Go

K19G

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Everything Go - Comprehensive Syllabus

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1. Foundations & Mindset

- **The Go Philosophy:** Why "boring" is a superpower.
- **2026 Learning Roadmap:** Focusing on essentials vs. hype.
- **The 3-Layer Practice System:** Read, Write, Ship.
- **Transitioning to Go:** Insights for Java and Node.js developers.

2. Core Language Essentials

- **Language Building Blocks:** Variables, types, and functions. New in 1.26: `new(expr)` initialization
- **Control Flow:** Effective use of `if`, `for`, and `switch`.
- **Data Structures:**
  - Structs and Interfaces (The "Go Way").
  - Arrays, Slices, and Maps internals.
  - Working with Time in Go.
- **Project Organization:** Organizing projects and defining names; standard project layout.

3. Pointers & Memory Management

- **The Mechanics:** Understanding Stack vs. Heap.
- **Memory Optimization:**
  - Escape Analysis: Where did my memory go?
  - Memory Alignment and Padding.
  - Garbage Collection (GC) tuning and `GOMEMLIMIT`. Go 1.26: Green Tea GC default
- **Pass by Value vs. Pass by Reference:** Performance tradeoffs.

4. Advanced Error Handling

- **Beyond `if err != nil`:** Senior techniques for robust handling.
- **Patterns:** Sentinel errors, custom error types, and error wrapping.
- **Techniques:** Error handling without a garbage collector (Odin comparison); the "Must" pattern.

5. Concurrency & Parallelism

- **Goroutines & Channels:** The heart of Go's concurrency model.
- **Sync Mechanisms:** WaitGroups, Mutexes, `sync.Map`, and the overlooked `sync.Cond`.
- **Execution Control:**
  - Context Package: Lifecycles, cancellation, and timeouts.
  - Worker Pools: Avoiding the chaos of uncontrolled concurrency.
  - Pipelines and complex concurrency patterns.

6. Web Development & Modern Stacks

- **The GOTH Stack:** Go + Templ + HTMX + Tailwind.
- **Frontend Interaction:**
  - Skeleton loading with Go and HTMX.
  - Live reloading with Air.
- **API Design:**
  - Building REST APIs with routing and middleware.
  - Microservices: Switching to gRPC.
  - Using Huma for OpenAPI-backed APIs.
- **Integrations:** Working with PostgreSQL and Redis.

7. Performance, Profiling & Tooling

- **Benchmarking:** Proof-based optimization using `go test -bench`.
- **Profiling:** Deep dives with `pprof` and `trace`.
- **Code Generation:** Using `sqlc` for type-safe SQL; `stringer` for enums.
- **The Modern Toolkit:**
  - `ripgrep`, `fd`, `fzf`, `zoxide`, `bat`, and `jq`.
  - `go fix` modernizers + `//go:fix inline`. New in 1.26
  - `gopsutil` for system and hardware stats.
- **Advanced Refactoring:** `gofmt`, `gopatch`, and `goimports`.

8. Infrastructure & Deployment

- **Containerization:** Multi-stage Docker builds for lean binaries.
- **Platform Guides:**
  - Deploying to Render and Leapcell.
  - Go on NixOS and FreeBSD.
  - Running Go on Mini-PCs for local AI (Llama 3).
- **CI/CD:** Automated vulnerability checking and hardening.

9. Security & Hardening

- **Security Tools:** `govulncheck`, `gosec`, `capslock`, and `nilaway`.
  - `crypto/hpke`, `testing/cryptotest`, and experimental `runtime/secret`. Go 1.26 additions
- **Hardening:** Production-grade Ubuntu hardening for Go apps.
- **Design Principles:** S.O.L.I.D principles in the context of Go.

10. Specialized Applications

- **Desktop Apps:** Cross-platform development with LCL, CEF, and Webview.
- **Observability:** Integrating OpenTelemetry.
- **Machine Learning:** Building LLM-powered applications in Go.
  - `simd/archsimd` (Experimental via `GOEXPERIMENT=simd`). New in 1.26
- **Systems Programming:** Debuggers, syscalls, and low-level internals.

Foundations

Why Go Exists

Overview

Go (also known as Golang) was created at Google in 2007 by Robert Griesemer, Rob Pike, and Ken Thompson. It was designed to address the challenges of building large-scale, concurrent software systems while maintaining simplicity and fast compilation times.

The Problems Go Was Designed to Solve

1. Slow Compilation Times

In large codebases (like those at Google), C++ compilation could take hours. Go was designed with fast compilation as a primary goal, enabling rapid development cycles even in massive projects.

2. Complexity in Modern Languages

Languages like C++ and Java had become increasingly complex with years of feature additions. Go aimed to be simple enough that a programmer could hold the entire language specification in their head.

3. Difficulty with Concurrency

As multi-core processors became standard, writing concurrent code with traditional threading models proved error-prone and difficult. Go introduced goroutines and channels as first-class citizens.

4. Dependency Management Chaos

"Dependency hell" plagued many ecosystems. Go's import system and later the module system were designed to solve versioning and dependency problems.

Go's Design Philosophy

```
// Go favors clarity over cleverness
func processItems(items []string) error {
    for _, item := range items {
        if err := process(item); err != nil {
            return fmt.Errorf("processing %s: %w", item, err)
        }
    }
    return nil
}
```

Key Principles

Principle	Description
Simplicity	Less is more—remove features rather than add them
Readability	Code is read more often than written
Orthogonality	Features should work well together without special cases
Composition	Prefer composition over inheritance
Explicit over implicit	Make behavior obvious rather than magical

What Makes Go Different

Compiled, Statically Typed, Fast

```
// Type safety caught at compile time, not runtime
var count int = 42
count = "hello"  // Compile error: cannot use "hello" as int
```

Built-in Concurrency

```
// Goroutines are lightweight and easy to use
go func() {
    // This runs concurrently
    processData()
}()
```

Single Binary Output

```
# Go compiles to a single binary with no dependencies
$ go build -o myapp main.go
$ ./myapp  # Just works, no runtime required
```

Standard Formatting

```
# One true style, enforced automatically
$ gofmt -w main.go
```

Who Uses Go

Go powers critical infrastructure across the industry:

- **Docker** - Container runtime
- **Kubernetes** - Container orchestration
- **Terraform** - Infrastructure as code
- **CockroachDB** - Distributed database
- **Hugo** - Static site generator
- **Prometheus** - Monitoring system

When to Choose Go

Good fit for: - Microservices and APIs - CLI tools and DevOps tooling - Concurrent/parallel processing - Networked services - Cloud-native applications

Consider alternatives for: - GUI desktop applications - Mobile development - Low-level systems (kernels, drivers) - Data science/ML (Python ecosystem is stronger)

Summary

Go exists because the software industry needed a language that could:

1. **Compile quickly** at any scale
2. **Handle concurrency** naturally and safely
3. **Remain simple** despite solving complex problems
4. **Produce efficient binaries** that deploy easily

Understanding these origins helps you write more idiomatic Go code that embraces the language's philosophy.

Related Topics

- Learning Go in 2026
- Installing and Running Go
- How Go Code Is Organized

Learning Go in 2026

Why Go is Worth Learning in 2026

Go (Golang) has moved beyond hype into the backbone of modern engineering. In 2026, it remains the language of choice for cloud-native systems, DevOps tooling, and scalable backend infrastructure.

Companies love Go for: - **Simplicity**: Minimalist syntax that is easy to read and maintain. - **Performance**: Compiled speed that rivals C++ and Java. - **Built-in Concurrency**: First-class support for parallel processing. - **Easy Deployment**: Compiles to a single static binary with no external dependencies.

The Go Mindset (Most People Get This Wrong)

Go is "boring" by design, and that is its greatest superpower. To succeed in Go, you must shift your mindset:

Instead of...	Go Prefers...
Clever Code	Clear Code
Deep Inheritance	Simple Composition
Complex Abstractions	Concrete Implementations
Magic/Implicit Behavior	Explicit Logic

> **Pro Tip**: Once you stop fighting Go's simplicity and embrace its explicitness, you become shockingly productive.

The Fastest Roadmap to Learn Go

1. Learn Only the Essentials First

Don't get bogged down in advanced features immediately. Focus on the core: - Variables & Types - Functions & Error Handling - Control Flow (`if`, `for`, `switch`) - Structs & Interfaces (The heart of Go's type system) - Packages & Modules

2. Learn Concurrency Early

Go without concurrency is like a ship without a sail. Don't delay learning: - **Goroutines**: Lightweight threads. - **Channels**: How goroutines communicate. - **Select**: Managing multiple channel operations. - **Sync Package**: WaitGroups and Mutexes for state management.

3. Build Tiny Programs Every Day

Forget massive projects at the start. Build real-world utility tools: - CLI Calculator - Log File Analyzer - API Health Checker - Simple REST API

The 3-Layer Practice System

This system ensures you don't just consume content but actually learn to build:

1. **Layer 1: Read**: Read clean, idiomatic Go code (like the standard library). Observe naming conventions and error handling patterns.
2. **Layer 2: Write**: Rewrite examples from memory. Don't copy-paste. Intentionally break things to see how the compiler and runtime react.
3. **Layer 3: Ship**: Push your code to GitHub. Use Go to solve your own small problems, like automating a repetitive task.

Go Projects That Make You Job-Ready

Build these in order to gain real-world experience: 1. **REST API**: Use the standard library or a lightweight router with middleware and JSON handling. 2. **CLI Tool**: Use flags and arguments to create a useful command-line utility. 3. **Concurrent Worker Pool**: Process data in parallel using goroutines and channels. 4. **Log Monitor**: A tool that watches files or streams and alerts on patterns. 5. **Microservice**: A simple service with environment-based configuration and health checks.

Why Go is a DevOps Superpower

If you are in DevOps or SRE, Go is a force multiplier. It allows you to: - Build internal CLI tools that are easily shared. - Write robust automation scripts that replace fragile shell scripts. - Extend CI/CD pipelines with custom logic. - Create Kubernetes Operators or Custom Resource Definitions (CRDs).

Go turns "glue code" into reliable software engineering.

Memory & Consistency

- **Practice daily**: 30–60 minutes is better than a 5-hour marathon.
- **Explain concepts**: Write short blog posts or notes to solidify your understanding.
- **Consistency beats intensity**: Every single time.

Go 1.26 Migration Checklist (Shared)

Use this checklist when upgrading existing projects to Go 1.26.

```
upgrade path

audit current toolchain
      |
      v
update go.mod/toolchain
      |
      v
run modernizers + full tests
      |
      v
enable selected experiments (only if needed)
      |
      v
ship + monitor memory/latency regressions
```

1. Pin Toolchain and Module Versions

```
go version
go mod tidy
```

If you use a `toolchain` directive, set it explicitly and keep CI aligned.

2. Run Modernization and Safety Baseline

```
go fix -modernize ./...
go vet ./...
govulncheck ./...
```

3. Re-Baseline Tests and Benchmarks

```
go test ./... -race -shuffle=on -count=1
go test ./... -bench=. -benchmem
```

Adopt `B.Loop` and deterministic concurrency tests (`testing/synctest`) in packages that were noisy/flaky.

4. Enable Experiments Deliberately

Only opt into experiments if there is a clear payoff and rollback plan:

```
GOEXPERIMENT=simd go test ./...
GOEXPERIMENT=nogreenteagc go test ./...
```

Document where each experiment is used and how to disable it quickly.

5. Observe Production After Rollout

Track: - P95/P99 latency - GC pause and heap goal trend - Error rates and timeout rates

Run canary first, then broad rollout.

Summary

Don't try to "finish" Go. Use Go to solve real problems, and the language will teach itself to you along the way. Stay curious, keep building, and embrace the simplicity.

Related Topics

- Why Go Exists
- Installing and Running Go
- Core Go Commands

The Go Philosophy

The Go Philosophy: Why "Boring" is a Superpower

In a software landscape obsessed with the "next big thing," Go stands out by explicitly trying *not* to be clever. Since its inception at Google in 2007 (and release in 2009), Go has adhered to a philosophy of simplicity, stability, and readability.

As we move through 2026, this philosophy hasn't just survived; it has proven to be a competitive advantage.

Boring Software is Reliable Software

The core tenet of Go's philosophy is often summarized as: **"Clear is better than clever."**

1. Readability Over Conciseness

Go is verbose. This is intentional. When you read Go code, you don't need to hold a complex mental model of hidden states, monkey-patched methods, or magical frameworks in your head. The control flow is visible. * **No inheritance:** You cannot hide logic in a base class three layers up. * **No method overloading:** `DoWork` and `DoWorkWithContext` are distinct. You know exactly which one is called. * **No circular dependencies:** The compiler forbids it, forcing you to keep your architecture clean.

2. One Way To Do It

While languages like Ruby or Scala offer ten ways to iterate over a list, Go gives you one: the `for` loop. This reduced cognitive load means you spend less time debating *style* and more time solving *problems*.

3. Stability is a Feature

Go's Go 1 compatibility promise is legendary. Code written in 2012 will likely compile and run today with little to no modification. In 2026, where JavaScript frameworks churn every six months, this stability allows organizations to build for the decade, not the demo.

> "Software engineering is what happens to programming when you add time and other programmers." — Russ Cox

The 2026 Context: AI and Complexity

With the rise of AI-generated code (Copilot, Gemini, etc.), simplicity is more vital than ever. * **AI generates bugs:** Complex languages with hidden magic allow AI to halluncinate plausible but broken code. Go's explicit error handling and type system catch these issues early. * **Reviewability:** Humans still need to review AI code. Go's simplicity makes it easier for a human to verify that the code does what the LLM claims it does.

Key Principles Summarized

Principle	Description
Simplicity	The language spec is small enough to hold in your head.
Orthogonality	Features interact in predictable ways (e.g., Goroutines work the same in `main` or a `handler`).
Punt Complexity	If a feature is complex to implement in the compiler *and* hard to understand (e.g., complex metaprogramming), Go leaves it out.

Conclusion

Go is designed for **engineering**, not just programming. It accepts that software is written once but read hundreds of times. By choosing "boring," Go enables you to build exciting, scalable, and reliable systems.

The 3-Layer Practice System

The 3-Layer Practice System: Read, Write, Ship

Learning a language like Go isn't about memorizing syntax; it's about building muscle memory. In 2026, the most effective way to master Go is through a cyclic system we call **Read, Write, Ship**.

Layer 1: Read (Input)

You cannot write idiomatic Go if you haven't seen idiomatic Go. Good writers are always avid readers.

What to Read

1. **The Standard Library:** The Go standard library is the gold standard.
   - Read `net/http` to see how interfaces are used.
   - Read `encoding/json` to understand reflection and tags.
   - Read `time` to see efficient data structures.
2. **High-Quality Open Source:**
   - Caddy Server: For modular architecture and interfaces.
   - HashiCorp Vault/Terraform: For CLI patterns and plugin systems.
   - NATS Server: For high-performance concurrency.

How to Read

Don't just skim. **Trace.** Pick a function call (like `http.ListenAndServe`) and follow it down the rabbit hole until you hit a syscall or assembly.

Layer 2: Write (Output)

Tutorials give you a false sense of competence. You must build things that break.

The "Clone" Technique

Don't wait for a unique idea. Clone existing tools to understand how they work. * **Beginner:** Write a CLI tool (clone `ls` or `cat`). * **Intermediate:** Write a load balancer (clone basic Nginx features). * **Advanced:** Write a distributed key-value store (clone a tiny Redis).

Constraints

Force yourself out of comfort zones: * Write a program without using `struct` tags. * Write a concurrent program without `sync.Mutex` (only channels). * Write a web server without a framework (only `net/http`).

Layer 3: Ship (Feedback)

Code on your laptop doesn't count. "Done" means deployed.

The Feedback Loop

1. **Linting:** `golangci-lint` is your first critic. Configure it to be strict.
2. **Code Review:** Even if solo, use PRs. Review your own diffs. AI tools can effectively review PRs now—use them to spot potential bugs.
3. **Production:** functionality implies running in a Linux container, on a cloud provider, with real traffic.
    - Deploy to **Render**, **Leapcell**, or a **VPS**.
    - Set up **Observability** (logs/metrics). You don't know your code until you see it fail in prod.

Summary

- **Read** to load the patterns into your brain.
- **Write** to test your understanding of those patterns.
- **Ship** to validate that your code actually solves the problem in the real world.

> "Amateurs practice until they get it right. Professionals practice until they can't get it wrong."

Transitioning to Go

Transitioning to Go: For Java and Node.js Developers

If you are coming from an Object-Oriented (Java/C#) or Event-Driven (Node.js/JS) background, Go will feel familiar yet frustratingly different. This chapter maps your existing mental models to Go's reality.

For the Java Developer

Java Concept	Go Equivalent	The Shift in Thinking
Class	**Struct**	Data and behavior are separate. Classes bundles them; Go defines a `type` (data) and `func (t MyType)` (behavior).
Interface	**Interface**	**Implicit.** You don't `implement` interfaces. If you have the methods, you satisfy the interface. This decouples packages.
Exception	**Error**	Errors are **values**, not control flow events. You check them (`if err != nil`), you don't catch them.
ThreadPool	**Goroutines**	Threads are expensive (MBs); Goroutines are cheap (KBs). You can spawn 100k goroutines without blinking.
Annotation	**Struct Tag**	Used strictly for metadata (JSON, DB), not for behavior injection (like Spring Magic).
Maven/Gradle	**Go Modules**	Simplistic dependency graph. No `mvn install`. Just `go mod tidy`.

The "Spring" Trap

Don't try to build "Spring in Go". Dependency Injection containers are largely unnecessary in Go. Pass dependencies explicitly in constructors (struct factories).

```
// Java: @Autowired Service service;
// Go:
func NewServer(db *sql.DB, logger *Logger) *Server {
    return &Server{db: db, logger: logger}
}
```

For the Node.js Developer

Node.js Concept	Go Equivalent	The Shift in Thinking
Promise / Async Await	**Blocking Code**	Go code *looks* synchronous but runs concurrently. The runtime handles the I/O scheduling. No "Callback Hell" or unwieldy `await` chains.
npm	**Go Modules**	No `node_modules` black hole. Dependencies are compiled into a single binary.
Event Loop	**Go Scheduler**	Node has one thread; block it and you die. Go has M:N scheduling; if one goroutine blocks, others keep running on other OS threads.
Dynamic Types	**Static Types**	You catch typos at compile time, not runtime. `interface{}` (or `any`) exists but use it sparingly.
Express/NestJS	**net/http**	The stdlib is production-ready. You often don't need a framework. `Chi` or `Echo` are light routers, not heavy frameworks.

The "Concurrency" Trap

In Node, you rely on `Promise.all` for concurrency. In Go, you use **Channels** and **WaitGroups**.

```
// Node
await Promise.all([task1(), task2()]);
```

```
// Go
var wg sync.WaitGroup
wg.Add(2)
go func() { defer wg.Done(); task1() }()
go func() { defer wg.Done(); task2() }()
wg.Wait()
```

Universal Truths in Go

1. **Composition over Inheritance:** You don't extend classes. You embed structs.
2. **Explicit is better than Implicit:** No magic checking. No global state if avoidable.
3. **Values matter:** Learn distinction between passing a copy (`T`) vs passing a pointer (`*T`). In JS/Java, object references are implicit; in Go, pointers are explicit.

Summary

- **Java Docs:** Drop the AbstractFactoryPatterns. Build simple structs.
- **Node Devs:** Embrace the type system and true parallelism (multi-core).
- **Everyone:** Respect the error. `if err != nil` is the heartbeat of a Go program.

Installing and Running Go

Overview

Setting up a Go development environment is straightforward. This chapter covers installation, verification, and the fundamental `go run` and `go build` workflow that you'll use throughout your Go journey.

Installation

macOS

Using Homebrew (recommended):

```
brew install go
```

Or download from go.dev/dl and run the installer package.

Linux

Download and extract:

```
# Download the latest version (check go.dev/dl for current version)
wget https://go.dev/dl/go1.26.0.linux-amd64.tar.gz

# Remove any previous installation and extract
sudo rm -rf /usr/local/go
sudo tar -C /usr/local -xzf go1.26.0.linux-amd64.tar.gz

# Add to PATH (add to ~/.bashrc or ~/.zshrc)
export PATH=$PATH:/usr/local/go/bin
```

Windows

Download the MSI installer from go.dev/dl and run it. The installer adds Go to your PATH automatically.

Verify Installation

```
$ go version
go version go1.24.0 darwin/arm64
```

Environment Variables

Variable	Purpose	Default
`GOROOT`	Go installation directory	Auto-detected
`GOPATH`	Workspace directory	`$HOME/go`
`GOBIN`	Binary installation directory	`$GOPATH/bin`

Check your environment:

```
$ go env
# Shows all Go environment variables

$ go env GOPATH
/Users/yourname/go
```

Your First Go Program

Create a file named `hello.go`:

```
package main

import "fmt"

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

The `go run` Command

`go run` compiles and executes in one step—perfect for development:

```
$ go run hello.go
Hello, Go!
```

How It Works

1. Compiles the source to a temporary binary
2. Executes that binary
3. Cleans up the temporary file

Running Multiple Files

```
# Run multiple files
$ go run main.go utils.go

# Run all Go files in current directory
$ go run .
```

The `go build` Command

`go build` creates a permanent executable:

```
$ go build hello.go
$ ls
hello    hello.go

$ ./hello
Hello, Go!
```

Common Build Options

```
# Specify output name
$ go build -o myapp hello.go

# Build for different OS/architecture
$ GOOS=linux GOARCH=amd64 go build -o myapp-linux

# Build with optimizations (strip debug info)
$ go build -ldflags="-s -w" -o myapp
```

Cross-Compilation

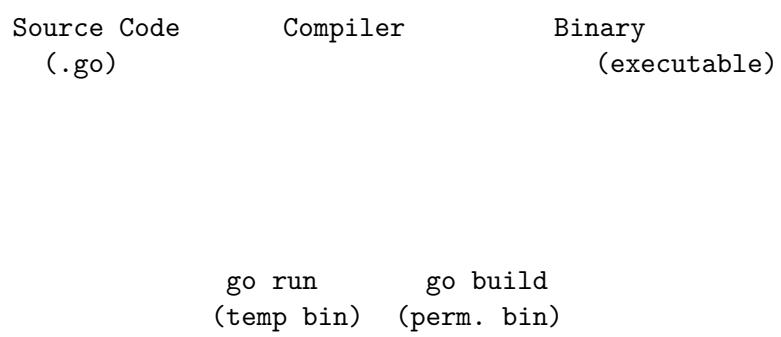
Go makes cross-compilation trivial:

```
# Build for Linux from macOS
$ GOOS=linux GOARCH=amd64 go build -o app-linux

# Build for Windows
$ GOOS=windows GOARCH=amd64 go build -o app.exe

# Build for ARM (Raspberry Pi)
$ GOOS=linux GOARCH=arm GOARM=7 go build -o app-arm
```

The Build Lifecycle



IDE and Editor Setup

Visual Studio Code

1. Install the Go extension
2. Open any `.go` file
3. Accept prompts to install Go tools

Recommended Tools (installed automatically)

- `gopls` - Language server
- `dlv` - Debugger
- `staticcheck` - Linter

GoLand

JetBrains GoLand is a commercial IDE with excellent Go support out of the box.

Neovim/Vim

Use `gopls` with your LSP client of choice (nvim-lspconfig, coc.nvim, etc.).

Project Structure Basics

```
myproject/
   go.mod          # Module definition
   go.sum          # Dependency checksums
   main.go         # Entry point
   internal/       # Private packages
       config/
           config.go
   pkg/            # Public packages (optional)
       utils/
           utils.go
```

Common Pitfalls

GOPATH vs Modules

Modern Go uses **modules** (introduced in Go 1.11). You don't need to work inside `$GOPATH/src` anymore:

```
# Initialize a new module anywhere
$ mkdir myproject && cd myproject
$ go mod init github.com/username/myproject
```

Executable vs Library

Only `package main` with a `main()` function creates executables:

```
// This creates a binary
package main

func main() { }
```

```
// This is a library (cannot run directly)
package mylib

func Helper() { }
```

Summary

Command	Purpose
`go run`	Compile and run (temporary)
`go build`	Compile to binary
`go install`	Compile and install to `$GOBIN`
`go env`	Show environment variables
`go version`	Show Go version

Exercises

1. Install Go and verify with `go version`
2. Create a "Hello, World!" program and run it with `go run`
3. Build the same program with `go build` and execute the binary
4. Cross-compile for a different operating system

Related Topics

- Why Go Exists
- Learning Go in 2026
- How Go Code Is Organized
- Core Go Commands

How Go Code Is Organized

Overview

Go has strong opinions about code organization. Understanding packages, imports, and project structure is essential for writing maintainable Go programs and for your code to work correctly with the Go toolchain.

Packages: The Building Blocks

Every Go file belongs to a package. Packages group related code and control visibility.

```
// File: greet.go
package greeting  // Package declaration (first line)

import "fmt"

func Hello(name string) string {
    return fmt.Sprintf("Hello, %s!", name)
}
```

Package Rules

Rule	Description
All files in a directory belong to the same package	You can't have `package foo` and `package bar` in the same folder
Package name matches directory name (by convention)	Directory `server/` contains `package server`
`package main` is special	It defines an executable, not a library

The `main` Package

Only `package main` can produce an executable. It must have a `main()` function:

```go
package main

import "fmt"

func main() {
    fmt.Println("This is the entry point")
}
```

Import System

Basic Imports

```go
import "fmt"              // Standard library
import "net/http"         // Nested standard library package
import "github.com/user/repo"  // External package
```

Import Block (Preferred Style)

```go
import (
    // Standard library (grouped first)
    "fmt"
    "net/http"

    // Third-party packages (blank line separator)
    "github.com/gin-gonic/gin"

    // Internal packages (blank line separator)
    "myproject/internal/config"
)
```

Import Aliases

```go
import (
    "crypto/rand"
    mrand "math/rand"  // Alias to avoid collision
)

// Usage
cryptoBytes, _ := rand.Read(buf)
randomInt := mrand.Intn(100)
```

Blank Imports (Side Effects Only)

```
import (
    "database/sql"
    _ "github.com/lib/pq"  // Import for side effects (driver registration)
)
```

Dot Imports (Avoid in Production)

```
import . "fmt"

// Now you can use Println directly
Println("Hello")  // Instead of fmt.Println
```

Visibility: Exported vs Unexported

Go uses capitalization to control visibility:

```
package user

// Exported (public) - starts with uppercase
type User struct {
    Name  string  // Exported field
    Email string  // Exported field
    age   int     // unexported field (private)
}

// Exported function
func CreateUser(name string) *User {
    return &User{Name: name}
}

// unexported function (private)
func validate(u *User) bool {
    return len(u.Name) > 0
}
```

Name	Visibility
`User`	Exported (accessible from other packages)
`Name`	Exported field
`age`	Unexported (only accessible within `user` package)
`CreateUser`	Exported function
`validate`	Unexported function

Modules: Modern Dependency Management

A **module** is a collection of packages with a `go.mod` file at the root.

Creating a Module

```
$ mkdir myproject && cd myproject
$ go mod init github.com/username/myproject
```

This creates `go.mod`:

```
module github.com/username/myproject

go 1.26
```

Module Structure

```
github.com/username/myproject/
   go.mod
   go.sum
   main.go
   config/
       config.go      # package config
   internal/
       database/
           db.go      # package database (private)
   pkg/
        api/
            api.go     # package api (public)
```

Internal Packages

The `internal/` directory has special meaning: packages inside it can only be imported by code within the same module tree.

```
myproject/
   internal/
       secret/
           secret.go   # Only myproject can import this
   cmd/
        app/
            main.go     # Can import internal/secret
```

```
// This works (same module)
import "github.com/username/myproject/internal/secret"

// This fails (different module trying to import internal)
// Error: use of internal package not allowed
```

Standard Project Layout

While Go doesn't mandate a structure, this layout is widely adopted:

```
myproject/
  cmd/                    # Main applications
    myapp/
      main.go
    worker/
      main.go
  internal/               # Private packages
    config/
    database/
    service/
  pkg/                    # Public libraries (optional)
    api/
  api/                    # OpenAPI/Swagger specs
  web/                    # Web assets
  scripts/                # Build/install scripts
  docs/                   # Documentation
  go.mod
  go.sum
  README.md
```

`cmd/` Directory

Each subdirectory in `cmd/` becomes a separate binary:

```
$ go build ./cmd/myapp
$ go build ./cmd/worker
```

Package Naming Conventions

Good	Bad	Why
`user`	`userPackage`	Avoid redundant suffixes
`http`	`httputil`	Only add suffix if necessary

Good	Bad	Why
`strconv`	`stringconversion`	Short but clear
`io`	`inputoutput`	Abbreviations OK if common

Avoid Meaningless Names

- `util` → Use specific names like `stringutil`, `timeutil`
- `common` → Be specific about what's common
- `misc` → Break into focused packages

Circular Import Prevention

Go prohibits circular imports. If you have:

```
package a → imports → package b
package b → imports → package a  // Error!
```

Solutions: 1. **Extract common code** to a third package 2. **Use interfaces** to break the dependency 3. **Restructure** your packages

Summary

Concept	Purpose
Package	Groups related code, controls visibility
Module	Collection of packages with version info
`internal/`	Private packages within a module
Uppercase	Exported (public)
Lowercase	Unexported (private)

Exercises

1. Create a module with two packages and have one import the other
2. Create an `internal/` package and verify external code can't import it
3. Create a project with `cmd/` containing multiple applications

Related Topics

- Core Go Commands
- Dependency Management

Core Go Commands

Overview

The go command is your Swiss Army knife for Go development. This chapter provides a deep dive into the essential commands you'll use daily, from building and testing to analyzing and maintaining your code.

Command Summary

Command	Purpose
`go build`	Compile packages and dependencies
`go run`	Compile and run Go program
`go test`	Run tests
`go get`	Add dependencies to module
`go mod`	Module maintenance
`go fmt`	Format source code
`go vet`	Report suspicious constructs
`go doc`	Show documentation
`go install`	Compile and install packages
`go clean`	Remove object files

`go build` - Compiling Code

Basic Usage

```
# Build current package
$ go build

# Build specific file
$ go build main.go

# Build with custom output name
$ go build -o myapp

# Build specific package
```

```
$ go build ./cmd/server
```

Build Flags

```
# Verbose output (show packages being compiled)
$ go build -v ./...

