Golang Fundamentals

"Go is expressive, concise, clean, and efficient"

Overview

Introductions

You:

- What is your job title?
- What do you do here?
- What's your programming background (including any Go)?
- What are you hoping to get out of this course?

Me:

- Who am I?

History

- Developed at Google (2009)
- Robert Griesemer, Rob Pike, Ken Thompson
- Born out of frustration and shared dislike of C++

Goals of a Programming Language

- efficient compilation
- efficient execution
- or ease of programming
- ...all three were not available in the same language!

Programmers were choosing ease over safety and efficiency by moving to dynamically typed languages (e.g., Python and JavaScript) rather than C++ or, to a lesser extent, Java

"Did the C++ committee really believe that was wrong with C++ was that it didn't have enough features?" –Rob Pike

"Clumsy type systems drive people to dynamically typed languages" -Robert Griesemer

"Old programs read like quiet conversations between a well-spoken research worker and a well-studied mechanical colleague, not as a debate with a compiler. Who'd have guessed sophistication brought such noise?" -Dick Gabriel

"The complexity of C++, and the resulting impact on productivity, is no longer justified. All the hoops that the C++ programmer had to jump through in order to use a C-compatible language make no sense anymore–they're just a waste of time and effort. Go makes much more sense for the

class of problems that C++ was originally intended to solve." -Bruce Eckel

Philosophy

A new programming language which addressed common criticisms of other languages
while keeping the good parts:

- static typing
- scalability to large systems (think Java, C++)
- networking and multiprocessing
- not requiring IDEs, but supporting them well

Another goal is...speed!

- should take at most a few seconds to build a large executable
- and coding itself should be speedy

Philosophy (cont'd)

- Programming = too much bookkeeping, repetition, and clerical work
- The sophistication is worthwhile—no one wants to go back to the old languages—but can it be more quietly achieved?
- Reduce the amount of *typing* in both senses of the word
- Reduce clutter and complexity
- No forward declarations and no header files–everything is declared exactly once
- Initialization is expressive, automatic, and easy to use

Sweet Spots

- Anywhere you need speed and scalability
- Back-end (web) development
- Automation
- Command-line tools
- Concurrency
- Systems programming (operating systems, utility software, device drivers, compilers, and linkers)
- What projects/tools do you know of that are written in Go...?

Written in Golang

- Docker
- Kubernetes
- Terraform
- Netflix
- Dropbox
- SoundCloud
- Uber
- Drone

13

Principles

Clean and Simple–Go strives to keep things small and beautiful. You should be able to do a lot in only a few lines of code.

Concurrent–Easy to "fire off" functions to be run as lightweight threads.

Channels–Communication with these goroutines is done, either via shared state or via channels.

Fast–Compilation is fast and execution is fast. The aim is to be as fast as C. Compilation time is measured in seconds.

Safe–Explicit casting and strict rules when converting one type to another. Go has garbage collection. No free()!...the language takes care of it.

Standard format–A Go program can be formatted in (almost) any way the programmers want, but an official format exists. The rule is very simple: The output of the filter gofmt is the officially endorsed format.

Postfix types–The type specification is given after the variable name, thus var a int, instead of int a.

UTF-8–UTF-8 is everywhere, in strings and in the program code. Finally you can use Φ=Φ+1 in your source code.

Open Source–The Go license is completely open source.

Fun–Programming with Go should be fun!

Let's Get...Up and Running

Installation

1. Download from https://golang.org/dl

2. Run installer (or follow installation instructions for your OS)

3. Installer should put go in your $PATH (you may need to restart any open terminal sessions for the change to take effect)

4. Create a new folder for your lab work during the course

5. Open that folder in your IDE (e.g., Visual Studio Code)

6. From the root of this folder, run `go mod init github.com/<your handle>/golab` - this will create a new go.mod file in folder

7. Inside this directory create a file `hello.go` containing the following (OK to copy/paste)

```
package main

func main() {
     println("Hey, let's go!")
}
```

17

- click the Run button above and on any slide which has that button

Running Slides Interactively

Clone GitHub repo using

```
git clone https://github.com/KernelGamut32/golang-live.git
```

From root of local folder run:

```
go install golang.org/x/tools/cmd/present@latest

present
```

Hit link in local browser and navigate to .slide file

Compiling/Running

1. Ensure you are in the folder where you've created hello.go
2. From that folder, run go build hello.go
   - this will create an executable in your directory
3. ./hello
   - you can also compile and run in one step: go run hello.go

Managing a Project in Go

The legacy way of organizing a project in go is called a workspace

Prior to go 1.13, go used workspaces in order to gather all the files necessary for a project

Working in workspace mode means that all of our project related files needs to be in one place referenced by the GOPATH environment variable

When we used to install any dependency packages using go get command, it would save the package files under the $GOPATH/src path

Introducing Go Modules

Go modules gives us a built-in dependency management system

As of go 1.13 modules are the official way to organize our source code as a project

A module is nothing but a directory containing Go packages - these can be distribution packages or executable packages

A module can also be treated as a package that contains nested packages

A module is also like a package that you can share with others

Modules allows us to work from any directory, not just GOPATH which gives us the flexibility to relocate our source code anywhere

Introducing Go Modules

Modules allows us to install the precise version of a dependency package to avoid breaking changes

Using modules we are able to import multiple versions of the same dependency package

Like package.json in NPM, each module has a go.mod file that houses the dependencies for our project

Retrieving dependencies

Often we will need to use third party libraries

As we did before with workspaces , we can run the following to fetch a dependent lib

$ go get github.com/gorilla/mux

If module not currently used in code, will be listed with an "indirect" comment in go.mod

Once we use the mux router the indirect comment will go away stating it knows that we are using the dependency

If we use the module in our code without running go get, `go mod tidy` can:
- clean up unused dependencies
- automatically get dependencies as required

The Golang Playground

- receives a Go program
- compiles, links, and runs the program inside a sandbox
- some limits on what we can do there: e.g., no keyboard input, random numbers are deterministic, time is constant (i.e., not current)

Go to https://play.golang.org/ to try it

Editors

many editors have Golang plugins

- VS Code
- MacVim
- Atom
- Sublime
- Eclipse
- ...remember that Golang's philosophy is that IDEs are not required

Primitive Types

Golang Basic Types

bool true or false
string immutable
uint either 32 or 64 bits
int same size as uint
uintptr an unsigned int large enough to store the uninterpreted bits of a pointer value
uint8 the set of all unsigned 8-bit integers (0 to 255)
uint16 the set of all unsigned 16-bit integers (0 to 65535)
uint32 the set of all unsigned 32-bit integers (0 to 4294967295)
uint64 the set of all unsigned 64-bit integers (0 to 18446744073709551615)
int8/int16/32/64 the set of all signed 8-/16-/32-/64-bit integers
float32/64 the set of all IEEE-754 32-/64-bit floating-point numbers
complex64/128 set of all complex numbers with float32/64 real and imaginary parts
byte alias for uint8
rune alias for int32 (represents a Unicode code point)

Declaring Variables

The var statement is used to declare one or more variables

```
var (
    name      string
    age       int
    almaMater string
)
```

or

```
var (
    name, almaMater string
    age             int
)
```

or individually:

```
var name      string
var age       int
var almaMater string
```

Initializing

all variables initialized to zero unless specified

```
var (
    name      string = "The Hamburglar"
    age       int    = 34
    almaMater string = "McDonalds University"
)
```

types are inferred if initializers are present

```
var (
    name      = "The Hamburglar"
    age       =  34
    almaMater = "McDonalds University"
)
```

single line initialization

```
var (
    name, almaMater, age = "The Hamburglar", "McDonalds University", 34
)
```

Declaration + Initialization Shorthand

- inside a function, the shorthand := can be used

```
func main() {
    name, almaMater := "The Hamburglar", "McDonalds University"
    age := 34
    println(name, age, almaMater)
}
```

Run

- outside functions, everything begins with a keyword (var, func, etc.) and the := shorthand is not available

30

Constants

- like variables, but declared with the `const` keyword (and of course can't be changed)
- integer, floating point, string, rune, boolean, and complex numbers
- can't use := with constants
- type inferred if not supplied
- typically written in `MixedCase` or all caps

```
const SpeedOfLight = 2.99792458e8 // meters per second
const PI = 3.1415926 // already defined in math package
const SeparatorChar rune = ':'
const SpaceChar byte = ' '
const Message string = "1...2...3...Go!"
const (
    StatusOK              = 0
    StatusConnectionReset = 1
    StatusOtherError      = 2
)
```

31

Constants (cont'd)

- `iota` is a predeclared identifier that represents successive untyped integer constants

```
const (
    StatusOK              = iota   // 0
    StatusConnectionReset          // 1
    StatusOtherError               // 2
)

func main() {
    println(StatusOK)
    println(StatusConnectionReset)
}
```

Run

32

Constants (cont'd)

- `iota` can be used in expressions so you can do things like this

```
type ByteSize float64

const (
    _           = iota // ignore first value by assigning to empty
    KB ByteSize = 1 << (10 * iota) // << is left shift operator
    MB
    GB
    TB
    PB
    EB
    ZB
)

func main() {
    println("GB =", GB)
    println("TB =", TB)
}
```

Run

- 1 << 10 = 0b1000000000 = 2^10 = 1024

Type Conversion/Casting

- `T(v)` converts the value v to the type T

```
var p int = int(PI)
var f float64 = float64(p)
var u uint = uint(f)
```

- no automatic type promotion (as is done in C and some other languages)
- **EDIT THE CODE** to fix the problem after running the below and identifying the problem

```
func myfunc(f float64) int {
    return int(f)
}

func main() {
    x := 3
    y := myfunc(x)
    println(y)
}
```

Run

34

Converting to/from Strings

https://pkg.go.dev/strconv for details on strconv package

- most common conversions are `strconv.Atoi()` (ASCII to integer) and `strconv.Itoa()` (vice versa)
- super useful functions in there

Outputting

The fmt Package

as we've seen, `print` and `println` are built in to Golang

But they may eventually go away - see https://golang.org/ref/spec#Bootstrapping

the `fmt` package contains versions that are more flexible (and it's considered more idiomatic to use `fmt`)

believe it or not, it's pronounced "`fumpt`"

fmt.Printf

- formatted print a la C/C++/Java
- %s = print a string value
- %d = print an integer value
- %f = print a float value

```
import (
    "fmt"  // we import packages in order to use them
    "math" // we'll use the math package too
)

func main() {
    var name, age = "The Hamburglar", 34
    fmt.Printf("Name is %s\n", name)
    fmt.Printf("%s is %d years old\n", name, age)
    fmt.Printf("The square root of %d is %f\n", age, math.Sqrt(float64(age)))
}
```

Run

38

fmt.Printf (cont'd)

- %v = print the value in a default format
- %T = print the type of the variable
- %t = print a Boolean value as true or false

```
import "fmt"

func main() {
    var f float64 = 38730204.3832
    fmt.Printf("%v\n", f)   // print f as a "value"
    fmt.Printf("%f\n", f)   // print f as a float
    fmt.Printf("%.2f\n", f) // restrict f to 2 places after decimal
    var i int = 13
    fmt.Printf("|%5d|\n", i)  // print i 5 spaces wide
    fmt.Printf("|%-5d|\n", i) // how is this different?
    var b bool = false
    fmt.Printf("%t\n", b)
    fmt.Printf("%T %T %T\n", f, i, b)
}
```

Run

fmt.Sprintf

- "print" into a string, rather than to the screen
- also `Sprint` and `Sprintln`

```
package main

import "fmt"

func main() {
    f := 1.23456789
    i := 123456789
    s := fmt.Sprintf("Float value %.3f and int |%15d|", f, i)
    fmt.Println(s)
}
```

Run

40

Logging

https://pkg.go.dev/log - Golang log package used for debugging

(by the way, we can use the godoc tool if we are offline)

- by default, log messages go to stderr
- can be configured to send log messages to files

much better than fmt, but somewhat lacking as loggers go

- doesn't provide levels (e.g., debug, notice, warning, etc.)
- doesn't let you configure separate loggers for each package
- Google gives you glog (https://godoc.org/github.com/golang/glog)
- also consider loggo (https://godoc.org/github.com/juju/loggo)

Simple Logging Example

```
package main

import (
    "fmt"
    "log"
    "time"
)

func main() {
    // set up a logger to include the date and time in microseconds
    log.SetFlags(log.Ldate | log.Lmicroseconds)
    // set up a prefix which for every log message
    log.SetPrefix("MyApp ")
    // Start program?
    log.Println("Kaaryakram shuroo karen")
    // do some stuff...
    time.Sleep(103871 * time.Microsecond)
    log.Println("Database connection dropped.")
    // cf. with standard fmt.Println
    fmt.Println("Database connection dropped.")
}
```

Run

42

Packages

What's a Package?

- every Go program is made up of packages, which are file(s) containing functions, variables, constants, etc.
- every Go program file has to be associated with a package via the package command at the top
- programs start running in

```
package main
```

44

Package Naming

- by convention, the package name is the same as the last element of the import path
- e.g., to import the `math/rand` package, one would type

```
import "math/rand"
```

but one would refer to objects inside the package, like so

```
rand.Int()
```

Source files for the `rand` package are prefaced with

```
package rand
```

https://github.com/golang/go/blob/master/src/math/rand/rand.go - view source code

The main Package

- as we know, execution begins in package main
- when building a standalone executable, main must exist
- when building a reusable package, there won't be a main

Importing Packages

- importing makes packages available in our programs
- packages can be given a nickname in the event of a name collision (two packages with the same name)
- you can import a package such that you don't need to use the package name prefix when accessing functions and data inside the package (not recommended)

```
package main

import "math/rand"
import myrand "other/rand"
import . "fmt"

func main() {
    rand.Seed(...)
    myrand.Something(...)
    Println("Hello, world!")
}
```

47

Packages: Identifiers Beginning with Upper Case Letters are Exported

- if you want something to be private, start its name with a lower case letter
- if you want something to be public, start its name with an upper case letter
- no public or private keyword

```
package example

var private = "This is not exported."
var Public = "This variable IS exported."

func nothing(x int) int {
        return x - 1
}

func Something(x int) int {
        return x + 1
}
```

48

Exercise: Packages

We'll walk through this one together...

- create your own package in your project directory
- define the package in a separate folder and make sure the package name matches the folder name
- be sure to export at least one function and one constant
- write a program in different subdirectory which imports your package
- test the client code

Possibly Painful Pedantry?

- Go complains about unused variables and imports
- ...and the Go compiler has no warnings
- you may be annoyed by this, but the Go team explains it well...

```
package main

import (
    "fmt"
    "math"
)

func main() {
    x := 1
    fmt.Println("Hello!")
}
```

Run

Try in the Go playground

50

Possibly Painful Pedantry? (cont'd)

“The presence of an unused variable may indicate a bug, while unused imports just slow down compilation, an effect that can become substantial as a program accumulates code and programmers over time. For these reasons, Go refuses to compile programs with unused variables or imports, trading short-term convenience for long-term build speed and program clarity.

The reason for having no warnings. If it’s worth complaining about, it’s worth fixing in the code. And if it’s not worth fixing, it’s not worth mentioning.

