointer(&x))
    isLE = (xb[0] == 0x00)
}
```

As I discussed in "Avoiding the init Function if Possible" on page 239, you should avoid using `init` functions, except when initializing a package-level value whose value is effectively immutable. Since the endianness of your processor isn't going to change while your program is running, this is a good use case.

On a little-endian platform, the bytes that represent `x` will be stored as [00 FF]. On a big-endian platform, `x` is stored in memory as [FF 00]. You use `unsafe.Pointer` to convert a number to an array of bytes, and you check what the first byte is to determine the value of `isLE`.

Likewise, if you wanted to write your `Data` back to the network, you could use safe Go:

```go
func BytesFromData(d Data) [dataSize]byte {
    out := [dataSize]byte{}
    binary.BigEndian.PutUint32(out[:4], d.Value)
    copy(out[4:14], d.Label[:])
    if d.Active {
        out[14] = 1
    }
    return out
}
```

Or you could use `unsafe`:

```go
func BytesFromDataUnsafe(d Data) [dataSize]byte {
    if isLE {
        d.Value = bits.ReverseBytes32(d.Value)
    }
    b := *(*[dataSize]byte)(unsafe.Pointer(&d))
    return b
}
```

If the bytes are stored in a slice, you can use the `unsafe.Slice` function to create a slice from the contents of `Data`. The `unsafe.SliceData` function is used to create a `Data` instance from the data stored in a slice:

```go
func BytesFromDataUnsafeSlice(d Data) []byte {
    if isLE {
        d.Value = bits.ReverseBytes32(d.Value)
    }
    bs := unsafe.Slice((*byte)(unsafe.Pointer(&d)), dataSize)
    return bs
}

func DataFromBytesUnsafeSlice(b []byte) Data {
    data := *(*Data)((unsafe.Pointer)(unsafe.SliceData(b)))
    if isLE {
        data.Value = bits.ReverseBytes32(data.Value)
    }
    return data
}
```

The first parameter to `unsafe.Slice` requires two casts. The first cast converts a pointer of the `Data` instance to an `unsafe.Pointer`. Then you need to cast again to a pointer of the type of data that you want the slice to hold. For a slice of bytes, you use `*byte`. The second parameter is the length of the data.

The `unsafe.SliceData` function takes in a slice and returns a pointer to the type of the data contained in the slice. In this case, you passed in a `[]byte`, so it returned a *byte. You then use unsafe.Pointer as a bridge between *byte and *Data to convert the contents of the slice into a Data instance.

Is this worth it? Here are the timings on an Apple Silicon M1 (which is little-endian):

```
BenchmarkBytesFromData-8             548607271  2.185 ns/op   0 B/op 0 allocs/op
BenchmarkBytesFromDataUnsafe-8      1000000000  0.8418 ns/op  0 B/op 0 allocs/op
BenchmarkBytesFromDataUnsafeSlice-8  91179056  13.14 ns/op   16 B/op 1 allocs/op
BenchmarkDataFromBytes-8             538443861  2.186 ns/op   0 B/op 0 allocs/op
BenchmarkDataFromBytesUnsafe-8      1000000000  1.160 ns/op   0 B/op 0 allocs/op
BenchmarkDataFromBytesUnsafeSlice-8 1000000000  0.9617 ns/op  0 B/op 0 allocs/op
```

Two things stand out in this chart. First, the conversion from a struct to a slice is by far the slowest operation, and it's the only one that allocates memory. This isn't surprising, since the slice's data needs to escape to the heap when it is returned from the function. Allocating memory on the heap is almost always slower than using memory on the stack. Converting from a slice to a struct is very fast, though.

If you are working with arrays, using unsafe is about 2–2.5 times faster than the standard approach. If you have a program with many of these kinds of conversions, or if you are trying to map a very large and complicated data structure, using these low-level techniques is worthwhile. But for the vast majority of programs, stick with the safe code.

Accessing Unexported Fields

Here's another bit of magic you can do with unsafe, but it's something to use only as a last resort. You can combine reflection and unsafe to read and modify unexported fields in structs. Let's see how.

First, define a struct in one package:

```go
type HasUnexportedField struct {
    A int
    b bool
    C string
}
```

Normally, code outside this package is unable to access b. However, let's see what you can do from another package by using unsafe:

```go
func SetBUnsafe(huf *one_package.HasUnexportedField) {
    sf, _ := reflect.TypeOf(huf).Elem().FieldByName("b")
    offset := sf.Offset
    start := unsafe.Pointer(huf)
    pos := unsafe.Add(start, offset)
    b := (*bool)(pos)
    fmt.Println(*b) // read the value
    *b = true       // write the value
}
```

You use reflection to access type information about field `b`. The `FieldByName` method returns a `reflect.StructField` instance for any field on a struct, even unexported ones. The instance includes the offset of its associated field. You then convert `huf` into an `unsafe.Pointer` and use the `unsafe.Add` method to add the offset to the pointer in order to find the location of `b` within the struct. All that remains is casting the `unsafe.Pointer` returned by `Add` to a `*bool`. Now you can read the value of `b` or set its value. You can try out this code in the *sample_code/unexported_field_access* directory in the Chapter 16 repository.

Using unsafe Tools

Go is a language that values tooling, and a compiler flag can help you find misuse of `Pointer` and `unsafe.Pointer`. Run your code with the flag `-gcflags=-d=checkptr` to add additional checks at runtime. Like the race checker, it's not guaranteed to find every `unsafe` problem and it does slow your program. However, it's a good practice while testing your code.

If you want to learn more about `unsafe`, read through the package documentation.

The `unsafe` package is powerful and low-level! Avoid using it unless you know what you are doing and you need the performance improvements that it provides.

Cgo Is for Integration, Not Performance

Just like reflection and `unsafe`, `cgo` is most useful at the border between Go programs and the outside world. Reflection helps integrate with external textual data, `unsafe` is best used with operating system and network data, and `cgo` is best for integrating with C libraries.

Despite being nearly 50 years old, C is still the *lingua franca* of programming languages. All the major operating systems are primarily written in either C or C++, which means that they are bundled with libraries written in C. It also means that nearly every programming language provides a way to integrate with C libraries. Go calls its foreign function interface (FFI) to C `cgo`.

As you have seen many times, Go is a language that favors explicit specification. Go developers sometimes deride automatic behaviors in other languages as "magic." However, using `cgo` feels a bit like spending time with Merlin. Let's take a look at this magical glue code.

You'll start with a very simple program that calls C code to do some math. The source code is in GitHub in the *sample_code/call_c_from_go* directory in the Chapter 16 repository. First, here's the code in *main.go*:

```
package main

import "fmt"

/*
    #cgo LDFLAGS: -lm
    #include <stdio.h>
    #include <math.h>
    #include "mylib.h"

    int add(int a, int b) {
        int sum = a + b;
        printf("a: %d, b: %d, sum %d\n", a, b, sum);
        return sum;
    }
*/
import "C"

func main() {
    sum := C.add(3, 2)
    fmt.Println(sum)
    fmt.Println(C.sqrt(100))
    fmt.Println(C.multiply(10, 20))
}
```

The *mylib.h* header is in the same directory as your *main.go*:

```
int multiply(int a, int b);
```

There is also *mylib.c*:

```
#include "mylib.h"

int multiply(int a, int b) {
    return a * b;
}
```

Assuming you have a C compiler installed on your computer, all you need to do is compile your program with `go build`:

```
$ go build
$ ./call_c_from_go
a: 3, b: 2, sum 5
5
10
200
```

What's going on here? The standard library doesn't have a real package named `C`. Instead, `C` is an automatically generated package whose identifiers mostly come from the C code embedded in the comments that immediately precede it. In this example, you declare a C function called `add`, and `cgo` makes it available to your Go program as the name `C.add`. You can also invoke functions or global variables that are imported into the comment block from libraries via header files, as you can see when you call `C.sqrt` from `main` (imported from *math.h*) or `C.multiply` (imported from *mylib.h*).

In addition to the identifier names that appear in the comment block (or are imported into the comment block), the `C` pseudopackage also defines types like `C.int` and `C.char` to represent the built-in C types and functions, such as `C.CString` to convert a Go string to a C string.

You can use more magic to call Go functions from C functions. Go functions can be exposed to C code by putting an `//export` comment before the function. You can see this in use in the *sample_code/call_go_from_c* directory in the Chapter 16 repository. In *main.go*, you export the doubler function:

```
//export doubler
func doubler(i int) int {
    return i * 2
}
```

When you export a Go function, you can no longer write C code directly in the comment before the `import "C"` statement. You can only list function headers:

```
/*
    extern int add(int a, int b);
*/
import "C"
```

Put your C code into a *.c* file in the same directory as your Go code and include the magic header `"cgo_export.h"`. You can see this in the *example.c* file:

```
#include "_cgo_export.h"

int add(int a, int b) {
    int doubleA = doubler(a);
    int sum = doubleA + b;
    return sum;
}
```

Running this program with `go build` give the following output:

```
$ go build
$ ./call_go_from_c
8
```

So far, this seems pretty simple, but one major stumbling block arises when using `cgo`: Go is a garbage-collected language, and C is not. This makes it difficult to integrate nontrivial Go code with C. While you can pass a pointer into C code, you cannot directly pass something that contains a pointer. This is very limiting, as things like strings, slices, and functions are implemented with pointers and therefore cannot be contained in a struct passed into a C function.

That's not all: a C function cannot store a copy of a Go pointer that lasts after the function returns. If you break these rules, your program will compile and run, but it may crash or behave incorrectly at runtime when the memory pointed to by the pointer is garbage collected.

If you find yourself needing to pass an instance of a type that contains a pointer from Go to C and then back into Go, you can use a `cgo.Handle` to wrap the instance. Here's a short example. You can find the source code in the *sample_code/handle* directory in the Chapter 16 repository.

First you have your Go code:

```
package main

/*
    #include <stdint.h>

    extern void in_c(uintptr_t handle);
*/
import "C"

import (
    "fmt"
    "runtime/cgo"
)

type Person struct {
    Name string
    Age  int
}

func main() {
    p := Person{
        Name: "Jon",
        Age:  21,
    }
    C.in_c(C.uintptr_t(cgo.NewHandle(p)))
}

//export processor
func processor(handle C.uintptr_t) {
    h := cgo.Handle(handle)
    p := h.Value().(Person)
    fmt.Println(p.Name, p.Age)
    h.Delete()
}
```

And this is the C code:

```
#include <stdint.h>
#include "_cgo_export.h"