# Rebuild all packages (ignore cache)
$ go build -a ./...

# Print commands but don't run them
$ go build -n

# Show build work directory (don't delete)
$ go build -work
```

Cross-Compilation

```
# Build for Linux (AMD64)
$ GOOS=linux GOARCH=amd64 go build -o app-linux

# Build for Windows
$ GOOS=windows GOARCH=amd64 go build -o app.exe

# Build for macOS ARM (Apple Silicon)
$ GOOS=darwin GOARCH=arm64 go build -o app-macos

# Build for Raspberry Pi
$ GOOS=linux GOARCH=arm GOARM=7 go build -o app-arm
```

Linker Flags

```
# Strip debug info (smaller binary)
$ go build -ldflags="-s -w" -o app

# Embed version information
$ go build -ldflags="-X main.version=1.0.0" -o app
```

```
// In your code
var version = "dev"  // Overwritten by -ldflags
```

```
func main() {
    fmt.Println("Version:", version)
}
```

`go run` - Quick Execution

```
# Run a single file
$ go run main.go

# Run multiple files
$ go run main.go helper.go

# Run all files in directory
$ go run .

# Run with arguments
$ go run main.go --port=8080 --debug
```

`go test` - Testing

```
# Run all tests in current package
$ go test

# Run all tests recursively
$ go test ./...

# Verbose output
$ go test -v

# Run specific test
$ go test -run TestFunctionName

# Run with coverage
$ go test -cover

# Generate coverage report
$ go test -coverprofile=coverage.out
$ go tool cover -html=coverage.out

# Run benchmarks
$ go test -bench=.
```

```
# Test with race detector
$ go test -race ./...
```

`go get` - Dependency Management

```
# Add a dependency (latest version)
$ go get github.com/gin-gonic/gin

# Add specific version
$ go get github.com/gin-gonic/gin@v1.9.0

# Add specific commit
$ go get github.com/gin-gonic/gin@a1b2c3d

# Update a dependency
$ go get -u github.com/gin-gonic/gin

# Update all dependencies
$ go get -u ./...

# Update only patch versions
$ go get -u=patch ./...
```

`go mod` - Module Operations

```
# Initialize a new module
$ go mod init github.com/username/project

# Download dependencies
$ go mod download

# Tidy up go.mod (add missing, remove unused)
$ go mod tidy

# Verify dependencies
$ go mod verify

# Create vendor directory
$ go mod vendor

# Show dependency graph
$ go mod graph
```

```
# Explain why a dependency is needed
$ go mod why github.com/some/package

# Edit go.mod programmatically
$ go mod edit -require github.com/pkg/errors@v0.9.1
```

`go fmt` / `gofmt` - Formatting

```
# Format all Go files in current directory
$ go fmt ./...

# Use gofmt directly with options
$ gofmt -w main.go        # Write changes to file
$ gofmt -d main.go        # Show diff
$ gofmt -l .              # List files that need formatting
$ gofmt -s main.go        # Simplify code
```

`go vet` - Static Analysis

```
# Vet current package
$ go vet

# Vet all packages
$ go vet ./...

# Run specific analyzers
$ go vet -composites=false ./...
```

Common issues `go vet` catches: - Printf format string mismatches - Unreachable code - Suspicious mutex usage - Struct field tag issues

`go doc` - Documentation

```
# Show package documentation
$ go doc fmt

# Show function documentation
$ go doc fmt.Println

# Show type documentation
```

```
$ go doc http.Client

# Show all documentation
$ go doc -all fmt

# Start documentation server
$ godoc -http=:6060
# Then visit http://localhost:6060
```

`go install` - Installing Binaries

```
# Install command to $GOBIN
$ go install

# Install specific version of a tool
$ go install golang.org/x/tools/gopls@latest

# Install from specific package
$ go install ./cmd/myapp
```

`go clean` - Cleanup

```
# Remove object files
$ go clean

# Remove cached build files
$ go clean -cache

# Remove test cache
$ go clean -testcache

# Remove all cached data
$ go clean -cache -testcache -modcache

# Show what would be removed
$ go clean -n
```

`go env` - Environment

```
# Show all environment variables
$ go env

# Show specific variable
$ go env GOPATH

# Set environment variable
$ go env -w GOBIN=/usr/local/bin

# Unset environment variable
$ go env -u GOBIN
```

`go list` - Package Information

```
# List current package
$ go list

# List all packages
$ go list ./...

# JSON output
$ go list -json ./...

# List dependencies
$ go list -m all

# List with template
$ go list -f '{{.ImportPath}} -> {{.Deps}}' ./...
```

`go generate` - Code Generation

```
# Run all generate directives
$ go generate ./...

# Run with verbose output
$ go generate -v ./...
```

```
// In source file
//go:generate stringer -type=Status
```

```
type Status int
```

Tool Installation Best Practices

```
# Install development tools
$ go install golang.org/x/tools/gopls@latest          # Language server
$ go install github.com/go-delve/delve/cmd/dlv@latest # Debugger
$ go install honnef.co/go/tools/cmd/staticcheck@latest # Linter

# Verify installation
$ which gopls
$ which dlv
```

Common Workflows

Development Cycle

```
# 1. Write code
# 2. Format
$ go fmt ./...
# 3. Vet
$ go vet ./...
# 4. Test
$ go test ./...
# 5. Build
$ go build -o app ./cmd/server
```

Release Build

```
# Production build with version
$ go build \
    -ldflags="-s -w -X main.version=$(git describe --tags)" \
    -o bin/app \
    ./cmd/server
```

Summary

Task	Command
Quick run	`go run main.go`

Task	Command
Build binary	`go build -o app`
Run tests	`go test ./...`
Format code	`go fmt ./...`
Check issues	`go vet ./...`
Add dependency	`go get github.com/pkg@version`
Clean modules	`go mod tidy`
View docs	`go doc package.Function`

Related Topics

- Formatting, Vetting, and Documentation
- Dependency Management

Formatting, Vetting, and Documentation

Overview

Go has a unique culture: there's one blessed way to format code, a built-in static analyzer for common mistakes, and a documentation system that extracts docs from comments. This chapter covers `gofmt`, `go vet`, and `godoc` standards.

Code Formatting with `gofmt`

Why Gofmt Exists

Unlike other languages where style guides vary (tabs vs. spaces, brace placement), Go has a single canonical format enforced by `gofmt`. This eliminates style debates and ensures all Go code looks the same.

> "Gofmt's style is no one's favorite, yet gofmt is everyone's favorite." — Rob Pike

Basic Usage

```
# Format a file (print to stdout)
$ gofmt main.go

# Format and overwrite file
$ gofmt -w main.go

# Format all files recursively
$ gofmt -w .

# Using go fmt (recommended)
$ go fmt ./...
```

Formatting Rules

`gofmt` enforces:

```
// BEFORE (your style)
func foo(x int,y string){
if x>0{
return
}
}

// AFTER (gofmt style)
func foo(x int, y string) {
    if x > 0 {
        return
    }
}
```

Rule	Gofmt Standard
Indentation	Tabs
Spacing	Spaces around operators
Braces	Opening brace on same line
Line length	No limit (but keep reasonable)
Blank lines	Strategic for readability

Code Simplification

Use `-s` to simplify code:

```
$ gofmt -s -w main.go
```

```
// Before
s[a:len(s)]
for x, _ := range v {}
[]int{1, 2, 3}[0:2]

// After -s
s[a:]
for x := range v {}
[]int{1, 2, 3}[:2]
```

Import Formatting with `goimports`

`goimports` does everything `gofmt` does, plus it manages imports:

```
# Install
$ go install golang.org/x/tools/cmd/goimports@latest
```

```
# Format and fix imports
$ goimports -w main.go
```

```
// Before (missing import, unused import)
package main
import (
    "unused"
)
func main() {
    fmt.Println("Hello")
}

// After goimports
package main

import "fmt"

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

Static Analysis with `go vet`

What Vet Catches

`go vet` detects code that compiles but is probably wrong:

```
$ go vet ./...
```

Common Issues Detected

Printf Format Errors

```
// go vet catches this
fmt.Printf("%d", "string")  // wrong type
fmt.Printf("%s %s", name)   // wrong number of args
```

Unreachable Code

```
func example() int {
    return 42
    fmt.Println("never runs")  // go vet: unreachable code
}
```

Suspicious Loop Variables

```
// go vet warns about this common bug
for i, v := range values {
    go func() {
        fmt.Println(i, v)  // captures loop variable
    }()
}
```

Useless Assignments

```
x := 5
x = x  // go vet: self-assignment
```

Invalid Struct Tags

```
type User struct {
    Name string `json:name`  // Missing quotes around "name"
}
```

Running Specific Checks

```
# List available analyzers
$ go tool vet help

# Run specific analyzer
$ go vet -composites=false ./...
$ go vet -printf=true ./...
```

Enhanced Linting with `staticcheck`

`staticcheck` provides additional checks beyond `go vet`:

```
# Install
$ go install honnef.co/go/tools/cmd/staticcheck@latest

# Run
$ staticcheck ./...
```

Checks include: - Unused code - Deprecated function usage - Simplification suggestions - Performance improvements - Common bugs

Documentation with `godoc`

Writing Documentation

Go extracts documentation from comments directly before declarations:

```
// Package math provides basic mathematical operations.
// It includes functions for arithmetic, trigonometry, and more.
package math

// Pi represents the mathematical constant  .
const Pi = 3.14159

// Add returns the sum of two integers.
// It handles overflow by wrapping around.
func Add(a, b int) int {
    return a + b
}

// Calculator provides stateful mathematical operations.
type Calculator struct {
    // Result holds the current calculation result.
    Result float64
}

// Add adds n to the current result.
func (c *Calculator) Add(n float64) {
    c.Result += n
}
```

Documentation Conventions

Rule	Example
Start with name	`// Add returns the sum...`
Complete sentences	End with period

Rule	Example
First sentence is summary	Shown in package lists
Blank line for paragraphs	Separate blocks

Code Examples in Docs

Create examples in `*_test.go` files:

```
// example_test.go
package math_test

import (
    "fmt"
    "myproject/math"
)

func ExampleAdd() {
    result := math.Add(2, 3)
    fmt.Println(result)
    // Output: 5
}

func ExampleCalculator_Add() {
    c := &math.Calculator{}
    c.Add(10)
    c.Add(5)
    fmt.Println(c.Result)
    // Output: 15
}
```

These examples: - Appear in documentation - Are tested by `go test` - Show real usage

Viewing Documentation

```
# Command line
$ go doc fmt
$ go doc fmt.Println
$ go doc -all fmt

# Local web server
$ go install golang.org/x/tools/cmd/godoc@latest
$ godoc -http=:6060
# Visit http://localhost:6060
```

Package Comments

For larger packages, use a `doc.go` file:

```
// doc.go

/*
Package server implements an HTTP server with middleware support.

# Getting Started

Create a new server and add routes:

    srv := server.New()
    srv.Get("/", handleHome)
    srv.Listen(":8080")

# Middleware

Add middleware to process all requests:

    srv.Use(server.Logger())
    srv.Use(server.Recovery())

# Configuration

Configure the server using options:

    srv := server.New(
        server.WithTimeout(30 * time.Second),
        server.WithMaxBodySize(1 << 20),
    )
*/
package server
```

Combining Tools in Workflow

Pre-commit Hook

```
#!/bin/bash
# .git/hooks/pre-commit

# Format
gofmt -l -w .
```

```
# Vet
go vet ./...
if [ $? -ne 0 ]; then
    echo "go vet failed"
    exit 1
fi

# Staticcheck
staticcheck ./...
if [ $? -ne 0 ]; then
    echo "staticcheck failed"
    exit 1
fi
```

Makefile Integration

```
.PHONY: check fmt vet lint

fmt:
    gofmt -w .

vet:
    go vet ./...

lint:
    staticcheck ./...

check: fmt vet lint
    @echo "All checks passed"
```

CI Pipeline (GitHub Actions)

```
- name: Check formatting
  run: |
    if [ "$(gofmt -l . | wc -l)" -gt 0 ]; then
      echo "Code is not formatted"
      gofmt -d .
      exit 1
    fi

- name: Vet
  run: go vet ./...

- name: Staticcheck
```

```
    run: |
      go install honnef.co/go/tools/cmd/staticcheck@latest
      staticcheck ./...
```

Summary

Tool	Purpose	Usage
`gofmt`	Format code	`gofmt -w .`
`goimports`	Format + manage imports	`goimports -w .`
`go vet`	Catch common mistakes	`go vet ./...`
`staticcheck`	Enhanced linting	`staticcheck ./...`
`godoc`	Generate documentation	`godoc -http=:6060`

Related Topics

- Core Go Commands
- Testing Fundamentals

Dependency Management

Overview

Go modules, introduced in Go 1.11 and default since Go 1.16, provide built-in dependency management. This chapter covers everything about `go.mod`, `go.sum`, versioning, and managing external libraries.

Understanding Go Modules

A module is a collection of packages with a `go.mod` file that defines: - Module path (import path) - Go version - Dependencies and their versions

Creating a Module

```
$ mkdir myproject && cd myproject
$ go mod init github.com/username/myproject
```

This creates `go.mod`:

```
module github.com/username/myproject

go 1.26
```

The `go.mod` File

Anatomy of go.mod

```
module github.com/username/myproject

go 1.26

require (
    github.com/gin-gonic/gin v1.9.1
    github.com/stretchr/testify v1.8.4
)
```

```
require (
    // indirect dependencies
    github.com/bytedance/sonic v1.9.1 // indirect
    golang.org/x/net v0.10.0 // indirect
)

exclude (
    github.com/broken/pkg v1.0.0
)

replace (
    github.com/old/module => github.com/new/module v2.0.0
    github.com/local/dev => ../local-dev
)

retract (
    v1.0.0 // Contains security vulnerability
    [v1.1.0, v1.2.0] // Accidental release
)
```

Directives Explained

Directive	Purpose
`module`	Module path (required)
`go`	Minimum Go version
`require`	Dependencies with versions
`exclude`	Versions to ignore
`replace`	Substitute modules
`retract`	Mark versions as broken

The `go.sum` File

`go.sum` contains cryptographic checksums representing module dependencies:

```
github.com/gin-gonic/gin v1.9.1 h1:4idEAncQnU5cB7BeOkPtxjfCSye0AAm1R0RVIqJ+Jmg=
github.com/gin-gonic/gin v1.9.1/go.mod h1:hPrL7YrpYKXt5YId3A/Tn+7r7IyQ4PGNmP1c42GGpvQ=
```

Each entry has: - Module path and version - Hash of module contents (`h1:`) - Hash of `go.mod` file

Never edit `go.sum` manually — it's managed by Go tools.

Adding Dependencies

Using `go get`

```
# Add latest version
$ go get github.com/gin-gonic/gin

# Add specific version
$ go get github.com/gin-gonic/gin@v1.9.1

# Add latest minor version
$ go get github.com/gin-gonic/gin@v1.9

# Add specific commit
$ go get github.com/gin-gonic/gin@a1b2c3d

# Add from branch
$ go get github.com/gin-gonic/gin@main
```

Automatic Detection

Simply import and run:

```
import "github.com/gin-gonic/gin"
```

```
$ go mod tidy  # Downloads and records dependency
```

Updating Dependencies

```
# Update specific package (latest minor/patch)
$ go get -u github.com/gin-gonic/gin

# Update to specific version
$ go get github.com/gin-gonic/gin@v1.10.0

# Update all dependencies
$ go get -u ./...

# Update only patch versions (safer)
$ go get -u=patch ./...
```

Semantic Versioning

Go modules expect Semantic Versioning:

`v1.2.3`

```
 Patch: bug fixes (backward compatible)
Minor: new features (backward compatible)
Major: breaking changes
```

Major Version Suffixes

For v2+, the module path includes the major version:

```
// go.mod
require github.com/user/project/v2 v2.1.0

// import
import "github.com/user/project/v2"
```

Managing go.mod

`go mod tidy`

The most important maintenance command:

```
$ go mod tidy
```

This: - Adds missing dependencies - Removes unused dependencies - Updates `go.sum`

Run this frequently, especially before commits.

`go mod download`

Pre-download all dependencies:

```
$ go mod download
```

Useful for CI caching or air-gapped environments.

`go mod verify`

Check that dependencies haven't been modified:

```
$ go mod verify
all modules verified
```

go mod why

Explain why a dependency is needed:

```
$ go mod why golang.org/x/net

# github.com/username/myproject
github.com/username/myproject
github.com/gin-gonic/gin
golang.org/x/net/html
```

go mod graph

Show dependency graph:

```
$ go mod graph
github.com/username/myproject github.com/gin-gonic/gin@v1.9.1
github.com/gin-gonic/gin@v1.9.1 github.com/bytedance/sonic@v1.9.1
...
```

Vendoring

Copy dependencies into your repository:

```
# Create vendor directory
$ go mod vendor

# Build using vendor
$ go build -mod=vendor
```

Vendoring pros: - Reproducible builds - Works offline - Audit dependencies

Vendoring cons: - Bloated repository - Manual updates

Replace Directive

Local Development

Replace a module with a local path:

```
replace github.com/some/package => ../local-package
```

Fork Substitution

Use your fork instead of original:

```
replace github.com/original/pkg => github.com/yourfork/pkg v1.2.3
```

Version Override

Force a specific version:

```
replace github.com/vulnerable/pkg v1.0.0 => github.com/vulnerable/pkg v1.0.1
```

Private Modules

GOPRIVATE

Configure private repository patterns:

```
$ go env -w GOPRIVATE=github.com/mycompany/*,gitlab.internal.com/*
```

Git Credentials

For private repos, configure Git:

```
# Use SSH
$ git config --global url."git@github.com:".insteadOf "https://github.com/"

# Or use access token
$ git config --global url."https://token:${TOKEN}@github.com/".insteadOf "https://github.com
```

Dependency Management Best Practices

1. Pin Dependencies

Always use exact versions in production:

```
# Good: exact version
$ go get github.com/pkg/errors@v0.9.1
```

```
# Risky: floating version
$ go get github.com/pkg/errors@latest
```

2. Regular Updates

Check for updates periodically:

```
$ go list -m -u all
```

3. Minimal Dependencies

Fewer dependencies = fewer problems: - Check if you really need that package - Consider stdlib alternatives - Watch for transitive dependencies

4. Security Scanning

Use vulnerability scanning:

```
# Built-in (Go 1.18+)
$ go install golang.org/x/vuln/cmd/govulncheck@latest
$ govulncheck ./...
```

Common Issues

Module Not Found

```
# Ensure GOPROXY is set
$ go env GOPROXY
https://proxy.golang.org,direct

# Try direct fetch
$ GOPROXY=direct go get github.com/some/package
```

Version Conflicts

```
# See what's required
$ go mod graph | grep conflicting-package

# Force specific version
$ go get conflicting-package@v1.2.3
```

Checksum Mismatch

```
# Clear cache and retry
$ go clean -modcache
$ go mod download
```

Summary

Command	Purpose
`go mod init`	Create new module
`go mod tidy`	Sync dependencies
`go get pkg@version`	Add/update dependency
`go mod download`	Pre-fetch dependencies
`go mod verify`	Verify checksums
`go mod vendor`	Create vendor directory

Related Topics

- Workspaces and Multi-Module Development
- How Go Code Is Organized

Workspaces and Multi-Module Development

Overview

Go workspaces, introduced in Go 1.18, solve the challenge of developing multiple related modules simultaneously. With `go.work`, you can work on a main project and its dependencies together without modifying `go.mod` files.

The Problem Workspaces Solve

Without Workspaces

When developing multiple modules together, you'd need `replace` directives:

```
// main-app/go.mod
module github.com/company/main-app

replace github.com/company/shared-lib => ../shared-lib
```

Problems: - Must edit `go.mod` (can accidentally commit) - Each developer has different paths - CI/CD requires cleanup

With Workspaces

```
$ go work init main-app shared-lib
```

```
// go.work
go 1.26

use (
    ./main-app
    ./shared-lib
)
```

Benefits: - No `go.mod` modifications - Works for entire team - Automatically ignored by Git

Creating a Workspace

Initial Setup

```
# Directory structure
workspace/
   go.work            # Workspace file
   main-app/          # Main application
       go.mod
       main.go
   shared-lib/        # Library module
       go.mod
       lib.go
```

```
# Create workspace
$ cd workspace
$ go work init ./main-app ./shared-lib
```

The `go.work` File

```
go 1.26

use (
    ./main-app
    ./shared-lib
)
```

All commands (`go build`, `go test`, etc.) now use local modules.

Workspace Commands

`go work init`

Create a new workspace:

```
# Initialize with modules
$ go work init ./module1 ./module2

# Initialize empty workspace
$ go work init
```

go work use

Add modules to workspace:

```
# Add single module
$ go work use ./new-module

# Add multiple modules
$ go work use ./mod1 ./mod2

# Recursively find and add all modules
$ go work use -r .
```

go work edit

Programmatically modify workspace:

```
# Add a use directive
$ go work edit -use ./new-module

# Remove a use directive
$ go work edit -dropuse ./old-module

# Set Go version
$ go work edit -go 1.26
```

go work sync

Sync workspace modules with their dependencies:

```
$ go work sync
```

This updates each module's `go.mod` to match workspace requirements.

Multi-Module Development Workflow

Project Structure

```
company-workspace/
  go.work
  api/
     go.mod          # module github.com/company/api
     api.go
     api_test.go
```

```
core/
    go.mod          # module github.com/company/core
    core.go
cli/
    go.mod          # module github.com/company/cli
    main.go
internal-tools/
    go.mod          # module github.com/company/tools
    tools.go
```

Setting Up

```
$ cd company-workspace
$ go work init ./api ./core ./cli ./internal-tools
```

Development Flow

```
# Changes in core/ are immediately available to cli/
$ cd cli
$ go build  # Uses local core package

# Run tests across all modules
$ cd ..
$ go test ./...

# Build all binaries
$ go build ./cli/...
```

Replace vs Workspace

When to Use `replace`

Use Case	Approach
Permanent fork	`replace` in `go.mod`
CI workaround	`replace` in `go.mod`
Single dev experiment	`replace` in `go.mod`

When to Use Workspace

Use Case	Approach
Multi-module development	`go.work`
Team development	`go.work`
Monorepo-style work	`go.work`

Workspace with Replace

You can combine both. `go.work` supports `replace`:

```
go 1.26

use (
    ./main-app
    ./shared-lib
)

replace github.com/external/dep => ./custom-fork
```

Best Practices

1. Git Ignore `go.work`

```
# .gitignore
go.work
go.work.sum
```

Each developer creates their own workspace.

2. Document Setup

Include setup instructions in README:

```
## Development Setup

1. Clone all repositories:
   ```bash
   git clone github.com/company/api
   git clone github.com/company/core
   git clone github.com/company/cli
```

2. Create workspace:
```

```
go work init ./api ./core ./cli
```
```

### 3. CI Without Workspaces

In CI, build each module independently:

```yaml
# GitHub Actions
jobs:
  test:
    strategy:
      matrix:
        module: [api, core, cli]
    steps:
      - uses: actions/checkout@v4
      - name: Test
        working-directory: ${{ matrix.module }}
        run: go test ./...
```

4. Shared Workspace for Monorepos

For monorepos, commit `go.work`:

```
monorepo/
   go.work            # Committed
   services/
       api/
       worker/
       gateway/
   packages/
       auth/
       database/
```

Common Patterns

Microservices Development

```
workspace/
   go.work
   services/
       user-service/
       order-service/
       payment-service/
```
```

```
shared/
    proto/
    middleware/
    database/
```

```
$ go work init
$ go work use -r .
```

Library Development

Testing a library change across consumers:

```
workspace/
  go.work
  my-library/          # The library
  app-using-library/   # Consumer 1
  another-consumer/    # Consumer 2
```

Troubleshooting

Module Not Found in Workspace

```
# Verify workspace includes module
$ cat go.work

# Re-add module
$ go work use ./missing-module
```

Wrong Version Used

Workspace modules take priority. To use published version:

```
# Temporarily disable workspace
$ GOWORK=off go build
```

Workspace Mode Detection

Check if workspace is active:

```
$ go env GOWORK
/path/to/go.work
```

Summary

Command	Purpose
`go work init`	Create workspace
`go work use`	Add modules
`go work edit`	Modify workspace
`go work sync`	Sync dependencies
`GOWORK=off`	Disable workspace

Exercises

1. Create a workspace with two modules where one depends on the other
2. Make changes to the dependency and verify the main module sees them
3. Add a third module to an existing workspace

Related Topics

- How Go Code Is Organized
- Dependency Management

Core

Predeclared Types

Overview

Go provides a set of built-in types that form the foundation of all programs. Understanding these predeclared types—booleans, numerics, strings, and the error interface—is essential for writing effective Go code.

Boolean Type

The `bool` type represents true/false values.

```
var enabled bool      // Zero value: false
active := true
disabled := false

// Boolean operators
result := active && disabled  // AND: false
result = active || disabled   // OR: true
result = !active              // NOT: false
```

Boolean Expressions

```
x := 10
y := 20

greater := x > y      // false
equal := x == y       // false
notEqual := x != y    // true
lessEqual := x <= y   // true
```

Numeric Types

Integer Types

Type	Size	Range
`int8`	8 bits	-128 to 127
`int16`	16 bits	-32,768 to 32,767
`int32`	32 bits	-2B to 2B
`int64`	64 bits	±9 quintillion
`int`	Platform	32 or 64 bits

```
var small int8 = 127
var medium int32 = 2_147_483_647  // Underscores for readability
var large int64 = 9_223_372_036_854_775_807
var auto int = 42  // Platform-dependent size
```

Unsigned Integers

Type	Size	Range
`uint8`	8 bits	0 to 255
`uint16`	16 bits	0 to 65,535
`uint32`	32 bits	0 to 4B
`uint64`	64 bits	0 to 18 quintillion
`uint`	Platform	32 or 64 bits

```
var age uint8 = 30
var count uint = 1000
```

Type Aliases

```
type byte = uint8   // Alias for byte data
type rune = int32   // Alias for Unicode code points
```

Floating-Point Types

Type	Size	Precision
`float32`	32 bits	~7 decimal digits
`float64`	64 bits	~15 decimal digits

```
var pi float32 = 3.14159
var precise float64 = 3.141592653589793

// Scientific notation
```

```
avogadro := 6.022e23
planck := 6.626e-34
```

Complex Numbers

```
var c1 complex64 = 3 + 4i
c2 := complex(5, 12)  // 5 + 12i

real := real(c2)      // 5
imag := imag(c2)      // 12
```

String Type

Strings are immutable sequences of bytes (typically UTF-8).

```
var greeting string = "Hello, World!"
name := "Go"

// String concatenation
message := greeting + " Welcome to " + name

// Multi-line strings (raw string literals)
poem := `Roses are red,
Violets are blue,
Go is awesome,
And so are you!`

// String length (bytes, not characters)
len(greeting)  // 13
```

Strings vs Runes

```
s := "Hello,  "

len(s)              // 13 bytes
len([]rune(s))      // 9 characters

// Iterate by byte
for i := 0; i < len(s); i++ {
    fmt.Printf("%x ", s[i])
}
```

```go
// Iterate by rune (character)
for i, r := range s {
    fmt.Printf("%d: %c\n", i, r)
}
```

The Error Type

`error` is a built-in interface type:

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

```go
import "errors"

func divide(a, b float64) (float64, error) {
    if b == 0 {
        return 0, errors.New("division by zero")
    }
    return a / b, nil
}

result, err := divide(10, 0)
if err != nil {
    fmt.Println("Error:", err)
}
```

Type Conversions

Go requires explicit type conversions:

```go
var i int = 42
var f float64 = float64(i)    // int to float64
var u uint = uint(i)          // int to uint

// String conversions
import "strconv"

s := strconv.Itoa(42)          // "42"
n, _ := strconv.Atoi("42")     // 42

fs := strconv.FormatFloat(3.14, 'f', 2, 64)  // "3.14"
```

Common Conversion Pitfalls

```
// Overflow (no error, just wraps)
var big int64 = 1000
var small int8 = int8(big)  // Overflow! Result: -24

// Float to int truncates
var f float64 = 3.9
var i int = int(f)  // 3 (not 4)
```

Type Information

```
import "fmt"

var x int = 42
fmt.Printf("Type: %T, Value: %v\n", x, x)
// Output: Type: int, Value: 42
```

Numeric Literals

```
// Decimal
decimal := 42

// Binary (0b prefix)
binary := 0b101010  // 42

// Octal (0o prefix)
octal := 0o52  // 42

// Hexadecimal (0x prefix)
hex := 0x2A  // 42

// With underscores for readability
billion := 1_000_000_000
```

Summary

Category	Types
Boolean	`bool`
Signed Integers	`int`, `int8`, `int16`, `int32`, `int64`

Category	Types
Unsigned Integers	`uint`, `uint8`, `uint16`, `uint32`, `uint64`
Floating Point	`float32`, `float64`
Complex	`complex64`, `complex128`
String	`string`
Aliases	`byte` (uint8), `rune` (int32)
Error	`error`

Related Topics

- Zero Values and Initialization
- Constants and Literals

Zero Values and Initialization

Overview

Every variable in Go has a value from the moment it's declared. If you don't explicitly initialize a variable, it gets a **zero value**—a sensible default that prevents undefined behavior.