Nowadays, most Go programmers use a tool, `goimports`, which automatically rewrites a Go source file to have the correct imports, eliminating the unused imports issue in practice.” 51

Functions

Functions: Declaration, Arguments, Return Values

- a named (maybe) bit of code which is typically reused
- introduced with func keyword
- accept any number of arguments, return any number of values

```
// return the square of a number
func squareit(val float64) float64 {
    return val * val
}

// return sum of two values
func sum(x int, y int) int { // equivalent: func sum(x, y int) int
    return x + y
}

func main() { // return nothing
    fmt.Printf("%f\n", squareit(4.5))
    fmt.Println(sum(13, -2))
}
```

Run

53

main Function

- as we've seen, the main program must be inside a function called `main`
- this function takes no arguments and returns nothing...

```
package main

func main() { // minimal Golang program
}
```

54

Returning Multiple Values

- Go functions can return multiple values (much like Python)
- unlike Python, types must of course be specified
- the blank identifier _ can be used to discard a value (also like Python)

```
package main

import "fmt"

func addmul(x, y int) (int, int) {
    return x + y, x * y
}

func main() {
    s, p := addmul(3, 5)
    fmt.Println("sum =", s, "product =", p)
    _, r := addmul(4, -8)
    fmt.Println("product =", r)
}
```

Run

55

Exercise: Functions

- write a function called `circleinfo` which accepts a float64 radius and returns two values, the area of the circle, and the circumference
- area = Pi * radius * radius
- circumference = Pi * radius * 2
- Pi is defined in the math package

More About Return Values

- you can name the return values
- you still need a `return` statement (AKA a "naked" return)
- **EDIT THE CODE** to remove the named return values and be sure it still runs properly

```
package main

import "fmt"

// if you name the parameters, you don't have to return them
// directly in the return statement...but I don't recommend it
func multival(x int) (square, cube int) {
    square = x * x
    cube = x * x * x
    return
}

func main() {
    fmt.Println(multival(3))
}
```

Run

57

Builtin Functions

- docs in https://pkg.go.dev/builtin but code is not actually in a package
- we've alread seen `print` and `println`
- `complex`, `real`, and `imag` are for imaginary numbers

```
func append(slice []Type, elems ...Type) []Type
func cap(v Type) int {} // capacity of...
func close(c chan<- Type)
func complex(r, i FloatType) ComplexType
func copy(dst, src []Type) int
func delete(m map[Type]Type1, key Type)
func imag(c ComplexType) FloatType
func len(v Type) int
func make(t Type, size ...IntegerType) Type
func new(Type) *Type
func panic(v interface{})
func print(args ...Type)
func println(args ...Type)
func real(c ComplexType) FloatType
func recover() interface{}
```

58

Anonymous Functions

- functions that live in memory, but have no name
- they still may be referred to
- often called lambda functions in other languages

```
// This function takes a function as a parameter. The function
// passed in must take an int argument and return an int.
func runsomething(f func(int) int, i int) int {
    return f(i)
}

func main() {
    // Here we call the above function and pass in an
    // anonymous function (or function literal)
    x := runsomething(
        func(a int) int {
            return a * 2
        }, -5)
    fmt.Println(x)
}
```

Run

59

Anonymous Functions (cont'd)

- functions are first class objects, that is, they can be assigned to variables as well as passed in to other functions

```
// This function takes a function as a parameter. The function
// passed in must take an int argument and return an int.
func runsomething(f func(int) int, i int) int {
    return f(i)
}

func main() {
    // Here we make the variable lambda refer to
    // the function, and then pass lambda into the
    // function above.
    lambda := func(a int) int {
        return a * 2
    }
    fmt.Println(runsomething(lambda, -5))
}
```

Run

60

init Function

- each source file can define its own niladic (zero argument) init function (actually each file can have multiple init functions)
- can be used to set up whatever state is required
- init is called after 1) all imported packages have been initialized; 2) all variable declarations in the package have evaluated their initializers
- a common use of init functions is to verify or repair correctness of the program state before real execution begins
- let's see an example...

init Function (cont'd)

```
package main

import "fmt"

var _ int = setup() // happens first

func init() { // happens second
    fmt.Println("init!")
}

func init() { // happens third
    fmt.Println("something else")
}

func setup() int {
    fmt.Println("calling setup()")
    return 1
}

func main() { // happens last
    fmt.Println("main")
}
```

Run

Calling Functions

- Golang is pass-by-value ONLY (like C, which was a starting point of sorts)
- that means if you pass a variable or other object to a function, the function cannot change the variable/object because it receives a copy of it

```
package main

import "fmt"

// this function cannot change the variable passed in to it
func increment(num int) {
    num++
}

func main() {
    val := 1
    increment(val)
    fmt.Println("Value after incrementing:", val)
}
```

Run

63

How to Modify Parameters to a Function?

- in order for a function to modify its parameters, the function must accept a *pointer* to the object it wants to modify
- a *pointer* is a variable which contains the memory address of another variable
- there are two operators for dealing with pointers
- the & operator takes the *address* of the object that follows it
- the * operator *dereferences* a pointer, that is, it gives you access to the object at the address contained in the pointer

Pointers

```
package main

import "fmt"

func main() {
    x := 1
    px := &x // The & operator takes the address of what follows it
    fmt.Printf("The value of x is %d\n", x)
    fmt.Printf("The address of x is %v\n", px)
    fmt.Printf("The canonical form of px is %#v\n", px)
}
```

Run

- now let's revisit our earlier attempt to have a function change its parameter, but this time we'll use pointers...

65

Pointers (cont'd)

```
package main

import "fmt"

// the argument to this function is a pointer to an integer
// "star int" = pointer to int
func increment(nump *int) {
    fmt.Printf("the value of nump is %v\n", nump)
    // now we increment the object that nump is pointing to
    *nump++
}

func main() {
    val := 1
    // this time we call increment, but pass a pointer to the val variable
    ptr_to_val := &val
    fmt.Printf("ptr_to_val is the address of val... %v\n", ptr_to_val)
    increment(ptr_to_val)
    fmt.Println("Value after incrementing:", val)
}
```

Run

- (of course we wouldn't use the intermediate variable `ptr_to_val`, it's there for instructive purposes)

Exercise: Pointers and Functions

Write a function `doubler` which takes a string argument and doubles it, i.e., "Golang" would become "GolangGolang"

- note that '+' is the way to concatenate two strings
- your function should not return anything, it should modify its argument directly
- write a main program to test your function
- once you've done that, make it so that `doubler` calls a second function, `doublerHelper` which actually does the doubling (to understand how to pass pointers around)

67

Functions as Arguments

```
package main

import "fmt"

// this function takes three arguments: 1) a function which takes two ints
// as parameters, 2) an int, and 3) another int and then invokes that function,
// passing the two ints as parameters to the called function
func funcrunner(f func(x, y int), x, y int) {
    f(x, y)
}

// this function takes 2 ints and prints their values
func printer(a, b int) {
    fmt.Println("a and b are", a, b)
}

func main() {
    // pass the printer function as the first argument
    // and 1 and 3 as the additional arguments
    funcrunner(printer, 1, 3)
}
```

Run

68

Getting Input from the User

Command-Line Args

- import the `os` package to gain access to the command-line arguments
- `os.Args` is an array of strings that we can inspect
- we can't run these in the playground–we need to compile and run locally, then pass command-line args

```
package main

import (
    "fmt"
    "os"
)

func main() {
    fmt.Println("All command-line args:", os.Args)
    fmt.Println("Number of args =", len(os.Args))
    fmt.Println("Arg 0 is", os.Args[0])
    fmt.Println("Args 1-3 are", os.Args[1:4])
}
```

70

Exercise: Command Line Args

- write a program which takes two command line args representing integers and prints out their sum
- test it on your machine since it won't run in the playground
- hint: remember Atoi in the `strconv` package (https://golang.org/pkg/strconv) and ignore errors for now

71

Interactive User Input

- `fmt` package contains `Scan`, `Scanf`, `Scanln` functions to read from keyboard
- as with the previous examples, we can't run these examples in the playground, since they require keyboard input
- let's start with `Scanln`, which reads until a newline is seen (but spaces count as newlines here)

```
package main

import "fmt"

func main() {
    var input string
    fmt.Print("Enter text: ")
    fmt.Scanln(&input)
    fmt.Println("I think you just entered...", input)
}
```

fmt.Scan

- read from standard input, storing successive space-separated values into successive arguments
- newlines count as space

```
package main

import "fmt"

func main() {
    var input string
    var n int
    fmt.Print("Enter text: ")
    fmt.Scan(&input, &n)
    fmt.Println("I think you just entered...", input, n)
}
```

fmt.Scanf

- reads text from standard input, storing successive space-separated values into successive arguments as determined by the format string
- newlines in the input must match newlines in the format
- one exception: the verb %c always scans the next char in the input, even if it is a space (or tab etc.) or newline

```
package main

import "fmt"

func main() {
    var word string
    var int1, int2 int
    var float1 float32

    fmt.Print("Enter text: ")
    fmt.Scanf("%d %f %d\n%s", &int1, &float1, &int2, &word)
    fmt.Println("I think you just entered...", int1, float1, int2, word)
}
```

Control Structures

if / else

- no parentheses required
- braces always required
- else clause is of course optional

```
package main

import "fmt"

func main() {
    x := 27
    if x % 2 == 0 {
        fmt.Println(x, "is even")
    } else {
        fmt.Println(x, "is odd")
    }
}
```

Run

76

compound if statement

- a statement can precede conditionals
- any variables declared in this statement are available in all branches
- very idiomatic in Golang

```
func somenumber() int {
    return -7
}

func main() {
    if num := somenumber(); num < 0 {
        fmt.Println(num, "is negative")
    } else if num < 10 {
        fmt.Println(num, "has 1 digit")
    } else {
        fmt.Println(num, "has multiple digits")
    }
}
```

Run

77

switch Statement

- express conditionals across many branches
- no parens
- simplest form...

```
import "time"
import "math/rand"

func main() {
    sec := time.Now().Unix() // get current time as seconds since 1970
    rand.Seed(sec)           // "seed" the random number generator
    i := rand.Int31n(4)      // generate random number between 0 and 3

    switch i {
    case 0:
        fmt.Print("zero...")
    case 1:
        fmt.Print("one...")
    case 2:
        fmt.Print("two...")
    }
    fmt.Println("ok")
}
```

Run

78

switch: Match Against Multiple Expressions

```
package main

import "fmt"

func location(city string) (string, string) {
    var region string
    var continent string

    switch city {
    case "Delhi", "Hyderabad", "Mumbai", "Kolkata", "Chennai", "Kochi":
        region, continent = "India", "Asia"
    case "Columbus", "Cleveland", "Dayton":
        region, continent = "Ohio, USA", "North America"
    default:
        region, continent = "Unknown", "Unknown"
    }
    return region, continent
}

func main() {
    region, continent := location("Columbus")
    fmt.Printf("Allen works in %s, %s\n", region, continent)
}
```

Run

79

switch: Invoke a Function

```
package main

import (
    "fmt"
    "time"
)

func main() {
    // time in playground is a constant, so should be run on your machine...
    switch time.Now().Weekday().String() {
    case "Monday", "Friday", "Sunday":
        fmt.Println("It's a 6-letter day")
    default:
        fmt.Println("It's NOT a 6-letter day")
    }
    // let's print out the day to check
    fmt.Println(time.Now().Weekday().String())
}
```

Run

80

switch: Condition Omitted

- condition can be omitted altogether, simulating an if
- ...or think of it as switch true

```
import (
    "fmt"
    "math/rand"
    "time"
)

func main() {
    rand.Seed(time.Now().Unix()) // use seconds since 1970 to seed random number generator
    r := rand.Float64()          // generate random number between 0 and 1

    switch {
    case r > 0.1:
        fmt.Println("Common case, 90% of the time")
    default:
        fmt.Println("10% of the time")
    }
}
```

Run

81

switch: Regular Expressions

- if you want to match a particular pattern, you can use Golang's regular expression package in conjunction with having switch call a function

```
import "regexp"

func main() {
    var email = regexp.MustCompile(`^[^@]+@[^@.]+\.[^@.]+`)
    var phone = regexp.MustCompile(`^[(]?[0-9][0-9][0-9][). \-]*[0-9][0-9][0-9][.\-]?[0-9][0-9]

    contact := "foo@bar.com"

    switch {
    case email.MatchString(contact):
        fmt.Println(contact, "is an email")
    case phone.MatchString(contact):
        fmt.Println(contact, "is a phone number")
    default:
        fmt.Println(contact, "is not recognized")
    }
}
```

Run

switch: fallthrough

- in C, each branch of a switch statement must be terminated with a `break` statement, or else execution will "fall through" to the next branch–WITHOUT RUNNING THE TEST–after a branch is executed
- in Go, if you want to fall through, you must explicitly state it

```
num := 1111

switch {
case num > 1000:
    fmt.Println("greater than 1000")
    fallthrough // go to next statement

case num > 100:
    fmt.Println("greater than 100") // (this is next statment)
    fallthrough                    // go to next statement

case num > 10:
    fmt.Println("greater than 10") // (this is next statement)

default:
    fmt.Println("less than 10")
}
```

Run

83

Exercise: Fizzbuzz

Write a function which accepts an integer and returns

- "fizz" if the number is divisible by 3
- "buzz" if the number is divisible by 5
- "fizzbuzz" if the number is divisible by BOTH 3 and 5
- otherwise it just returns the string version of the number, e.g., "4"

Test your function with these inputs: 3, 5, 15, 4

for Loop

Go only has one looping construct

- basic for loop looks as it does in C/C++/Java, except
- no parens
- braces required
- as in C/C++/Java, you can have empty pre and post statements

```
func main() {
    sum := 0
    for i := 1; i <= 100; i++ {
        sum += i
    }
    fmt.Println("sum of 1..100 is", sum)
}
```

Run

85

Exercise: for Loops

implement a square root function using Newton's method:

- starting with some guess for the square root of x, we can adjust it based on how close $guess^2$ is to x, producing a better guess:
- $guess = guess - (guess^2 - x) / (2 * guess)$
- repeating the above makes the guess better and better
- use a starting guess of 1.0, regardless of the input (it works quite well)
- repeat the calculation 10 times and print each guess along the way

OR: implement the factorial function, n! = n * (n - 1) * ... * 1

for Loop: Empty Pre Statement

```
package main

import (
    "fmt"
    "math/rand"
    "time"
)

func main() {
    sec := time.Now().Unix()   // seconds since 1970...
    rand.Seed(sec)             // seed the random number generator
    num := rand.Int31n(10) + 5 // generate random num between 5 and 14

    for ; num > 0; num-- {
        fmt.Println(num)
    }
    fmt.Println("Blast off!")
}
```

Run

87

for loop as while loop

```
package main

import (
    "fmt"
    "math/rand"
    "time"
)

func main() {
    var num int64
    rand.Seed(time.Now().Unix()) // seed the random number generator

    for num != 5 {
        num = rand.Int63n(15)
        fmt.Println(num)
    }
}
```

Run

88

Exercise: for Loop as while Loop

Write a function which implements the Collatz Conjecture:

- it should accept an integer >= 1 (return `false` if < 1)
- if it's even, divide it by 2
- if it's odd, multiply it by 3 and add 1
- stop when the the result is 1
- return `true` for success

for loop as Infinite Loop

- as we are no doubt used to from other languages, we can break out of the enclosing loop with the keyword `break`

```
import (
    "fmt"
    "math/rand"
    "time"
)

func main() {
    var num int32
    sec := time.Now().Unix() // seconds since 1970...
    rand.Seed(sec)           // seed the random number generator

    for {
        fmt.Print("Infinite loop...")
        if num = rand.Int31n(10); num == 5 {
            fmt.Println("break!")
            break
        }
        fmt.Println(num)
    }
}
```

Run

90

Exercise: for Loop as Infinite Loop

- write an infinite loop that reads a string using `fmt.Scanf` and then uses `strconv.Atoi` to convert it to an integer
- if the conversion fails to produce an integer, print an error message and prompt the user again
- since we don't yet know how to deal with errors returned from functions, just examine the int returned from `strconv.Atoi` and treat 0 as an error
- stop the loop when the user complies, i.e., an integer is entered

continue Statement

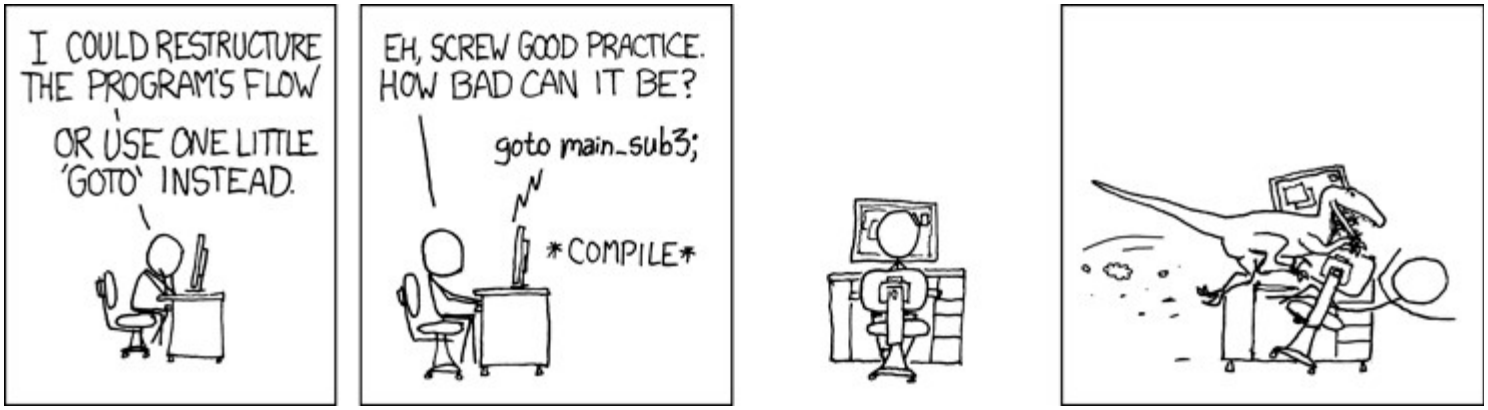
- skips the current iteration of the loop
- you don't really need continue, since any code written with a continue can be written without one
- they can be handy in cases where you don't want to execute the loop until you've checked some error conditions

```
package main

import "fmt"

func main() {
    sum := 0
    for num := 1; num <= 100; num++ {
        if num % 5 == 0 {
            continue
        }
        sum += num
    }
    fmt.Println("sum 1..100 excluding nums divisible by 5 is", sum)
}
```

Run

92

goto ("Considered Harmful")



- Go has a goto statement – judicious use can make your code easier to understand
- jump to a named label
- must not skip over any variable declarations
- a goto outside a block cannot jump to a label inside that block

goto Statement: Cleanly Exiting a Function

- you may allocate resources and need to exit in multiple places
- putting cleanup code at end of the function with goto simplifies code
- you don't have to write cleanup code at every "exit point" of function

goto Statement: Cleanly Exiting a Function (example)

```
func foo(bar int) int {
    return_value := 0

    if ret1, err := do_something(bar); err {
        goto error_1
    }

    if ret2, err := init_stuff(ret1); err {
        goto error_2
    }

    if ret3, err := prepare_stuff(ret2); err {
        goto error_3
    }

    return_value = do_the_thing(ret3)
error_3:
    cleanup_3()
error_2:
    cleanup_2()
error_1:
    cleanup_1()
    return return_value
}
```

95

break with a Label

- useful inside multiple nested loops

```
package main

import "fmt"

func main() {
loop:
    for i := 1; i <= 5; i++ {
        for j := 1; j <= 5; j++ {
            if i*j == 9 {
                fmt.Println("---")
                break loop // skip rest of both loops
            }
            fmt.Println(i, j)
        }
    }
}
```

Run

96

continue with a Label

```
package main

import "fmt"

func main() {
loop:
    for i := 1; i <= 5; i++ {
        for j := 1; j <= 5; j++ {
            if i*j == 9 {
                fmt.Println("---")
                continue loop // skip rest of this loop
            }
            fmt.Println(i, j)
        }
        fmt.Println("j loop finished")
    }
}
```

Run

97

defer

`defer` pushes a function call onto a stack, and the saved calls are executed just prior to the surrounding function returning

commonly used to simplify functions with cleanup actions

three rules

- deferred function's arguments are evaluated when the defer statement is evaluated
- deferred function calls are executed in Last In First Out order
- deferred functions may read/assign to the returning function's named return values

```
func main() {
    for i := 1; i <= 4; i++ {
        defer fmt.Println("deferred", -i)
        fmt.Println("regular", i)
    }
}
```

Run

98

Exercise: defer

- write a program which repeatedly asks to enter an integer
- your program should quit when the user enters a 0
- if the number is negative, the program should print an error and quit
- your program should perform a "cleaup action" when it quits, and this cleanup action should occur regardless of whether it quits normally or if there was an error (negative number)
- put your cleanup action in a deferred anonymous function

99

panic

- built-in function that stops the ordinary flow of control and begins "panicking"
- when function F calls `panic()`, execution of F stops, any deferred functions in F are executed normally, and then F returns to its caller
- to the caller, F then behaves like a call to `panic()`
- process continues up the stack until all functions have returned, at which point the program crashes
- panics can also be caused by runtime errors, such as out-of-bounds array accesses
- let's see an example of `defer` plus `panic()`...

100

panic (cont'd)

```
package main

import "fmt"

func main() {
    f()
    fmt.Println("Back from f()")
}

func f() {
    fmt.Println("Calling g()")
    g(0)
    fmt.Println("Back from g()")
}

func g(i int) {
    if i > 3 {
        fmt.Println("Panicking!")
        panic("Panic in g() (major)")
    }
    defer fmt.Println("Defer in g()", i)
    fmt.Println("Printing in g()", i)
    g(i + 1)
}
```

Run

101

recover

- built-in function that regains control of a panicking goroutine
- only useful inside deferred functions
- during normal execution, a call to `recover()` will return nil (like NULL in other languages) and have no other effect
- if current goroutine is panicking, a call to recover() will capture the value passed to `panic()` and resume normal execution
- let's add `recover()` to previous example...

recover (cont'd)

```
func main() {
    f()
    fmt.Println("Back from f()")
}
func f() {
    defer func() {
        if r := recover(); r != nil {
            fmt.Println("Recovered in f", r)
        }
    }()
    fmt.Println("Calling g()")
    g(0)
    fmt.Println("Back from g()")
}
func g(i int) {
    if i > 3 {
        fmt.Println("Panicking!")
        panic("Panic in g() (major)")
    }
    defer fmt.Println("Defer in g", i)
    fmt.Println("Printing in g", i)
    g(i + 1)
}
```

Run

Exercise: panic/recover

- modify the previous exercise to `panic` when a negative number is entered (we wouldn't really use `panic` for something like this)
- use the `math/rand` module to `panic` randomly, say 10% of the time, with a different panic message
- have the calling function `recover`, but only if the panic was due to a negative number-if the random panic occurs, the program should crash with a panic

Scope

Scoping Rules

- the scope of a predeclared identifier is the universe block, e.g., true, false, nil, iota, types, and built-in functions
- the scope of an identifier denoting a constant, type, variable, or function (but not method) declared at top level (outside any function) is the package block
- the scope of the package name of an imported package is the file block of the file containing the import declaration
- the scope of a function parameter or result variable is the function body
- the scope of a constant or variable declared inside a function begins at the end of the ConstSpec or VarSpec and ends at the end of the innermost containing block
- an identifier declared in a block may be redeclared in an inner block

while the identifier of the inner declaration is in scope, it denotes the entity declared by the inner declaration

Scope Example

```
package main

import "fmt"

func main() {
    f := 1
    // i defined only inside the for block
    for i := 1; i < 2; i++ {
        fmt.Println("i is in scope here", i)
    }
    // fmt.Println(i) => i NOT in scope here
    if j := 4.5; j > 10 {
        fmt.Println("j is in scope here:", j)
    } else {
        fmt.Println("j also is in scope here:", j)
    }
    // fmt.Println(j) => j NOT in scope here
    if f == 1 {
        f := "new f, inside this block, hides the outer f"
        fmt.Println("in the block, f is", f)
    }
    fmt.Println(f)
}
```

Run

Data Structures

Arrays

- both type of element and length are part of the type
- cannot be resized
- zero-valued by default
- brittle, but still useful

```
func main() {
    var a [10]int // array of 10 integers, initialized to 0 by default
    fmt.Println(a)
    for i := 0; i < len(a); i++ {
        a[i] = i + 101
    }
    fmt.Println(a)
    fmt.Println("a[3] =", a[3]) // array indexing
}
```

Run

109

Arrays (cont'd)

- can be initialized when declared

```
func main() {
    // Arrays can be initialized when they are declared
    cities := [5]string{"Hyderabad", "Delhi", "Pune", "Kochi", "Chennai"}
    fmt.Println("Cities:", cities)
}
```

Run

110

Arrays (cont'd)

- no need to specify size when initializing

```
func main() {
    // ellipsis (...) can be used in place of size
    // if array is being intialized
    nums := [...]float32{ 1.4, 2.67, -3.56 }
    fmt.Println("len(nums) =", len(nums))
    chars := [...]rune{ 'G', 'o', 'l', 'a', 'n', 'g', '€' }
    fmt.Printf("%q\n", chars) // %q == quoted
    fmt.Println(chars) // values are actually int32
}
```

Run

111

2-D Arrays

- array of arrays
- each row is a 1-D array

```
func main() {
    var twoD [3][5]int // 2-dimensional array
    for i := 0; i < 3; i++ {
        for j := 0; j < 5; j++ {
            twoD[i][j] = (i + 1) * (j + 1)
        }
        fmt.Println("Row", i, twoD[i])
    }
    fmt.Println("\nAll at once:", twoD)
    look(twoD[1]) // send one row to a function...
}

func look(thing [5]int) {
    fmt.Println("I see:", thing)
}
```

Run

112

Slices

- key datatype in Go
- more powerful interface to sequences than arrays
- slices are typed only by elements they contain (not number of elements)
- to create an empty slice with non-zero length, use builtin `make` function

```
func main() {
    // create a slice of strings of size 3
    s := make([]string, 3)
    fmt.Printf("initial slice: %v, len = %d\n", s, len(s))
    s[0] = "zero" // set just like an array
    s[1] = "one"
    s[2] = "two"
    fmt.Println("now:", s)
    fmt.Println("get:", s[2]) // get like an array
}
```

Run

113

Slices: append()

- append( ) returns a new slice containing appended items
- Why is the syntax of append( ) the way it is?

```
func main() {
    s := make([]string, 3) // slice of strings of size 3
    fmt.Println("initial slice:", s)
    s[0] = "zero" // set just like an array
    s[1] = "one"
    s[2] = "two"
    fmt.Println("now:", s)
    fmt.Println("get:", s[2]) // get like an array
    fmt.Println("len of slice:", len(s))
    s = append(s, "three")
    s = append(s, "four", "five")
    fmt.Println("after append:", s)
}
```

Run

114

Slicing Slices

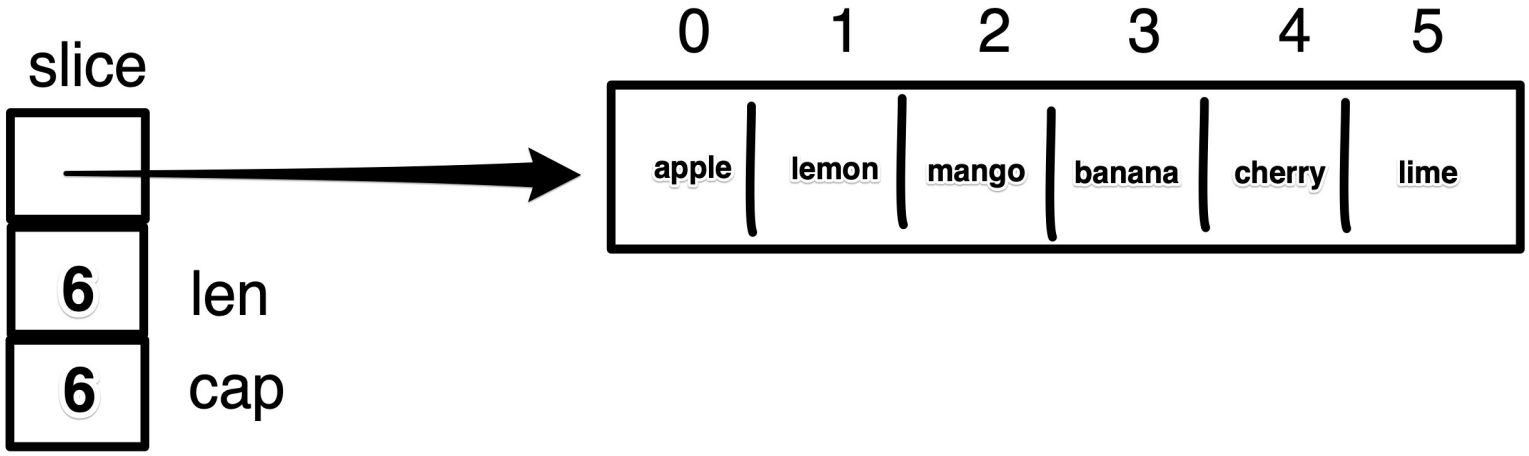
- slices (and arrays) support a slicing operator (much like Python)

```
func main() {
    slice := make([]string, 0)
    slice = append(slice, "apple", "lemon", "mango", "banana", "cherry", "lime")
    fmt.Println(slice)
    // Slices support a "slice" operator with the syntax slice[low:high]
    slice1 := slice[2:5]
    fmt.Println("slice1:", slice1)
    // This slices up to (but excluding) `s[5]`.
    slice2 := slice[:5]
    fmt.Println("slice2:", slice2)
    // And this slices up from (and including) `s[2]`.
    slice3 := slice[2:]
    fmt.Println("slice3:", slice3)
}
```