void in_c(uintptr_t handle) {
    processor(handle);
}
```

In the Go code, you're passing a `Person` instance into the C function `in_c`. This function in turn calls the Go function `processor`. You can't safely pass a `Person` into C via `cgo`, because one of its fields is a `string`, and every `string` contains a pointer. To make this work, use the `cgo.NewHandle` function to convert `p` to a `cgo.Handle`. You then cast the `Handle` to a `C.uintptr_t` so you can pass it to the C function `in_c`. The function takes in a single parameter of type `uintptr_t`, which is a C type that is analogous to Go's `uintptr` type. The `in_c` function calls the Go function `process`, which also takes in a single parameter of type `C.uintptr_t`. It casts this parameter to a `cgo.Handle`, and then uses a type assertion to convert the `Handle` to a `Person` instance. You print out the fields in `p`. Now that you are done using the `Handle`, you call the `Delete` method to delete it.

In addition to working with pointers, other `cgo` limitations exist. For example, you cannot use `cgo` to call a variadic C function (such as `printf`). Union types in C are converted into byte arrays. And you cannot invoke a C function pointer (but you can assign it to a Go variable and pass it back into a C function).

These rules make using `cgo` nontrivial. If you have a background in Python or Ruby, you might think that using `cgo` is worth it for performance reasons. Those developers write the performance-critical parts of their programs in C. The speed of NumPy is due to the C libraries that are wrapped by Python code.

In most cases, Go code is many times faster than Python or Ruby, so the need to rewrite algorithms in a lower-level language is greatly reduced. You might think that you could save `cgo` for those situations when you do need additional performance gains, but unfortunately, using `cgo` to make your code faster is difficult. Because of the mismatches in the processing and memory models, calling a C function from Go is roughly 29 times slower than a C function calling another C function.

At CapitalGo 2018, Filippo Valsorda gave a talk, called "Why cgo is slow." Unfortunately, the talk wasn't recorded, but slides are available. They explain why `cgo` is slow and why it will not be made appreciably faster in the future. In his blog post "CGO Performance in Go 1.21," Shane Hansen measured the overhead of a `cgo` call in Go 1.21 at roughly 40ns on an Intel Core i7-12700H.

Since cgo isn't fast, and it isn't easy to use for nontrivial programs, the only reason to use cgo is if you must use a C library and there is no suitable Go replacement. Rather than writing cgo yourself, see if a third-party module already provides the wrapper. For example, if you want to embed SQLite in a Go application, look at GitHub. For ImageMagick, check out this repository.

If you find yourself needing to use an internal C library or third-party library that doesn't have a wrapper, you can find additional details on how to write your integration in the Go documentation. For information on the sorts of performance and design trade-offs that you are likely to encounter when using cgo, read Tobias Grieger's blog post called "The Cost and Complexity of Cgo."

Exercises

Now it's time to test yourself to see if you can write small programs using reflection, unsafe, and cgo. Answers for the exercises are found in the *exercise_solutions* directory in the Chapter 16 repository.

1. Use reflection to create a simple minimal string-length validator for struct fields. Write a ValidateStringLength function that takes in a struct and returns an error if one or more of the fields is a string, has a struct tag called minStrlen, and the length of the value in the field is less than the value specified in the struct tag. Nonstring fields and string fields that don't have the minStrlen struct tag are ignored. Use errors.Join to report all invalid fields. Be sure to validate that a struct was passed in. Return nil if all fields are of the proper length.
2. Use unsafe.Sizeof and unsafe.Offsetof to print out the size and offsets for the OrderInfo struct defined in *ch16/tree/main/sample_code/orders*. Create a new type, SmallOrderInfo, that has the same fields, but reordered to use as little memory as possible.
3. Copy the C code at *ch16/tree/main/sample_code/mini_calc* into your own module and use cgo to call it from a Go program.

Wrapping Up

In this chapter, you've learned about reflection, unsafe, and cgo. These features are probably the most exciting parts of Go because they allow you to break the rules that make Go a boring, type-safe, memory-safe language. More importantly, you've learned *why* you would want to break the rules and why you should avoid doing so most of the time.

You've completed your journey through Go and how to use it idiomatically. As with any graduation ceremony, it's time for a few closing words. Let's look back at what was said in the preface. "[P]roperly written, Go is boring….Well-written Go programs tend to be straightforward and sometimes a bit repetitive." I hope you can now see why this leads to better software engineering.

Idiomatic Go is a set of tools, practices, and patterns that makes it easier to maintain software across time and changing teams. That's not to say the cultures around other languages don't value maintainability; it just may not be their highest priority. Instead, they emphasize things like performance, new features, or concise syntax. There is a place for these trade-offs, but in the long run, I suspect Go's focus on crafting software that lasts will win out. I wish you the best as you create the software for the next 50 years of computing.

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About the Author

Jon Bodner has been a software engineer, lead developer, and architect for over 25 years. In that time, he has worked on software across many fields, including education, finance, commerce, healthcare, law, government, and internet infrastructure.

Jon is currently a staff engineer at Datadog, working on improving the onboarding experience for customers.

Previously, Jon was a senior distinguished engineer at Capital One, where he worked on commercialization of technology, contributed to the company's development and testing workflow, developed patented techniques for web payment page detection and population, and coauthored tools for finding and managing software development issues.

Jon is a frequent speaker at Go conferences, and his blog posts on Go and software engineering have been viewed more than 300,000 times. He is the creator of the Proteus data access library and codeveloper of checks-out, a fork of the LGTM project.

Colophon

The animal on the cover of *Learning Go* is a plains pocket gopher (*Geomys bursarius*), a burrowing mammal found across the Great Plains of North America. These rodents are highly adapted to digging and live primarily underground.

Plains pocket gophers are covered in brown fur and have a nearly naked tail. Physical adaptations to digging include small eyes, short ears, and large, clawed front feet. They also have a tolerance for low oxygen and high carbon dioxide levels. The gophers are named for their external cheek pouches, which can be used for carrying food.

The gophers are territorial and aggressive, and will rarely enter another's burrow. They spend nearly three-quarters of their time in their own burrows, which contain their nests and food caches of roots and grasses. They go above ground to search for food and mates.

The plains pocket gopher's conservation status is of least concern. Many of the animals on O'Reilly covers are endangered; all of them are important to the world.

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