Zero Values by Type

Type	Zero Value
`bool`	`false`
`int`, `int8`, …	`0`
`uint`, `uint8`, …	`0`
`float32`, `float64`	`0.0`
`complex64`, `complex128`	`(0+0i)`
`string`	`""` (empty string)
`pointer`	`nil`
`slice`	`nil`
`map`	`nil`
`channel`	`nil`
`function`	`nil`
`interface`	`nil`

Demonstrating Zero Values

```
package main

import "fmt"

func main() {
    var b bool
    var i int
    var f float64
    var s string
    var p *int
    var sl []int
```

```
    var m map[string]int
    var ch chan int
    var fn func()
    var iface interface{}

    fmt.Printf("bool: %v\n", b)      // false
    fmt.Printf("int: %v\n", i)       // 0
    fmt.Printf("float64: %v\n", f)   // 0
    fmt.Printf("string: %q\n", s)    // ""
    fmt.Printf("pointer: %v\n", p)   // <nil>
    fmt.Printf("slice: %v\n", sl)    // []
    fmt.Printf("map: %v\n", m)       // map[]
    fmt.Printf("channel: %v\n", ch)  // <nil>
    fmt.Printf("func: %v\n", fn)     // <nil>
    fmt.Printf("interface: %v\n", iface) // <nil>
}
```

Struct Zero Values

Struct fields get their respective zero values:

```
type User struct {
    Name    string
    Age     int
    Active  bool
    Balance float64
}

var user User
// user.Name = ""
// user.Age = 0
// user.Active = false
// user.Balance = 0.0
```

Nested Structs

```
type Address struct {
    Street string
    City   string
}

type Person struct {
    Name    string
    Address Address  // Embedded struct gets zero values too
```

```
}

var p Person
// p.Name = ""
// p.Address.Street = ""
// p.Address.City = ""
```

Array Zero Values

Arrays are initialized with zero values for each element:

```
var arr [5]int        // [0, 0, 0, 0, 0]
var strs [3]string    // ["", "", ""]
var bools [2]bool     // [false, false]
```

Why Zero Values Matter

1. Eliminates Undefined Behavior

```
// In Go, this is safe and predictable
var count int
count++  // count is now 1

// In C, this would be undefined behavior
// int count;
// count++;  // Undefined! Could be anything
```

2. Reduces Boilerplate

```
// No need for explicit initialization
type Config struct {
    Debug   bool
    Timeout int
    Host    string
}

cfg := Config{}  // All zeros, ready to use selectively
cfg.Host = "localhost"  // Only set what differs from zero
```

3. Enables "Usable Zero Value" Pattern

Well-designed types work correctly with zero values:

```
import "bytes"

// bytes.Buffer works without initialization
var buf bytes.Buffer
buf.WriteString("Hello, ")
buf.WriteString("World!")
fmt.Println(buf.String())  // "Hello, World!"

// sync.Mutex works without initialization
var mu sync.Mutex
mu.Lock()
mu.Unlock()
```

Initialization Methods

Short Variable Declaration

```
name := "Alice"      // Inferred type: string
count := 42          // Inferred type: int
price := 19.99       // Inferred type: float64
```

Explicit Type Declaration

```
var name string = "Alice"
var count int = 42
var active bool = true
```

Type Inference (var)

```
var name = "Alice"   // Type inferred from value
var count = 42       // int
```

Multiple Variable Declaration

```
var (
    name   = "Alice"
    age    = 30
    active = true
)

// Or inline
x, y, z := 1, 2, 3
```

Composite Literal Initialization

```
// Struct
user := User{
    Name:   "Alice",
    Age:    30,
    Active: true,
}

// Partially initialized (rest are zero values)
user := User{Name: "Bob"}  // Age: 0, Active: false

// Array
arr := [3]int{1, 2, 3}

// Slice
sl := []string{"a", "b", "c"}

// Map
m := map[string]int{"one": 1, "two": 2}
```

nil vs Zero Value

`nil` is the zero value for pointers, slices, maps, channels, functions, and interfaces.

nil Slice vs Empty Slice

```
var nilSlice []int        // nil slice
emptySlice := []int{}     // empty slice (not nil)

nilSlice == nil           // true
```

```
emptySlice == nil         // false

len(nilSlice)             // 0
len(emptySlice)           // 0

// Both work with append
nilSlice = append(nilSlice, 1)      // [1]
emptySlice = append(emptySlice, 1)  // [1]
```

nil Map Danger

```
var m map[string]int  // nil map

// Reading is safe
val := m["key"]       // Returns 0 (zero value)

// Writing panics!
m["key"] = 42         // panic: assignment to nil map

// Always initialize before writing
m = make(map[string]int)
m["key"] = 42         // Now safe
```

The `new` vs `make` Functions

`new(T)`

Allocates zeroed memory and returns a pointer:

```
ptr := new(int)      // *int pointing to 0
*ptr = 42

user := new(User)    // *User with zero-valued fields
user.Name = "Alice"
```

`make(T, args)`

Creates and initializes slices, maps, and channels:

```
// Slice with length and capacity
sl := make([]int, 5)        // [0, 0, 0, 0, 0]
sl := make([]int, 0, 10)    // [] with capacity 10
```

```go
// Map
m := make(map[string]int)   // Empty, ready to use

// Channel
ch := make(chan int)        // Unbuffered channel
ch := make(chan int, 10)    // Buffered channel
```

Summary

Concept	Description
Zero Value	Default value assigned to uninitialized variables
Purpose	Eliminates undefined behavior, reduces boilerplate
`new(T)`	Allocates zeroed memory, returns `*T`
`make(T)`	Creates initialized slice, map, or channel
`nil`	Zero value for pointers, slices, maps, channels, funcs, interfaces

Related Topics

- Predeclared Types
- Variables and Scope

Constants and Literals

Overview

Constants in Go are values determined at compile time that cannot be changed during program execution. Go distinguishes between typed and untyped constants, with untyped constants having special flexibility.

Declaring Constants

Basic Declaration

```
const Pi = 3.14159
const MaxSize = 1024
const Greeting = "Hello, World!"
```

Constant Block

```
const (
    StatusOK       = 200
    StatusNotFound = 404
    StatusError    = 500
)
```

Typed vs Untyped Constants

```
// Untyped constant (more flexible)
const untypedPi = 3.14159

// Typed constant (explicit type)
const typedPi float64 = 3.14159
```

Untyped Constants

Untyped constants have a **kind** but not a fixed type, allowing them to adapt:

```
const answer = 42  // Untyped integer constant

var i int = answer       // Works: becomes int
var f float64 = answer   // Works: becomes float64
var c complex128 = answer // Works: becomes complex128
```

Why This Matters

```
// Untyped constant can be used with any compatible type
const billion = 1e9

var i int64 = billion     //  Works
var f float32 = billion   //  Works

// Typed constant is locked to its type
const typedBillion int64 = 1e9
var f float64 = typedBillion  //  Error: cannot use int64 as float64
```

Constant Kinds

Kind	Examples
Boolean	`true`, `false`
Integer	`42`, `0x2A`, `0b101010`
Floating-point	`3.14`, `6.022e23`
Complex	`1 + 2i`
String	`"hello"`, `` `raw string` ``
Rune	`'A'`, `' '`

The `iota` Constant Generator

`iota` generates sequential integer constants, starting from 0 and incrementing by 1 for each constant in the block.

Basic Usage

```
const (
    Sunday = iota    // 0
    Monday           // 1
    Tuesday          // 2
    Wednesday        // 3
    Thursday         // 4
    Friday           // 5
    Saturday         // 6
)
```

Skip Values

```
const (
    _ = iota         // 0 (skipped)
    KB = 1 << (10 * iota)  // 1 << 10 = 1024
    MB                     // 1 << 20 = 1,048,576
    GB                     // 1 << 30 = 1,073,741,824
    TB                     // 1 << 40
)
```

Bit Flags with iota

```
const (
    FlagRead    = 1 << iota  // 1 (0001)
    FlagWrite                // 2 (0010)
    FlagExecute              // 4 (0100)
)

permissions := FlagRead | FlagWrite  // 3 (0011)

hasRead := permissions & FlagRead != 0   // true
hasExec := permissions & FlagExecute != 0 // false
```

Multiple iota in One Line

```
const (
    A, B = iota, iota + 10  // A=0, B=10
    C, D                    // C=1, D=11
    E, F                    // E=2, F=12
)
```

Reset iota

Each `const` block resets `iota` to 0:

```
const (
    First = iota   // 0
    Second         // 1
)

const (
    Third = iota   // 0 (reset!)
    Fourth         // 1
)
```

Constant Expressions

Constants can be computed from other constants at compile time:

```
const (
    SecondsPerMinute = 60
    MinutesPerHour   = 60
    SecondsPerHour   = SecondsPerMinute * MinutesPerHour
    SecondsPerDay    = SecondsPerHour * 24
)
```

Allowed in Constant Expressions

- Arithmetic operators: `+`, `-`, `*`, `/`, `%`
- Comparison operators: `==`, `!=`, `<`, `>`, `<=`, `>=`
- Logical operators: `&&`, `||`, `!`
- Bit operators: `&`, `|`, `^`, `<<`, `>>`, `&^`
- Built-in functions: `len()`, `cap()` (for some values), `real()`, `imag()`, `complex()`

Not Allowed

```
const x = math.Sin(0)  // Error: function call not allowed
const y = len(someVar)  // Error: variable not allowed
```

Numeric Literals

Integer Literals

```
decimal := 42          // Base 10
binary := 0b101010     // Base 2 (Go 1.13+)
octal := 0o52          // Base 8 (Go 1.13+)
oldOctal := 052        // Base 8 (legacy)
hex := 0x2A            // Base 16
```

Floating-Point Literals

```
f1 := 3.14
f2 := .5               // 0.5
f3 := 1.               // 1.0
f4 := 6.022e23         // Scientific notation
f5 := 6.022E23         // Same
f6 := 1.5e-10          // 0.00000000015
```

Hexadecimal Floats (Go 1.13+)

```
f := 0x1.fp+2  // (1 + 15/16) * 2^2 = 7.75
```

Imaginary Literals

```
i := 3i
c := 2 + 3i
```

Digit Separators

Go 1.13+ allows underscores in numeric literals for readability:

```
billion := 1_000_000_000
binary := 0b_1010_1010
hex := 0xFF_FF_FF_FF
```

String and Rune Literals

Interpreted Strings

```
s := "Hello, World!\n"  // Escape sequences processed
s := "Tab:\tNewline:\n"
s := "Quote: \"Go\""
```

Escape Sequences

Escape	Meaning
`\n`	Newline
`\t`	Tab
`\\`	Backslash
`\"`	Double quote
`\r`	Carriage return
`\xNN`	Hex byte
`\uNNNN`	Unicode code point (4 hex)
`\UNNNNNNNN`	Unicode code point (8 hex)

Raw String Literals

```
raw := `No escape sequences: \n \t \\
Multiple lines work!
Useful for regex: \d+\.\d+`
```

Rune Literals

```
r1 := 'A'      // 65
r2 := ' '     // 19990
r3 := '\n'     // 10
r4 := '\x41'   // 65 (hex)
r5 := '\u4e16' // 19990 (unicode)
```

Common Patterns

Enum Pattern

```
type Status int

const (
    StatusPending Status = iota
    StatusApproved
    StatusRejected
)

func (s Status) String() string {
    switch s {
    case StatusPending:
        return "Pending"
    case StatusApproved:
        return "Approved"
    case StatusRejected:
        return "Rejected"
    default:
        return "Unknown"
    }
}
```

Configuration Constants

```
const (
    DefaultTimeout = 30 * time.Second
    MaxRetries     = 3
    BufferSize     = 4096
)
```

Summary

Concept	Description
`const`	Compile-time immutable value
Untyped	Flexible, adapts to context
Typed	Fixed to a specific type
`iota`	Auto-incrementing generator
Literal	Numeric, string, or rune value in source

Related Topics

- Predeclared Types
- Variables and Scope

Variables and Scope

Overview

Variables in Go store values that can change during program execution. Understanding declaration patterns and visibility rules (scope) is fundamental to writing correct Go programs.

Variable Declaration

Using `var`

```
// Explicit type
var name string
var age int

// With initialization
var name string = "Alice"
var age int = 30

// Type inference
var name = "Alice"  // Inferred as string
var age = 30        // Inferred as int
```

Short Variable Declaration (`:=`)

Inside functions, use `:=` for concise declaration:

```
func main() {
    name := "Alice"   // var name = "Alice"
    age := 30         // var age = 30
    active := true    // var active = true
}
```

When to Use `var` vs `:=`

Use `var`	Use `:=`
Package-level variables	Inside functions
Explicit type needed	Type can be inferred
Zero value is desired	Initialization value provided

```
// Package level (var only)
var globalConfig Config

func main() {
    // Function level (either works, := preferred)
    count := 0

    // Explicit type needed
    var ratio float64 = 0  // := 0 would be int
}
```

Multiple Variables

```
// Same type
var x, y, z int

// Different values
var a, b, c = 1, "hello", true

// Short declaration
name, age, active := "Alice", 30, true
```

Variable Block

```
var (
    name   string = "Alice"
    age    int    = 30
    active bool   = true
)
```

Redeclaration and Shadowing

Redeclaration with :=

`:=` can redeclare if at least one variable is new:

```
x := 1
x, y := 2, 3  // x redeclared, y is new (allowed)

// This fails:
// x := 4  // Error: no new variables on left side
```

Variable Shadowing

An inner scope can declare a variable with the same name as an outer scope:

```
x := 1
fmt.Println(x)  // 1

if true {
    x := 2       // New x, shadows outer x
    fmt.Println(x)  // 2
}

fmt.Println(x)  // 1 (outer x unchanged)
```

Warning: Shadowing often creates bugs:

```
var err error

if condition {
    result, err := someFunc()  // err shadows! Outer err unchanged
    // ...
}

if err != nil {  // This checks outer err, always nil!
    // Never reached
}
```

Fix:

```
var err error
var result Result

if condition {
    result, err = someFunc()  // No :=, uses outer err
}
```

Scope Levels

Package Scope

Variables declared outside functions are visible to the entire package:

```
package mypackage

var packageVar = "visible to all files in mypackage"

func init() {
    packageVar = "can modify here"
}

func SomeFunc() {
    fmt.Println(packageVar)  // Accessible
}
```

File Scope (Imports)

Import names are scoped to the file:

```
// file1.go
import "fmt"  // fmt available only in this file

// file2.go
import "fmt"  // Must import again
```

Function Scope

Parameters and local variables are visible within the function:

```
func greet(name string) {
    message := "Hello, " + name  // Local to greet
    fmt.Println(message)
}

// name and message are not accessible here
```

Block Scope

Variables declared in blocks (`{}`) are visible only within that block:

```go
if x > 0 {
    y := x * 2  // Only visible inside if block
    fmt.Println(y)
}
// y is not accessible here

for i := 0; i < 10; i++ {
    // i is visible only in the loop
}
// i is not accessible here

switch n := getValue(); n {
case 1:
    // n is visible in switch block
}
// n is not accessible here
```

Visibility (Exported vs Unexported)

Go uses capitalization for visibility across packages:

```go
package user

var PublicVar = "accessible from other packages"   // Exported
var privateVar = "only in user package"            // Unexported

func PublicFunc() {}   // Exported
func privateFunc() {}  // Unexported

type PublicType struct {
    PublicField  string  // Exported
    privateField string  // Unexported
}
```

The Blank Identifier (_)

Use _ to discard unwanted values:

```go
// Discard second return value
value, _ := someFunc()

// Discard loop index
for _, item := range items {
```

```
    process(item)
}

// Import for side effects only
import _ "github.com/lib/pq"
```

Variable Lifetime

Stack vs Heap

Go decides where to allocate based on escape analysis:

```
func createValue() int {
    x := 42  // Likely on stack
    return x // Copy returned, x can be reclaimed
}

func createPointer() *int {
    x := 42   // Must go on heap
    return &x // Pointer escapes function
}
```

Garbage Collection

You don't need to free memory—Go's garbage collector handles it:

```
func process() {
    data := make([]byte, 1024*1024)  // 1MB allocated
    // Use data...
}  // data becomes garbage, will be collected
```

Common Patterns

Zero Value Initialization

```
var config Config  // All fields are zero values
config.Timeout = 30 * time.Second  // Set only what differs
```

Conditional Initialization

```
var s string
if condition {
    s = "yes"
} else {
    s = "no"
}

// Or with short declaration
s := "default"
if condition {
    s = "override"
}
```

Multiple Assignment

```
// Swap without temp variable
a, b = b, a

// Multiple returns
x, y, z := multiReturn()
```

Common Pitfalls

Accidental Shadowing

```
// Bug: err is shadowed
var err error
if x > 0 {
    y, err := compute()  // New err!
    _ = y
}
// Original err still nil

// Fix: declare y separately
var err error
var y int
if x > 0 {
    y, err = compute()  // Uses outer err
}
```

Loop Variable Capture

```
// Bug: all goroutines see last value
for _, v := range values {
    go func() {
        fmt.Println(v)  // v is shared!
    }()
}

// Fix: pass as parameter
for _, v := range values {
    go func(v int) {
        fmt.Println(v)
    }(v)
}

// Go 1.22+ fixes this by default
```

Summary

Declaration	Usage
`var x T`	Zero value, explicit type
`var x = value`	Type inference
`x := value`	Short declaration (functions only)
`var x, y T`	Multiple same type
`x, y := a, b`	Multiple with inference

Scope	Visibility
Package	All files in package
File	Imports
Function	Function body
Block	`{}` boundaries

Related Topics

- Constants and Literals
- Functions in Depth

Conditional Logic

Overview

Go provides `if/else` statements and `switch` statements for conditional logic. Both are straightforward but have unique features compared to other languages.

The `if` Statement

Basic Syntax

```
if condition {
    // code
}
```

With `else`

```
if x > 0 {
    fmt.Println("Positive")
} else {
    fmt.Println("Non-positive")
}
```

With `else if`

```
if x > 0 {
    fmt.Println("Positive")
} else if x < 0 {
    fmt.Println("Negative")
} else {
    fmt.Println("Zero")
}
```

Initialization Statement

Go allows a statement before the condition:

```
if err := doSomething(); err != nil {
    // Handle error
    // err is only visible in this if/else block
    return err
}
// err is not accessible here
```

This is idiomatic for error handling:

```
if file, err := os.Open("data.txt"); err != nil {
    log.Fatal(err)
} else {
    defer file.Close()
    // Use file
}
```

No Parentheses Required

Unlike C-style languages, conditions don't need parentheses:

```
// Go style
if x > 0 {
}

// Not idiomatic (but valid)
if (x > 0) {
}
```

Braces Required

Braces are mandatory, even for single statements:

```
// Error: missing braces
if x > 0
    fmt.Println("yes")

// Correct
if x > 0 {
    fmt.Println("yes")
}
```

Boolean Expressions

Comparison Operators

Operator	Meaning
`==`	Equal
`!=`	Not equal
`<`	Less than
`>`	Greater than
`<=`	Less than or equal
`>=`	Greater than or equal

Logical Operators

Operator	Meaning
`&&`	AND (short-circuit)
`||`	OR (short-circuit)
`!`	NOT

```
// Short-circuit evaluation
if x != 0 && y/x > 1 {
    // y/x only evaluated if x != 0
}

if ptr != nil && ptr.Value > 0 {
    // Ptr.Value only accessed if ptr != nil
}
```

The `switch` Statement

Basic Switch

```
switch day {
case "Monday":
    fmt.Println("Start of week")
case "Friday":
    fmt.Println("Almost weekend!")
case "Saturday", "Sunday":
    fmt.Println("Weekend!")
default:
    fmt.Println("Midweek")
```

```
}
```

No Fall-Through by Default

Unlike C, cases don't fall through:

```
switch n {
case 1:
    fmt.Println("One")
    // No break needed, stops here
case 2:
    fmt.Println("Two")
}
```

Explicit Fallthrough

Use `fallthrough` keyword when needed:

```
switch n {
case 1:
    fmt.Println("One")
    fallthrough
case 2:
    fmt.Println("Two")
}
// Input: 1
// Output:
// One
// Two
```

Switch with Initialization

```
switch os := runtime.GOOS; os {
case "darwin":
    fmt.Println("macOS")
case "linux":
    fmt.Println("Linux")
default:
    fmt.Println(os)
}
```

Expression-less Switch

A `switch` without an expression is equivalent to `switch true`:

```
t := time.Now()

switch {
case t.Hour() < 12:
    fmt.Println("Good morning!")
case t.Hour() < 17:
    fmt.Println("Good afternoon!")
default:
    fmt.Println("Good evening!")
}
```

This is often cleaner than chained `if/else if`:

```
switch {
case x < 0:
    return "negative"
case x == 0:
    return "zero"
case x > 0:
    return "positive"
}
```

Type Switch

Special form for interface type assertions:

```
func describe(i interface{}) {
    switch v := i.(type) {
    case int:
        fmt.Printf("Integer: %d\n", v)
    case string:
        fmt.Printf("String: %s\n", v)
    case bool:
        fmt.Printf("Boolean: %t\n", v)
    default:
        fmt.Printf("Unknown type: %T\n", v)
    }
}

describe(42)        // Integer: 42
describe("hello")   // String: hello
describe(true)      // Boolean: true
```

```
describe(3.14)      // Unknown type: float64
```

Common Patterns

Error Checking

```
result, err := someOperation()
if err != nil {
    return fmt.Errorf("operation failed: %w", err)
}
// Use result
```

Boolean Assignment

```
var status string
if success {
    status = "completed"
} else {
    status = "failed"
}

// Note: Go doesn't have a ternary operator
// This doesn't work: status := success ? "completed" : "failed"
```

Guard Clauses

```
func processUser(user *User) error {
    if user == nil {
        return errors.New("user cannot be nil")
    }
    if user.Name == "" {
        return errors.New("user name required")
    }
    if user.Age < 0 {
        return errors.New("invalid age")
    }

    // Main logic here
    return nil
}
```

ok-idiom

```
// Map lookup
if val, ok := myMap[key]; ok {
    fmt.Println("Found:", val)
} else {
    fmt.Println("Not found")
}

// Type assertion
if str, ok := value.(string); ok {
    fmt.Println("String:", str)
}

// Channel receive
if val, ok := <-ch; ok {
    fmt.Println("Received:", val)
} else {
    fmt.Println("Channel closed")
}
```

Comma-ok Pattern

```
// Check map existence
if _, exists := users[id]; exists {
    // User exists
}

// Check channel state
if _, open := <-ch; !open {
    // Channel is closed
}
```

Switch vs If/Else

Prefer Switch When:

```
// Multiple discrete values
switch status {
case "pending", "processing":
    queue()
case "done":
    complete()
```

```
case "error":
    retry()
}
```

Prefer If/Else When:

```
// Complex conditions
if x > 0 && y > 0 && x*y < 100 {
    // ...
} else if x < 0 || y < 0 {
    // ...
}
```

Summary

Feature	Description
`if`	Basic conditional
`if x := val; condition`	If with initialization
`switch expr`	Multi-way branching
`switch { case cond: }`	Expression-less switch
`switch v := x.(type)`	Type switch
`fallthrough`	Explicit fall-through in switch

Related Topics

- Loops and Iteration
- Errors as Values

Loops and Iteration

Overview

Go has only one looping construct: the `for` loop. This single keyword handles all looping patterns.

The Basic `for` Loop

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

The `while` Loop (Condition Only)

```
n := 1
for n < 100 {
    n *= 2
}
```

The Infinite Loop

```
for {
    if done {
        break
    }
}
```

The `range` Loop

Slices and Arrays

```
nums := []int{10, 20, 30}

for i, v := range nums {
    fmt.Printf("%d: %d\n", i, v)
}

for _, v := range nums {  // Value only
    fmt.Println(v)
}
```

Maps

```
ages := map[string]int{"Alice": 30, "Bob": 25}

for key, value := range ages {
    fmt.Printf("%s: %d\n", key, value)
}
```

Strings

```
for i, r := range "Hello" {
    fmt.Printf("%d: %c\n", i, r)
}
```

Channels

```
for v := range ch {  // Exits when channel closes
    fmt.Println(v)
}
```

Iterators (Go 1.23+)

Go 1.23 introduced "range-over-func," allowing you to use `range` with custom iterator functions.

Sequence Iterators

A sequence iterator is a function that takes a yield function: `func(yield func(V) bool)` (single value) or `func(yield func(K, V) bool)` (key-value).

```
func All[T any](s []T) iter.Seq[T] {
    return func(yield func(T) bool) {
        for _, v := range s {
            if !yield(v) {
                return
            }
        }
    }
}

// Usage
for v := range All(nums) {
    fmt.Println(v)
}
```

Pull Iterators

For more control, you can use pull iterators:

```
next, stop := iter.Pull(All(nums))
defer stop()

for {
    v, ok := next()
    if !ok {
        break
    }
    fmt.Println(v)
}
```

Loop Control

`break` and `continue`

```
for i := 0; i < 10; i++ {
    if i == 5 {
        break     // Exit loop
    }
    if i%2 == 0 {
```

```
        continue  // Skip to next iteration
    }
    fmt.Println(i)
}
```

Labels for Nested Loops

```
outer:
for i := 0; i < 3; i++ {
    for j := 0; j < 3; j++ {
        if i == 1 && j == 1 {
            break outer  // Break both loops
        }
    }
}
```

Common Patterns

```
// Reverse iteration
for i := len(items) - 1; i >= 0; i-- {
    process(items[i])
}

// Step by N
for i := 0; i < 100; i += 10 {
    fmt.Println(i)
}
```

Summary

Pattern	Syntax
Classic for	`for i := 0; i < n; i++ {}`
While loop	`for condition {}`
Infinite loop	`for {}`
Range	`for i, v := range slice {}`
Iterators	`for v := range myIter() {}`

Related Topics

- Arrays and Slices

- Maps

Arrays and Slices

Overview

Arrays and slices are Go's primary sequence types. Arrays are fixed-size, while slices are dynamic views into arrays.

Arrays

Declaration

```
var arr [5]int                    // Zero values: [0 0 0 0 0]
arr := [5]int{1, 2, 3, 4, 5}     // Literal
arr := [...]int{1, 2, 3}          // Size inferred: [3]int
```

Properties

- Fixed size (part of type): `[5]int` ≠ `[6]int`
- Value semantics: copying creates independent copy
- Zero value: array of zero values

```
a := [3]int{1, 2, 3}
b := a        // Copy!
b[0] = 99
fmt.Println(a)  // [1 2 3] (unchanged)
```

Slices

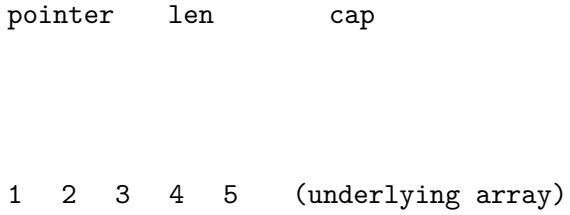
Creation

```
var s []int                       // nil slice
s := []int{1, 2, 3}              // Literal
s := make([]int, 5)              // Length 5, capacity 5
s := make([]int, 0, 10)          // Length 0, capacity 10
```

From Array

```
arr := [5]int{1, 2, 3, 4, 5}
s := arr[1:4]  // [2 3 4] - shares memory with arr
```

Slice Internals



Length and Capacity

```
s := make([]int, 3, 5)
len(s)  // 3 (elements accessible)
cap(s)  // 5 (space available)
```

Slice Operations

Append

```
s := []int{1, 2, 3}
s = append(s, 4)           // [1 2 3 4]
s = append(s, 5, 6, 7)     // [1 2 3 4 5 6 7]
s = append(s, other...)    // Append another slice
```

Slicing

```
s := []int{0, 1, 2, 3, 4, 5}
s[1:4]   // [1 2 3]
s[:3]    // [0 1 2]
s[3:]    // [3 4 5]
s[:]     // [0 1 2 3 4 5] (copy of slice header)
```

Copy

```
src := []int{1, 2, 3}
dst := make([]int, len(src))
copy(dst, src)
```

The `slices` Package (Go 1.21+)

The standard library `slices` package provides generic utilities for common operations.

```
import "slices"

slices.Sort(nums)             // Sort in place
slices.Reverse(nums)          // Reverse in place
slices.Contains(nums, 42)     // Search
slices.Index(nums, 42)        // Find index
slices.Delete(nums, i, j)     // Remove range [i, j)
slices.Clone(nums)            // Shallow copy
slices.Equal(s1, s2)          // Compare
```

Modern Loop Pattern (Go 1.23+)

Using iterators with slices:

```
for i, v := range slices.All(nums) { /* ... */ }
for v := range slices.Values(nums) { /* ... */ }
```

nil vs Empty Slice

```
var nilSlice []int     // nil
emptySlice := []int{}  // not nil, but empty

nilSlice == nil        // true
emptySlice == nil      // false
len(nilSlice)          // 0
len(emptySlice)        // 0
```

Common Patterns

Remove Element

```
s = append(s[:i], s[i+1:]...)  // Remove element at index i
```

Insert Element

```
s = append(s[:i], append([]int{v}, s[i:]...)...)
```

Stack

```
stack = append(stack, v)              // Push
v, stack = stack[len(stack)-1], stack[:len(stack)-1]  // Pop
```

Summary

Feature	Array	Slice
Size	Fixed	Dynamic
Type	`[n]T`	`[]T`
Zero value	Array of zeros	`nil`
Comparison	`==` works	Not comparable

Related Topics

- Working with Strings
- Maps

Working with Strings

Overview

Strings in Go are immutable sequences of bytes, typically UTF-8 encoded. Understanding the distinction between bytes and runes is essential.