Run

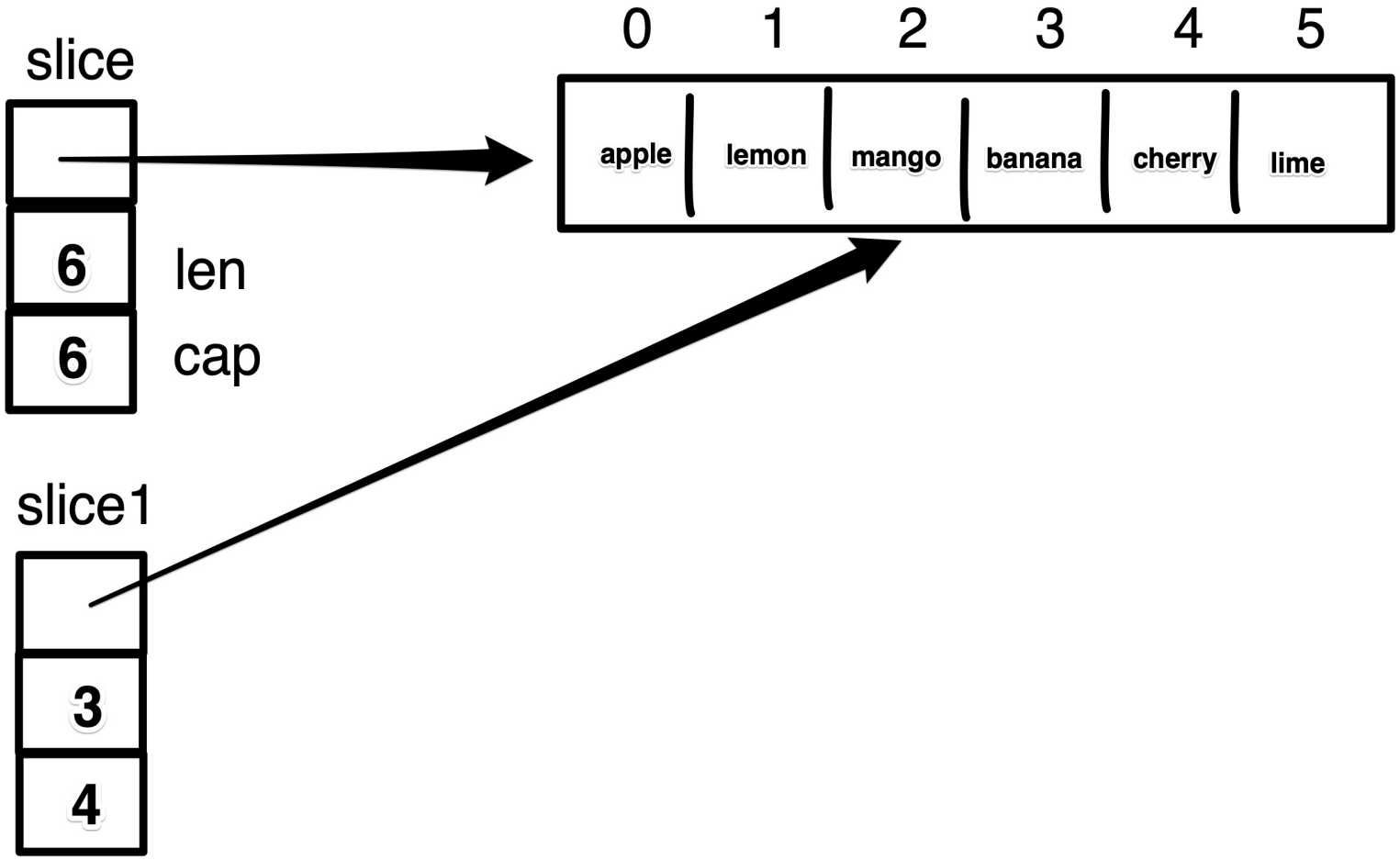
115

What does slice our look like?



116

...and slice1?


0
1
2
3
4
5
slice
apple
lemon
mango
banana
cherry
lime
6
len
6
cap
slice1
3
4

Slices: copy()

- if we want to make a copy of a slice we need to use the copy() function
- ...but first we need to make a new slice to receive the copy

```
func main() {
    s := make([]string, 3)
    s[0], s[1], s[2] = "zero", "one", "two"
    fmt.Println("initial slice:", s)
    copy_of_s := make([]string, len(s))
    copy(copy_of_s, s)
    copy_of_s[0] = "ZERO!"
    fmt.Printf("%v\n%v", copy_of_s, s)
}
```

Run

118

Slices without make()

- we can declare a slice inline, without using `make()`

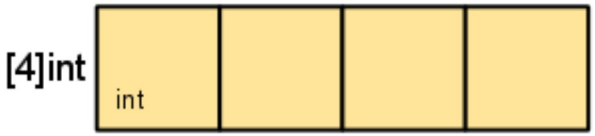
```
func main() {
    s := []string{"raspberry", "orange", "guava"}
    fmt.Println("declared slice:", s)
    t := []string{"cherry", "banana"}
    s = append(s, t[0], t[1])
    fmt.Println(s, len(s), cap(s))
}
```

Run

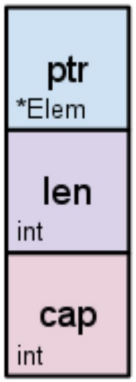
119

Slices vs. Arrays

- an array type definition specifies both length and element type
- for e.g., [4]int is an array of 4 ints



- a slice, on the other hand, is a descriptor of a segment of an array
- a slice consists of a pointer to the array, the length of the segment, and its capacity



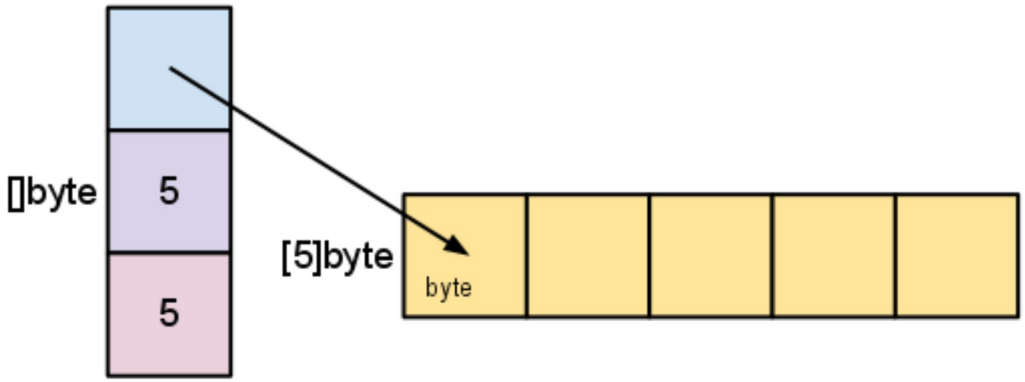
blog.golang.org/go-slices-usage-and-internals (https://blog.golang.org/go-slices-usage-and-internals)

Slices vs. Arrays (cont'd)

- consider the following slice

```
s := make([]byte, 5)
```

- under the hood it looks like this

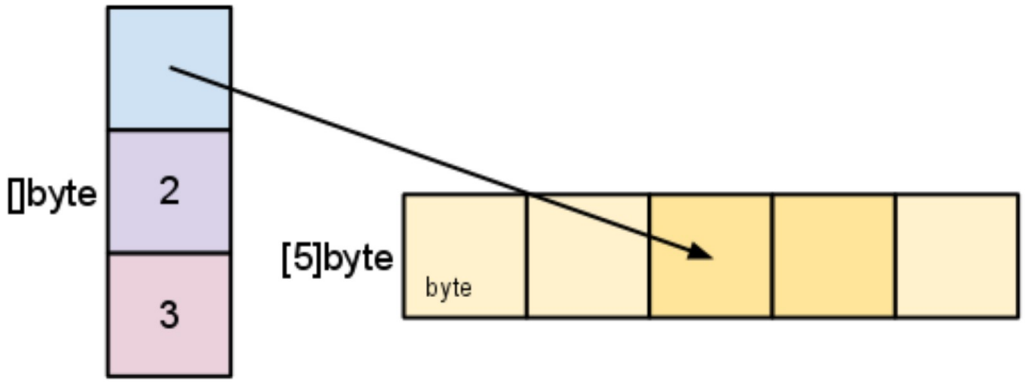


- what if we slice that slice?

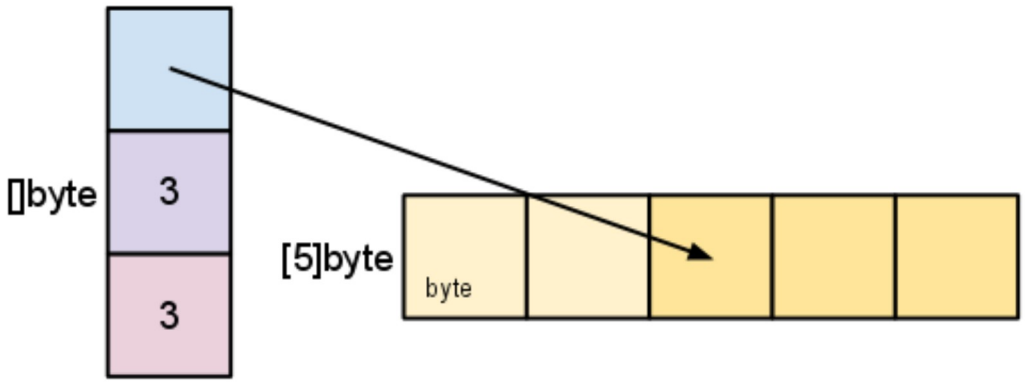
blog.golang.org/go-slices-usage-and-internals (https://blog.golang.org/go-slices-usage-and-internals)

Slices vs. Arrays (cont'd)

```
s = s[2:4]
```




```
s = s[:cap(s)]
```



122

nil slice vs. empty slice

- the zero value of a slice is nil
- a nil slice has a length and capacity of 0, but has no underlying array
- a nil slice is not the same as an empty slice, which have an underlying array of size 0

```
func main() {
    var n []int
    z := make([]int, 0)

    fmt.Printf("n is %#v %d %d\n", n, len(n), cap(n))
    if n == nil {
        fmt.Println("n is nil!\n")
    }

    fmt.Printf("z is %#v %d %d\n", z, len(z), cap(z))
    if z == nil {
        fmt.Println("z is nil!")
    } else {
        fmt.Println("z is NOT NOT NOT nil!")
    }
}
```

Run

123

Exercise: Slices

- there are two main ways to write a function that uses slices...either accept a slice as input and iterate through it, or have your function return a slice that it allocates from within the function

1. write a function `minmaxavg` which accepts a float64 slice and returns four values: the minimum value in the slice, the maximum value in the slice, the average of all the values, and an indication of success (as we did previously)

2. write a function `fib` that returns a slice containing the first n Fibonacci numbers

- the Fibonacci sequence is 1, 1, 2, 3, 5, 8...
- each number is the sum of the previous Fibonacci numbers
- so `fib(6)` should return an int slice of size 6 containing 1, 1, 2, 3, 5, 8
- in the event of an error, fib should return the nil slice

Variadic Functions

- can be called with any number of arguments
- e.g., `fmt.Println` is a variadic function

3. write a function counter which accepts a slice of strings and returns a new slice of the strings which contains 3 or more e's
- check out the `strings` package

```
import "fmt"

func variadic(words ...string) {
    for i := 0; i < len(words); i++ {
        fmt.Print(words[i])
        if len(words[i]) == 6 {
            fmt.Print(" ***")
        }
        fmt.Println()
    }
}

func main() {
    // Variadic functions can be called in the usual way with individual arguments
    variadic("this", "that", "hello", "Golang")
    variadic("C++", "Python")
    variadic()
```

125

```
}
```

Run

Variadic Functions (cont'd)

- if you already have the args in a slice, you can pass them as individual args using the ... notation

```
func main() {
    words := []string{"local", "locale", "localize"}
    variadic(words...)
}
```

Run

126

Exercise: Variadic Functions

- write a variadic function called `product` which takes a variable number of integers and returns their product
- if no integers are passed, `product` should return 1
- e.g., `product(1, 2, 3)` should return 6

Maps

- Go's built-in associative datatype (like Python dictionaries)
- key/value pairs
- a missing key does not cause an error (as it does in Python)

```
func main() {
    continents := map[string]string{
        "United States": "North America",
        "India": "Asia",
        "Namibia": "Africa",
        "Germany": "Europe",
        "Mexico": "North America",
        "Ireland": "Europe",
        "Iceland": "Europe",
    }
    c := "Iceland"
    fmt.Println(c, "is in", continents[c])
    fmt.Printf("%#v\n", continents)
    c = "Freedonia"
    fmt.Println(c, "is in", continents[c])
}
```

Run

128

Maps (cont'd)

- we can also create an empty map and add to it later
- `len()` returns size of map (number of key/value pairs)
- `delete()` deletes items from a map

```
func main() {
    // To create an empty map, use make
    sbux := make(map[string]int)
    // Set key/value pairs
    sbux["tall"] = 12
    sbux["grande"] = 16
    sbux["venti"] = 20
    fmt.Println(sbux)
    fmt.Println("len:", len(sbux))
    delete(sbux, "grande")
    fmt.Println(sbux)

    // Optional second return value indicates if key was in map.
    // Used to disambiguate between missing keys and zero values.
    _, present := sbux["grande"]
    fmt.Println("grande present?", present)
}
```

Run

range

- range iterates over elements in a variety of data structures

```
func main() {
    nums := []int{5, 13, 27, 19, -1}
    sum := 0
    for index, num := range nums {
        sum += num
        fmt.Println("Added element", index)
    }
    fmt.Println("sum of", nums, "is", sum)
}
```

Run

- if we don't need the index...

```
func main() {
    nums := []int{5, 13, 27, 19, -1}
    sum := 0
    for _, num := range nums {
        sum += num
    }
    fmt.Println("sum of", nums, "is", sum)
}
```

Run

130

range on a Map

- ...iterates over key/value pairs

```
func main() {
    continents := map[string]string{
        "United States": "North America",
        "India":         "Asia",
        "Namibia":       "Africa",
        "Germany":       "Europe",
        "Mexico":        "North America",
        "Ireland":       "Europe",
        "Iceland":       "Europe",
    }
    for country, continent := range continents {
        fmt.Println(country, "is in", continent)
    }
}
```

Run

131

range on a Map (cont'd)

- ...or just over the keys

```
func main() {
    continents := map[string]string{
        "United States": "North America",
        "India":         "Asia",
        "Namibia":       "Africa",
        "Germany":       "Europe",
        "Mexico":        "North America",
        "Ireland":       "Europe",
        "Iceland":       "Europe",
    }
    for country := range continents {
        fmt.Println(country)
    }
}
```

Run

132

range on a string...

- ...iterates over Unicode code points
- the first value is the starting byte index of the rune
- the second value is the rune itself

```
func main() {
    for index, char := range "Golang" {
        // print each letter as a rune (int32) and character
        fmt.Printf("%d %d %c\n", index, char, char)
    }
}
```

Run

133

Exercise: Maps

- use a map to translate Roman numerals into their Arabic equivalents
- load the map with Roman numerals M (1000), D (500), C (100), L (50), X (10), V (5), I (1)
- read in a Roman numeral
- print Arabic equivalent
- try it with MCLX = 1000 + 100 + 50 + 10 = 1160
- complain if invalid Roman digits (e.g., 'Z') are found
- EXTRA: if you have time, deal with the case where a smaller number precedes a larger number, e.g., XC = 100 - 10 = 90, or MCM = 1000 + (1000-100) = 1900

Additional Exercise: Maps

- create four calculator functions: add, sub, mul, div
- each function should take 2 integers and return an integer result
- create a map which maps the strings representing the operators to the *functions*
- that is, "+" would be mapped to `add()`, "-" would be mapped to `sub()`...
- have your program read in lines like "2 + 4" and have it determine the result by parsing the line and then using the operator ("+" in this case) to find the appropriate function to invoke

135

sort Package

- methods are specific to builtin type
- sorting occurs in place

```
import "sort"

func main() {
    strs := []string{"pear", "apple", "lemon"}
    sort.Strings(strs)
    fmt.Println("sorted:", strs)
    // Sorting integers
    ints := []int{7, 2, -4}
    sort.Ints(ints)
    fmt.Println("sorted:", ints)
    // Check if a slice is already sorted
    s := sort.StringsAreSorted(strs)
    fmt.Println("Are strings sorted?", s)
}
```

Run

136

User-Defined Types

struct

- typed collections of fields
- useful for grouping data together (like structs in other languages)

```
type Mountain struct {
    name      string
    elevation int
}

func main() {
    k2 := Mountain{"K2", 8611} // create a new struct
    fmt.Println(k2)
    fmt.Printf("%+v\n", k2)
    fmt.Printf("%#v\n", k2)
}
```

Run

138

struct (cont'd)

- you can name the fields when initializing a struct
- you can leave out fields, which will be set to zero
- & operator yields a pointer to the struct
- use a dot to access the fields

```
func main() {
    everest := Mountain{elevation: 8848, name: "Mt. Everest"}
    fmt.Printf("%#v\n", everest)
    fmt.Println(Mountain{name: "Flat"})
    fmt.Println(&Mountain{name: "Long's Peak", elevation: 4346})
    nd := Mountain{name: "Nanda Devi", elevation: 7815}
    fmt.Println(nd.name)
    sp := &nd
    fmt.Println(sp.elevation)
    sp.elevation++
    fmt.Println(sp.elevation)
}
```

Run

Anonymous struct

- why an anonymous struct?
- e.g., grouped globals

```
var config struct {
    APIKey string
    IPAddr string
}
config.APIKey = "BADC0C0A"
config.IPAddr = "1.1.1.1"
```

- test tables

```
var indexRuneTests = []struct {
    s    string
    rune rune
    out  int
}{
    {"a A x", 'A', 2},
    {"some_text=some_value", '=', 9},
    {"finster", "E", -1},
}
```

140

Methods

- Go is not object oriented...or is it?
- Go does not have classes, but we can define methods on `struct` types
- types and methods allow for an OO style of progamming
- Go does not support inheritance, but later we'll see the use of composition and interfaces
- suppose we define a type called triangle

```
type triangle struct {
    side1, side2, side3 int
}
```

- ...and we'd like to be able to perform certain operations on objects of type `triangle`

Methods (cont'd)

- here a method to compute the perimeter of a triangle...

```
// compute perimeter of triangle
func (t triangle) perimeter() int {
    return t.side1 + t.side2 + t.side3
}
```

- notice that the function (or method) above has a different syntax
- the above is a *method*, and the *method receiver* (the type that the method acts upon) appears in its own argument list between the func keyword and the method name
- here's a method to compute the area of a triangle using Heron's formula...

```
// compute area of triangle using Heron's formula
func (t triangle) area() int {
    s := (t.side1 + t.side2 + t.side3) / 2
    return int(math.Sqrt(float64(s * (s - t.side1) * (s - t.side2) * (s - t.side3))))
}
```

Methods (cont'd)

- to call a method on an object, we use a dotted notation common to object-oriented languages: *object.method(...)*

```
import "math"
type triangle struct {
    side1, side2, side3 int
}

// compute area of triangle using Heron's formula
func (t triangle) area() int {
    s := (t.side1 + t.side2 + t.side3) / 2
    return int(math.Sqrt(float64(s * (s - t.side1) * (s - t.side2) * (s - t.side3))))
}

// compute perimeter of triangle
func (t triangle) perimeter() int {
    return t.side1 + t.side2 + t.side3
}

func main() {
    t := triangle{3, 4, 5}
    fmt.Println("area: ", t.area(), "\nperim:", t.perimeter())
}
```

Run

143

Methods (cont'd)

- if we want to be able to modify the struct, our method will have to accept a pointer receiver

```
// scale the sides of a triangle
func (t *triangle) scale(factor int) {
    t.side1 *= factor
    t.side2 *= factor
    t.side3 *= factor
}
```

- we generally want all of our methods to receive either a pointer or a type, rather than having a mix of receiver types, but this will not be obvious until we know a bit more...

Methods (cont'd)

```
func (t *triangle) area() int {
    s := (t.side1 + t.side2 + t.side3) / 2
    return int(math.Sqrt(float64(s * (s - t.side1) * (s - t.side2) * (s - t.side3))))
}

func (t *triangle) perimeter() int {
    return t.side1 + t.side2 + t.side3
}

func (t *triangle) scale(factor int) {
    t.side1 *= factor
    t.side2 *= factor
    t.side3 *= factor
}

func main() {
    t := triangle{3, 4, 5}
    t.scale(3)
    fmt.Println("sides: ", t.side1, t.side2, t.side3)
}
```

Run

145

Defining Methods on Other Types

- you can define methods on any type in your package (not just `struct`)
- you can't define a method on a type from another package
- you can't define a method on a basic type, but you can create your own type via Go's type extensibility

```
import "strings"

type MyStr string // can't define a method on a basic type

func (s MyStr) Uppercase() string {
    return strings.ToUpper(string(s))
}

func main() {
    s := MyStr("Golang is fun!")
    fmt.Println(s.Uppercase())
}
```

Run

EDIT THE CODE so that the Uppercase method takes a parameter *suffix*, which is appended to the end of the string

146

Exercise: User-Defined Methods

- create a bank package which defines a type called a `BankAccount`
- at the very least, the `BankAccount` type should have an owner name (string) and a balance (float64)
- add methods `Deposit`, `Withdraw`, `CheckBalance`
- EXTRA: add a method to combine two accounts into a joint account

147

Embedding

- including ("embedding") a type as a nameless parameter within another type
- this makes the exported parameters and methods of the *embedded* type accessible through the *embedding* type
- compiler does this via promotion–the exported properties and methods of the embedded type are promoted to the embedding type

Embedding (cont'd)

- suppose in addition to our `mountain` type, we also want to represent a `climb`, in which a climber climbs a particular mountain...

```
type Climb struct {
    Mountain
    Climber   string
}
```

- the fields in `Mountain` (*name* and *elevation*) are promoted to be part of `Climb`

Embedding (cont'd)

- we can initialize a Climb in two ways, the first of which demonstrates the promotion of the fields from the embedded Mountain:

```
c1 := Climb{}
fmt.Println(c1)
c1.Name = "K2"
c1.Elevation = 8111 // i.e., missed the summit by 500 m
c1.Climber = "Arjun Climber"
fmt.Println(c1)

c2 := Climb{
    Mountain{"K2", 8111},
    "Arjun Climber",
}
fmt.Println(c2)
```

Run

- in addition to promotion of the fields, the methods of the embedded structs are also promoted...

150

Embedding (cont'd)

- let's make a silly method for Mountains called `HowBig()`

```
type Mountain struct {
    name      string
    elevation int
}

func (m Mountain) HowBig() string {
    if m.elevation > 8800 {
        return "HUGE"
    }
    return "NORMAL"
}

func main() {
    everest := Mountain{elevation: 8848, name: "Mt. Everest"}
    fmt.Println(everest.HowBig())
}
```

Run

151

Embedding (cont'd)

- now we'll demonstrate the object of type Climb can invoke the `HowBig()` method

```
type Climb struct {
    Mountain
    climber  string
}

func (m Mountain) HowBig() string {
    if m.elevation > 8800 {
        return "HUGE"
    }
    return "NORMAL"
}

func main() {
    everest := Mountain{elevation: 8848, name: "Mt. Everest"}
    fmt.Println(everest.HowBig())
    arjun := Climb{Mountain{"K2", 8111}, "Arjun Climber"}
    fmt.Println(arjun.HowBig())
}
```

Run

152

Exercise: Embedding

- create a `Customer` type in your Bank package
- add a `Customer` method such as ChangeName
- embed a `Customer` inside a `BankAccount` object
- demonstrate that you can change the customer's name via the BankAccount object

Overloading

- suppose we want the *embedding* type to *override* a method in the *embedded* type
- that is, we want a method in the embedding type to have the same name as a method in the embedded type
- the method in `Mountain` will be "overriden" by the method in `Climb`

```
type Climb struct {
    Mountain
    Climber string
}

func (m Mountain) HowBig() string {
    if m.Elevation > 8800 {
        return "HUGE"
    }
    return "NORMAL"
}

func (c Climb) HowBig() string {
    return "OVERRIDE!"
}
```

Overloading (cont'd)

- ...but we can access the overriden method by referring to it explicitly

```
func (m Mountain) HowBig() string {
    if m.Elevation > 8800 {
        return "HUGE"
    }
    return "NORMAL"
}

// This method overrides the one above
func (c Climb) HowBig() string {
    return "OVERRIDE!"
}

func main() {
    c2 := Climb{
        Mountain{"K2", 8111}, "Arjun Climber",
    }
    // will call overriding method
    fmt.Println(c2.HowBig())
    // will call overridden method
    fmt.Println(c2.Mountain.HowBig())
}
```

Run

155

Encapsulation

- hiding implementation details when an interface to user-defined types is provided
- as a simple example, let's consider a singleton object (i.e., only one copy of the object exists at any given time)

```
package thing

// thing type is NOT exported
type thing struct {
        val int
}

// this variable is NOT exported
var privateThing thing

func ReadThing() int {
        return privateThing.val
}

func WriteThing(val int) {
        privateThing.val = val
}
```

Encapsulation (cont'd)

- via encapsulation, we can manipulate the singleton object, but can't see its implementation
- the package writer could change the implementation and as long as the same API was exposed, everything would still work

```
package main

import (
        "fmt"
        "thing"    // singleton, i.e., only one object
)

func main() {
    // try singleton "thing"
    fmt.Println(thing.ReadThing())
    thing.WriteThing(-5)
    fmt.Println(thing.ReadThing())
}
```

157

Interfaces

- an interface is a type, defined by a set of methods
- or, an interface is a named collection of method signatures
- to implement an interface, we implement all methods in the interface
- we don't need to tell the compiler we are implementing an interface–the compiler figures that out automatically

```
type MyInterface interface {
    Method() // for something to be of type MyInterface it must implement this method
}

type MyText string

func (text MyText) Method() { // this method means type MyText implements MyInterface
    fmt.Println(text)
}

func main() {
    var inter MyInterface = MyText("Hyderabad")
    inter.Method()
}
```

Run

158

Interfaces (cont'd)

```
type geometry interface {
    area() float64
    perim() float64
}
```

here we implement geometry on rectangles:

```
type rect struct {
    width, height float64
}

func (r rect) area() float64 {
    return r.width * r.height
}

func (r rect) perim() float64 {
    return 2*r.width + 2*r.height
}
```

Interfaces (cont'd)

here we implement geometry on circles:

```
type circle struct {
    radius float64
}

func (c circle) area() float64 {
    return math.Pi * c.radius * c.radius
}

func (c circle) perim() float64 {
    return 2 * math.Pi * c.radius
}
```

if a variable has an interface type, we can call methods in the interface

here's a generic measure function which works on any geometry

```
func measure(g geometry) {
    fmt.Println(g, g.area(), g.perim())
}
```

Interfaces (cont'd)

```
type geometry interface {
    area() float64
    perim() float64
}

func measure(g geometry) {
    fmt.Println(g)
    fmt.Println(g.area())
    fmt.Println(g.perim())
}

func main() {
    r := rect{width: 3, height: 4}
    c := circle{radius: 5}
    // The circle and rect struct types both implement
    // the geometry interface so we can use instances of
    // of these structs as arguments to measure()
    measure(r)
    measure(c)
}
```

Run

161

Interface Values

- under the hood, interface values can be thought of as a tuple of a value and a concrete type: (value, type)
- an interface value holds a value of a specific underlying concrete type

```
type MyInterface interface {
    Method()
}

type Text struct {
    String string
}

func (t Text) Method() {
    fmt.Println(t.String)
}

type MyFloat struct {
    val float64
}

func (f MyFloat) Method() {
    fmt.Println(f.val)
}
```

Interface Values (cont'd)

```
func describe(i MyInterface) {
    fmt.Printf("(%v, %T)\n", i, i)
}

func main() {
    var inter MyInterface
    inter = &Text{"Hello"} // pointer to Text object
    describe(inter)
    inter.Method()
    inter = MyFloat{math.Pi}
    describe(inter)
    inter.Method()
}
```

Run

163

Interface Values with nil Underlying Value

- if the value inside the interface is nil, the method will be called with a nil receiver
- in some languages this would yield a null pointer exception–it's common in Go to write methods that handle being called with a nil receiver

```
type MyInterface interface {
    Method()
}
type Text struct {
    String string
}

func (t *Text) Method() {
    if t == nil {
        fmt.Println("<nil>")
    } else {
        fmt.Println(t.String)
    }
}

func describe(i MyInterface) {
    fmt.Printf("(%v, %T)\n", i, i)
}
```

Interface Values with nil Underlying Value (cont'd)

```
func main() {
    var i MyInterface
    var t *Text

    i = t
    describe(i)
    i.Method()

    i = &Text{"hello"}
    describe(i)
    i.Method()
}
```

Run

165

nil Interface Value

- a nil interface value holds neither value nor type
- calling a method on a nil interface is a run-time error

```
type MyInterface interface {
    Method()
}

func describe(i MyInterface) {
    fmt.Printf("(%v, %T)\n", i, i)
}

func main() {
    var i MyInterface
    describe(i)
    i.Method()
}
```

Run

166

The Empty Interface

- the interface type that specifies zero methods is known as the empty interface: `interface{}`
- an empty interface may hold values of any type, since every type implements at least zero methods
- use case–code that handles values of unknown type (e.g., `fmt.Println` takes any number of arguments of type `interface{}`)

```
func describe(i interface{}) {
    fmt.Printf("(%v, %T)\n", i, i)
}

func main() {
    var i interface{}
    describe(i)
    i = 42
    describe(i)
    i = "hello"
    describe(i)
}
```

Run

167

Type Assertions

- a type assertion provides access to an interface value's underlying concrete value

```
t := i.(T)
```

- the above statement asserts that the interface value i holds the concrete type T and assigns the underlying T value to the variable t
- if i does not hold a T, the statement will trigger a panic
- to test whether an interface value holds a specific type, a type assertion can return two values–the underlying value and a boolean that reports whether the assertion succeeded

```
t, ok := i.(T)
```

- if i holds a T, then t will be the underlying value and ok will be true
- otherwise, ok will be false and t will be the zero value of type T, and no panic occurs
- NOTE: this syntax is similar to that of reading from a map

Type Assertions (cont'd)

```
package main

import "fmt"

func main() {
    var i interface{} = "hello"
    s := i.(string)
    fmt.Println(s)
    s, ok := i.(string)
    fmt.Println(s, ok)
    f, ok := i.(float64)
    fmt.Println(f, ok)
    f = i.(float64) // panic
    fmt.Println(f)
}
```