String Basics

```
s := "Hello, World!"
s := `Raw string with
multiple lines`
```

Immutability

```
s := "hello"
// s[0] = 'H'  // Error: cannot assign to s[0]
s = "Hello"    // OK: reassign entire string
```

Bytes vs Runes

```
s := "Hello,  "

len(s)              // 13 (bytes)
len([]rune(s))      // 9 (characters)
```

Iterating

```
// By byte
for i := 0; i < len(s); i++ {
    fmt.Printf("%x ", s[i])
}

// By rune (character)
```

```go
for i, r := range s {
    fmt.Printf("%d: %c\n", i, r)
}
```

String Operations

Concatenation

```go
s := "Hello" + ", " + "World"

// Efficient building
var b strings.Builder
b.WriteString("Hello")
b.WriteString(", World")
result := b.String()
```

Comparison

```go
s1 == s2              // Equality
s1 < s2               // Lexicographic
strings.EqualFold(s1, s2)  // Case-insensitive
```

strings Package

```go
import "strings"

strings.Contains(s, "sub")      // true/false
strings.HasPrefix(s, "pre")     // true/false
strings.HasSuffix(s, "suf")     // true/false
strings.Index(s, "sub")         // Position or -1
strings.Split(s, ",")           // []string
strings.Join(parts, ",")        // string
strings.ToUpper(s)              // UPPERCASE
strings.ToLower(s)              // lowercase
strings.TrimSpace(s)            // Remove whitespace
strings.Replace(s, "old", "new", n)  // Replace n times
strings.ReplaceAll(s, "old", "new")  // Replace all
```

strconv Package

```
import "strconv"

// String to int
n, err := strconv.Atoi("42")

// Int to string
s := strconv.Itoa(42)

// Parse float
f, err := strconv.ParseFloat("3.14", 64)

// Format float
s := strconv.FormatFloat(3.14, 'f', 2, 64)
```

fmt Package

```
// Formatting
s := fmt.Sprintf("Name: %s, Age: %d", name, age)

// Parsing
var name string
var age int
fmt.Sscanf("Alice 30", "%s %d", &name, &age)
```

Rune Operations

```
r := 'A'
unicode.IsLetter(r)    // true
unicode.IsDigit(r)     // false
unicode.ToUpper(r)     // 'A'
unicode.ToLower(r)     // 'a'
```

Summary

Operation	Method
Length (bytes)	`len(s)`
Length (chars)	`len([]rune(s))`
Concatenate	`+` or `strings.Builder`

Operation	Method
Contains	`strings.Contains()`
Split/Join	`strings.Split()`, `strings.Join()`
Convert	`strconv.Atoi()`, `strconv.Itoa()`

Related Topics

- Predeclared Types
- I/O and Streaming

Maps

Overview

Maps are Go's built-in hash table type, providing O(1) average-time lookups, insertions, and deletions.

Creating Maps

```
var m map[string]int           // nil map (read-only!)
m := make(map[string]int)      // Empty, ready to use
m := make(map[string]int, 100) // With capacity hint
m := map[string]int{           // Literal
    "one": 1,
    "two": 2,
}
```

Basic Operations

Set

```
m["key"] = value
```

Get

```
val := m["key"]  // Returns zero value if missing
```

Delete

```
delete(m, "key")  // No-op if key doesn't exist
```

Check Existence

```
val, ok := m["key"]
if ok {
    // Key exists
}

if _, exists := m["key"]; exists {
    // Key exists
}
```

nil Map Behavior

```
var m map[string]int  // nil

val := m["key"]       // OK: returns 0
m["key"] = 1          // PANIC! Cannot write to nil map
```

Always initialize before writing:

```
m := make(map[string]int)
m["key"] = 1  // OK
```

Iteration

```
for key, value := range m {
    fmt.Printf("%s: %d\n", key, value)
}

for key := range m {  // Keys only
    fmt.Println(key)
}
```

Warning: Iteration order is randomized!

Common Patterns

Set (Unique Values)

```
set := make(map[string]struct{})
set["item"] = struct{}{}
if _, exists := set["item"]; exists {
    // Item is in set
}
delete(set, "item")
```

Counter

```
counter := make(map[string]int)
for _, word := range words {
    counter[word]++  // Zero value works!
}
```

Grouping

```
groups := make(map[string][]User)
for _, user := range users {
    groups[user.Country] = append(groups[user.Country], user)
}
```

Default Value

```
val := m["key"]
if val == 0 {
    val = defaultValue
}
```

Concurrency Warning

Maps are **not** goroutine-safe:

```
// Unsafe: concurrent read/write
go func() { m["key"] = 1 }()
go func() { _ = m["key"] }()
```

```
// Use sync.Map or mutex
var mu sync.Mutex
mu.Lock()
m["key"] = 1
mu.Unlock()
```

The `maps` Package (Go 1.21+)

The standard library `maps` package provides generic utilities for common operations.

```
import "maps"

maps.Clone(m)                 // Shallow copy
maps.Equal(m1, m2)            // Compare
maps.DeleteFunc(m, func(k K, v V) bool {
    return v < 10             // Conditional delete
})
```

Modern Loop Pattern (Go 1.23+)

Using iterators with maps:

```
for k, v := range maps.All(m) { /* ... */ }
for k := range maps.Keys(m) { /* ... */ }
for v := range maps.Values(m) { /* ... */ }
```

Map Internals

- Keys must be comparable (== must work)
- Valid key types: bool, numeric, string, pointer, channel, interface, structs/arrays of comparable types
- Invalid: slices, maps, functions

Summary

Operation	Syntax
Create	`make(map[K]V)`
Set	`m[key] = value`
Get	`val := m[key]`
Check	`val, ok := m[key]`

Operation	Syntax
Delete	`delete(m, key)`
Length	`len(m)`

Related Topics

- Arrays and Slices
- Synchronization

Structs and Data Modeling

Overview

Structs are Go's primary mechanism for creating custom composite types. They group related fields together.

Defining Structs

```
type Person struct {
    Name    string
    Age     int
    Email   string
    Active  bool
}
```

Creating Instances

```
// Zero value
var p Person  // All fields get zero values

// Literal (named fields - preferred)
p := Person{
    Name:  "Alice",
    Age:   30,
    Email: "alice@example.com",
}

// Literal (positional - fragile)
p := Person{"Alice", 30, "alice@example.com", true}

// Using new
p := new(Person)  // *Person with zero values

// Expression-based new (Go 1.26+)
p := new(Person{Name: "Alice"})  // *Person initialized with values
```

```
Embedded fields (composition)

Employee
|-- Person
|    |-- Name
|    |-- Age
|-- Address
|    |-- City
|-- Title
```

Accessing Fields

```
p.Name = "Bob"
fmt.Println(p.Age)

// Pointer access (automatic dereference)
ptr := &p
ptr.Name = "Carol"  // Same as (*ptr).Name
```

Anonymous Structs

```
point := struct {
    X, Y int
}{10, 20}

// Useful for one-off data
data := struct {
    ID    int
    Value string
}{1, "test"}
```

Embedding (Composition)

```
type Address struct {
    Street string
    City   string
}

type Employee struct {
    Person    // Embedded
```

```
    Address   // Embedded
    Title string
}

e := Employee{
    Person:  Person{Name: "Alice", Age: 30},
    Address: Address{City: "NYC"},
    Title:   "Engineer",
}

// Promoted fields
e.Name    // Same as e.Person.Name
e.City    // Same as e.Address.City
```

Struct Tags

Metadata for serialization and other tools:

```
type User struct {
    ID        int    `json:"id" db:"user_id"`
    Name      string `json:"name,omitempty"`
    Password  string `json:"-"`  // Omit from JSON
    CreatedAt time.Time `json:"created_at"`
}
```

Reading Tags

```
import "reflect"

t := reflect.TypeOf(User{})
field, _ := t.FieldByName("Name")
tag := field.Tag.Get("json")  // "name,omitempty"
```

Comparison

Structs are comparable if all fields are comparable:

```
p1 := Person{Name: "Alice"}
p2 := Person{Name: "Alice"}
p1 == p2  // true
```

Constructors

Go uses factory functions:

```
func NewPerson(name string, age int) *Person {
    return &Person{
        Name:   name,
        Age:    age,
        Active: true,  // Default
    }
}

func NewPersonWithDefaults() *Person {
    return &Person{
        Active: true,
    }
}
```

Summary

Pattern	Usage
Define	`type Name struct { fields }`
Create	`Name{Field: value}`
Embed	Include type name without field name
Tags	`Field Type` \key:“value”‘`| |` `Constructor` |func NewType() *Type‘

Related Topics

- Methods and Receivers
- Designing with Interfaces

Time and Scheduling

Overview

The `time` package provides functionality for measuring and displaying time.

Current Time

```
now := time.Now()
fmt.Println(now)  // 2024-01-15 10:30:00 -0500 EST
```

Duration

```
d := 5 * time.Second
d := time.Minute + 30*time.Second
d := time.ParseDuration("1h30m")
```

Sleeping

```
time.Sleep(2 * time.Second)
```

Timers

```
// One-shot timer
timer := time.NewTimer(5 * time.Second)
<-timer.C  // Blocks until timer fires

// Cancel timer
if !timer.Stop() {
    <-timer.C
}
```

Tickers

```
ticker := time.NewTicker(1 * time.Second)
defer ticker.Stop()

for t := range ticker.C {
    fmt.Println("Tick at", t)
}
```

Formatting

```
// Format uses reference time: Mon Jan 2 15:04:05 MST 2006
now := time.Now()
fmt.Println(now.Format("2006-01-02"))           // 2024-01-15
fmt.Println(now.Format("15:04:05"))             // 10:30:00
fmt.Println(now.Format(time.RFC3339))           // 2024-01-15T10:30:00-05:00
```

Parsing

```
t, err := time.Parse("2006-01-02", "2024-01-15")
t, err := time.Parse(time.RFC3339, "2024-01-15T10:30:00Z")
```

Time Zones

```
loc, _ := time.LoadLocation("America/New_York")
t := time.Now().In(loc)

utc := time.Now().UTC()
```

Comparisons

```
t1.Before(t2)
t1.After(t2)
t1.Equal(t2)
t1.Sub(t2)    // Duration between
t1.Add(d)     // Add duration
```

Summary

Type/Function	Purpose
`time.Now()`	Current time
`time.Duration`	Time interval
`time.Timer`	One-shot delay
`time.Ticker`	Repeated intervals
`time.Format()`	Time to string
`time.Parse()`	String to time

Related Topics

- Context and Cancellation
- I/O and Streaming

Memory

Functions in Depth

Overview

Functions are fundamental building blocks in Go. They support multiple return values, named returns, variadic parameters, and closures.

Function Declaration

```
func name(params) returnType {
    // body
}

func add(a, b int) int {
    return a + b
}

func greet(name string) {
    fmt.Println("Hello,", name)
}
```

Multiple Return Values

```
func divide(a, b float64) (float64, error) {
    if b == 0 {
        return 0, errors.New("division by zero")
    }
    return a / b, nil
}

result, err := divide(10, 2)
```

Named Return Values

```
func split(sum int) (x, y int) {
    x = sum * 4 / 9
    y = sum - x
    return  // Naked return
}
```

Variadic Functions

```
func sum(nums ...int) int {
    total := 0
    for _, n := range nums {
        total += n
    }
    return total
}

sum(1, 2, 3)           // 6
sum([]int{1, 2, 3}...) // Spread slice
```

Closures

Functions can capture variables from their enclosing scope:

```
func counter() func() int {
    count := 0
    return func() int {
        count++
        return count
    }
}

c := counter()
c()  // 1
c()  // 2
c()  // 3
```

Defer

Defer postpones execution until the surrounding function returns:

```go
func readFile(name string) error {
    f, err := os.Open(name)
    if err != nil {
        return err
    }
    defer f.Close()  // Executes when function returns

    // Use file...
    return nil
}
```

Defer Order (LIFO)

```go
defer fmt.Println("1")
defer fmt.Println("2")
defer fmt.Println("3")
// Output: 3, 2, 1
```

Function Signatures

```go
// Function type
type Operation func(int, int) int

func apply(op Operation, a, b int) int {
    return op(a, b)
}

add := func(a, b int) int { return a + b }
result := apply(add, 2, 3)  // 5
```

Summary

Feature	Syntax
Multiple returns	`func f() (T1, T2)`
Named returns	`func f() (x T1, y T2)`
Variadic	`func f(args ...T)`
Closure	`func() { /* capture vars */ }`
Defer	`defer cleanup()`

Related Topics

- Functions as Values
- Methods and Receivers

Functions as Values

Overview

In Go, functions are first-class citizens—they can be assigned to variables, passed as arguments, and returned from other functions.

Function Variables

```
// Assign function to variable
add := func(a, b int) int {
    return a + b
}

result := add(2, 3)  // 5

// Reassign
add = func(a, b int) int {
    return a + b + 1  // Different implementation
}
```

Function Types

```
type BinaryOp func(int, int) int

var op BinaryOp = func(a, b int) int {
    return a + b
}
```

Higher-Order Functions

Functions as Parameters

```
func apply(nums []int, fn func(int) int) []int {
    result := make([]int, len(nums))
    for i, n := range nums {
        result[i] = fn(n)
    }
    return result
}

double := func(n int) int { return n * 2 }
result := apply([]int{1, 2, 3}, double)  // [2, 4, 6]
```

Functions as Return Values

```
func multiplier(factor int) func(int) int {
    return func(n int) int {
        return n * factor
    }
}

double := multiplier(2)
triple := multiplier(3)

double(5)  // 10
triple(5)  // 15
```

Common Patterns

Callback Pattern

```
func fetchData(url string, callback func(data []byte, err error)) {
    // Async operation
    go func() {
        data, err := http.Get(url)
        callback(data, err)
    }()
}
```

Option Pattern

```
type Server struct {
    port    int
    timeout time.Duration
}

type Option func(*Server)

func WithPort(p int) Option {
    return func(s *Server) { s.port = p }
}

func WithTimeout(t time.Duration) Option {
    return func(s *Server) { s.timeout = t }
}

func NewServer(opts ...Option) *Server {
    s := &Server{port: 8080, timeout: 30 * time.Second}
    for _, opt := range opts {
        opt(s)
    }
    return s
}

srv := NewServer(WithPort(9000), WithTimeout(time.Minute))
```

Middleware Pattern

```
type Handler func(http.ResponseWriter, *http.Request)

func WithLogging(h Handler) Handler {
    return func(w http.ResponseWriter, r *http.Request) {
        log.Printf("%s %s", r.Method, r.URL)
        h(w, r)
    }
}
```

Anonymous Functions

```
// Immediate invocation (IIFE)
result := func(x int) int {
    return x * x
}(5)  // 25

// In goroutines
go func() {
    fmt.Println("async")
}()
```

Summary

Pattern	Use Case
Function variable	Store/swap implementations
Higher-order	Transform, filter, reduce
Closures	Capture state
Options	Flexible configuration

Related Topics

- Functions in Depth
- Designing with Interfaces

Methods and Receivers

Overview

Methods are functions with a receiver argument, allowing you to define behavior on types.

Method Syntax

```
type Rectangle struct {
    Width, Height float64
}

func (r Rectangle) Area() float64 {
    return r.Width * r.Height
}

rect := Rectangle{10, 5}
area := rect.Area()  // 50
```

Value vs Pointer Receivers

Value Receiver

```
func (r Rectangle) Scale(factor float64) Rectangle {
    return Rectangle{r.Width * factor, r.Height * factor}
}

// Original unchanged
r := Rectangle{10, 5}
scaled := r.Scale(2)  // New rectangle
```

Pointer Receiver

```
func (r *Rectangle) ScaleInPlace(factor float64) {
    r.Width *= factor
    r.Height *= factor
}

// Original modified
r := Rectangle{10, 5}
r.ScaleInPlace(2)  // r is now {20, 10}
```

When to Use Pointer Receivers

Use pointer receiver when: - Method needs to modify the receiver - Receiver is a large struct (avoid copying) - Consistency: if any method needs pointer, use pointer for all

```
type Buffer struct {
    data []byte
}

func (b *Buffer) Write(p []byte) {
    b.data = append(b.data, p...)
}

func (b *Buffer) String() string {
    return string(b.data)  // Even though it doesn't modify, use * for consistency
}
```

Methods on Any Type

```
type MyInt int

func (m MyInt) Double() MyInt {
    return m * 2
}

n := MyInt(5)
n.Double()  // 10
```

Automatic Dereferencing

Go automatically handles `*` and `&` for method calls:

```go
r := Rectangle{10, 5}
(&r).ScaleInPlace(2)  // Explicit pointer
r.ScaleInPlace(2)     // Go handles it automatically

ptr := &Rectangle{10, 5}
(*ptr).Area()         // Explicit dereference
ptr.Area()            // Go handles it automatically
```

Embedding and Method Promotion

```go
type Animal struct {
    Name string
}

func (a Animal) Speak() string {
    return "..."
}

type Dog struct {
    Animal  // Embedded
    Breed string
}

d := Dog{Animal: Animal{Name: "Rex"}, Breed: "Labrador"}
d.Speak()  // Promoted method: "..."
d.Name     // Promoted field: "Rex"
```

Method Override

```go
func (d Dog) Speak() string {
    return "Woof!"
}

d.Speak()         // "Woof!" (Dog's method)
d.Animal.Speak()  // "..." (Animal's method)
```

Summary

Receiver	Use Case
`(t T)`	Read-only, small types
`(t *T)`	Modify state, large types

Receiver	Use Case

Feature	Description
Auto-deref	Go handles `*` and `&`
Embedding	Methods are promoted
Override	Inner type's method shadows embedded

Related Topics

- Pointers Explained
- Designing with Interfaces

Understanding Memory in Go

Overview

Go manages memory automatically through its runtime, but understanding stack vs heap allocation helps write more efficient code.

Stack vs Heap

Stack

- Fast allocation/deallocation
- Function-local variables
- Fixed size per goroutine (~2KB initial)
- Automatically cleaned up when function returns

Heap

- Dynamic allocation
- Survives function scope
- Managed by garbage collector
- More expensive than stack

Escape Analysis

Go's compiler decides where to allocate based on **escape analysis**:

```
func stackAlloc() int {
    x := 42      // Stays on stack
    return x     // Value copied
}

func heapAlloc() *int {
    x := 42      // Escapes to heap
    return &x    // Pointer returned
}
```

Check Escape Analysis

```
go build -gcflags="-m" main.go
# Shows: "moved to heap" for escaped variables
```

What Causes Escape

```
// 1. Returning pointer to local
func escape1() *int {
    n := 1
    return &n  // Escapes
}

// 2. Storing in interface
func escape2() {
    n := 1
    fmt.Println(n)  // Escapes (interface{} argument)
}

// 3. Closure capturing variable
func escape3() func() int {
    n := 1
    return func() int { return n }  // Escapes
}

// 4. Size too large for stack
func escape4() {
    _ = make([]byte, 10<<20)  // 10MB, escapes
}
```

Memory Layout

Value Types

```
type Point struct { X, Y int }
p := Point{1, 2}  // 16 bytes inline
```

Reference Types

```
s := make([]int, 10)  // Slice header on stack, data on heap
m := make(map[string]int)  // Map structure on heap
```

Best Practices

Reduce Allocations

```
// Bad: allocates each iteration
for i := 0; i < n; i++ {
    data := make([]byte, 1024)
    process(data)
}

// Good: reuse allocation
data := make([]byte, 1024)
for i := 0; i < n; i++ {
    process(data)
}
```

Preallocate Slices

```
// Bad: multiple reallocations
var result []int
for _, v := range data {
    result = append(result, v)
}

// Good: preallocate
result := make([]int, 0, len(data))
for _, v := range data {
    result = append(result, v)
}
```

Use Value Semantics When Possible

```go
// May allocate
func process(p *Point) { }

// Stays on stack
func process(p Point) { }
```

Summary

Location	Characteristics
Stack	Fast, automatic, limited size
Heap	Dynamic, GC-managed, survives scope

Causes Escape	Example
Return pointer	`return &x`
Interface	`fmt.Println(x)`
Closure	`func() { use(x) }`
Large size	`make([]byte, 1MB)`

Related Topics

- Pointers Explained
- Garbage Collection

Pointers Explained

Overview

Pointers hold memory addresses. In Go, they're simple and safe—no pointer arithmetic allowed.

Pointer Basics

```
x := 42
p := &x      // p is *int, holds address of x
fmt.Println(*p)  // 42 (dereference)
*p = 100     // Modify x through pointer
fmt.Println(x)   // 100
```

Declaration

```
var p *int       // nil pointer
p = &x           // Point to x

// Classic new (zero value)
p := new(int)    // *int to 0

// Expression-based new (Go 1.26+)
p := new(42)     // *int to 42
```

```
Stack/heap view (simplified)

x: 42          p: 0xABC
 |               |
 +------ addr ---+
         |
       [42]
```

Why Use Pointers

1. Modify Variables in Functions

```
func increment(n *int) {
    *n++
}

x := 1
increment(&x)
fmt.Println(x)  // 2
```

2. Avoid Copying Large Structs

```
type BigStruct struct {
    Data [1000]int
}

// Bad: copies entire struct
func process(b BigStruct) { }

// Good: passes pointer (8 bytes)
func process(b *BigStruct) { }
```

3. Share Data

```
type Config struct {
    Debug bool
}

func loadConfig() *Config {
    return &Config{Debug: true}
}

cfg := loadConfig()  // All code shares same Config
```

nil Pointers

```
var p *int  // nil

if p != nil {
    fmt.Println(*p)  // Safe
}

// Dereferencing nil panics!
// *p = 1  // panic: runtime error
```

Safe pattern for optional fields in APIs:

```
type UpdateUserRequest struct {
    Name  *string `json:"name,omitempty"`
    Email *string `json:"email,omitempty"`
}
```

Pointer to Pointer

```
x := 42
p := &x
pp := &p  // **int

**pp = 100
fmt.Println(x)  // 100
```

Pointers and Slices/Maps

Slices and maps are already reference types:

```
func modify(s []int) {
    s[0] = 100  // Modifies original
}

nums := []int{1, 2, 3}
modify(nums)
fmt.Println(nums[0])  // 100

// But reassigning needs pointer
func replace(s *[]int) {
    *s = []int{4, 5, 6}
}
```

Common Patterns

Return Pointer for "No Result"

```
func find(id int) *User {
    if found {
        return &user
    }
    return nil  // Not found
}

if user := find(1); user != nil {
    // Use user
}
```

Constructor Pattern

```
func NewUser(name string) *User {
    return &User{
        Name:      name,
        CreatedAt: time.Now(),
    }
}
```

Summary

Operation	Syntax
Get address	`&x`
Dereference	`*p`
Allocate	`new(T)`
Check nil	`p != nil`

Related Topics

- Methods and Receivers
- Mutability and Data Sharing

Mutability and Data Sharing

Overview

Understanding when data is copied vs shared is crucial for avoiding bugs and writing efficient Go code.

Value vs Reference Semantics

Value Types (Copied)

```
// Integers, floats, bools, strings, arrays, structs
a := 1
b := a
b = 2
fmt.Println(a)  // 1 (unchanged)

arr := [3]int{1, 2, 3}
arr2 := arr
arr2[0] = 100
fmt.Println(arr[0])  // 1 (unchanged)
```

Reference Types (Shared)

```
// Slices, maps, channels, pointers
s := []int{1, 2, 3}
s2 := s
s2[0] = 100
fmt.Println(s[0])  // 100 (changed!)

m := map[string]int{"a": 1}
m2 := m
m2["a"] = 100
fmt.Println(m["a"])  // 100 (changed!)
```

Controlling Mutability

Immutable by Design

```
// Return new instead of modifying
func addItem(items []string, item string) []string {
    return append(items, item)  // May return new slice
}
```

Defensive Copy

```
func process(s []int) {
    local := make([]int, len(s))
    copy(local, s)  // Safe to modify local
}
```

Deep Copy

```
type User struct {
    Name    string
    Friends []string
}

func (u User) Clone() User {
    friends := make([]string, len(u.Friends))
    copy(friends, u.Friends)
    return User{Name: u.Name, Friends: friends}
}
```

Function Parameters

```
// Value: caller's data safe
func process(u User) {
    u.Name = "modified"  // Doesn't affect caller
}

// Pointer: can modify caller's data
func process(u *User) {
    u.Name = "modified"  // Affects caller
}
```

Struct Field Mutability

```
type Counter struct {
    count int
}

// Value receiver: cannot modify
func (c Counter) Increment() {
    c.count++  // Modifies copy, original unchanged
}

// Pointer receiver: modifies original
func (c *Counter) Increment() {
    c.count++  // Original modified
}
```

Slice Gotchas

```
// Append may or may not share backing array
s := []int{1, 2, 3}
s2 := s[:2]           // Shares backing array
s2 = append(s2, 4)    // Might overwrite s[2]!

// Safer: force new allocation
s2 := append([]int(nil), s[:2]...)
```

Summary

Type	Behavior	Copy When…
int, bool, string	Value	Always copied
struct	Value	Always copied
array	Value	Always copied
slice	Reference	Use `copy()`
map	Reference	Rebuild manually
pointer	Reference	-

Related Topics

- Pointers Explained
- Concurrency Design Guidelines

Garbage Collection

Overview

Go uses automatic garbage collection (GC) to manage memory. Understanding how it works helps you write GC-friendly code.

Modern GC Architecture

Concurrent Mark and Sweep

Go's GC is concurrent and non-moving. At a high level: 1. **Mark Setup**: (STW) Prepare for marking. 2. **Marking**: (Concurrent) Mark reachable objects. 3. **Mark Termination**: (STW) Finalize marking. 4. **Sweeping**: (Concurrent) Reclaim memory.

```
GC cycle (simplified)

Roots ---> [mark queue] ---> reachable objects marked
  |                                  |
  +---- stack/globals                +-- write barrier keeps invariants

unmarked heap objects ---> sweep ---> free spans for reuse
```

Go 1.26: Green Tea GC

Go 1.26 switched the default collector to **Green Tea GC (GTGC)** for lower pause times and better locality in pointer-heavy workloads.

- Better cache locality from span-aware scanning.
- Lower overhead for high-allocation services.
- If needed for debugging/regression checks, you can opt out with:

```
GOEXPERIMENT=nogreenteagc go test ./...
```

GOGC and Memory Limits

Think of `GOGC` and `GOMEMLIMIT` as two controls:

- `GOGC` controls *when* to trigger based on heap growth.
- `GOMEMLIMIT` puts a soft cap on total Go-managed memory.

```
Heap growth trigger                Memory budget trigger
live heap * (1 + GOGC/100)         total Go memory near GOMEMLIMIT
```

Tuning with GOGC

```
# Default: GC when heap doubles (100% growth)
GOGC=100 ./myapp

# More aggressive: GC at 50% growth (uses less memory)
GOGC=50 ./myapp

# Less frequent: GC at 200% growth (faster, more memory)
GOGC=200 ./myapp

# Disable GC (not recommended)
GOGC=off ./myapp
```

Tuning with GOMEMLIMIT

```
# Keep process around 2 GiB Go-managed memory
GOMEMLIMIT=2GiB ./myapp
```

Programmatic control:

```
import "runtime/debug"

func init() {
    debug.SetMemoryLimit(2 << 30) // 2 GiB
}
```

Memory Stats

```
var m runtime.MemStats
runtime.ReadMemStats(&m)

fmt.Printf("Alloc: %d MB\n", m.Alloc/1024/1024)
fmt.Printf("Total Alloc: %d MB\n", m.TotalAlloc/1024/1024)
fmt.Printf("Heap Objects: %d\n", m.HeapObjects)
fmt.Printf("GC Cycles: %d\n", m.NumGC)
```

A low-overhead option for production telemetry:

```
import "runtime/metrics"

samples := []metrics.Sample{
    {Name: "/gc/heap/live:bytes"},
    {Name: "/gc/heap/goal:bytes"},
}
metrics.Read(samples)
```

Reducing GC Pressure

1. Reduce Allocations

```
// Bad: allocates each call
func getBuffer() []byte {
    return make([]byte, 1024)
}

// Good: reuse with sync.Pool
var bufPool = sync.Pool{
    New: func() any { return make([]byte, 1024) },
}

func getBuffer() []byte {
    return bufPool.Get().([]byte)
}

func putBuffer(b []byte) {
    bufPool.Put(b)
}
```

2. Preallocate

```
result := make([]int, 0, expectedSize)
```

3. Use Value Types

```
// More allocations
type Points []*Point

// Fewer allocations
type Points []Point
```

4. Avoid String Concatenation in Loops

```
// Bad: allocates each iteration
s := ""
for _, part := range parts {
    s += part
}

// Good: single allocation
var b strings.Builder
for _, part := range parts {
    b.WriteString(part)
}
s := b.String()
```

Profiling

```
# CPU profile
go test -cpuprofile=cpu.out
go tool pprof cpu.out

# Memory profile
go test -memprofile=mem.out
go tool pprof mem.out

# View allocations
go tool pprof -alloc_space mem.out
```

Summary

Optimization	Technique
Reuse memory	`sync.Pool`
Preallocate	`make([]T, 0, cap)`
Values vs pointers	Use values for small types
String building	`strings.Builder`

Related Topics

- Understanding Memory in Go
- Performance Tuning

Stack Mechanics & Optimizations

Understanding Memory: Stack vs. Heap in Go

To write high-performance Go, you must understand where your variables live. Go abstracts memory management, but it doesn't eliminate the physics of hardware.