Run

169

Type switch

- a switch construct that permits several type assertions in series
- like a regular switch statement, but the cases in a type switch specify types (not values), and those values are compared against the type of the value held by the given interface value

```
func check_type(i interface{}) {
    switch v := i.(type) {
    case int:
        fmt.Printf("Twice %v is %v\n", v, v*2)
    case string:
        fmt.Printf("%q is %v bytes long\n", v, len(v))
    default:
        fmt.Printf("I don't know about type %T!\n", v)
    }
}

func main() {
    check_type(21)
    check_type("hello")
    check_type(true)
}
```

Run

170

Stringers

- one of the most ubiquitous interfaces is Stringer

```
type Stringer interface {
    String() string
}
```

- a type that can describe itself as a string
- the fmt package (and many others) look for this interface to print values

```
type Person struct {
    Name, AlmaMater string
}

func (p Person) String() string {
    return fmt.Sprintf("%v (Alma Mater: %v)", p.Name, p.AlmaMater)
}

func main() {
    rs := Person{"The Hamburglar", "McDonalds University"}
    ab := Person{"Colonel Sanders", "KFC Technical College"}
    fmt.Printf("%s\n%s\n", rs, ab)
}
```

Run

171

Exercise: Stringers

1. Add a Stringer method to your Bank object so that a `BankAccount` can be printed out in a nice human-readable way

2. Given the following type:

```
type IPAddr [4]byte
```

- Define a map which maps hostnames (string) to `IPAddr`
- Add a few hostnames to your map, e.g., "localhost.com" (the addresses don't have to be correct)
- Add a `Stringer` method to `IPAddr` so that it is printed out in dotted notation (e.g., "127.0.0.1")
- Test your code in the playground or locally

172

Error Handling

Error Handling

- Go does not have exceptions, as we're used to in Python, Java, etc.
- it's idiomatic to communicate errors via a separate return value
- the ability to return multiple values is an improvement over C, where programmers often overload a single result value to indicate error
- error detection and handling in Go is easy since we can use the same language constructs we're used to
- by convention, errors are the last return value and are of type `error`:

```
type error interface {
    Error() string
}
```

- ...in other words, any type that has an `Error()` method that returns a string
- let's see an example using Go's built-in `errors` package

Error Handling (cont'd)

- an error of `nil` means no error
- `errors.New()` returns a basic error which your functions can return

```
import "errors"

var FilenameErr = errors.New("Invalid filename!")
var NotFoundErr = errors.New("File not found!")
...
if something_bad_happened {
    return 0, NotFoundErr
}
```

175

Error Handling (cont'd)

- in addition, you can use `fmt.Errorf` to do `Printf`-like formatting and returns the result as an `error` created by `errors.New`

```
if f < 0 {
   return 0, fmt.Errorf("math: square root of negative number %g", f)
}
```

176

Error Handling (cont'd)

```
import "errors"

var CountErr = errors.New("Invalid count")
var EmptyErr = errors.New("Can't replicate empty string!")

// Like Python * for strings, i.e., string replication
func stringstar(str string, count int) (string, error) {
    result := ""
    if count < 1 {
        return "", CountErr
    }
    if str == "" {
        return "", EmptyErr
    }
    for i := 1; i <= count; i++ {
        result += str
    }
    return result, nil
}

func main() {
    res, err := stringstar("Golang", 4)
    fmt.Println("result:", res, "\nerror:", err)
}
```

Run

177

Error Handling (cont'd)

- we can create our own error type, perhaps adding a timestamp, as long as we implement the error interface

```
type MyError struct {
    When time.Time
    What string
}

func (e MyError) Error() string {
    return fmt.Sprintf("at %v, %s", e.When, e.What)
}

func run() error {
    return MyError{
        time.Now(),
        "it didn't work", }
}

func main() {
    if err := run(); err != nil {
        fmt.Println(err)
    }
}
```

Run

178

Error Handling (cont'd)

- if you need to access the data in a custom error, you need to use type assertion in order to get the error as an instance of your custom error:

```
type MyError struct {
    Num int
    Msg string
}

func (e MyError) Error() string {
    return fmt.Sprintf("%s (%d)", e.Msg, e.Num)
}

func do_something() (int, error) {
    return 0, MyError{42, "failure message"}
}

func main() {
    _, err := do_something()
    if me, ok := err.(MyError); ok { // assert err is of type MyError
        fmt.Println("Num =", me.Num)
        fmt.Println("What =", me.Msg)
    }
}
```

Run

179

Exercise : Error Handling

- modify your square root (or Withdraw) function from earlier to return a custom error as well as the existing return value
- test it with a main program that sends a valid argument as well as an invalid argument
- access the fields of the custom error programmatically using type assertion

Error Handling: Best Practices

always check for errors, not just when you expect them

whenever possible, error strings should identify their origin, e.g., a prefix naming the operation or package that generated the error

- e.g., "<package_name>: unknown format"

pre-define errors when possible

know when to panic:

- when the user explicity says so
- during initialization (maybe, if can't recover)

Reading/Writing Files

Reading Files

- the interfaces `io.Reader` and `io.Writer` are central to input/output in Go

```
type Reader interface {
        Read(p []byte) (n int, err error)
}

type Writer interface {
        Write(p []byte) (n int, err error)
}
```

183

Reading Files

- here's an example using the os package to read from `/etc/passwd`

```
func check(e error) { // helper function for error checking
    if e != nil {
        panic(e)
    }
}

func main() {
    buf := make([]byte, 1024) // create a buffer
    f, e := os.Open("/etc/passwd")
    check(e)
    defer f.Close() // idiomatic to defer a Close just after Open
    for {
        n, e := f.Read(buf)
        if n == 0 { // 0 means we've hit EOF
            break
        }
        check(e)
        os.Stdout.Write(buf[:n])
    }
}
```

Run

184

Writing Files

```
func main() {
    // Dump a string (or just bytes) into a file
    d1 := []byte("hello\ngo\n")
    err := ioutil.WriteFile("/tmp/dat1", d1, 0644)
    check(err)
    // For more granular writes, open a file for writing
    f, err := os.Create("/tmp/dat2")
    check(err)
    defer f.Close()
    d2 := []byte{115, 111, 109, 101, 10} // "some"
    n2, err := f.Write(d2)              // you can Write byte slices as you'd expect
    check(err)
    fmt.Printf("wrote %d bytes\n", n2)
    n3, err := f.WriteString("writes\n") // write a string
    fmt.Printf("wrote %d bytes\n", n3)
    f.Sync() // flushes writes to stable storage
}
```

Run

185

More Reading Files

```
func main() {
// Slurping a file's entire contents into memory
    dat, err := ioutil.ReadFile("/tmp/dat1")
    check(err)
    fmt.Print(string(dat))
    // or...
    f, err := os.Open("/tmp/dat1")
    check(err)
    defer f.Close()
    // Read up to 5 bytes from beginning of file.
    // Note how many actually were read.
    b1 := make([]byte, 5)
    n1, err := f.Read(b1)
    check(err)
    fmt.Printf("%d bytes: %s\n", n1, string(b1))
    o2, err := f.Seek(6, 0) // seek to known location in file and read from there
    check(err)
    b2 := make([]byte, 2)
    n2, err := f.Read(b2)
    check(err)
    fmt.Printf("%d bytes @ %d: %s\n", n2, o2, string(b2))
```

More Reading Files (cont'd)

```
    // io package provides helpful functions for file reading. Reads
    // like the ones above can be more robustly implemented with ReadAtLeast.
    o3, err := f.Seek(6, 0)
    check(err)
    b3 := make([]byte, 2)
    n3, err := io.ReadAtLeast(f, b3, 2)
    check(err)
    fmt.Printf("%d bytes @ %d: %s\n", n3, o3, string(b3))
    _, err = f.Seek(0, 0) // no built-in rewind, but Seek(0, 0) does the trick
    check(err)
    // bufio package implements a buffered reader–useful both for efficiency
    // with many small reads and additional reading methods it provides
    r4 := bufio.NewReader(f)
    b4, err := r4.Peek(5)
    check(err)
    fmt.Printf("5 bytes: %s\n", string(b4))
}
```

Run

187

Reading a Text File Line by Line

- easiest to use a `Scanner` in the `bufio` package
- substitute `os.Stdin` to read from standard input

```
import (
    "bufio"
    "fmt"
    "os"
)

func main() {
    f, err := os.Open("poem.txt")
    if err != nil {
        panic(err)
    }
    scanner := bufio.NewScanner(f)
    for scanner.Scan() {
        fmt.Println(scanner.Text())
    }
    if err := scanner.Err(); err != nil {
        fmt.Fprintln(os.Stderr, "reading standard input:", err)
    }
}
```

Run

188

Exercise: Reading from Files

- write a Go program to read a file and count the number of occurrences of each word in the file
- use a `map` indexed by word, to count the occurrences
- treat **The** and **the** as the same word when counting
- NOTE: the `strings` package has several functions that will be helpful
- NOTE 2: ideally we would sort by counts, from most common to least common, but this is much more difficult to do in Go than it is in Python
- EXTRA: remove punctuation, so **Hamlet,** == **Hamlet**

Test on Shakespeare's Hamlet (http://bit.ly/BillShak)

189

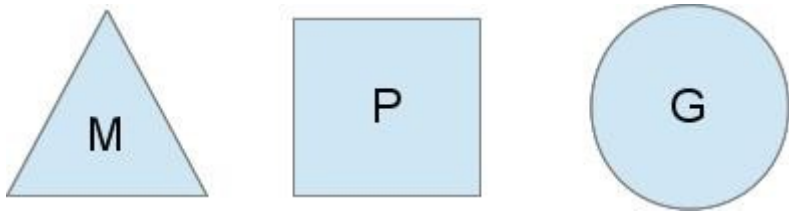
Concurrency

What is Concurrency?

- Hint: it's not parallelism
- concurrency = the composition of independently executing things (e.g., functions)
- parallelism = simultaneous execution of multiple things (which may or may not be related)
- concurrency is about dealing with many things at once (i.e., it's about structure)
- parallelism is about doing many things at once (i.e., it's about execution)
- consider an OS which manages a number of I/O devices: mouse, keyboard, video, etc.
- it's concurrent, but if only one CPU, clearly not parallel

Go Scheduler Overview

- a goroutine (G) is like a lightweight thread which we will examine shortly
- in order for an M (operating system thread) to execute a G it must acquire a (logical) processor (P), also known as a context

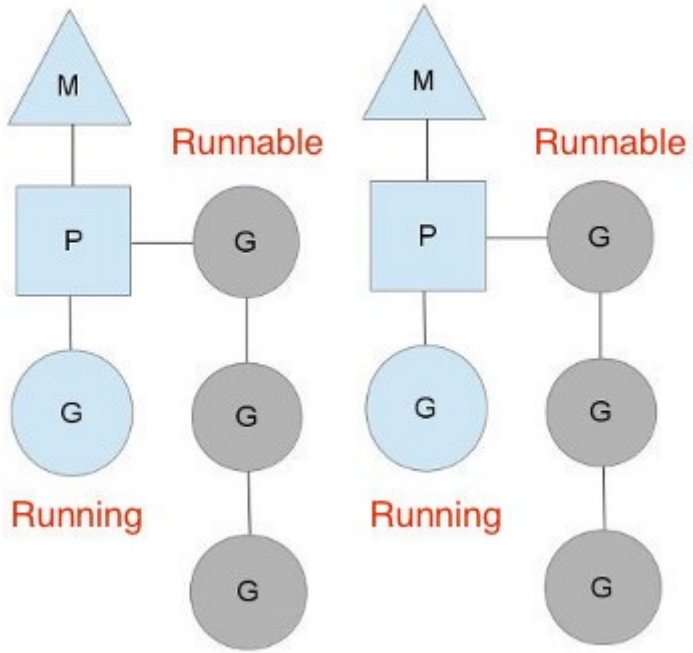


morsmachine.dk/go-scheduler (http://morsmachine.dk/go-scheduler)

192

Go Scheduler Overview (cont'd)

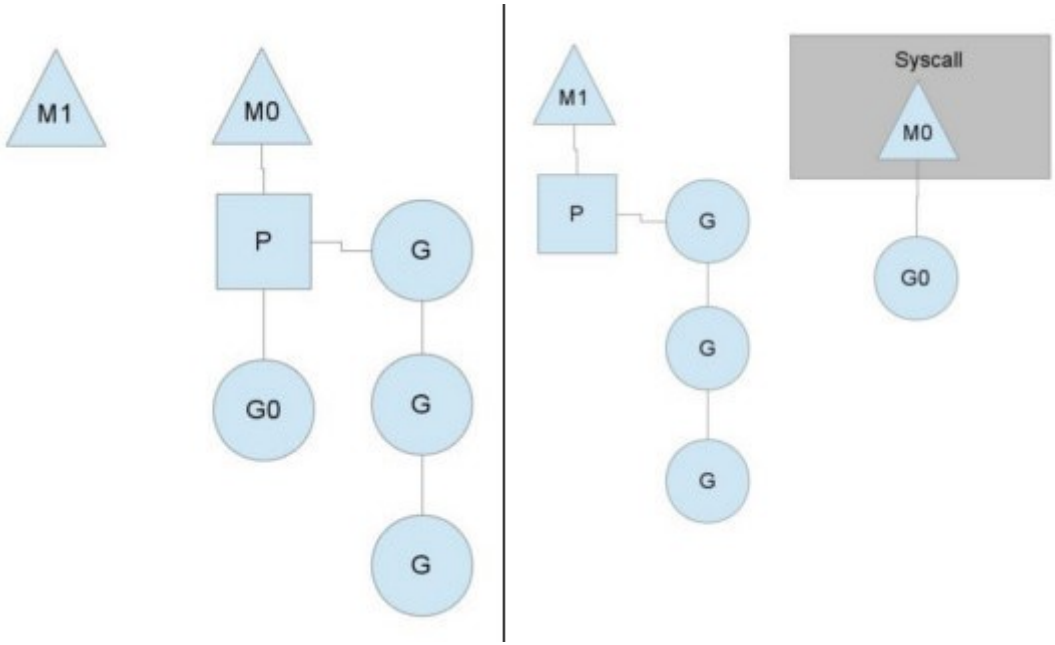
M will run G until it stops:



- making a system call (e.g., I/O)
- blocking on a channel operation (discussed shortly)
- pre-empted (which only happens at a safe point–when it makes a function call)

193

Go Scheduler Overview (cont'd)



if G blocks on a system call, it releases the P but remains running on the M

- a system monitor thread wakes up every so often
- if it sees runnable G and available P it will wake a sleeping M (or start a new one)– that M will acquire a P and run a runnable G

when a G completes a system call it will either reacquire the P or be marked runnable and go to sleep

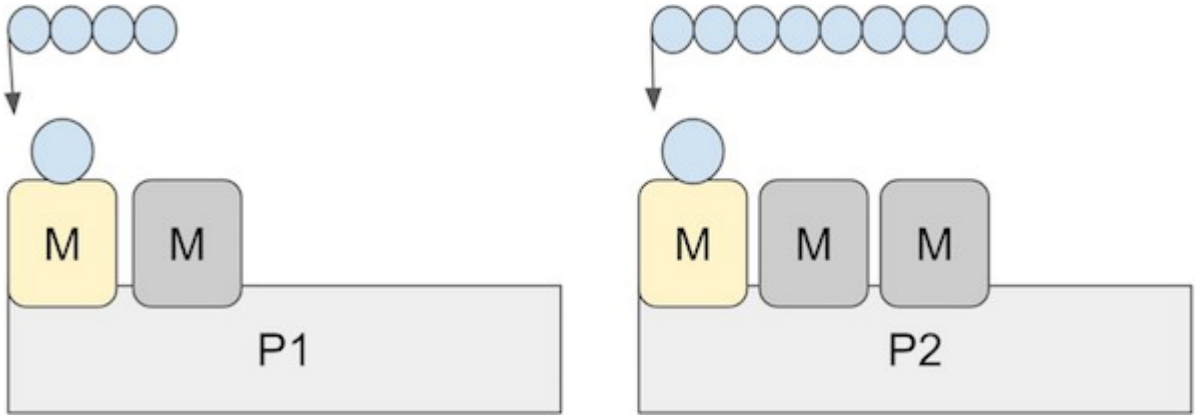
194

Go Scheduler Overview (cont'd)

if G blocks on a channel operation, it gets placed in a queue

- M looks for another runnable G
- if no runnable G, M will release P and go to sleep

when a channel operation succeeds, it will wake the other goroutine, mark it runnable, and, if there is an available P wake up a M to run it



195

Concurrency: Go vs. Others

concurrent programming is often difficult due to the subtleties required to correctly access shared data

Go takes a different approach–shared data are passed back and forth on channels

- they are not, in fact, actively shared by separate threads
- only one goroutine has access to the data at any given time
- data races cannot occur, by design

to encourage this way of thinking Golang has reduced it to a slogan: 196

Do not communicate by sharing memory; instead, share memory by communicating!

Concurrency: Go vs. Others (cont'd)

- of course, this approach can be taken too far...
- e.g., reference counts may be best implemented by putting a mutex (essentially, a "lock") around an integer

Go includes low-level concurrency primitives as well, but you often need not concern yourself with low-level details

198

Goroutines

- a lightweight thread of execution (not an actual OS thread)
- invoked by keyword go preceding a function call (or anonymous function)

```
package main

import (
    "fmt"
    "time"
)
func thrice(from string) {
    for i := 1; i <= 3; i++ {
        time.Sleep(10 * time.Millisecond)
        fmt.Println(from, i)
    }
}
func main() {
    thrice("direct") // no concurrency at this point
    go thrice("goroutine") // invoke the function in a goroutine
    go thrice("hey!") // and another...concurrent with main program
    time.Sleep(1000 * time.Millisecond) // sleep 1 second
}
```

Run

199

Gouroutines (cont'd)

- another example...run directly, not in playground

```
package main

import "fmt"

var done bool = false

func ask() {
        var input string
        fmt.Print("Enter some text: ")
        fmt.Scanln(&input)
        done = true
}

func main() {
        var square, count uint64 = 0, 0
        go ask()
        for ; !done; count++ {
                square = count * count
        }
        fmt.Printf("While waiting, computed %d * %d = %d\n", count, count, square)
}
```

200

Channels

- typed "conduits" through which you can send and receive data using the channel operator <-
- data moves in the direction of the arrow
- create a new channel using built-in function `make()`
- sending and receiving are blocking operations

```
func pinger(c chan string) {
    fmt.Println("pinger about to send")
    c <- "ping...ping...ping" // send a value into a channel ... blocking operation
}

func main() {
    mychan := make(chan string) // Create a new channel
    go pinger(mychan) // run pinger() as a goroutine
    fmt.Println("goroutine started...waiting 3 seconds before receiving")
    time.Sleep(3 * time.Second)
    msg := <-mychan // receive value from channel ... this is a blocking operation
    fmt.Println(msg)
}
```

Run

201

Exercise: Relay Race

- write a program to simulate a relay race with 4 runners
- create a func called runner with an int channel as a parameter
- the function should receive the "baton" via that channel (in reality it will receive a runner number, from 1-4)
- once the baton is received, it will print a message saying "Runner x is running" and then it will fire off the next goroutine representing the next runner in line
- when runner 4 receives the baton, it is the last runner, so it should not fire off another goroutine

202

Buffered Channels

- channels are unbuffered by default, i.e., they only accept a send operation if there is a corresponding receive operation ready to receive the data
- buffered channels receive and hold send ops without a corresponding receiver

```
import "fmt"
import "time"

func main() {
    // make a buffered channel of up to 4 strings
    bchan := make(chan string, 4)
    // We can send 4 values without a corresponding receive
    bchan <- "1"   // will not block
    bchan <- "2"   // will not block
    bchan <- "3"   // will not block
    bchan <- "go!" // will not block
    fmt.Println("4 values sent...")
    time.Sleep(1 * time.Second)
    for i := 1; i <= 4; i++ { // Later we can receive these values as usual
        fmt.Println(<-bchan)
    }
}
```

Run

203

Buffered Channels (cont'd)

- but if you try to put too much in the buffered channel...

```
package main

import "fmt"

func main() {
    // make a buffered channel of up to 2 strings
    bchan := make(chan string, 2)

    bchan <- "1"
    bchan <- "2"
    bchan <- "3"

    // Later we can receive these values as usual
    for i := 1; i <= 3; i++ {
        fmt.Println(<-bchan)
    }
}
```

Run

204

Buffered Channels (cont'd)

- but if we use a goroutine, it will work...

```
package main

import "fmt"

func main() {
    // make a buffered channel of up to 2 strings
    bchan := make(chan string, 2)

    bchan <- "1"
    bchan <- "2"
    go func() {
            bchan <- "3"
    } ()

    // Later we can receive these values as usual
    for i := 1; i <= 3; i++ {
        fmt.Println(<-bchan)
    }
}
```

Run

205

Channel Synchonization

- channels can be used to synchronize execution across goroutines
- we will use a blocking receive to wait for our goroutine to finish
- (here's a case where the parameter name is the same as the variable name, on purpose)

```
func worker(done chan bool) {
    for i := 1; i <= 5; i++ {
        fmt.Print("working...")
        time.Sleep(600 * time.Millisecond)
    }
    done <- true // we are done!
}
func main() {
    done := make(chan bool)
    go worker(done)
    // block until we receive a notification
    <-done
    fmt.Println("done!")
}
```

Run

206

Channel Directions

- when using a channel as a parameter to a function, you can specify whether the channel is meant to send or receive

```
// It would be a compile-time error to try to receive on this channel
func ping(schan chan<- string, msg string) {
    fmt.Printf("ping sending %#v\n", msg)
    schan <- msg
}

// Accepts one channel for receives and a second for sends
func pong(rchan <-chan string, schan chan<- string) {
    msg := <-rchan // receive a message
    fmt.Printf("pong received %#v\n", msg)
    schan <- msg
    fmt.Println("and sent it...")
}

func main() {
    pings := make(chan string, 1)
    pongs := make(chan string, 1)
    go ping(pings, "secret message")
    go pong(pings, pongs)
    fmt.Printf("main received %#v\n", <-pongs)
}
```

Run

207

The select Statement

- lets a goroutine wait on multiple communication operations
- blocks until one of its cases can run, then it executes that case
- if more than one are ready it chooses one at random

```
c1, c2 := make(chan string), make(chan string)
go func() { // wait 3 seconds, then send
    time.Sleep(3 * time.Second)
    c1 <- "one"
}()
go func() { // wait 1 seconds, then send
    time.Sleep(1 * time.Second)
    c2 <- "two"
}()
for i := 0; i < 2; i++ { // await both of these values simultaneously
    select {
    case msg1 := <-c1:
        fmt.Println("received", msg1)
    case msg2 := <-c2:
        fmt.Println("received", msg2)
    }
}
```

Run

208

Timeouts

we need to be able to time out if

- we're connecting to external resources
- we need to bound execution time
- channels plus the `select` statement let us time out elegantly

```
func main() {
    c1 := make(chan string, 1)

    go func() { // sleep 2 seconds, then send
        time.Sleep(2 * time.Second)
        c1 <- "Secret message"
    }()

    select { // wait up to 1 second to get message on c1
    case res := <-c1:
        fmt.Println(res)
    // time.After waits for duration to elapse then sends current time on the returned channel
    case <-time.After(1 * time.Second):
        fmt.Println("Timed out; Message not received.")
    }
}
```

Run

209

Non-Blocking Channel Operations

- sends and receives on channels are blocking
- ...but, we can use `select` with `default` to implement non-blocking send/receive

```
messages := make(chan string)
select { // non-blocking send
case messages <- "hi":
    fmt.Println("sent message")
default:
    fmt.Println("no message sent")
}

go func() {
    messages <- "Here's a message"
}()
time.Sleep(1 * time.Second)

select { // non-blocking receive
case msg := <-messages:
    fmt.Println("received message:", msg)
default:
    fmt.Println("no message received")
}
```

Run

210

Non-Blocking Channel Operations (cont'd)

- here is a non-blocking multi-way `select`

```
package main

import "fmt"

func main() {
    messages := make(chan string)
    signals := make(chan bool)
    // Multi-way non-blocking select
    select {
    case msg := <-messages:
        fmt.Println("received message", msg)
    case sig := <-signals:
        fmt.Println("received signal", sig)
    default:
        fmt.Println("no activity")
    }
}
```

Run

211

Closing Channels

```
jobs := make(chan int, 5) // holds work to be done
done := make(chan bool)

go func() {
    for {
        j, more := <-jobs // more will be false if channel closed
        if more {
            fmt.Println("running job", j)
            time.Sleep(time.Second)
        } else {
            fmt.Println("no more work to do")
            done <- true // signal main program
            return
        }
    }
}()
for j := 1; j <= 3; j++ { // sends 3 jobs to the worker over the jobs channel, then close
    jobs <- j
    fmt.Println("sent job", j)
}
close(jobs)
fmt.Println("sent all jobs")

<-done // await worker
```

Run

212

Range on a Channel

- receive values repeatedly from a channel until it is closed
- we can close a channel with data still in it, and have the data received afterwards

```
// Compute Fibonacci sequence up to n and send results to the channel
func fibonacci(n int, c chan int) {
    x, y := 1, 1
    for i := 0; i < n; i++ {
        c <- x
        x, y = y, x+y
    }
    close(c) // close channel to signal all done
}

func main() {
    c := make(chan int, 10) // buffered channel, 10 slots
    go fibonacci(cap(c), c) // run fibonacci up to capacity of channel
    for i := range c {
        fmt.Println(i)
    }
}
```

Run

213

Signal Handling

- sometimes we'd like our programs to intelligently handle Linux signals
- e.g., want a server to gracefully shut down when it receives a SIGTERM
- doesn't work in playground, run directly!

```
import "os"
import "os/signal"
import "syscall"

func main() {
    sigs := make(chan os.Signal, 1) // channel to receive os.Signal notifications
    done := make(chan bool, 1) // channel to notify us when the program can exit
    // Register the given channel to receive signal notifications
    signal.Notify(sigs, syscall.SIGINT, syscall.SIGTERM)
    go func() { // Execute a blocking receive for signals
        sig := <-sigs
        fmt.Println("\n", sig)
        done <- true
    }()
    fmt.Println("awaiting signal") // Wait here until goroutine is done
    <-done
    fmt.Println("exiting")
}
```

Run

214

Waiting for Goroutines

- a sync.WaitGroup waits for a collection of goroutines to finish

```
var wg sync.WaitGroup

func process(thing string) {
    defer wg.Done() // decrement counter when goroutine completes
    time.Sleep(time.Duration(len(thing) * 100) * time.Millisecond)
    fmt.Println(thing, "processed")
}

func main() {
    var items = []string{
        "short",
        "longer",
        "even longer",
        "supercalifragilisticexpialidocious",
    }
    for _, item := range items {
        wg.Add(1) // increment the WaitGroup counter
        go process(item)
    }
    fmt.Println("main waiting...")
    wg.Wait() // wait for all processing to complete
}
```

Run

Exercise: Waiting for Goroutines

- create 25,000 goroutines, each of which sleeps a random number of seconds before completing
- after sleeping, the go routine should print a message like *Goroutine n done* where n is the number of the goroutine
- when all 25,000 are done, the main program should notify you that all goroutines have finished

More Interesting Example

- go get a bunch of URLs
- spin up a goroutine for each one

```
func main() {
    var wg sync.WaitGroup

    var urls = []string{
        "http://www.golang.org/", "http://www.google.com/", "http://www.zzz1983x.com/",
    }
    for _, url := range urls {
        wg.Add(1) // increment the WaitGroup counter
        go func(url string) { // launch goroutine to fetch URL
            defer wg.Done() // decrement counter when goroutine completes
            if resp, err := http.Get(url); err == nil {
                fmt.Println(url, resp.Status)
            } else {
                fmt.Println(url, err)
            }
        }(url)
    }
    wg.Wait() // Wait for all HTTP fetches to complete
}
```

Run

217

Mutual Exclusion (sync.Mutex)

- what if we just want to make sure only one goroutine can access a variable at a time to avoid conflicts?
- this concept is called mutual exclusion and the data structure that provides it is typically called a mutex
- Go provides `sync.Mutex` and its two methods, `Lock` and `Unlock`
- if a `sync.Mutex` object is already locked when a goroutine tried to lock it, the goroutine will block until the holder of the lock unlocks it

```
import "sync"
var state = make(map[int]int) // For our example the `state` will be a map
var mutex sync.Mutex          // This `mutex` will synchronize access to `state`
var readOps uint64            // We'll keep track of how many read...
var writeOps uint64           // ...and write operations we do
```

218

Mutual Exclusion (cont'd)

```
import "sync/atomic" // also "math/rand" and "time"

func read_state() {
    total := 0
    for {
        key := rand.Intn(5)           // pick a random map entry
        mutex.Lock()                  // lock the shared state
        total += state[key]           // read it!
        mutex.Unlock()                // unlock
        atomic.AddUint64(&readOps, 1) // atomically increment count
        time.Sleep(time.Millisecond)
    }
}
func write_state() {
    for {
        key := rand.Intn(5)           // pick a random map position
        val := rand.Intn(100)         // pick a random number to write
        mutex.Lock()                  // lock the shared state
        state[key] = val              // write it!
        mutex.Unlock()                // unlock
        atomic.AddUint64(&writeOps, 1) // atomically increment count
        time.Sleep(time.Millisecond)
    }
}
```

Mutual Exclusion (cont'd)

```
func main() {
    for r := 0; r < 100; r++ { // Start 100 goroutines to execute repeated reads
        go read_state()
    }
    for w := 0; w < 10; w++ { // Start 10 goroutines to simulate writes
        go write_state()
    }
    time.Sleep(time.Second)
    readOpsFinal := atomic.LoadUint64(&readOps) // Report final operation counts
    fmt.Println("readOps:", readOpsFinal)
    writeOpsFinal := atomic.LoadUint64(&writeOps)
    fmt.Println("writeOps:", writeOpsFinal)
    mutex.Lock()
    fmt.Println("state:", state)
    mutex.Unlock()
}
```

Run

220

Race Detection

- a data race occurs when two goroutines access the same variable concurrently and at least one of the accesses is a write
- among the most common/most difficult to debug issues in concurrent systems

```
package main

import "fmt"

func main() {
    c := make(chan bool)
    m := make(map[string]string)
    go func() {
        m["1"] = "a" // First conflicting access.
        c <- true
    }()
    m["2"] = "b" // Second conflicting access.
    <-c
    for k, v := range m {
        fmt.Println(k, v)
    }
}
```

Run

221

Race Detection (cont'd)

- The Go race detector can detect data races while your program is running, but the executable must be instrumented with special code to perform the detection
- To add race detection to your binary:

```
go build -race mycmd
```

and then run it

- You can, as you'd expect do this all in one step

```
go run -race mysrc.go
```

- And you can use `go install` to add race detection to a package

```
go install -race mypkg
```

Exercise

- create a program which uses a goroutine to simulate a database server
- your "database server" should simply be a goroutine which accepts an integer representing some "work" to do and it sleeps for that amount of time before accepting more work
- your main routine should get integers from the user, and pass those to the "server"
- once you have that working, make it more complex...
- add a second server goroutine, and use a select statement to send the work to whichever server is able to accept it (to test this, send a big chunk of work, i.e., a large int, to one of them, and then be sure the other can do subsequent work in the meantime)

223

Exercise (cont'd)

- still more...how about a load balancer goroutine which spins up new server routines as needed up to some maximum (i.e., if it sees that no servers are available, it spins up more)
- to do this effectively you'll likely need reflection, so let's simplify by just trying to send to each server, and if they are all busy, launch a new goroutine
- you'll likely need an array/slice of channels
- make it so each server goroutine shuts down if it hasn't done work for a while, so even if you hit your max of, say 10, servers, they should start shutting down as the workload decreases

Exercise (cont'd)

- although we normally would share memory by communicating...
- add a shared queue, which can simply a slice of ints that you add to by appending, and remove from by slicing the queue, i.e.,

```
// remove an item from the queue
item = queue[0]
queue = queue[1:]
```

- wrap the queue in a `Mutex` to prevent simultaneous accesses
- the queue holds work to be performed and is filled by the main routine and drained by the load balancer, or remove the load balancer and let the workers remove something from the queue as they are free
- also let workers randomly reject work and place it back in the wqqueue...