The Two Worlds

1. The Stack

- **What it is:** A pre-allocated, contiguous block of memory for each goroutine (starts at 2KB).
- **Allocation:** Instant (move a pointer).
- **Deallocation:** Instant (move a pointer back).
- **GC Cost: Zero.** The Garbage Collector (GC) does not scan the stack.
- **Cache Locality:** Excellent.

2. The Heap

- **What it is:** A global pool of memory for dynamic allocations.
- **Allocation:** Slow (search for free block, possibly lock).
- **Deallocation:** Garbage Collected (expensive scan).
- **GC Cost:** High. Pointers on the heap must be traced.
- **Cache Locality:** Poor (scattered).

Go's Optimization Goal

Keep everything on the stack.

If the compiler can prove a variable's life cycle is contained within a function (it doesn't "escape"), it allocates it on the stack.

Stack Growth (Contiguous Stacks)

Goroutines start with 2KB stacks. If a function call needs more space, the runtime: 1. Allocates a larger stack (e.g., 4KB). 2. **Copies** everything from old stack to new stack. 3. Updates pointers to the new stack. 4. Frees the old stack.

Note: This "copying" is why pointers to stack variables are safe only if they don't escape. If they escaped to the heap, moving the stack would invalidate external pointers.

2026: The "Mid-Stack" Inlining

Recent Go versions have become aggressive about inlining function calls mid-stack. * If `UserFunc` calls `AllocFunc`, and `AllocFunc` is small, the compiler copies `AllocFunc`'s body into `UserFunc`. * This removes the function call overhead *and* allows variables that might have escaped (due to being return values) to stay on the stack.

Visualization

Variable Scenario	Destination	Why?
`x := 42`	**Stack**	Never leaves function references.
`y := &x` (used locally)	**Stack**	Address taken, but scope is local.
`return &x`	**Heap**	Escapes to caller; stack frame dies on return.
`fmt.Println(x)`	**Heap** (usually)	`fmt.Println` takes `interface{}`, which often causes escape.
`make([]byte, 1024)`	**Stack**	Size known at compile time, fits in stack.
`make([]byte, n)`	**Heap**	Size unknown at compile time.

Practical Rule

Don't fear the Heap, but respect the Stack. If you are writing a hot loop (a game loop, a high-frequency trading handler), ensure your temporary variables do not escape to the heap.

Use detailed analysis tools to verify this (covered in next chapter).

Escape Analysis & Alignment

Escape Analysis & Memory Alignment

Memory optimization usually comes down to two questions: 1. Did it hit the heap when it didn't need to? (Excessive allocation) 2. Is it wasting space? (Poor alignment)

Part 1: Escape Analysis

"Escape Analysis" is the compiler phase that decides Stack vs. Heap.

Asking the Compiler

You don't need to guess. Ask the compiler what it decided:

```
go build -gcflags="-m" main.go
```

Output Interpretation: * `can inline main`: Good. * `x does not escape`: Great (Stack). * `moved to heap: x`: Bad (Heap).

Common Escape Triggers

1. **Returning Pointers:** `func New() *T { return &T{} }` -> Escapes.
2. **Interfaces:** `func Log(v interface{})`. The concrete type inside the interface box often escapes.
3. **Closures:** Variables captured by a closure *might* escape if the closure outlives the function.
4. **Unknown Size:** `make([]int, n)` always escapes if `n` is dynamic.

The "Mid-Stack" Trick

If you need a large buffer inside a hot loop, allocate it *once* outside the loop or reuse a `sync.Pool`. * **Bad:** `for { b := make([]byte, 1024); process(b) }` (Trash on heap every loop) * **Better:** `b := make([]byte, 1024); for { process(b) }` (One alloc) * **Best (Stack):** `b := [1024]byte{}; for { process(b[:]) }` (Stack alloc if small enough)

Part 2: Memory Alignment (Padding)

CPU reads memory in words (e.g., 64-bit / 8 bytes). If a field doesn't align with a word boundary, the compiler adds **Padding** (wasted bytes).

The Struct Layout Game

Consider this struct:

```
type BadStruct struct {
    Flag    bool    // 1 byte
    Counter int64   // 8 bytes
    Active  bool    // 1 byte
}
```

Total Size: * `bool` (1) + `padding` (7) -> to align `int64` * `int64` (8) * `bool` (1) + `padding` (7) -> to align struct size to 8 * **Total:** 24 bytes

Reshuffled:

```
type GoodStruct struct {
    Counter int64   // 8 bytes (0-7)
    Flag    bool    // 1 byte  (8)
    Active  bool    // 1 byte  (9)
    // padding (6) -> to align struct size to multiple of 8 (16)
}
```

Total: 16 bytes. **33% savings just by reordering fields.**

Tools used in 2026

Do not optimize manually unless you are bored. Use tools.

- **`fieldalignment`**: `bash go install golang.org/x/tools/go/analysis/passes/fieldalignment/cm fieldalignment ./...` It will report structs that use too much memory and suggest a fix.
- **`betteralign`**: A more modern wrapper that can automatically apply changes (`-apply`).

When does this matter?

- **Single struct:** Who cares? 8 bytes is nothing.
- **Slice of 100 million structs:** 8 bytes * 100M = 800MB of RAM wasted. This triggers GC more often, costs money on cloud bills, and slows down cache.

Rule: Optimize alignment for "Data Types" (things you store in DB/Arrays). Ignore it for "Service Types" (singletons, handlers).

Generics

Designing with Interfaces

Overview

Go interfaces enable polymorphism through implicit satisfaction—types implement interfaces by having matching methods, without explicit declarations.

Interface Basics

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

// Any type with Read method satisfies Reader
type File struct { /* ... */ }
func (f *File) Read(p []byte) (int, error) { /* ... */ }

type Buffer struct { /* ... */ }
func (b *Buffer) Read(p []byte) (int, error) { /* ... */ }
```

Implicit Satisfaction

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

type Person struct {
    Name string
}

// Person implicitly implements Stringer
func (p Person) String() string {
    return p.Name
}

var s Stringer = Person{Name: "Alice"}  // Works!
```

The Empty Interface

```
interface{}  // Matches any type
any          // Alias (Go 1.18+)

func print(v any) {
    fmt.Println(v)
}

print(42)
print("hello")
print(true)
```

Interface Values

An interface value holds a (type, value) pair:

```
var r io.Reader
r = os.Stdin       // (type: *os.File, value: stdin)
r = &bytes.Buffer{}  // (type: *bytes.Buffer, value: buf)
```

nil Interface vs nil Value

```
var r io.Reader    // nil interface (no type, no value)
var f *os.File     // nil pointer

r = f              // Interface holds (*os.File, nil)
r == nil           // false! Has type, value is nil
```

Common Patterns

Accept Interface, Return Concrete

```
// Accept interface
func Process(r io.Reader) error { }

// Return concrete type
func NewBuffer() *bytes.Buffer {
    return &bytes.Buffer{}
}
```

Small Interfaces

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

type Writer interface {
    Write([]byte) (int, error)
}

type ReadWriter interface {
    Reader
    Writer
}
```

Assert Interface Compliance

```
var _ io.Reader = (*MyReader)(nil)  // Compile-time check
```

Summary

Concept	Description
Implicit	No `implements` keyword
`any`/`interface{}`	Matches all types
Small interfaces	Prefer 1-3 methods
Accept interface	Flexible function parameters

Related Topics

- Interface Best Practices
- Type Assertions

Interface Best Practices

Overview

Well-designed interfaces make Go code flexible, testable, and maintainable.

Keep Interfaces Small

```
// Good: small, focused
type Reader interface {
    Read([]byte) (int, error)
}

// Avoid: too many methods
type DataProcessor interface {
    Read([]byte) (int, error)
    Write([]byte) (int, error)
    Close() error
    Flush() error
    Seek(int64, int) (int64, error)
    // ...10 more methods
}
```

Define Interfaces at Consumer

```
// In the package that USES the interface
package myapp

type Storage interface {
    Save(data []byte) error
}

func Process(s Storage) {
    s.Save([]byte("data"))
}

// NOT in the package that implements it
```

Accept Interfaces, Return Structs

```
// Accept interface (flexible)
func ParseJSON(r io.Reader) (*Config, error)

// Return concrete type (clear)
func NewFileReader(path string) *FileReader
```

Interface Composition

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

type Closer interface {
    Close() error
}

type ReadCloser interface {
    Reader
    Closer
}
```

Avoid Interface Pollution

```
// Don't create interfaces for single implementations
// Just use the concrete type

// Unnecessary
type UserService interface {
    GetUser(id int) *User
}
type userServiceImpl struct{}

// Better: just use the struct directly
type UserService struct{}
func (s *UserService) GetUser(id int) *User
```

Testing with Interfaces

```
type EmailSender interface {
    Send(to, subject, body string) error
}

// Production
type SMTPSender struct{}
func (s *SMTPSender) Send(to, subject, body string) error

// Test mock
type MockSender struct {
    SentEmails []string
}
func (m *MockSender) Send(to, subject, body string) error {
    m.SentEmails = append(m.SentEmails, to)
    return nil
}
```

Summary

Practice	Reason
Small interfaces	Easy to implement and mock
Consumer-defined	Loose coupling
Accept interfaces	Flexibility
Return structs	Clarity
Compose	Build from small pieces

Related Topics

- Designing with Interfaces
- Testing Fundamentals

Type Assertions and Reflection Boundaries

Overview

Type assertions extract concrete types from interfaces. Reflection provides runtime type inspection but should be used sparingly.

Type Assertions

```
var i interface{} = "hello"

s := i.(string)        // Panic if wrong type
s, ok := i.(string)    // Safe: ok is false if wrong type

if s, ok := i.(string); ok {
    fmt.Println(s)
}
```

Type Switches

```
func describe(i interface{}) {
    switch v := i.(type) {
    case int:
        fmt.Println("int:", v*2)
    case string:
        fmt.Println("string:", len(v))
    case bool:
        fmt.Println("bool:", !v)
    default:
        fmt.Printf("unknown: %T\n", v)
    }
}
```

The reflect Package

```
import "reflect"

v := 42
t := reflect.TypeOf(v)   // int
val := reflect.ValueOf(v)  // 42

fmt.Println(t.Name())      // "int"
fmt.Println(t.Kind())      // int
fmt.Println(val.Int())     // 42
```

Struct Reflection

```
type User struct {
    Name string `json:"name"`
    Age  int    `json:"age"`
}

u := User{Name: "Alice", Age: 30}
t := reflect.TypeOf(u)

for i := 0; i < t.NumField(); i++ {
    field := t.Field(i)
    fmt.Printf("%s: %s\n", field.Name, field.Tag.Get("json"))
}
```

When to Use Reflection

Good uses: - Serialization (JSON, XML) - ORM field mapping - Generic testing utilities - Dependency injection

Avoid for: - Performance-critical code - Simple type checking - Normal business logic

Performance Cost

```
// Direct access: ~1ns
user.Name

// Reflection: ~100ns+
reflect.ValueOf(user).FieldByName("Name").String()
```

Prefer Generics Over Reflection

```go
// Go 1.18+: Use generics instead of reflect
func PrintSlice[T any](s []T) {
    for _, v := range s {
        fmt.Println(v)
    }
}
```

Summary

Approach	Use Case
Type assertion	Extract known concrete type
Type switch	Handle multiple types
reflect	Runtime introspection (last resort)
Generics	Compile-time type safety

Related Topics

- Why Generics Matter
- Encoding and Serialization

Why Generics Matter

Overview

Generics (type parameters), introduced in Go 1.18, allow writing functions and types that work with multiple types while maintaining type safety.

The Problem Before Generics

```
// Without generics: duplicate code or use interface{}
func MinInt(a, b int) int {
    if a < b { return a }
    return b
}

func MinFloat(a, b float64) float64 {
    if a < b { return a }
    return b
}

// Or lose type safety
func Min(a, b interface{}) interface{} {
    // Requires type assertions, runtime checks
}
```

With Generics

```
func Min[T constraints.Ordered](a, b T) T {
    if a < b {
        return a
    }
    return b
}

Min(1, 2)         // int
Min(1.5, 2.5)     // float64
Min("a", "b")     // string
```

Type Parameters

```
func Print[T any](v T) {
    fmt.Println(v)
}

// Multiple type parameters
func Pair[K, V any](k K, v V) (K, V) {
    return k, v
}
```

Constraints

```
import "golang.org/x/exp/constraints"

// Built-in constraints
any           // No requirements
comparable    // Supports == and !=

// From constraints package
constraints.Ordered    // Supports < > <= >=
constraints.Integer    // Int types
constraints.Float      // Float types
```

Custom Constraints

```
type Number interface {
    int | int32 | int64 | float32 | float64
}

func Sum[T Number](nums []T) T {
    var total T
    for _, n := range nums {
        total += n
    }
    return total
}
```

Generic Type Aliases (Go 1.24+)

Go 1.24 introduced support for generic type aliases, allowing you to create aliases for generic types.

```go
type Set[T comparable] map[T]struct{}

// Type alias (Go 1.24+)
type IntSet = Set[int]
type AnySet[T comparable] = Set[T]
```

This is particularly useful for refactoring and maintaining compatibility while migrating to generic implementations.

Benefits

1. **Type safety**: Errors caught at compile time
2. **No code duplication**: One implementation for many types
3. **Performance**: No interface boxing/unboxing
4. **Better documentation**: Types are explicit

Summary

Before	After
Code duplication	Single generic function
`interface{}`	Type parameters
Runtime errors	Compile-time errors
Type assertions	Direct usage

Related Topics

- Generic Functions
- Generic Types

Generic Functions

Overview

Generic functions use type parameters to work with multiple types while maintaining type safety.

Basic Syntax

```
func FunctionName[T constraint](params) returnType {
    // body
}
```

Examples

Map

```
func Map[T, U any](slice []T, fn func(T) U) []U {
    result := make([]U, len(slice))
    for i, v := range slice {
        result[i] = fn(v)
    }
    return result
}

doubled := Map([]int{1, 2, 3}, func(n int) int { return n * 2 })
// [2, 4, 6]
```

Filter

```
func Filter[T any](slice []T, fn func(T) bool) []T {
    var result []T
    for _, v := range slice {
        if fn(v) {
            result = append(result, v)
        }
```

```
    }
    return result
}

evens := Filter([]int{1, 2, 3, 4}, func(n int) bool { return n%2 == 0 })
// [2, 4]
```

Find

```
func Find[T any](slice []T, fn func(T) bool) (T, bool) {
    for _, v := range slice {
        if fn(v) {
            return v, true
        }
    }
    var zero T
    return zero, false
}
```

Contains

```
func Contains[T comparable](slice []T, target T) bool {
    for _, v := range slice {
        if v == target {
            return true
        }
    }
    return false
}
```

Keys/Values

```
func Keys[K comparable, V any](m map[K]V) []K {
    keys := make([]K, 0, len(m))
    for k := range m {
        keys = append(keys, k)
    }
    return keys
}

func Values[K comparable, V any](m map[K]V) []V {
    vals := make([]V, 0, len(m))
```

```
    for _, v := range m {
        vals = append(vals, v)
    }
    return vals
}
```

Type Inference

Go infers type arguments when possible:

```
// Explicit
result := Map[int, int](nums, double)

// Inferred (preferred)
result := Map(nums, double)
```

Summary

Pattern	Signature
Transform	`func Map[T, U any]([]T, func(T) U) []U`
Filter	`func Filter[T any]([]T, func(T) bool) []T`
Find	`func Find[T any]([]T, func(T) bool) (T, bool)`
Contains	`func Contains[T comparable]([]T, T) bool`

Related Topics

- Generic Types
- Idiomatic Generics

Generic Types

Overview

Generic types let you create data structures that work with any type while maintaining type safety.

Basic Syntax

```
type TypeName[T constraint] struct {
    // fields using T
}
```

Stack

```
type Stack[T any] struct {
    items []T
}

func (s *Stack[T]) Push(item T) {
    s.items = append(s.items, item)
}

func (s *Stack[T]) Pop() (T, bool) {
    if len(s.items) == 0 {
        var zero T
        return zero, false
    }
    item := s.items[len(s.items)-1]
    s.items = s.items[:len(s.items)-1]
    return item, true
}

// Usage
stack := &Stack[int]{}
stack.Push(1)
stack.Push(2)
v, _ := stack.Pop()  // 2
```

Set

```
type Set[T comparable] map[T]struct{}

func NewSet[T comparable]() Set[T] {
    return make(Set[T])
}

func (s Set[T]) Add(item T) {
    s[item] = struct{}{}
}

func (s Set[T]) Contains(item T) bool {
    _, ok := s[item]
    return ok
}

func (s Set[T]) Remove(item T) {
    delete(s, item)
}

// Usage
set := NewSet[string]()
set.Add("a")
set.Contains("a")  // true
```

Pair

```
type Pair[T, U any] struct {
    First  T
    Second U
}

func NewPair[T, U any](first T, second U) Pair[T, U] {
    return Pair[T, U]{first, second}
}

p := NewPair("age", 30)
// Pair[string, int]{First: "age", Second: 30}
```

Result (Option Pattern)

```
type Result[T any] struct {
    value T
    err   error
}

func Ok[T any](v T) Result[T] {
    return Result[T]{value: v}
}

func Err[T any](err error) Result[T] {
    return Result[T]{err: err}
}

func (r Result[T]) Unwrap() (T, error) {
    return r.value, r.err
}
```

LinkedList

```
type Node[T any] struct {
    Value T
    Next  *Node[T]
}

type LinkedList[T any] struct {
    Head *Node[T]
}

func (l *LinkedList[T]) Add(v T) {
    node := &Node[T]{Value: v, Next: l.Head}
    l.Head = node
}
```

Summary

Type	Purpose
`Stack[T]`	LIFO collection
`Set[T]`	Unique elements
`Pair[T, U]`	Key-value tuple
`Result[T]`	Error handling

Related Topics

- Generic Functions
- Idiomatic Generics

Idiomatic Generics

Overview

Generics are powerful but should be used judiciously. This chapter covers when to use generics vs interfaces, and best practices.

When to Use Generics

Good uses: - Container types (Stack, Set, Queue) - Utility functions (Map, Filter, Reduce) - Type-safe concurrent constructs - Avoiding reflection

Don't use when: - Interface works fine - Only one type will ever be used - Adding complexity without benefit

Generics vs Interfaces

Use Interface When:

```
// Behavior-based polymorphism
type Writer interface {
    Write([]byte) (int, error)
}

func Save(w Writer, data []byte) error {
    _, err := w.Write(data)
    return err
}
```

Use Generics When:

```
// Type preservation needed
func Reverse[T any](s []T) []T {
    result := make([]T, len(s))
    for i, v := range s {
        result[len(s)-1-i] = v
    }
```

```
    return result
}
```

Guidelines

1. Start with Concrete Types

```
// Start here
func ReverseInts(s []int) []int { }

// Generalize only when needed
func Reverse[T any](s []T) []T { }
```

2. Use Meaningful Constraints

```
// Too broad
func Process[T any](v T) { }

// Better: documents requirements
func Process[T constraints.Ordered](v T) { }
```

3. Don't Over-Constrain

```
// Over-constrained
type Number interface {
    int | int8 | int16 | int32 | int64 |
    uint | uint8 | uint16 | uint32 | uint64 |
    float32 | float64
}

// Better: use existing constraint
func Sum[T constraints.Integer | constraints.Float](nums []T) T
```

4. Type Inference is Your Friend

```
// Let Go infer when obvious
result := Map(nums, double)

// Explicit only when needed
result := Convert[int, float64](nums)
```

Common Patterns

slices Package (stdlib)

```
import "slices"

slices.Sort(nums)
slices.Reverse(nums)
slices.Contains(nums, 5)
slices.Index(nums, 5)
```

maps Package (stdlib)

```
import "maps"

maps.Clone(m)
maps.Keys(m)
maps.Values(m)
```

Summary

Decision	Choice
Need type preservation	Generics
Need polymorphic behavior	Interface
Operating on containers	Generics
Method set requirements	Interface

Related Topics

- Why Generics Matter
- Interface Best Practices

Errors

Errors as Values

Overview

Go treats errors as values, not exceptions. Functions return errors alongside results, making error handling explicit and visible.

The error Interface

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

Returning Errors

```
func divide(a, b float64) (float64, error) {
    if b == 0 {
        return 0, errors.New("division by zero")
    }
    return a / b, nil
}

result, err := divide(10, 0)
if err != nil {
    log.Fatal(err)
}
```

Creating Errors

```
import "errors"

// Simple error
err := errors.New("something went wrong")

// Formatted error
```

```
err := fmt.Errorf("failed to open %s: %v", filename, originalErr)
```

Error Handling Patterns

Check Immediately

```
result, err := doSomething()
if err != nil {
    return err
}
// Use result
```

Early Return

```
func process() error {
    data, err := fetch()
    if err != nil {
        return err
    }

    result, err := transform(data)
    if err != nil {
        return err
    }

    return save(result)
}
```

Add Context

```
data, err := readFile(path)
if err != nil {
    return fmt.Errorf("loading config: %w", err)
}
```

Custom Error Types

```
type ValidationError struct {
    Field   string
    Message string
}

func (e *ValidationError) Error() string {
    return fmt.Sprintf("%s: %s", e.Field, e.Message)
}

func validate(u User) error {
    if u.Name == "" {
        return &ValidationError{Field: "name", Message: "required"}
    }
    return nil
}
```

Sentinel Errors

```
var ErrNotFound = errors.New("not found")
var ErrPermission = errors.New("permission denied")

func find(id int) (*User, error) {
    if !exists(id) {
        return nil, ErrNotFound
    }
    // ...
}

// Check
if err == ErrNotFound {
    // Handle not found
}
```

Summary

Pattern	Usage
`errors.New()`	Simple error
`fmt.Errorf()`	Formatted error
Custom type	Structured error data
Sentinel	Known error values

Related Topics

- Wrapping and Inspecting Errors
- panic, recover, and Failure Modes

Wrapping and Inspecting Errors

Overview

Go 1.13 introduced error wrapping, allowing you to add context while preserving the original error for inspection.

Wrapping Errors

```
originalErr := errors.New("file not found")

// %w wraps the error
wrappedErr := fmt.Errorf("loading config: %w", originalErr)

// The error chain: wrappedErr -> originalErr
```

Unwrapping

```
err := fmt.Errorf("outer: %w",
    fmt.Errorf("middle: %w",
        errors.New("inner")))

inner := errors.Unwrap(err)  // middle: inner
```

errors.Is

Check if any error in the chain matches:

```
var ErrNotFound = errors.New("not found")

err := fmt.Errorf("user lookup: %w", ErrNotFound)

if errors.Is(err, ErrNotFound) {
    // Handle not found
}
```

errors.As

Extract specific error types:

```
type ValidationError struct {
    Field string
}

func (e *ValidationError) Error() string {
    return "validation: " + e.Field
}

err := fmt.Errorf("processing: %w", &ValidationError{Field: "email"})

var valErr *ValidationError
if errors.As(err, &valErr) {
    fmt.Println("Invalid field:", valErr.Field)
}
```

Custom Wrappers

```
type WrappedError struct {
    Context string
    Err     error
}

func (e *WrappedError) Error() string {
    return fmt.Sprintf("%s: %v", e.Context, e.Err)
}

func (e *WrappedError) Unwrap() error {
    return e.Err
}
```

Best Practices

```
// Add context when crossing boundaries
func LoadUser(id int) (*User, error) {
    data, err := db.Query(id)
    if err != nil {
        return nil, fmt.Errorf("LoadUser(%d): %w", id, err)
    }
```

```
    return parse(data)
}
```

Summary

Function	Purpose
`fmt.Errorf("%w", err)`	Wrap error
`errors.Unwrap(err)`	Get wrapped error
`errors.Is(err, target)`	Check chain for match
`errors.As(err, &target)`	Extract typed error

Related Topics

- Errors as Values
- panic, recover, and Failure Modes

panic, recover, and Failure Modes

Overview

`panic` and `recover` handle unrecoverable errors. Unlike normal errors, panics crash the program unless recovered.

When to Panic

Appropriate: - Programmer errors (bugs) - Impossible conditions - Failed invariants - During initialization

Avoid for: - Expected errors (file not found, network timeout) - User input validation - Anything recoverable

Panic

```
func divide(a, b int) int {
    if b == 0 {
        panic("division by zero")  // Terminates program
    }
    return a / b
}
```

Common Panic Sources

```
// nil pointer dereference
var p *int
*p = 1  // panic

// Index out of range
arr := []int{1, 2}
arr[10]  // panic

// Invalid type assertion
var i interface{} = "string"
i.(int)  // panic
```

Recover

Recover catches panics in deferred functions:

```
func safeCall() (err error) {
    defer func() {
        if r := recover(); r != nil {
            err = fmt.Errorf("panic recovered: %v", r)
        }
    }()

    dangerousOperation()
    return nil
}
```

HTTP Server Pattern

```
func handler(w http.ResponseWriter, r *http.Request) {
    defer func() {
        if err := recover(); err != nil {
            log.Printf("panic: %v\n%s", err, debug.Stack())
            http.Error(w, "Internal Server Error", 500)
        }
    }()

    // Handle request
}
```

Panic vs Error

```
// Return error for expected failures
func ReadFile(name string) ([]byte, error) {
    if !exists(name) {
        return nil, ErrNotFound  // Expected case
    }
    // ...
}

// Panic for bugs
func MustCompile(pattern string) *Regexp {
    r, err := Compile(pattern)
    if err != nil {
        panic(err)  // Invalid pattern is programmer error
```

```
    }
    return r
}
```

Summary

Keyword	Purpose
`panic`	Unrecoverable error (crash)
`recover`	Catch panic in defer
`error`	Expected, recoverable failures

Use panic for	Use error for
Bugs	Expected failures
Invariant violations	User/external input
Initialization failures	I/O, network errors

Related Topics

- Errors as Values
- Testing Fundamentals

The Must Pattern & No-GC Handling

Advanced Error Patterns: The "Must" & The "Odin" Way

Go's error handling (`if err != nil`) is explicit, but sometimes you need different strategies for initialization vs. runtime, or you want to adopt patterns from systems languages like Odin/Zig.

1. The "Must" Pattern

Rule: Return errors to callers; Panic only on programmer error or unrecoverable startup failure.

The "Must" pattern is a convention for functions that wrap a standard error-returning function but `panic` instead of returning the error.

When to use it?

- **Global/Package Initialization:** `var t = template.Must(template.New(...))`
- **Startup Configuration:** If your compiled regex is invalid, the app is broken. Don't start.

Implementation

```
func Must[T any](obj T, err error) T {
    if err != nil {
        panic(err)
    }
    return obj
}

// Usage
var db = Must(sql.Open("postgres", "..."))
var regex = Must(regexp.Compile("^[a-z]+$"))
```

With Generics (Go 1.18+), you can write a universal `Must` wrapper one time and use it everywhere.

---

2. Linear Error Handling (The Odin/Zig Influence)

Languages like **Odin** (a data-oriented C alternative) handle errors by treating them as distinct return values, much like Go, but often with syntactic sugar (`or_return`) or strict definitions.

While Go doesn't have `try` or `?` operators, we can adopt the **"Guard Clause" mentality**.

The Happy Path must remain left-aligned

Bad (Nested):

```
func process() error {
    err := step1()
    if err == nil {
        err = step2()
        if err == nil {
            return step3()
        }
    }
    return err
}
```

Good (Guard Clauses / "Odin Style"):

```
func process() error {
    if err := step1(); err != nil {
        return fmt.Errorf("step1: %w", err)
    }

    // The "Happy Path" stays at indentation 0
    if err := step2(); err != nil {
        return fmt.Errorf("step2: %w", err)
    }

    return step3()
}
```

No-GC Thinking: Errors as Resource Cleanup Triggers

In non-GC languages, an error often implies manual resource cleanup (`defer` in Swift/Zig). Go automates memory, but not *resources* (Files, Sockets, DB Connections).

The `defer` Trap in Loops:

```
for _, file := range files {
    f, err := os.Open(file)
```

```
    if err != nil { return err }
    defer f.Close() // DANGEROUS: Closes only at end of function, not loop!
    // FD exhaustion possible.
}
```

The Fix (Anonymous Function):

```
for _, file := range files {
    err := func() error {
        f, err := os.Open(file)
        if err != nil { return err }
        defer f.Close() // Closes at end of this anonymous func
        return process(f)
    }()
    if err != nil { return err }
}
```

3. Errors in 2026: "Join" and Structure

Since Go 1.20+, `errors.Join` allows returning *multiple* errors at once (e.g., from parallel validation).

```
func validate(u User) error {
    var errs error
    if u.Name == "" {
        errs = errors.Join(errs, errors.New("missing name"))
    }
    if u.Age < 0 {
        errs = errors.Join(errs, errors.New("invalid age"))
    }
    return errs // Returns nil if no errors joined
}
```

This is cleaner than older `multierror` libraries.

Summary

1. **Must**: Use for hard startup dependencies. Crash early.
2. **Left-Align**: Keep your happy path on the left edge.
3. **Defer scope**: Remember `defer` is function-scoped, not block-scoped.

Testing

Testing Fundamentals

Overview

Go has built-in testing support. Test files end with `_test.go` and use the `testing` package.

Writing Tests

```
// math.go
package math

func Add(a, b int) int {
    return a + b
}
```

```
// math_test.go
package math

import "testing"

func TestAdd(t *testing.T) {
    result := Add(2, 3)
    if result != 5 {
        t.Errorf("Add(2, 3) = %d; want 5", result)
    }
}
```

Running Tests

```
go test              # Current package
go test ./...        # All packages
go test -v           # Verbose
go test -run TestAdd # Specific test
```

Test Functions

```
func TestXxx(t *testing.T)          // Test
func BenchmarkXxx(b *testing.B)     // Benchmark
func ExampleXxx()                   // Example
func FuzzXxx(f *testing.F)          // Fuzz test
```

t.Error vs t.Fatal

```
func TestExample(t *testing.T) {
    // Continues after failure
    t.Error("failed but continuing")

    // Stops test immediately
    t.Fatal("failed, stopping now")
}
```

Helper Functions

```
func assertEqual(t *testing.T, got, want int) {
    t.Helper()  // Marks this as helper
    if got != want {
        t.Errorf("got %d, want %d", got, want)
    }
}

func TestMath(t *testing.T) {
    assertEqual(t, Add(1, 2), 3)
}
```

Setup and Teardown

```
func TestMain(m *testing.M) {
    // Setup
    setup()

    code := m.Run()  // Run tests

    // Teardown
    teardown()
```

```
    os.Exit(code)
}
```

Parallel Tests

```
func TestParallel(t *testing.T) {
    t.Parallel()  // Run in parallel
    // Test code
}
```

Summary

Command	Purpose
`go test`	Run tests
`go test -v`	Verbose output
`go test -cover`	Show coverage
`go test -race`	Race detection

Related Topics

- Test Organization and Coverage
- Advanced Testing

Test Organization and Coverage

Overview

Well-organized tests and good coverage help maintain code quality over time.

File Organization

```
mypackage/
   user.go          # Implementation
   user_test.go     # Tests
   user_internal_test.go  # Internal tests
   testdata/        # Test fixtures
       users.json
```

Package Naming

```
// Same package (white-box testing)
package mypackage

// External package (black-box testing)
package mypackage_test
```

Testdata Directory

```
func TestParseConfig(t *testing.T) {
    data, err := os.ReadFile("testdata/config.json")
    if err != nil {
        t.Fatal(err)
    }
    // Use data
}
```

Code Coverage

```
# Show coverage percentage
go test -cover

# Generate coverage profile
go test -coverprofile=coverage.out

# View in browser
go tool cover -html=coverage.out

# Show coverage by function
go tool cover -func=coverage.out
```

Coverage Modes

```
# Statement coverage (default)
go test -covermode=set

# Count mode (how many times)
go test -covermode=count

# Atomic (for concurrent tests)
go test -covermode=atomic
```

Test Groups

```
func TestUser(t *testing.T) {
    t.Run("Create", func(t *testing.T) {
        // Test creation
    })

    t.Run("Update", func(t *testing.T) {
        // Test update
    })

    t.Run("Delete", func(t *testing.T) {
        // Test deletion
    })
}
```

Skipping Tests

```
func TestIntegration(t *testing.T) {
    if testing.Short() {
        t.Skip("skipping in short mode")
    }
    // Long test
}
```

```
go test -short  # Skip long tests
```

Summary

Flag	Purpose
`-cover`	Show coverage %
`-coverprofile=file`	Generate profile
`-short`	Skip long tests
`-run=Pattern`	Run matching tests

Related Topics

- Testing Fundamentals
- Advanced Testing

Advanced Testing

Overview

Table-driven tests, subtests, and test helpers make Go tests maintainable and expressive.

```
Fast feedback test loop

unit tests -------> deterministic concurrency tests -----> benchmarks
    |                           |                              |
  <1s target                race-safe                    track regressions
```

Table-Driven Tests

```
func TestAdd(t *testing.T) {
    tests := []struct {
        name     string
        a, b     int
        expected int
    }{
        {"positive", 2, 3, 5},
        {"negative", -1, -2, -3},
        {"zero", 0, 0, 0},
        {"mixed", -1, 5, 4},
    }

    for _, tt := range tests {
        t.Run(tt.name, func(t *testing.T) {
            result := Add(tt.a, tt.b)
            if result != tt.expected {
                t.Errorf("Add(%d, %d) = %d; want %d",
                    tt.a, tt.b, result, tt.expected)
            }
        })
    }
}
```

Subtests

```
func TestAPI(t *testing.T) {
    t.Run("GET", func(t *testing.T) {
        t.Run("success", func(t *testing.T) { })
        t.Run("not_found", func(t *testing.T) { })
    })

    t.Run("POST", func(t *testing.T) {
        t.Run("valid", func(t *testing.T) { })
        t.Run("invalid", func(t *testing.T) { })
    })
}
```

Test Helpers

```
func newTestServer(t *testing.T) *httptest.Server {
    t.Helper()
    return httptest.NewServer(http.HandlerFunc(func(w http.ResponseWriter, r *http.Request)
        w.Write([]byte("OK"))
    }))
}

func TestClient(t *testing.T) {
    server := newTestServer(t)
    defer server.Close()
    // Use server.URL
}
```

Cleanup

```
func TestWithCleanup(t *testing.T) {
    tmpDir := t.TempDir()  // Auto-removed

    f, _ := os.CreateTemp(tmpDir, "test")
    t.Cleanup(func() {
        f.Close()
    })
}
```

Deterministic Concurrency (`testing/synctest`)

For Go 1.26 codebases, adopt `testing/synctest` where timers, goroutines, and scheduling made tests flaky before.

```
import "testing/synctest"

func TestRateLimiter(t *testing.T) {
    synctest.Run(func() {
        rl := NewRateLimiter(1 * time.Second)
        // Time is virtual and controlled within synctest.Run
        if !rl.Allow() { t.Error("should allow") }
        synctest.Wait() // Wait for internal goroutines
    })
}
```

Tip: keep business logic outside goroutine setup so `synctest.Run` stays small and focused.

Efficient Benchmarks (`B.Loop`)

Prefer `B.Loop` in modern toolchains for cleaner benchmark loops and fewer loop-control mistakes.

```
func BenchmarkAdd(b *testing.B) {
    for b.Loop() {
        Add(1, 2)
    }
}
```

Migration pattern:

```
// old
func BenchmarkParseOld(b *testing.B) {
    for i := 0; i < b.N; i++ {
        Parse(input)
    }
}

// new
func BenchmarkParse(b *testing.B) {
    for b.Loop() {
        Parse(input)
    }
}
```

Go 1.26 Testing Upgrade Checklist

1. Use `t.Cleanup`, `t.TempDir`, and `t.Setenv` instead of manual teardown.
2. Move flaky concurrency tests into `testing/synctest`.
3. Standardize benchmark style on `B.Loop`.
4. Run strict CI test command:

```
go test ./... -race -shuffle=on -count=1
```

Parallel Subtests

```
func TestParallel(t *testing.T) {
    tests := []struct{ name string }{{"a"}, {"b"}, {"c"}}

    for _, tt := range tests {
        t.Run(tt.name, func(t *testing.T) {
            t.Parallel()
            // Runs concurrently
        })
    }
}
```

Benchmarks

```
func BenchmarkAdd(b *testing.B) {
    for i := 0; i < b.N; i++ {
        Add(1, 2)
    }
}
```

```
go test -bench=.
go test -bench=. -benchmem  # Include memory
```

Summary

Technique	Purpose
Table-driven	Test multiple cases
Subtests	Organize and filter
`t.Helper()`	Clean error reporting
`t.Cleanup()`	Guaranteed cleanup

Technique	Purpose
`t.Parallel()`	Concurrent tests

Related Topics

- Testing Fundamentals
- Integration Testing

Integration and System Testing

Overview

Integration tests verify components work together, testing against real databases, APIs, and external services.

```
Test layers

unit (many, fast)
   |
integration (fewer, realistic deps)
   |
system/e2e (fewest, highest confidence)
```

HTTP Testing

```
import "net/http/httptest"

func TestHandler(t *testing.T) {
    req := httptest.NewRequest("GET", "/users", nil)
    w := httptest.NewRecorder()

    handler(w, req)

    if w.Code != http.StatusOK {
        t.Errorf("status = %d; want 200", w.Code)
    }
}
```

Test Server

```
func TestAPIClient(t *testing.T) {
    server := httptest.NewServer(http.HandlerFunc(
        func(w http.ResponseWriter, r *http.Request) {
            w.Write([]byte(`{"id": 1}`))
        }))
```

```
    defer server.Close()

    client := NewClient(server.URL)
    user, err := client.GetUser(1)
    // Assert...
}
```

Database Testing

```
func TestUserRepository(t *testing.T) {
    if testing.Short() {
        t.Skip("skipping integration test")
    }

    db := setupTestDB(t)
    t.Cleanup(func() { db.Close() })

    repo := NewUserRepository(db)

    // Test operations
    err := repo.Create(&User{Name: "test"})
    if err != nil {
        t.Fatal(err)
    }
}
```

Build Tags

```
//go:build integration
// +build integration

package myapp_test

// Only runs with: go test -tags=integration
```

Environment-Based Tests

```
func TestWithEnv(t *testing.T) {
    url := os.Getenv("API_URL")
    if url == "" {
        t.Skip("API_URL not set")
    }
    // Test against real API
}
```

Docker Integration

```
func TestWithDocker(t *testing.T) {
    if testing.Short() {
        t.Skip("skipping docker test")
    }

    // Use testcontainers-go or similar
    container, err := startPostgres()
    if err != nil {
        t.Fatal(err)
    }
    t.Cleanup(func() { container.Terminate(ctx) })

    // Run tests against container
}
```

Go 1.26 Integration Testing Upgrades

Use a two-lane CI strategy:

1. Default lane (every push): fast unit + short integration.
2. Full lane (main/nightly): DB containers, external API contract checks, and race detector.

```
# default
go test ./... -short -shuffle=on

# full
go test ./... -tags=integration -race -count=1
```

For external APIs, always assert status + schema shape, not only status codes:

```go
func assertUserShape(t *testing.T, body []byte) {
    t.Helper()
    var got map[string]any
    if err := json.Unmarshal(body, &got); err != nil {
        t.Fatal(err)
    }
    if _, ok := got["id"]; !ok {
        t.Fatal("missing id")
    }
}
```

Summary

Tool	Use Case
`httptest`	HTTP handlers
Build tags	Separate test suites
Env vars	External dependencies
`testing.Short()`	Skip slow tests

Related Topics

- Testing Fundamentals
- Advanced Testing

Concurrency Parallelism

Concurrency Basics

Overview

Go's concurrency model uses goroutines (lightweight threads) and channels for communication.

Goroutines

```
go func() {
    // Runs concurrently
    fmt.Println("Hello from goroutine")
}()

go processData()  // Named function
```

Goroutines are cheap (~2KB stack, can have millions).

Creating Goroutines

```
func main() {
    go sayHello()
    go sayWorld()
    time.Sleep(100 * time.Millisecond)  // Wait (not ideal)
}

func sayHello() { fmt.Println("Hello") }
func sayWorld() { fmt.Println("World") }
```

Waiting with WaitGroup

```
var wg sync.WaitGroup

for i := 0; i < 5; i++ {
    wg.Add(1)
    go func(n int) {
```

```
        defer wg.Done()
        fmt.Println(n)
    }(i)
}

wg.Wait()  // Block until all done
```

Channels

```
ch := make(chan int)      // Unbuffered
ch := make(chan int, 10)  // Buffered

ch <- 42      // Send
value := <-ch // Receive
```

Basic Channel Pattern

```
func main() {
    ch := make(chan string)

    go func() {
        ch <- "Hello"
    }()

    msg := <-ch
    fmt.Println(msg)
}
```

Worker Pool

```
func worker(id int, jobs <-chan int, results chan<- int) {
    for job := range jobs {
        results <- job * 2
    }
}

func main() {
    jobs := make(chan int, 100)
    results := make(chan int, 100)

    // Start workers
```

```
    for w := 0; w < 3; w++ {
        go worker(w, jobs, results)
    }

    // Send jobs
    for j := 0; j < 10; j++ {
        jobs <- j
    }
    close(jobs)

    // Collect results
    for r := 0; r < 10; r++ {
        fmt.Println(<-results)
    }
}
```

Summary

Concept	Purpose
`go func()`	Start goroutine
`sync.WaitGroup`	Wait for completion
`make(chan T)`	Create channel
`ch <-` / `<-ch`	Send/receive

Related Topics

- Channel Patterns
- Synchronization

Channel Patterns

Overview

Channels enable safe communication between goroutines. This chapter covers essential channel patterns.

Channel Directions

```
chan T     // Bidirectional
chan<- T   // Send-only
<-chan T   // Receive-only

func producer(out chan<- int) { }
func consumer(in <-chan int) { }
```

Buffered vs Unbuffered

```
// Unbuffered: send blocks until receive
ch := make(chan int)

// Buffered: send blocks when full
ch := make(chan int, 10)
```

Closing Channels

```
close(ch)

// Check if closed
v, ok := <-ch
if !ok {
    // Channel closed
}

// Range over channel
```

```go
for v := range ch {
    // Receives until closed
}
```

Select

```go
select {
case v := <-ch1:
    fmt.Println("from ch1:", v)
case v := <-ch2:
    fmt.Println("from ch2:", v)
case ch3 <- x:
    fmt.Println("sent to ch3")
default:
    fmt.Println("no channel ready")
}
```

Timeout Pattern

```go
select {
case result := <-ch:
    fmt.Println(result)
case <-time.After(1 * time.Second):
    fmt.Println("timeout")
}
```

Done Channel

```go
done := make(chan struct{})

go func() {
    // Work...
    close(done)  // Signal completion
}()

<-done  // Wait for signal
```

Fan-Out/Fan-In

```
// Fan-out: multiple goroutines read from one channel
func fanOut(in <-chan int, workers int) []<-chan int {
    outs := make([]<-chan int, workers)
    for i := 0; i < workers; i++ {
        outs[i] = worker(in)
    }
    return outs
}

// Fan-in: merge multiple channels into one
func fanIn(ins ...<-chan int) <-chan int {
    out := make(chan int)
    var wg sync.WaitGroup
    for _, in := range ins {
        wg.Add(1)
        go func(ch <-chan int) {
            defer wg.Done()
            for v := range ch {
                out <- v
            }
        }(in)
    }
    go func() {
        wg.Wait()
        close(out)
    }()
    return out
}
```

Summary

Pattern	Use Case
Unbuffered	Synchronization
Buffered	Decouple speed
Select	Multiple channels
Done channel	Cancellation signal
Fan-out/in	Parallel processing

Related Topics

- Concurrency Basics

- Context and Cancellation

Synchronization

Overview

The `sync` package provides low-level synchronization primitives for coordinating goroutines.

sync.Mutex

```
var (
    mu    sync.Mutex
    count int
)

func increment() {
    mu.Lock()
    count++
    mu.Unlock()
}

// With defer
func safe() {
    mu.Lock()
    defer mu.Unlock()
    // Critical section
}
```

sync.RWMutex

```
var (
    mu   sync.RWMutex
    data map[string]string
)

func read(key string) string {
    mu.RLock()
    defer mu.RUnlock()
    return data[key]
```

```
}

func write(key, value string) {
    mu.Lock()
    defer mu.Unlock()
    data[key] = value
}
```

sync.WaitGroup

```
var wg sync.WaitGroup

for i := 0; i < 5; i++ {
    wg.Add(1)
    go func(n int) {
        defer wg.Done()
        work(n)
    }(i)
}

wg.Wait()
```

sync.Once

```
var (
    once   sync.Once
    config *Config
)

func getConfig() *Config {
    once.Do(func() {
        config = loadConfig()  // Runs exactly once
    })
    return config
}
```

sync.Pool

```
var pool = sync.Pool{
    New: func() any {
        return make([]byte, 1024)
    },
}

func process() {
    buf := pool.Get().([]byte)
    defer pool.Put(buf)
    // Use buf
}
```

sync.Map

```
var m sync.Map

m.Store("key", "value")
v, ok := m.Load("key")
m.Delete("key")
m.Range(func(k, v any) bool {
    fmt.Println(k, v)
    return true  // Continue iteration
})
```

atomic Package

```
import "sync/atomic"

var counter int64

atomic.AddInt64(&counter, 1)
value := atomic.LoadInt64(&counter)
atomic.StoreInt64(&counter, 0)
```

Summary

Type	Purpose
`Mutex`	Exclusive lock
`RWMutex`	Reader/writer lock
`WaitGroup`	Wait for goroutines
`Once`	Single execution
`Pool`	Object reuse
`Map`	Concurrent map

Related Topics

- Concurrency Basics
- Concurrency Design Guidelines

Context and Cancellation

Overview

The `context` package manages deadlines, cancellation, and request-scoped values across API boundaries.

Creating Contexts

```
ctx := context.Background()  // Root context
ctx := context.TODO()        // Placeholder
```

Cancellation

```
ctx, cancel := context.WithCancel(context.Background())
defer cancel()

go func() {
    select {
    case <-ctx.Done():
        fmt.Println("cancelled:", ctx.Err())
        return
    case <-time.After(time.Hour):
        fmt.Println("completed")
    }
}()

cancel()  // Signal cancellation
```

Timeout

```
ctx, cancel := context.WithTimeout(context.Background(), 5*time.Second)
defer cancel()

select {
```

```
case result := <-doWork(ctx):
    fmt.Println(result)
case <-ctx.Done():
    fmt.Println("timeout:", ctx.Err())
}
```

Deadline

```
deadline := time.Now().Add(10 * time.Second)
ctx, cancel := context.WithDeadline(context.Background(), deadline)
defer cancel()
```

Passing Context

```
func handleRequest(ctx context.Context) {
    result, err := fetchData(ctx)
    if err != nil {
        return
    }
    processData(ctx, result)
}

func fetchData(ctx context.Context) (Data, error) {
    req, _ := http.NewRequestWithContext(ctx, "GET", url, nil)
    return http.DefaultClient.Do(req)
}
```

Context Values

```
type key string
const userKey key = "user"

ctx := context.WithValue(ctx, userKey, "alice")

user := ctx.Value(userKey).(string)
```

Best Practices

- Pass context as first parameter

- Never store context in structs
- Always call cancel() (use defer)
- Only use context values for request-scoped data

Summary

Function	Purpose
`WithCancel`	Manual cancellation
`WithTimeout`	Duration-based timeout
`WithDeadline`	Absolute time limit
`WithValue`	Request-scoped data

Related Topics

- Channel Patterns
- HTTP and Networking

Concurrency Design Guidelines

Overview

Concurrency can introduce subtle bugs. Follow these guidelines to write safe concurrent code.

Share by Communicating

```
// Prefer: communicate over channels
result := <-worker.Results()

// Avoid: shared memory with locks
mu.Lock()
result := sharedData
mu.Unlock()
```

Avoid Goroutine Leaks

```
// Bad: goroutine leaks if nobody receives
go func() {
    ch <- result  // Blocks forever
}()

// Good: use context cancellation
go func() {
    select {
    case ch <- result:
    case <-ctx.Done():
    }
}()
```

Always Close Channels from Sender

```
// Producer closes
func producer(out chan<- int) {
    for i := 0; i < 10; i++ {
        out <- i
    }
    close(out)  // Only sender closes
}

// Consumer ranges
for v := range in {
    process(v)
}
```

Race Detection

```
go test -race ./...
go run -race main.go
```

Common Patterns

Worker Pool

```
jobs := make(chan Job)
for i := 0; i < workers; i++ {
    go worker(jobs)
}
```

Bounded Concurrency

```
sem := make(chan struct{}, maxConcurrent)

for _, task := range tasks {
    sem <- struct{}{}
    go func(t Task) {
        defer func() { <-sem }()
        process(t)
    }(task)
}
```

Deadlock Prevention

```
// Deadlock: circular wait
ch := make(chan int)
ch <- 1    // Blocks: no receiver
<-ch       // Never reached

// Fix: buffer or separate goroutine
ch := make(chan int, 1)
ch <- 1
<-ch
```

Summary

Guideline	Reason
Share by communicating	Clearer ownership
Use context for cancellation	Prevent leaks
Only sender closes	Avoid panic
Run race detector	Catch data races

Related Topics

- Synchronization
- Context and Cancellation

Worker Pools

Worker Pools: Controlling Chaos

Go makes it easy to spawn 100,000 goroutines. The OS makes it easy to crash when you open 100,000 file descriptors.

Unbounded concurrency is a bug. You must limit parallelism to match your resource limits (CPU, Memory, Network/DB Connections).

Pattern 1: The Semaphore (Simple Limiter)

The easiest way to limit concurrency is a buffered channel (semaphore).

```
func ProcessItems(items []string) {
    sem := make(chan struct{}, 10) // Limit to 10 concurrent
    var wg sync.WaitGroup

    for _, item := range items {
        wg.Add(1)
        go func(val string) {
            defer wg.Done()

            sem <- struct{}{}        // Acquire token (blocks if full)
            defer func() { <-sem }() // Release token

            DoWork(val)
        }(item)
    }
    wg.Wait()
}
```

Pros: Trivial to implement. **Cons:** Still spawns N goroutines (memory cost), just blocks them from *executing* the heavy work.

Pattern 2: The Worker Pool (Fixed Goroutines)

Instead of spawning a goroutine per item, spawn a fixed number of workers (e.g., `runtime.NumCPU()`) and feed them work.

```go
func WorkerPool(jobs <-chan Job, results chan<- Result, workers int) {
    var wg sync.WaitGroup

    // Spawn fixed workers
    for i := 0; i < workers; i++ {
        wg.Add(1)
        go func(id int) {
            defer wg.Done()
            for job := range jobs {
                results <- process(job)
            }
        }(i)
    }

    wg.Wait()
    close(results) // Close results when all workers satisfy
}

func main() {
    jobs := make(chan Job, 100)
    results := make(chan Result, 100)

    go func() {
        // Enqueue jobs
        jobs <- Job{...}
        close(jobs) // Important: Tell workers no more jobs coming
    }()

    // Start pool
    WorkerPool(jobs, results, 5)

    // Consume results
    for res := range results {
        fmt.Println(res)
    }
}
```

Pros: Fixed memory footprint. Zero waste. **Cons:** Slightly more code.

2026: `errgroup` with Limits

The `golang.org/x/sync/errgroup` package handles error propagation and limits.

```go
g := new(errgroup.Group)
g.SetLimit(10) // New in recent versions
```

```
for _, item := range items {
    item := item
    g.Go(func() error {
        return process(item)
    })
}

if err := g.Wait(); err != nil {
    return err
}
```

This is the preferred modern way. It handles wait groups, error propagation (first error cancels context), and concurrency limits in one standard package.

Summary

- Never use `go func()` inside a loop without a limit mechanism.
- Use `errgroup.SetLimit` for 90% of cases.
- Use manual Worker Patterns for complex, long-lived background processing queues.

Pipelines & Complex Patterns

Pipelines and `sync.Cond`

Beyond simple worker pools, Go concurrency shines in **Data Pipelines** (streaming data through stages) and **Signaling** (complex coordination).

1. The Pipeline Pattern (Fan-Out / Fan-In)

Pipelines allow you to process streams of data where each stage runs concurrently.

Stages: 1. **Generator:** Converts data (file lines, DB rows) into a channel. 2. **Transformer:** Reads one channel, modifies/filters, writes to another. 3. **Sink:** Consumes final output.

```
func Generator(nums ...int) <-chan int {
    out := make(chan int)
    go func() {
        for _, n := range nums { out <- n }
        close(out)
    }()
    return out
}

func Square(in <-chan int) <-chan int {
    out := make(chan int)
    go func() {
        for n := range in { out <- n * n }
        close(out)
    }()
    return out
}

func Merge(channels ...<-chan int) <-chan int {
    // Advanced: Fan-In multiple channels to one
    var wg sync.WaitGroup
    out := make(chan int)

    output := func(c <-chan int) {
        defer wg.Done()
        for n := range c { out <- n }
    }
```

```
    wg.Add(len(channels))
    for _, c := range channels {
        go output(c)
    }

    go func() {
        wg.Wait()
        close(out)
    }()
    return out
}
```

Cancellation: Real pipelines must pass `context.Context` to every stage to support early cancellation (e.g., stop processing if the user disconnects).

2. The Overlooked `sync.Cond`

Channels are for passing data. Mutexes are for locking data. **`sync.Cond`** is for **broadcasting signals**.

Use Case: You have 100 goroutines waiting for a specific event (e.g., "Configuration Loaded" or "Queue is not empty"). * **Channels:** Sending 100 messages is O(N). * **Channels (Close):** Closing a channel broadcasts to all, but you can only do it *once*. * **sync.Cond:** Can `Broadcast()` multiple times.

Example: The Race Start

```
var mu sync.Mutex
cond := sync.NewCond(&mu)
ready := false

// Workers
for i := 0; i < 10; i++ {
    go func(id int) {
        mu.Lock()
        for !ready {
            cond.Wait() // Atomically unlocks mu and suspends execution
        }
        mu.Unlock()
        fmt.Println("Worker", id, "started")
    }(i)
}

// Coordinator
time.Sleep(1 * time.Second)
```

```
mu.Lock()
ready = true
mu.Unlock()
cond.Broadcast() // Wakes all 10 workers simultaneously
```

Warning: `cond.Wait()` *must* be in a loop (spurious wakeups are possible, though rare in Go, logic dictates checking the condition again).

Summary

- **Pipelines:** Composable, streaming architecture. Great for ETL jobs.
- **Fan-In:** Merging multiple concurrent streams.
- **sync.Cond:** For "One-to-Many" signaling where the event can happen multiple times (unlike `close(ch)` which is one-off).

Web

The GOTH Stack

The GOTH Stack: Go, Templ, HTMX, Tailwind

In 2026, the pendulum has swung back. The complexity of React/Next.js/Hydration/ServerComponents has pushed many developers toward simpler, server-driven architectures.

Enter the **GOTH Stack**: * **G**o: Backend logic and router. * **O** (Templ?): Usually **Templ**, a type-safe templating language for Go. * **T**ailwind: Utility-first CSS. * **H**TMX: High-power tools for HTML.

Why GOTH?

It combines the type safety and speed of Go with the interactivity of an SPA, without the JSON-serialization overhead or state synchronization nightmares (Redux/Zustand).

1. Templ: Type-Safe HTML

Standard Go `html/template` is loosely typed. If you misspell a variable, it renders nothing. **Templ** compiles `.templ` files into Go code.

```
// hello.templ
package main

templ Hello(name string) {
    <div class="p-4 bg-blue-100 text-blue-800 rounded">
        <h1>Hello, { name }!</h1>
    </div>
}
```

If you pass an `int` to `Hello`, the Go compiler screams. This is revolutionary for backend rendering.

2. HTMX: The Engine

HTMX allows you to swap parts of the page via AJAX attributes directly in HTML.

```
<!-- When clicked, POST to /clicked, and replace this button with the response -->
<button hx-post="/clicked" hx-swap="outerHTML">
    Click Me
</button>
```

No JavaScript required. The server returns the *new HTML* (rendered via Templ), and HTMX injects it.

3. Tailwind: The Style

Since HTMX swaps HTML chunks, scoping CSS classes is hard. Tailwind solves this by embedding styles *in* the HTML. When HTMX injects a new `<div>`, it brings its styles with it.

A Simple Handler Example

```
func Handler(w http.ResponseWriter, r *http.Request) {
    // 1. Logic
    user := db.GetUser()

    // 2. Render Component
    component := components.UserProfile(user)

    // 3. Serve
    component.Render(r.Context(), w)
}
```

When NOT to use GOTH

- **Offline-first Apps:** If you need it to work in a tunnel, you need a heavy client (React/Flutter).
- **Complex Canvas/Games:** WebGL implementations.

For 95% of CRUD apps, Dashboards, and SaaS tools, the GOTH stack is faster to build and orders of magnitude faster to run.

Skeleton Loading & HTMX

Skeleton Loading with Go & HTMX

Users hate waiting. If your dashboard takes 2 seconds to calculate "Total Revenue," the entire page shouldn't hang for 2 seconds.

In standard MPAs (Multi-Page Apps), the browser waits for the full HTML response. In the GOTH stack, we use **Lazy Loading** with Skeleton screens.

The Pattern

1. **Initial Load:** Return the page structure immediately (Header, Sidebar, Footer) but fill the "Slow Widgets" with **Skeleton Loaders** (grey pulsing boxes).
2. **Trigger:** The Skeleton HTML includes `hx-trigger="load"` to immediately ask the server for the real content.
3. **Swap:** The server calculates the expensive data and returns the real HTML, swapping out the skeleton.