Testing

Testing

- Go comes with great unit testing capabilities built in
- let's build a small package and see how to test it

```
package stack

// A simple stack object with 10 slots for integers
type Stack struct {
    ptr  int
    items [10]int
}
// Push an item onto the stack
func (s *Stack) Push(i int) {
    s.items[s.ptr] = i
    s.ptr++
}
// Pop an item from the stack
func (s *Stack) Pop() int {
    s.ptr--
    return s.items[s.ptr]
}
```

227

Testing (cont'd)

- let's create test file(s) named `*_test.go` in the same folder as our code
- first we have to import the testing package

pkg.go.dev/testing (https://pkg.go.dev/testing)

- then create one or more functions named `Test*` which accept a `*testing.T` (that object manages state for the test)

```
package stack

import "testing"

func TestPushPop(t *testing.T) {
        s := Stack{} // cf. s := new(Stack)
        s.Push(1)
        if s.Pop() != 1 {
                t.Log("Pop() failed to return 1")
                t.Fail()
        }
}
```

228

Testing (cont'd)

```
$ go test -v
=== RUN   TestPushPop
--- PASS: TestPushPop (0.00s)
PASS
ok      stack    0.006s
```

229

Exercise: Testing

add additional methods to the Stack module:
- Top: returns the top element but does not remove it
- `IsEmpty`: return a Boolean indicating whether stack is empty
- `Size`: returns number of elements on stack (could be used by IsEmpty)
- add tests for each of these methods

add tests to your bank package
- try to Deposit/Withdraw a negative amount
- try to Withdraw more than your balance
- try to create a `bankAccount` with no name
- anything else you can think of...

"Example" Tests

- like unit tests, but instead of verifying results programmatically, it verifies output
- the correct output lives in comments after the commands

```
func ExampleSalutations() {
    fmt.Println("hello, and")
    fmt.Println("goodbye")
    // Output:
    // hello, and
    // goodbye
}
```

- output from running the examples

```
$ go test -v
=== RUN   ExampleSalutations
--- PASS: ExampleSalutations (0.00s)
PASS
ok      example    0.005s
```

231

"Example" Tests (cont'd)

- the comment prefix "Unordered output:" matches any line order:

```
package perm_test

import "math/rand"

func ExamplePerm() {
    for _, value := range rand.Perm(4) {
        fmt.Println(value)
    }
    // Unordered output:
    // 2
    // 1
    // 3
    // 0
}
```

232

Exercise: Example Tests

- write a Golang program that takes a string message such as "Hello from GoLang", splits it into words, and then enters the words as keys in a map (the values are up to you)
- iterate through the map and output the keys, which will be in a random order
- write an "example" test to ensure the output is correct

Test Coverage

- test coverage refers to the percentage of statements in your code that are executed by your tests
- what is the "right" percentage of coverage we should actually target?

```
package size

func Size(a int) string {
    switch {
    case a < 0:
        return "negative"
    case a == 0:
        return "zero"
    case a < 10:
        return "small"
    case a < 100:
        return "big"
    case a < 1000:
        return "huge"
    }
    return "enormous"
}
```

234

Test Coverage (cont'd)

- here's a test-let's see how it does

```
type Test struct { // a "Test" consists of an input and an output
    in  int
    out string
}
var tests = []Test{ // Clearly are missing some cases here
    {-1, "negative"},
    {5, "small"},
}
func TestSize(t *testing.T) {
    for i, test := range tests {
        size := Size(test.in)
        if size != test.out {
            t.Errorf("#%d: Size(%d)=%s; want %s", i, test.in, size, test.out)
        }
    }
}
```

235

Test Coverage (cont'd)

```
$ go test
PASS
ok      size    0.08s
```

- the tests pass, but let's look at coverage

```
$ go test -cover
PASS
coverage: 42.9% of statements
ok      size    0.008s
```

- coverage is quite poor–it's fairly obvious why in this toy example

Test Coverage (cont'd)

- go test runs the cover tool which rewrites the source code like this

```
func Size(a int) string {
    GoCover.Count[0] = 1
    switch {
    case a < 0:
        GoCover.Count[2] = 1 // each assignment statement is a single move instruction,
        return "negative"    // therefore FAST
    case a == 0:
        GoCover.Count[3] = 1
        return "zero"
    case a < 10:
        GoCover.Count[4] = 1
        return "small"
    case a < 100:
        GoCover.Count[5] = 1
        return "big"
    case a < 1000:
        GoCover.Count[6] = 1
        return "huge"
    }
    GoCover.Count[1] = 1    // 7 paths through the code, and only 3 of them were executed
    return "enormous"
}
```

Coverage Profile

```
$ go test -coverprofile=coverage.out
PASS
coverage: 42.9% of statements
ok      size    0.08s
```

- we can examine coverage per function (but not very interesting here since there's only one function)

```
$ go tool cover -func=coverage.out
size/size.go:3: Size            42.9%
total:          (statements)    42.9%
```

- let's see it graphically...

```
$ go tool cover -html=coverage.out
```

Coverage Profile (cont'd)

size/size.go (42.9%) not tracked not covered covered

```
package size

func Size(a int) string {
    switch {
    case a < 0:
        return "negative"
    case a == 0:
        return "zero"
    case a < 10:
        return "small"
    case a < 100:
        return "big"
    case a < 1000:
        return "huge"
    }
    return "enormous"
}
```

Sub-Tests

- we can use the t.Run() method to group tests together, in order to share setup and teardown and create hierarchical tests

```
func TestSize(t *testing.T) {
    t.Log("Setup!") // common setup code can go here
    t.Run("neg", func(t *testing.T) {
        if Size(-1) != "negative" {
            t.Error("-1 not negative")
        }
    })
    t.Run("big", func(t *testing.T) {
        if Size(9) != "big" {
            t.Error("9 not big")
        }
    })
    t.Log("Teardown!") // common teardown code can go here
}
```

- each subtest has a unique name–the name of the top-level test plus the sequence of names passed to t.Run(), separated by slashes, with an optional trailing sequence number for disambiguation

240

Sub-Tests (cont'd)

- we can specify which test should run using command-line args

```
go test -run ''       # Run all tests (same as __`go test`__)
go test -run Size     # Run top-level tests matching "Size", such as "TestSize"
go test -run Size/ne  # For top-level tests matching "Size", run subtests matching "ne"
go test -run /ne      # For all top-level tests, run subtests matching "ne"
```

Testing Best Practices

put tests in a different package

- if they're in the same package they have access to the package internals
- in a different package you are limited to the exposed API

put internal tests in a different file, e.g., foo_internal_test.go

- good for TDD

use test tables
aim for 100% coverage

- but only if your tests are actually testing what they should be

Benchmarking

Benchmarks

- examine the performance of your Go code
- part of the `testing` package
- placed inside `*_test.go` files, prefaced with `Benchmark` as opposed to Test
- benchmark functions take a single argument, a pointer to a testing.B
- executed with go test -bench <regexp>
- use . to run all benchmarks
- benchmarks are run several times by the testing package
- the value of b.N will increase each time until the benchmark runner is satisfied with the stability of the benchmark

244

Benchmarks (cont'd)

```
func Fib(n int) int {
        if n < 2 {
                return n
        }
        return Fib(n - 1) + Fib(n - 2)
}

func BenchmarkFib10(b *testing.B) {
        // run the Fib function b.N times
        for n := 0; n < b.N; n++ {
                Fib(10)
        }
}
```

.

How to Write Benchmarks in Go (https://dave.cheney.net/2013/06/30/how-to-write-benchmarks-in-go)

Benchmarks (cont'd)

```
$ go test -bench=.
goos: darwin
goarch: amd64
pkg: fib
BenchmarkFib10-4        5000000           359 ns/op
PASS
ok      fib     2.184s
```

- PASS output is from running tests
- use -run <regexp> if you want to avoid running tests
- second line is number of times test was run (i.e., b.N), followed by average execution time for the test

How to Write Benchmarks in Go (https://dave.cheney.net/2013/06/30/how-to-write-benchmarks-in-go)

Benchmarking Various Inputs

- given that the Fib function is the classic recursive implementation, we'd expect it to slow down exponentially for large values of n
- we can rewrite our benchmark slightly using a common pattern

```
func benchmarkFib(i int, b *testing.B) {
	for n := 0; n < b.N; n++ {
		Fib(i)
	 }
}

func BenchmarkFib1(b *testing.B)  { benchmarkFib(1, b) }
func BenchmarkFib2(b *testing.B)  { benchmarkFib(2, b) }
func BenchmarkFib3(b *testing.B)  { benchmarkFib(3, b) }
func BenchmarkFib10(b *testing.B) { benchmarkFib(10, b) }
func BenchmarkFib20(b *testing.B) { benchmarkFib(20, b) }
func BenchmarkFib40(b *testing.B) { benchmarkFib(40, b) }
```

- note that `benchmarkFib` has to be private to prevent the testing driver from trying to run it directly

How to Write Benchmarks in Go (https://dave.cheney.net/2013/06/30/how-to-write-benchmarks-in-go)

Benchmarking Various Inputs (cont'd)

```
$ go test -bench=.
goos: darwin
goarch: amd64
pkg: fib
BenchmarkFib1-4         1000000000               2.59 ns/op
BenchmarkFib2-4         200000000                7.07 ns/op
BenchmarkFib3-4         100000000               12.0 ns/op
BenchmarkFib10-4         3000000               433 ns/op
BenchmarkFib20-4           30000             52993 ns/op
BenchmarkFib40-4               2         779718761 ns/op
PASS
ok      fib     12.440s
```

- each benchmark runs for a minimum of 1 second by default
- if the second has not elapsed when the Benchmark function returns, the value of b.N is increased in the sequence 1, 2, 5, 10, 20, 50, … and the function run again
- the final `BenchmarkFib40` only ran twice with the average just under 1s per run
- we can increase the minimum benchmark time using the -benchtime flag to produce a more accurate result

Benchmarking Gotchas

- two examples of a faulty benchmark...

```
func BenchmarkFibWrong(b *testing.B) {
        for n := 0; n < b.N; n++ {
                Fib(n)
        }
}

func BenchmarkFibWrong2(b *testing.B) {
        Fib(b.N)
}
```

- these benchmarks will never complete because the runtime of the benchmark increases as b.N grows

249

Documentation

Documentation

- Go takes documentation seriously
- documentation is integral to making software accessible and maintainable
- docs should be coupled to the code so they evolve along with the code
- historically it hasn't been so easy to produce docs
- Python has Docstrings, Java has Javadoc ... Go has godoc
- the easier it is for programmers to produce good docs, the better for everyone
- godoc parses Go source code–including comments-and produces documentation as HTML or plain text
- the result is documentation tightly coupled with the code it documents
- conceptually related to Docstring and Javadoc but simpler
- comments read by godoc are not language constructs (like Docstrings)
- the comments don't have to have their own machine-readable syntax (like Javadoc)

How Does godoc Work?

- to document a type/variable/constant/function/package, write a regular comment directly preceding its declaration, w/no intervening blank line
- godoc presents that comment as text alongside the item it documents
- for e.g., this is the documentation for `fmt.Fprint`

```
// Fprint formats using the default formats for its operands and writes to w.
// Spaces are added between operands when neither is a string.
// It returns the number of bytes written and any write error encountered.
func Fprint(w io.Writer, a ...interface{}) (n int, err error) {
```

the above comment is a complete sentence, beginning with the name of the element it describes, which is an important convention allowing:

- documentation to be generated in a variety of formats, from plain text to HTML to UNIX man pages
- makes it read better when tools truncate it for brevity

How Does godoc Work? (cont'd)

- comments on package declarations should provide general package documentation, and can be short–like the sort package's brief description:

```
// Package sort provides primitives for sorting slices and user-defined
// collections.
package sort
```

- comments not adjacent to a top-level declaration are omitted from godoc's output
- ...except for top-level comments beginning with the word `BUG(who)`, which are included in the Bugs section of the package documentation
- the who part is the user name of someone who could provide more information
- for e.g., this is a known issue from the bytes package:

```
// BUG(r): The rule Title uses for word boundaries does not handle Unicode
// punctuation properly.
```

- let's try it with our stack package...

Resources

Official Docs (https://golang.org/doc/)

Playground (https://play.golang.org/)

Tour of Go (https://tour.golang.org/welcome/1)

Go Modules (https://blog.golang.org/migrating-to-go-modules)

Effective Go (https://golang.org/doc/effective_go.html)

Go for Pythonistas (https://talks.golang.org/2013/go4python.slide)

Concurrency is not Parallelism (https://blog.golang.org/concurrency-is-not-parallelism)

Less is Exponentially More (https://commandcenter.blogspot.com/2012/06/less-is-exponentially-more.html)

Go frameworks, libraries and software! (https://awesome-go.com/)

Go Slice Tricks (https://github.com/golang/go/wiki/SliceTricks)

Go 2.0 Draft: Error Handling (https://go.googlesource.com/proposal/+/master/design/go2draft-error-handling.md)

Go 2.0 Error Handling — Problem Overview (https://go.googlesource.com/proposal/+/master/design/go2draft-error-handling-overview.md)

Thank you