Implementation

1. The Dashboard Handler (Fast)

```
func DashboardHandler(w http.ResponseWriter, r *http.Request) {
    // Render the layout immediately.
    // Notice we don't fetch revenue here.
    Layout(
        // Inject Skeletons
        components.RevenueSkeleton(),
        components.UsersSkeleton(),
    ).Render(r.Context(), w)
}
```

2. The Skeleton Component (Templ)

```
templ RevenueSkeleton() {
    <div hx-get="/api/revenue"
         hx-trigger="load"
         hx-swap="outerHTML"
```

```
          class="animate-pulse bg-gray-200 h-32 rounded">
        <!-- Pulsing Grey Box -->
    </div>
}
```

3. The Real Data Handler (Slow)

```
func RevenueHandler(w http.ResponseWriter, r *http.Request) {
    // Extensive DB calculation...
    time.Sleep(1 * time.Second)
    amount := db.CalculateRevenue()

    // Return real component
    components.RevenueCard(amount).Render(r.Context(), w)
}
```

Why this wins

- **TTFB (Time To First Byte):** 10-20ms. The user sees the UI instantly.
- **Perceived Performance:** The app feels alive while data loads in parallel.
- **Simplicity:** No `useEffect`, no `isLoading` state management, no JSON parsing. Just HTML swapping.

Advanced: Request Coalescing

If 10 widgets all fire `hx-get` at once, you might hit browser connection limits (HTTP/1.1 limit is 6). * **HTTP/2 or HTTP/3:** Go's `net/http` supports these automatically if you use TLS. They multiplex requests, so 10 requests cost nearly the same connection overhead as 1. * Ensure your server supports TLS (Let's Encrypt) to enable H2/H3.

Microservices & gRPC

Microservices: Switching to gRPC (and Connect)

REST is fine for public APIs. But for internal communication between microservices, JSON over HTTP/1.1 is inefficient (text parsing, no types, high overhead).

gRPC (Google Remote Procedure Call) is the standard for high-performance internal traffic.

The Protocol Buffers (Protobuf)

You define your data and service in a `.proto` file.

```
syntax = "proto3";

service UserService {
  rpc GetUser (UserRequest) returns (UserResponse);
}

message UserRequest {
  string id = 1;
}

message UserResponse {
  string name = 1;
  int32 age = 2;
}
```

Then, you compile this using `protoc` to generate Go code. * **Strict Types:** The generated code guarantees the wire format matches the struct. * **Binary:** Messages are binary (smaller, faster to parse than JSON).

The gRPC Complexity (and the Solution: ConnectRPC)

Classic gRPC requires special load balancers (because it breaks HTTP/1.1 framing) and is hard to debug with `curl`.

In 2026, we prefer **ConnectRPC** (by Buf). * **It's just HTTP:** It supports gRPC but *also* standard HTTP/JSON. * You can `curl` a Connect service with JSON, but talk to it via gRPC from other Go services.

Connect Example

```
package main

import (
    "context"
    "net/http"
    "connectrpc.com/connect"
    user "example/gen/user/v1" // Generated code
    "example/gen/user/v1/userv1connect"
)

type UserServer struct {}

func (s *UserServer) GetUser(
    ctx context.Context,
    req *connect.Request[user.UserRequest],
) (*connect.Response[user.UserResponse], error) {
    return connect.NewResponse(&user.UserResponse{
        Name: "Alice",
        Age:  30,
    }), nil
}

func main() {
    mux := http.NewServeMux()
    path, handler := userv1connect.NewUserServiceHandler(&UserServer{})
    mux.Handle(path, handler)
    http.ListenAndServe(":8080", mux)
}
```

When to use Microservices?

Default to Monolith. Microservices introduce: 1. Network Latency. 2. Distributed Tracing requirements. 3. Deployment complexity.

Only switch to Microservices (and gRPC) when: * You have distinct teams who need to deploy independently. * You have distinct scaling requirements (e.g., the Video Encoder needs 100 GPUs, but the Login server needs 1 CPU).

Huma & OpenAPI

Modern APIs: Huma & OpenAPI

Writing REST APIs involves two pains: 1. Validation (Checking JSON inputs). 2. Documentation (Keeping Swagger/OpenAPI YAML in sync with code).

In the past, we wrote code, then manually wrote YAML. The YAML effectively lied because it drifted from the code.

Enter Huma

Huma (huma.rocks) is the modern (2025/2026) framework of choice for building APIs. * **Code-First OpenAPI:** It generates the OpenAPI 3.1 Spec *from* your Go structs. * **Automatic Validation:** It validates inputs based on struct tags.

Huma Example

```
package main

import (
    "context"
    "net/http"
    "github.com/danielgtaylor/huma/v2"
    "github.com/danielgtaylor/huma/v2/adapters/humachi"
    "github.com/go-chi/chi/v5"
)

// 1. Define Request/Response
type GreetingInput struct {
    Name string `query:"name" maxLength:"30" doc:"Name to greet"`
}

type GreetingOutput struct {
    Body struct {
        Message string `json:"message" example:"Hello, World!"`
    }
}

func main() {
    router := chi.NewMux()
```

```
    api := humachi.New(router, huma.DefaultConfig("My API", "1.0.0"))

    // 2. Register Operation
    huma.Register(api, huma.Operation{
        OperationID: "get-greeting",
        Method:      http.MethodGet,
        Path:        "/greeting",
        Summary:     "Get a welcome message",
    }, func(ctx context.Context, input *GreetingInput) (*GreetingOutput, error) {
        // Only executes if validation passes!
        resp := &GreetingOutput{}
        resp.Body.Message = "Hello, " + input.Name
        return resp, nil
    })

    http.ListenAndServe(":8888", router)
}
```

Why Huma?

1. **Documentation:** Visit `/docs` (or similar) and you get a beautiful, interactive Scalar or Swagger UI automatically.
2. **Safety:** Meaningful error messages for users ("Field 'name' is too long").
3. **Standard Library Compatible:** It works on top of `http.ServeMux`, `Chi`, or `Gin`. It doesn't lock you into a monolithic ecosystem.

This replaces the older `swag` comment-based generation which was error-prone and brittle.

Integrations: PostgreSQL & Redis

Integrations: PostgreSQL & Redis

Most Go backends in 2026 rely on this "boring" but powerful trio: Go + Postgres + Redis.

PostgreSQL: `pgx`

Don't use `lib/pq`. It is in maintenance mode. Use **`jackc/pgx`**. It is faster, safer, and supports more features (COPY, Listen/Notify).

Connection Pooling

Always use `pgxpool`, not a single connection.

```
import "github.com/jackc/pgx/v5/pgxpool"

func NewDB(ctx context.Context, connString string) (*pgxpool.Pool, error) {
    config, err := pgxpool.ParseConfig(connString)
    // Tuning
    config.MaxConns = 25
    config.MinConns = 5
    config.MaxConnLifetime = 1 * time.Hour

    return pgxpool.NewWithConfig(ctx, config)
}
```

Type-Safe SQL: sqlc

Don't write ORM code (GORM) unless you love runtime crashes and slow queries. Use **sqlc**. You write SQL, it generates type-safe Go structs and interfaces. (See Chapter 59 "Code Generation" for details).

Redis: `go-redis`

Use `github.com/redis/go-redis/v9`.

Patterns

1. **Caching (Look-aside):** `go val, err := rdb.Get(ctx, key).Result() if err == redis.Nil { // Miss: Fetch DB, Set Redis val = fetchFromDB() rdb.Set(ctx, key, val, 10*time.Minute) } else if err != nil { return err // Real error } // Hit: use val`
2. **Rate Limiting:** Redis is atomic. `INCR` and `EXPIRE` are perfect for API limits.
3. **Queues:** Redis Streams or simple Lists (`LPUSH`/`BRPOP`) make for excellent lightweight worker queues before you upgrade to Kafka or NATS.

Context Awareness

Both `pgx` and `go-redis` require `context.Context` in every method call. **Always pass the context.** This allows your database queries to automatically timeout if the user cancels the HTTP request, preventing zombie queries from eating your database CPU.

```
// Good
row := db.QueryRow(ctx, "SELECT ...")

// Bad (cancelling request won't stop query)
row := db.QueryRow(context.Background(), "SELECT ...")
```

HTTP and Networking

Overview

Go's `net/http` package provides a complete HTTP client and server implementation.

HTTP Client

```
// Simple GET
resp, err := http.Get("https://api.example.com/data")
if err != nil {
    log.Fatal(err)
}
defer resp.Body.Close()

body, _ := io.ReadAll(resp.Body)
```

Custom Request

```
req, _ := http.NewRequest("POST", url, bytes.NewBuffer(data))
req.Header.Set("Content-Type", "application/json")
req.Header.Set("Authorization", "Bearer "+token)

client := &http.Client{Timeout: 10 * time.Second}
resp, err := client.Do(req)
```

With Context

```
ctx, cancel := context.WithTimeout(context.Background(), 5*time.Second)
defer cancel()

req, _ := http.NewRequestWithContext(ctx, "GET", url, nil)
resp, err := http.DefaultClient.Do(req)
```

HTTP Server

```
func handler(w http.ResponseWriter, r *http.Request) {
    fmt.Fprintf(w, "Hello, %s!", r.URL.Path[1:])
}

func main() {
    http.HandleFunc("/", handler)
    log.Fatal(http.ListenAndServe(":8080", nil))
}
```

JSON API

```
func userHandler(w http.ResponseWriter, r *http.Request) {
    user := User{Name: "Alice"}

    w.Header().Set("Content-Type", "application/json")
    json.NewEncoder(w).Encode(user)
}
```

Middleware

```
func logging(next http.Handler) http.Handler {
    return http.HandlerFunc(func(w http.ResponseWriter, r *http.Request) {
        log.Printf("%s %s", r.Method, r.URL)
        next.ServeHTTP(w, r)
    })
}

http.Handle("/", logging(http.HandlerFunc(handler)))
```

ServeMux

```
mux := http.NewServeMux()
mux.HandleFunc("/users", usersHandler)
mux.HandleFunc("/posts", postsHandler)

http.ListenAndServe(":8080", mux)
```

Static Files

```
fs := http.FileServer(http.Dir("./static"))
http.Handle("/static/", http.StripPrefix("/static/", fs))
```

Summary

Function	Purpose
`http.Get()`	Simple GET request
`http.Post()`	Simple POST request
`http.NewRequest()`	Custom request
`http.HandleFunc()`	Register handler
`http.ListenAndServe()`	Start server

Related Topics

- Context and Cancellation
- Encoding and Serialization

Encoding and Serialization

Overview

Go provides standard encoding packages for JSON, XML, and binary data.

JSON

```
import "encoding/json"

type User struct {
    Name  string `json:"name"`
    Email string `json:"email,omitempty"`
    Age   int    `json:"-"`  // Ignored
}

// Encode
user := User{Name: "Alice", Email: "a@b.com"}
data, _ := json.Marshal(user)
// {"name":"Alice","email":"a@b.com"}

// Decode
var u User
json.Unmarshal(data, &u)

// Pretty print
data, _ := json.MarshalIndent(user, "", "  ")
```

Streaming JSON

```
// Encode to writer
encoder := json.NewEncoder(w)
encoder.Encode(user)

// Decode from reader
decoder := json.NewDecoder(r)
decoder.Decode(&user)
```

XML

```
import "encoding/xml"

type Person struct {
    XMLName xml.Name `xml:"person"`
    Name    string   `xml:"name"`
    Age     int      `xml:"age,attr"`
}

data, _ := xml.MarshalIndent(person, "", "  ")
xml.Unmarshal(data, &p)
```

Gob (Go Binary)

```
import "encoding/gob"

// Encode
var buf bytes.Buffer
enc := gob.NewEncoder(&buf)
enc.Encode(data)

// Decode
dec := gob.NewDecoder(&buf)
dec.Decode(&result)
```

CSV

```
import "encoding/csv"

// Write
w := csv.NewWriter(file)
w.Write([]string{"a", "b", "c"})
w.Flush()

// Read
r := csv.NewReader(file)
records, _ := r.ReadAll()
```

Base64

```
import "encoding/base64"

encoded := base64.StdEncoding.EncodeToString(data)
decoded, _ := base64.StdEncoding.DecodeString(encoded)
```

Summary

Package	Format
`encoding/json`	JSON
`encoding/xml`	XML
`encoding/gob`	Go binary
`encoding/csv`	CSV
`encoding/base64`	Base64

Related Topics

- I/O and Streaming
- HTTP and Networking

Performance Tooling

Reflection in Practice

Overview

The `reflect` package provides runtime type inspection. Use sparingly—prefer generics or interfaces when possible.

Type and Value

```
import "reflect"

x := 42
t := reflect.TypeOf(x)   // Type information
v := reflect.ValueOf(x)  // Value information

fmt.Println(t.Name())    // int
fmt.Println(t.Kind())    // int
fmt.Println(v.Int())     // 42
```

Inspecting Structs

```
type User struct {
    Name  string `json:"name"`
    Email string `json:"email"`
}

u := User{Name: "Alice", Email: "a@b.com"}
t := reflect.TypeOf(u)
v := reflect.ValueOf(u)

for i := 0; i < t.NumField(); i++ {
    field := t.Field(i)
    value := v.Field(i)
    tag := field.Tag.Get("json")
    fmt.Printf("%s: %v (tag: %s)\n", field.Name, value, tag)
}
```

Modifying Values

```
x := 42
v := reflect.ValueOf(&x).Elem()  // Need pointer for modification
v.SetInt(100)
fmt.Println(x)  // 100
```

Calling Methods

```
type Calculator struct{}
func (c Calculator) Add(a, b int) int { return a + b }

c := Calculator{}
v := reflect.ValueOf(c)
method := v.MethodByName("Add")
args := []reflect.Value{reflect.ValueOf(2), reflect.ValueOf(3)}
result := method.Call(args)
fmt.Println(result[0].Int())  // 5
```

When to Use

Appropriate: - Serialization/deserialization - ORM mapping - Dependency injection - Test utilities

Avoid: - Performance-critical paths - Simple type conversions - When generics suffice

Summary

Function	Purpose
`TypeOf()`	Get type info
`ValueOf()`	Get value wrapper
`Kind()`	Base type category
`Field()`	Access struct field
`MethodByName()`	Access method

Related Topics

- Type Assertions
- Performance Tuning

Unsafe Code

Overview

The `unsafe` package bypasses Go's type safety. Use only when absolutely necessary for performance or interoperability.

unsafe.Pointer

```
import "unsafe"

// Convert between pointer types
var x int = 42
p := unsafe.Pointer(&x)
fp := (*float64)(p)  // Reinterpret as float64 pointer
```

Common Uses

Memory Layout

```
type Data struct {
    a int32
    b int64
}

fmt.Println(unsafe.Sizeof(Data{}))    // Size in bytes
fmt.Println(unsafe.Alignof(Data{}))   // Alignment
fmt.Println(unsafe.Offsetof(Data{}.b)) // Field offset
```

String to Bytes (Zero-Copy)

```
func stringToBytes(s string) []byte {
    return unsafe.Slice(unsafe.StringData(s), len(s))
}
```

Accessing Unexported Fields

```
// Not recommended, but possible
type hidden struct {
    secret int
}

h := hidden{secret: 42}
p := unsafe.Pointer(&h)
secretPtr := (*int)(p)
fmt.Println(*secretPtr)
```

Dangers

- Not portable across platforms
- May break with Go versions
- Undefined behavior if misused
- Bypasses garbage collector

Guidelines

1. **Avoid if possible** - Use safer alternatives first
2. **Document thoroughly** - Explain why unsafe is needed
3. **Isolate usage** - Keep in small, well-tested functions
4. **Test extensively** - Including on target platforms

Summary

Function	Purpose
`unsafe.Pointer`	Generic pointer type
`unsafe.Sizeof`	Size in bytes
`unsafe.Alignof`	Alignment requirement
`unsafe.Offsetof`	Field offset

Related Topics

- Understanding Memory
- Cgo

Cgo and Foreign Function Interfaces

Overview

Cgo enables calling C code from Go. It's useful for interfacing with system libraries but adds complexity.

Basic Cgo

```
package main

/*
#include <stdio.h>

void hello() {
    printf("Hello from C!\n");
}
*/
import "C"

func main() {
    C.hello()
}
```

Passing Data

```
/*
int add(int a, int b) {
    return a + b;
}
*/
import "C"

func main() {
    result := C.add(C.int(2), C.int(3))
    fmt.Println(int(result))  // 5
}
```

Strings

```
/*
#include <stdlib.h>
#include <string.h>

char* greet(const char* name) {
    char* buf = malloc(100);
    sprintf(buf, "Hello, %s!", name);
    return buf;
}
*/
import "C"
import "unsafe"

func main() {
    name := C.CString("World")
    defer C.free(unsafe.Pointer(name))

    result := C.greet(name)
    defer C.free(unsafe.Pointer(result))

    fmt.Println(C.GoString(result))
}
```

Linking Libraries

```
// #cgo LDFLAGS: -lssl -lcrypto
// #include <openssl/sha.h>
import "C"
```

Downsides

- **No cross-compilation** without toolchain
- **CGO_ENABLED=1** required
- **Performance overhead** at boundaries
- **Complicates deployment**

When to Use

Use for: - System libraries (OpenSSL, SQLite) - Hardware interfaces - Legacy code integration

Avoid for: - Simple functionality - When pure Go libraries exist - Cross-platform tools

Summary

Task	Approach
Call C	Import pseudo-package “C”
Pass string	`C.CString()` / `C.GoString()`
Free memory	`C.free(unsafe.Pointer(...))`
Link library	`#cgo LDFLAGS: -lname`

Related Topics

- Unsafe Code
- Building and Releasing

Performance Tuning

Overview

Go provides built-in profiling tools for CPU, memory, and execution analysis.

Benchmarks

```
func BenchmarkFoo(b *testing.B) {
    for i := 0; i < b.N; i++ {
        Foo()
    }
}
```

```
go test -bench=. -benchmem
```

CPU Profiling

```
go test -cpuprofile=cpu.out -bench=.
go tool pprof cpu.out
```

pprof Commands

```
(pprof) top10          # Top functions
(pprof) list FuncName  # Annotated source
(pprof) web            # Visual graph
```

Memory Profiling

```
go test -memprofile=mem.out -bench=.
go tool pprof -alloc_space mem.out
```

HTTP Profiling

```
import _ "net/http/pprof"

// Endpoints:
// /debug/pprof/
// /debug/pprof/heap
// /debug/pprof/goroutine
// /debug/pprof/profile
```

Tracing

```
go test -trace=trace.out
go tool trace trace.out
```

Optimization Tips

Reduce Allocations

```
// Preallocate
s := make([]int, 0, expectedSize)

// Reuse with sync.Pool
var pool = sync.Pool{New: func() any { return &Buffer{} }}

// strings.Builder for concatenation
var b strings.Builder
```

Avoid Copying

```
// Pass pointer for large structs
func process(data *LargeStruct)

// Use slices instead of arrays
func process(data []byte)
```

Summary

Tool	Purpose
`go test -bench`	Benchmarking
`go tool pprof`	Profile analysis
`go tool trace`	Execution tracing
`-gcflags=-m`	Escape analysis

Related Topics

- Garbage Collection
- Understanding Memory

Advanced Profiling (pprof/trace)

Performance: Deep Dives with pprof & trace

Optimization without measurement is just guesswork. Go has arguably the best built-in profiling tools of any compiled language.

1. pprof: The Sampling Profiler

`pprof` creates a statistical profile of your program.

Usage

Add one line to your `main`:

```
import _ "net/http/pprof"

func main() {
    go func() {
        http.ListenAndServe("localhost:6060", nil)
    }()
    // ... app code ...
}
```

Now, while your app runs under load, grab a profile:

```
go tool pprof -http=:8081 http://localhost:6060/debug/pprof/profile?seconds=30
```

This opens a web UI. Look at: * **Flame Graph:** The widest bars are using the most CPU. * **Alloc Space:** Who allocated the most memory (Heap). * **Alloc Objects:** Who created the most *count* of objects (high GC pressure).

Mutex Profiling

If your CPU usage is low but performance sucks, you have contention. Enable mutex profiling in code: `runtime.SetMutexProfileFraction(1)` Then look at `/debug/pprof/mutex` to see who is waiting for locks.

2. Execution Tracer (`go tool trace`)

While pprof aggregates data, **Trace** shows you a timeline of *every event*. * When did a Goroutine start? * When did it block on a channel? * When did GC pause execution?

Capture a trace:

```
curl -o trace.out http://localhost:6060/debug/pprof/trace?seconds=5
go tool trace trace.out
```

Use Case: Debugging latency spikes. You might see a 100ms gap where *nothing* ran. Zooming in, you might find a Stop-The-World GC event or a single mutex holding up 50 goroutines.

3. Benchmarks as Profiling Inputs

You can profile specific functions using benchmarks:

```
go test -bench=. -cpuprofile=cpu.out
go tool pprof -http=:8080 cpu.out
```

Summary

- **pprof:** For "Where is my CPU/RAM going?"
- **trace:** For "Why is there latency?" and "What is the scheduler doing?"
- Optimization loop: Measure -> Fix -> Verify (Benchmark).

The Modern Toolkit

The Modern 2026 Toolkit

A senior Go engineer is defined by their tools. Using standard grep/find is slow. Upgrade your terminal.

General Tools (Rust-powered, Go-essential)

These aren't written in Go, but every Go dev uses them. 1. **ripgrep (`rg`)**: The fastest text search. * `rg "func main" -t go`: Find main in Go files only. 2. **fd**: Faster `find`. * `fd -e go`: Find all Go files. 3. **fzf**: Fuzzy finder. Pipe `fd` into `fzf` to open files instantly. 4. **jq**: JSON processor. Crucial for debugging API responses or logs (`zap`/`slog` JSON output).

Go-Specific Tools

`gopsutil`

If you are building system tools (agents, monitors), `github.com/shirou/gopsutil` is the standard for reading CPU/Memory/Disk stats cross-platform.

`go fix` Modernizers (New in 1.26)

Go 1.26 extends `go fix` modernizers and adds inline directives for local fixes.

```
go fix -modernize ./...
```

Examples of what it fixes: * Replaces manual loops with `slices.Contains`. * Updates older `interface{}` to `any`. * Updates deprecated package usage.

Inline fix for one location:

```
//go:fix inline
func has(xs []string, x string) bool {
    for _, v := range xs {
        if v == x {
            return true
        }
    }
    return false
}
```

`govulncheck`

The official vulnerability scanner.

```
go install golang.org/x/vuln/cmd/govulncheck@latest
govulncheck ./...
```

It tells you if *your code actually calls* the vulnerable function in a dependency. This drastically reduces false positives compared to generic scanners (Dependabot).

Workflow Integration

Don't run these manually. Put them in a **Makefile** or **Taskfile** (Task is a modern Make alternative written in Go).

```
# Taskfile.yaml
tasks:
  audit:
    cmds:
      - go vet ./...
      - staticcheck ./...
      - govulncheck ./...
```

Designing for the Long Term

Overview

Maintainable Go code follows consistent patterns and architectural principles.

Package Design

```
myapp/
   cmd/          # Entry points
      server/
   internal/     # Private packages
      auth/
      database/
      handlers/
   pkg/          # Public libraries
   api/          # API definitions
```

Dependency Direction

```
cmd → internal → pkg
         ↓
      external
```

Lower layers should not import higher layers.

Interface Segregation

```
// Small, focused interfaces
type Reader interface { Read([]byte) (int, error) }
type Writer interface { Write([]byte) (int, error) }

// Compose when needed
type ReadWriter interface {
    Reader
    Writer
```

```
}
```

Options Pattern

```
type Server struct {
    host    string
    port    int
    timeout time.Duration
}

type Option func(*Server)

func WithPort(p int) Option {
    return func(s *Server) { s.port = p }
}

func NewServer(opts ...Option) *Server {
    s := &Server{host: "localhost", port: 8080}
    for _, opt := range opts {
        opt(s)
    }
    return s
}
```

Error Handling

```
// Wrap with context
return fmt.Errorf("repository.GetUser: %w", err)

// Custom error types for inspection
type NotFoundError struct{ ID int }
func (e NotFoundError) Error() string { ... }
```

Testing Strategy

- Unit tests for business logic
- Integration tests for boundaries
- Table-driven tests for coverage
- Mocks for external dependencies

Guidelines

1. **Keep packages small** - Single responsibility
2. **Accept interfaces** - Flexible dependencies
3. **Return structs** - Clear types
4. **Handle errors early** - Fail fast
5. **Document exported APIs** - Clear comments

Summary

Principle	Implementation
Encapsulation	`internal/` packages
Abstraction	Small interfaces
Flexibility	Options pattern
Testability	Dependency injection

Related Topics

- Interface Best Practices
- How Go Code Is Organized

Static Analysis and Security

Overview

Go provides built-in and third-party tools for code quality and security analysis.

go vet

```
go vet ./...
```

Catches: - Printf format errors - Unreachable code - Suspicious constructs

staticcheck

```
go install honnef.co/go/tools/cmd/staticcheck@latest
staticcheck ./...
```

Catches: - Deprecated APIs - Simplifications - Performance issues

golangci-lint

```
# Install
go install github.com/golangci/golangci-lint/cmd/golangci-lint@latest

# Run all linters
golangci-lint run
```

govulncheck

```
go install golang.org/x/vuln/cmd/govulncheck@latest
govulncheck ./...
```

Checks dependencies for known vulnerabilities.

gosec

```
go install github.com/securego/gosec/v2/cmd/gosec@latest
gosec ./...
```

Security-focused linter: - SQL injection - Hardcoded credentials - Weak crypto

Common Security Issues

```
// SQL injection - BAD
query := "SELECT * FROM users WHERE id = " + id

// Use parameters - GOOD
db.Query("SELECT * FROM users WHERE id = ?", id)

// Path traversal - BAD
path := filepath.Join(baseDir, userInput)

// Sanitize - GOOD
if strings.Contains(userInput, "..") {
    return errors.New("invalid path")
}
```

CI Integration

```
# .github/workflows/lint.yml
- name: Lint
  run: golangci-lint run

- name: Security scan
  run: |
    govulncheck ./...
    gosec ./...
```

Summary

Tool	Focus
`go vet`	Basic correctness
`staticcheck`	Advanced analysis
`golangci-lint`	Multiple linters

Tool	Focus
`govulncheck`	Vulnerability scan
`gosec`	Security issues

Related Topics

- Formatting, Vetting, Docs
- Building and Releasing

Code Generation and Embedding

Overview

`go generate` runs commands to generate code, and `//go:embed` embeds files into binaries.

go generate

```
//go:generate stringer -type=Status

type Status int

const (
    Pending Status = iota
    Approved
    Rejected
)
```

```
go generate ./...
```

Common Generators

- `stringer` - String methods for enums
- `mockgen` - Mock interfaces for testing
- `protoc` - Protocol buffer code

Embedding Files

```
import "embed"

//go:embed config.json
var configData []byte

//go:embed templates/*
var templates embed.FS
```

```
//go:embed static
var staticFiles embed.FS
```

Reading Embedded Files

```
//go:embed data.txt
var data string  // As string

//go:embed data.bin
var data []byte  // As bytes

//go:embed files/*
var fs embed.FS  // As filesystem

content, _ := fs.ReadFile("files/config.json")
```

HTTP File Server

```
//go:embed static/*
var static embed.FS

func main() {
    fs := http.FileServer(http.FS(static))
    http.Handle("/static/", fs)
    http.ListenAndServe(":8080", nil)
}
```

Templates

```
//go:embed templates/*.html
var templates embed.FS

tmpl := template.Must(template.ParseFS(templates, "templates/*.html"))
```

Summary

Directive	Purpose
`//go:generate cmd`	Run code generator
`//go:embed file`	Embed as string/bytes
`//go:embed dir/*`	Embed as filesystem

Related Topics

- Core Go Commands
- Building and Releasing

Index

Quick Reference Guide

Essential Commands

Command	Purpose
`go run main.go`	Compile and run
`go build`	Build binary
`go test ./...`	Run tests
`go mod tidy`	Sync dependencies
`go fmt ./...`	Format code
`go vet ./...`	Check for issues

Common Patterns

Pattern	Chapter
Error handling	Ch 33
Table-driven tests	Ch 38
Options pattern	Ch 58
Worker pool	Ch 40
Context cancellation	Ch 43

Type Reference

Type	Zero Value
`bool`	`false`
`int`	`0`
`string`	`""`
`pointer`	`nil`
`slice`	`nil`
`map`	`nil`

Key Packages

Package	Purpose
`fmt`	Formatted I/O
`io`	I/O interfaces
`os`	OS operations
`net/http`	HTTP client/server
`encoding/json`	JSON encoding
`sync`	Synchronization
`context`	Cancellation
`testing`	Test framework

Resources

- go.dev - Official site
- pkg.go.dev - Package docs
- Go by Example
- Effective Go

Documentation and APIs

Overview

Good documentation makes code usable. Go has built-in tools for extracting docs from source comments.

Writing Doc Comments

```
// Package math provides mathematical utilities.
//
// It includes functions for basic arithmetic and
// statistical calculations.
package math

// Pi represents the mathematical constant  .
const Pi = 3.14159

// Add returns the sum of a and b.
func Add(a, b int) int {
    return a + b
}

// Calculator provides stateful calculations.
type Calculator struct {
    // Result holds the current value.
    Result float64
}
```

Conventions

- Start with the name being documented
- Use complete sentences
- First sentence is the summary

Examples

```
func ExampleAdd() {
    result := Add(2, 3)
    fmt.Println(result)
    // Output: 5
}
```

Viewing Docs

```
go doc fmt
go doc fmt.Println
go doc -all mypackage
```

pkg.go.dev

Public packages are automatically documented at:

`https://pkg.go.dev/github.com/user/package`

API Design Guidelines

```
// Accept interfaces, return structs
func Process(r io.Reader) (*Result, error)

// Use functional options
func NewServer(opts ...Option) *Server

// Clear error messages
return fmt.Errorf("user %d: %w", id, err)
```

Summary

Tool	Purpose
`go doc`	View documentation
`godoc`	Local doc server
pkg.go.dev	Public package docs
Examples	Testable documentation

Related Topics

- Formatting, Vetting, Docs
- Interface Best Practices

Infrastructure

Containerization (Docker)

Containerization: Multi-Stage Builds

Go compiles to a static binary. This is its deployment superpower. You do not need the Go compiler on your production server.

The Multi-Stage Pattern

We use a "Builder" image to compile, and a "Scratch" (or distroless) image to run.

```
# Stage 1: Build
FROM golang:1.26-alpine AS builder

WORKDIR /app
COPY go.mod go.sum ./
RUN go mod download

COPY . .
# CGO_ENABLED=0 is critical for static binaries (no libc dependency)
# -ldflags="-w -s" strips debug info for smaller size
RUN CGO_ENABLED=0 GOOS=linux go build -ldflags="-w -s" -o myapp ./cmd/server

# Stage 2: Runtime
# "scratch" is an empty image (0 bytes).
# "gcr.io/distroless/static" is better (includes CA Certs and Timezone data).
FROM gcr.io/distroless/static-debian12

COPY --from=builder /app/myapp /myapp

ENTRYPOINT ["/myapp"]
```

Why this matters

1. **Size:** The final image is ~10MB (Binary) + 2MB (OS overhead). Compared to Node/Python images (500MB+), this is tiny.
2. **Security:** The runtime image has no shell (`/bin/sh`). Attackers cannot "shell into" your container because there is no shell.
3. **Speed:** Pulling and starting a 12MB image is instant.

Gotchas

- **CA Certificates:** If your app talks to HTTPS APIs, `scratch` will fail because it lacks Root CA certs. Use `distroless/static` or manually copy `/etc/ssl/certs` from the builder.
- **Timezones:** Similarly, `scratch` lacks `tzdata`. If you rely on `time.LoadLocation`, copy the timezone database.

Platform Guides: Render & Leapcell

Deploying Go: Render & Leapcell

In 2026, Heroku is a distant memory. Modern PaaS (Platform as a Service) providers handle Go natively.

Render (render.com)

Render detects Go apps automatically.

1. Push code to GitHub.
2. Connect Repo to Render.
3. **Build Command:** `go build -o server ./cmd/server`
4. **Start Command:** `./server`

Pros: Excellent free tier, managed Postgres/Redis, Private Networks.

Leapcell (leapcell.io)

Leapcell is designed for **Serverless Go**. Instead of running a container 24/7, Leapcell scales your Go binary to zero when not used, and spins it up in milliseconds (using Firecracker microVMs).

Difference from AWS Lambda: * AWS Lambda forces you to write specific handlers. * Leapcell runs standard `net/http` servers. You just deploy your binary.

Config: Usually configured via a `leapcell.yaml`.

```
runtime: go
entrypoint: ./server
```

VPS Deployment (Systemd)

If you run on a bare Linux VPS (DigitalOcean/Hetzner) for $5/mo:

1. **SCP** the binary to the server.
2. Create a systemd unit: `/etc/systemd/system/myapp.service`

```
[Unit]
Description=My Go App
After=network.target
```

```
[Service]
User=appuser
ExecStart=/usr/local/bin/myapp
Restart=always
EnvironmentFile=/etc/myapp.env

[Install]
WantedBy=multi-user.target
```

3. `systemctl enable --now myapp`

This is the "Old Reliable" way. Cheap, robust, but manual.

Go on NixOS & FreeBSD

Beyond Linux: NixOS & FreeBSD

Go is famous for its cross-compilation support.

Cross Compilation

You can build a binary for ANY OS from your Mac.

```
# Build for Linux (AMD64)
GOOS=linux GOARCH=amd64 go build -o app-linux

# Build for FreeBSD (ARM64) - e.g., Raspberry Pi on FreeBSD
GOOS=freebsd GOARCH=arm64 go build -o app-bsd

# Build for Windows
GOOS=windows GOARCH=amd64 go build -o app.exe
```

Go on NixOS

NixOS is purely functional. You can't just `go build` and expect it to run if you link against C libraries, because standard paths (`/lib`) don't exist.

Pure Go

If you use `CGO_ENABLED=0`, your binary works perfectly on NixOS without modification. This is why Go devs love NixOS.

Development Environment (Flakes)

Use a `flake.nix` to define your dev shell. This guarantees that every developer on your team uses the *exact* same version of Go, `gopls`, and `golangci-lint`.

```
{
  inputs.nixpkgs.url = "github:NixOS/nixpkgs/nixos-unstable";
  outputs = { self, nixpkgs }:
    let pkgs = nixpkgs.legacyPackages.x86_64-linux;
    in {
```

```
      devShells.x86_64-linux.default = pkgs.mkShell {
        buildInputs = [ pkgs.go_1_26 pkgs.gopls ];
      };
    };
}
```

Go on FreeBSD

FreeBSD is a fantastic server OS (ZFS, Jails). Go treats it as a first-class citizen. * **Performance:** Go's scheduler maps efficiently to FreeBSD `kqueues`. * **Wait:** `fsnotify` uses `kqueue` on BSD instead of `inotify`, which is efficient.

Note: If you use low-level networking code, verify if libraries support BSD. But the stdlib (`net/http`) works flawlessly.

CI/CD & Hardening

CI/CD Pipelines & Security Hardening

Automate the “Boring” stuff.

The GitHub Actions Pipeline

Here is a standard 2026 pipeline for Go.

```yaml
name: Go Build & Test
on: [push, pull_request]

jobs:
  build:
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v4

      - name: Setup Go
        uses: actions/setup-go@v5
        with:
          go-version: '1.26'
          cache: true # Auto-cache modules

      - name: Lint
        uses: golangci/golangci-lint-action@v4

      - name: Vuln Check
        run: |
          go install golang.org/x/vuln/cmd/govulncheck@latest
          govulncheck ./...

      - name: Test
        # -race is critical for catching concurrency bugs
        run: go test -race -cover ./...

      - name: Build
        run: go build -v ./...
```

Hardening the Pipeline

1. **Pin Actions:** Use SHA hashes (`uses: actions/checkout@a5ac7...`) instead of versions (`@v4`) to prevent supply chain attacks on the actions themselves.
2. **Least Privilege:** Giving the `GITHUB_TOKEN` only read permissions unless it needs to publish releases.

Hardening the Binary

When building for production, enable security flags:

```
go build -trimpath \
  -ldflags="-s -w" \
  -buildmode=pie \
  -o app
```

- `-trimpath`: Removes file paths from the binary (privacy).
- `-s -w`: Strips debug symbols (harder to reverse engineer, smaller).
- `pie` (Position Independent Executable): Makes memory randomization (ASLR) more effective, hardering exploits.

Signing (Cosign)

In 2026, it is standard to **sign** your container images or binaries using **Cosign** (part of Sigstore). This proves to users that the binary actually came from your CI pipeline and wasn't tampered with.

Building and Releasing Software

Overview

Go compiles to static binaries, making deployment simple. This chapter covers building, cross-compilation, and release workflows.

Basic Build

```
go build -o myapp ./cmd/server
```

Production Build

```
go build \
    -ldflags="-s -w" \
    -o bin/myapp \
    ./cmd/server
```

Flags: - `-s` - Strip symbol table - `-w` - Strip DWARF debugging info

Version Injection

```
var (
    version = "dev"
    commit  = "none"
    date    = "unknown"
)
```

```
go build -ldflags="-X main.version=1.0.0 -X main.commit=$(git rev-parse HEAD)"
```

Cross-Compilation

```
# Linux
GOOS=linux GOARCH=amd64 go build -o app-linux

# Windows
GOOS=windows GOARCH=amd64 go build -o app.exe

# macOS ARM
GOOS=darwin GOARCH=arm64 go build -o app-darwin

# All platforms
for os in linux darwin windows; do
    for arch in amd64 arm64; do
        GOOS=$os GOARCH=$arch go build -o bin/app-$os-$arch
    done
done
```

Docker

```
# Multi-stage build
FROM golang:1.26-alpine AS builder
WORKDIR /app
COPY . .
RUN go build -o /app/server ./cmd/server

FROM alpine:latest
COPY --from=builder /app/server /server
ENTRYPOINT ["/server"]
```

GitHub Actions

```
name: Release
on:
  push:
    tags: ['v*']

jobs:
  build:
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v4
```

```
      - uses: actions/setup-go@v5
        with:
          go-version: '1.26'
      - run: go build -o app
      - uses: softprops/action-gh-release@v1
        with:
          files: app
```

GoReleaser

```
# .goreleaser.yaml
builds:
  - main: ./cmd/server
    goos: [linux, darwin, windows]
    goarch: [amd64, arm64]

archives:
  - format: tar.gz
```

```
goreleaser release
```

Summary

Task	Command
Build	`go build -o app`
Optimize	`-ldflags="-s -w"`
Cross-compile	`GOOS=linux GOARCH=amd64`
Version inject	`-ldflags="-X main.version=x"`

Related Topics

- Core Go Commands
- Documentation and APIs

Security

Security Tools

Security Tools: Automating Defense

Security shouldn't be an afterthought. In Go, we have tools to detect vulnerabilities statically.

Security Pipeline (Suggested)

```
commit --> static checks --> vuln scan --> crypto tests --> release
           |                 |              |
           +-- gosec         +-- govulncheck +-- testing/cryptotest
           +-- nilaway
```

1. `govulncheck`: Reachability-Based Vulnerability Scanner

Use `govulncheck` first because it reports vulnerabilities your code can actually reach.

```
go install golang.org/x/vuln/cmd/govulncheck@latest
govulncheck ./...
```

2. `gosec`: The Security Linter

`gosec` scans your AST for bad patterns.

```
gosec ./...
```

Common things it catches: * Hardcoded credentials/tokens. * SQL injection risks (string concatenation in queries). * Weak random number generation (`math/rand` vs `crypto/rand`). * Permissions (e.g., `0777` on files).

3. `capslock`: Capability Analysis

Google's `capslock` is a fascinating tool. It tells you what *capabilities* a package uses.

Does that innocent looking `leftpad` library also import `net/http` and send your ENV vars to a server? `capslock` will tell you.

```
capslock -packages ./...
```

It outputs capability classes such as Network, FileSystem, Reflection. If a simple helper package needs Network, treat it as suspicious.

4. `nilaway`: Compile-time Nil Panics

Uber's `nilaway` is a static analyzer that detects potential nil pointer dereferences. It is more powerful than standard linters because it traces flows across functions. It effectively brings a degree of "Option Type" safety to Go pointers.

5. Go 1.26 Crypto Additions

`crypto/hpke`

Go 1.26 adds HPKE (Hybrid Public Key Encryption) in the standard library, useful for modern envelope encryption and E2E protocols.

`testing/cryptotest`

Go 1.26 adds `testing/cryptotest` to validate cryptographic implementations against correctness properties.

6. Experimental: `runtime/secret`

`runtime/secret` is an experiment in Go 1.26 for handling sensitive values with tighter lifetime controls.

```
//go:build goexperiment.runtimesecret

import "runtime/secret"

func useSecret() {
    token := []byte("api-token")
    secret.Do(func() {
        // work with token inside protected lifetime window
        _ = token
    })
}
```

Use experiments deliberately:

```
GOEXPERIMENT=runtimesecret go test ./...
```

SOLID in Go

SOLID Principles in Go

SOLID is often associated with Java/OOP. However, its core principles (decoupling, cohesion) apply perfectly to Go, just implemented differently.

S: Single Responsibility Principle (SRP)

"A package should have one reason to change."

Go enforces this with its package system. * **Bad:** `package utils` (The junk drawer). * **Good:** `package hash`, `package user`, `package http`.

O: Open/Closed Principle

"Open for extension, closed for modification."

In Go, we achieve this via **Interfaces**. If a function accepts an interface, you can extend its behavior by passing a new struct that satisfies the interface, without modifying the function.

```
type Shape interface { Area() float64 }

func TotalArea(shapes []Shape) float64 {
    var total float64
    for _, s := range shapes {
        total += s.Area()
    }
    return total
}
```

You can add `Triangle` later without touching `TotalArea`.

L: Liskov Substitution Principle

"Subtypes must be substitutable for their base types."

In Go, this is implicit. If `*MyWriter` satisfies `io.Writer`, it *is* an `io.Writer`. However, you must ensure behavioral compatibility (e.g., don't panic in a `Write` method).

I: Interface Segregation Principle

"Clients should not be forced to depend on methods they do not use."

This is the most important rule in Go. * **Java:** Define big interfaces upfront (`IUser`). * **Go:** Define tiny interfaces *where you use them.*

Bad:

```
type User interface {
    Save()
    Delete()
    SendEmail()
    Validate()
}

func Emailer(u User) { ... } // Forces dependence on Save/Delete
```

Good:

```
type EmailSender interface {
    SendEmail()
}

func Emailer(e EmailSender) { ... } // Only depends on what it needs
```

D: Dependency Inversion Principle

"Depend on abstractions, not concretions."

Don't accept structs; accept interfaces.

Bad:

```
func NewService(db *sql.DB) // Concretion
```

Good:

```
type Datastore interface {
    Query(string) Rows
}

func NewService(db Datastore) // Abstraction
```

This allows you to swap `sql.DB` for a Mock DB during testing.

Summary

SOLID in Go is simpler than in OOP. * **S:** Small packages. * **O / D:** Accept interfaces, return structs. * **I:** Define 1-method interfaces locally.

Specialized

Desktop Apps

Desktop Apps: Wails & Fyne

Go is excellent for cross-platform desktop apps. You have two main paths:

1. Wails (The Electron Alternative)

Wails (`wails.io`) is "Electron for Go", but lighter. * **Frontend:** HTML/JS/CSS (React, Vue, Svelte, or vanilla). * **Backend:** Go. * **Renderer:** Uses the native System WebView (WebKit on Mac, WebView2 on Windows). **No bundled Chrome.**

Binary Size: ~15 MB (Go) vs ~150 MB (Electron).

Architecture

You write your logic in Go structs. Wails automatically generates JavaScript bindings.

```
// Go
func (a *App) Greet(name string) string {
    return "Hello " + name
}
```

```
// JS (Generated)
import {Greet} from '../wailsjs/go/main/App';
Greet("World").then(result => console.log(result));
```

2. Fyne (Native UI)

Fyne (`fyne.io`) renders its own widgets using OpenGL. It does *not* use HTML/CSS. * **Look & Feel:** Material Design-ish. Consistent across Mac/Windows/Linux/Mobile. * **Performance:** Very fast (GPU accelerated). * **Mobile:** Fyne apps run on iOS and Android with zero changes.

```
func main() {
    a := app.New()
    w := a.NewWindow("Hello")

    w.SetContent(widget.NewLabel("Hello Fyne!"))
    w.ShowAndRun()
}
```

3. Gio (Immediate Mode)

Gio (`gioui.org`) is for experts who want pixel-perfect control. It is an "Immediate Mode GUI" (like game engines). It is extremely efficient but requires drawing your own components often.

Recommendation (2026)

- **Building a SaaS / Dashboard / Tool?** Use **Wails**. You can reuse your web frontend skills (Tailwind/React).
- **Building a Graphics Tool / Game / Consistent UI?** Use **Fyne**.

Machine Learning & LLMs

AI & LLMs in Go

Python owns Model *Training*. Go owns Model *Serving* and *Orchestration*.

In 2026, you rarely train a model from scratch. You run a pre-trained model (Llama 3, Mistral) and build "Agents" around it. Go is perfect for this high-concurrency glue code.

1. Running Local Models (Ollama)

The easiest way to integrate LLMs is **Ollama**. Ollama runs the model; Go talks to it via API.

Use **LangChainGo** (`github.com/tmc/langchaingo`):

```
llm, err := ollama.New(ollama.WithModel("llama3"))
ctx := context.Background()
completion, err := llms.GenerateFromSinglePrompt(ctx, llm, "Explain Go channels")
```

2. Go 1.26 SIMD Support (Experimental)

Go 1.26 introduces experimental SIMD support via `simd` and `archsimd` packages (enabled with `GOEXPERIMENT=simd`). This is critical for: * **Vector Search:** Calculating Cosine Similarity between embeddings is just a dot product. SIMD makes this 100x faster. * **Inference:** Running small neural nets directly in Go.

```
GOEXPERIMENT=simd go test ./...
```

```
RAG request path

query text
   |
   v
embedding model --> vector (float32[])
   |
   v
SIMD dot product / ANN prefilter
   |
   v
top-k chunks --> prompt assembly --> LLM response
```

3. Embeddings & Vector Databases

Go is the standard language for Vector DBs (Milvus, Weaviate are written in Go).

Workflow: 1. Receive Text -> Send to Embedding Model (via API or Local binding). 2. Get `[]float32`. 3. Store in Postgres (`pgvector`) or Weaviate.

Concrete retrieval stub:

```
type Chunk struct {
    ID    string
    Text  string
    Score float32
}

func topK(ctx context.Context, q []float32, k int) ([]Chunk, error) {
    // Use pgvector distance operator and ORDER BY distance LIMIT k.
    return nil, nil
}
```

Summary

Don't use Python for the API layer of your AI app. * **Python:** Research code, PyTorch. * **Go:** The API server, the RAG pipeline, the WebSocket handler.

Systems Programming

Systems Programming: Low Level Go

Go was written to replace C++ at Google. It has deep system capabilities.

1. Syscalls (`golang.org/x/sys/unix`)

Go doesn't use `libc` for syscalls (on Linux). It makes raw syscalls. The `syscall` package is frozen. Use `golang.org/x/sys/unix`.

```
// Example: Lock memory to prevent swapping (mlock)
unix.Mlock(data)
```

2. Debuggers (Delve)

Delve (`dlv`) is the Go debugger. * **Remote Debugging:** Run your app on a Linux server, connect your IDE (VS Code) from your Mac. * **Core Dumps:** If your app crashes in prod, configure it to write a core dump. Open the core dump with Delve to see the *exact* state of memory when it died.

```
dlv core ./myapp core.1234
```

3. eBPF (Cilium/Ebpf)

eBPF is the kernel superpower of 2026. You can write programs that run *inside the Linux Kernel* to filter packets or trace functions safely.

Go is the primary language for writing eBPF *userspace* controllers (Cilium, Falco). Library: `github.com/cilium/ebpf`.

4. `unsafe` Pointer Magic

Sometimes you need to read a C struct or cast bytes to floats instantly.

```
import "unsafe"

func BytesToFloat(b []byte) float64 {
```

```
    return *(*float64)(unsafe.Pointer(&b[0]))
}
```

Warning: This is dangerous. It bypasses types. But it's necessary for zero-copy parsing of network packets or binary formats.

I/O and Streaming

Overview

Go's `io` package defines fundamental interfaces for streaming data.

Core Interfaces

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

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

type Closer interface {
    Close() error
}
```

Reading

```
// Read from file
f, _ := os.Open("file.txt")
defer f.Close()

buf := make([]byte, 1024)
n, err := f.Read(buf)

// Read all
data, err := io.ReadAll(f)
```

Writing

```
f, _ := os.Create("output.txt")
defer f.Close()

f.Write([]byte("Hello"))
f.WriteString("World")
```

Copying

```
// Copy all data
io.Copy(dst, src)

// Copy with limit
io.CopyN(dst, src, 1024)
```

Bufio

```
import "bufio"

// Buffered reading
reader := bufio.NewReader(f)
line, _ := reader.ReadString('\n')

// Buffered writing
writer := bufio.NewWriter(f)
writer.WriteString("data")
writer.Flush()

// Scanner (line by line)
scanner := bufio.NewScanner(f)
for scanner.Scan() {
    fmt.Println(scanner.Text())
}
```

Bytes Buffer

```
var buf bytes.Buffer
buf.WriteString("Hello")
buf.Write([]byte(" World"))
content := buf.String()
```

Pipe

```
pr, pw := io.Pipe()

go func() {
    pw.Write([]byte("data"))
    pw.Close()
}()

data, _ := io.ReadAll(pr)
```

Summary

Interface	Method
`Reader`	`Read([]byte) (int, error)`
`Writer`	`Write([]byte) (int, error)`
`Closer`	`Close() error`
`ReadWriter`	Both Read and Write

Related Topics

- Encoding and Serialization
- HTTP and Networking

Logging and Observability

Overview

Production applications need structured logging, metrics, and tracing for debugging and monitoring.

Standard log Package

```
import "log"

log.Println("Info message")
log.Printf("User %d logged in", userID)
log.Fatal("Critical error")  // Calls os.Exit(1)
log.Panic("Panic!")          // Calls panic()
```

JSON Output

```
logger := slog.New(slog.NewJSONHandler(os.Stdout, &slog.HandlerOptions{
    Level: slog.LevelDebug,
}))
slog.SetDefault(logger)
```

Context Integration

`slog` can automatically extract values from `context` using a custom handler or `slog.Attr`.

```
func handler(w http.ResponseWriter, r *http.Request) {
    logger := slog.With("request_id", r.Header.Get("X-Request-ID"))
    logger.Info("started")
}
```

Log Levels

slog provides four levels by default: Debug, Info, Warn, and Error. - `slog.Debug("debug info")` - `slog.Info("informational")` - `slog.Warn("warning")` - `slog.Error("error", "err", err)`

Custom Logger

```
logger := log.New(os.Stderr, "API: ", log.Ldate|log.Ltime|log.Lshortfile)
logger.Println("Starting server")
```

Metrics

```
import "expvar"

var (
    requests = expvar.NewInt("requests")
    errors   = expvar.NewInt("errors")
)

func handler(w http.ResponseWriter, r *http.Request) {
    requests.Add(1)
    // ...
}

// Expose at /debug/vars
import _ "expvar"
```

Tracing

```
import "runtime/trace"

f, _ := os.Create("trace.out")
trace.Start(f)
defer trace.Stop()

// Run with: go tool trace trace.out
```

Summary

Package	Purpose
`log`	Simple logging
`log/slog`	Structured logging
`expvar`	Metrics exposure
`runtime/trace`	Execution tracing

Related Topics

- Static Analysis and Security
- Performance Tuning

Network Systems

130 Network Systems Index

130 Network Systems

This section introduces production networking in Go as a systems discipline, not just API usage.

You will move from connection-level behavior to service-level reliability:

1. TCP service construction with framing, deadlines, and backpressure.
2. HTTP service resilience with end-to-end timeout budgets.
3. Reverse proxy design for routing, failure isolation, and operability.

The goal is to build a precise mental model for how network software behaves under load, packet loss, slow downstreams, and partial failure.

131 TCP Services Deep Dive

131 TCP Services Deep Dive

TCP is a byte stream, not a message protocol. Most production bugs in custom TCP systems come from this single misunderstanding.

Core Mental Model

```
application message A+B+C
        |
        v
TCP stream bytes: [A-part][A-rest+B][C-part]...
```

Your code must define message boundaries explicitly.

Framing Strategy

A robust approach is length-prefix framing:

```
[4-byte length][payload bytes]
```

This allows the receiver to know exactly how many bytes belong to one logical message.

Connection Lifecycle

```
accept -> set deadlines -> read frame -> validate -> handle -> write response -> close/reuse
```

Each stage needs failure policy. For example, malformed frames should be rejected quickly, while slow clients should hit read deadlines instead of consuming handlers forever.

Production Concerns

- Deadlines: Every read/write path should have bounded time.
- Memory: Never allocate unbounded payload buffers.
- Concurrency: Limit active handlers to avoid overload collapse.
- Observability: Record accepts, active conns, frame errors, and timeouts.

Design Notes

When throughput matters, separate IO and business logic pools so slow CPU work does not block socket reading. When reliability matters, prioritize predictable timeouts and explicit protocol errors over maximum raw throughput.

132 HTTP Client and Server Resilience

132 HTTP Client and Server Resilience

Resilience in HTTP systems is budget management: every inbound request has limited time, and each downstream call spends part of that budget.

Budget-First Thinking

```
total request budget: 1200ms
|-- auth --|-- cache --|-- db --|-- upstream API --|-- encode response --|
```

If one component consumes too much budget, upstream callers see latency spikes and timeouts.

Server-Side Guardrails

- `ReadHeaderTimeout` to protect against slowloris-style abuse.
- `ReadTimeout` and `WriteTimeout` to bound request/response processing.
- `IdleTimeout` to control keep-alive resource usage.

Client-Side Guardrails

- Default `http.Client` timeout for hard cap.
- Per-call `context.WithTimeout` for operation-specific budgets.
- Retry only idempotent operations and only within remaining budget.

Failure Classification

Treat failures differently:

- Timeout/cancel: likely capacity or dependency latency issue.
- 5xx: downstream error, candidate for controlled retry.
- 4xx: usually caller/input issue, no retry.

Operational Insight

Services become stable when timeout and retry policy is explicit, consistent, and visible in logs/metrics. Hidden defaults are the most common source of cascading failure.

133 Reverse Proxy and Load Balancing

133 Reverse Proxy and Load Balancing

A reverse proxy is a reliability boundary: it enforces routing policy, mediates failures, and protects backend services.

Request Path

```
client -> edge proxy -> route match -> upstream selection -> backend
                     -> policy layer (auth, limits, timeout)
```

Routing Model

Keep routing deterministic and debuggable:

- Exact routes first.
- Prefix/wildcard routes second.
- Explicit default/fallback behavior.

Upstream Selection

Round-robin is a baseline, but production systems also need health awareness:

- Remove failing nodes quickly.
- Reintroduce nodes only after recovery checks.
- Prevent hot-spotting during partial outages.

Timeout and Retry Boundaries

Proxy retries can multiply load if misconfigured. Always apply:

- Attempt limits.
- Retryable method/status rules.
- Total request budget cap.

Why This Chapter Matters

Most distributed outages are coordination failures across otherwise healthy components. A well-designed proxy reduces blast radius by making policies explicit and centrally observable.

Systems Programming

140 Systems Programming Index

140 Systems Programming

This section covers how Go programs interact with the operating system: processes, signals, files, and stream-oriented command design.

The emphasis is operational correctness:

1. Process lifecycle and graceful shutdown behavior.
2. Filesystem safety patterns for automation tools.
3. Unix pipeline conventions for composable CLIs.

By the end, you should be able to design tools that behave predictably in production shells, CI environments, and long-running supervisors.

141 Processes, Signals, and Supervisors

141 Processes, Signals, and Supervisors

Process supervision is about controlling state transitions under uncertainty.

Lifecycle Model

```
starting -> running -> stopping -> exited
                |          ^
                +-> crash-+
```

A production supervisor defines what happens in each transition, including restart policy and shutdown deadlines.

Signal Semantics

- `SIGTERM`: request graceful shutdown.
- `SIGINT`: interactive stop (often treated similarly).
- `SIGKILL`: immediate termination (no cleanup).

Programs should handle `SIGTERM`/`SIGINT` by draining in-flight work, closing listeners, and exiting with clear status.

Restart Policy

Blind restart loops can worsen incidents. Prefer bounded backoff with jitter and an upper retry ceiling.

Observability Requirements

A supervisor should emit structured events for:

- process start/exit code
- restart reason
- shutdown duration
- signal received

These events are essential during incident reconstruction.

142 Filesystem Automation and Safe IO

142 Filesystem Automation and Safe IO

Filesystem automation fails in subtle ways: partial writes, interrupted updates, and accidental destructive path handling.

Safe Write Pattern

```
write temp -> fsync temp -> rename atomic -> fsync parent directory
```

This pattern minimizes corruption risk during crashes or power loss.

Path Safety

Treat every path as untrusted until normalized and validated relative to an expected root.

```
input path -> clean -> join(root, path) -> verify prefix(root) -> operate
```

Operational Tradeoffs

- Durability vs speed: `fsync` improves safety but costs latency.
- Simplicity vs flexibility: stricter path policy reduces accidental misuse.
- Portability vs specialization: filesystem semantics vary by OS and mount type.

Design Principle

For automation tools, predictability is more valuable than peak throughput. It is better to be slower and safe than fast and destructive.

143 Unix Pipeline Style CLI Tools

143 Unix Pipeline Style CLI Tools

Good CLI tools are composable components in a data stream.

Pipeline Contract

```
stdin -> transform/filter -> stdout
          diagnostics -> stderr
```

Respecting this contract allows your tool to fit naturally into shell workflows.

Behavioral Expectations

- Read from stdin when explicit files are not provided.
- Emit data-only output on stdout.
- Emit warnings/errors on stderr.
- Return meaningful exit codes for automation.

Output Modes

Offer stable machine-readable output (JSON/TSV) and human-readable output separately. Mixing them breaks scriptability.

Why This Matters

Pipeline-compatible design turns one-off utilities into reusable operational building blocks.

Distributed Infra

150 Distributed Infra Index

150 Distributed Infrastructure

This section introduces distributed reliability patterns used in production Go systems.

Focus areas:

1. Discovery and health as routing inputs.
2. Retry/circuit-breaker behavior under dependency failure.
3. Queue-worker throughput with explicit backpressure.

The objective is to reason about failure as a normal operating condition.

151 Service Discovery and Health Checks

151 Service Discovery and Health Checks

Discovery systems answer two questions: where instances are, and whether they are currently safe to route to.

System Shape

```
instance -> register/heartbeat -> registry
router   -> query endpoints   -> select healthy target
```

Health Semantics

Use distinct checks:

- Liveness: process is alive.
- Readiness: instance can serve traffic.

Routing on liveness alone creates avoidable errors during warmup, migrations, and degraded dependencies.

Expiration Strategy

TTL-based registration prevents stale endpoints from receiving traffic when instances crash or disconnect unexpectedly.

Reliability Principle

Discovery quality directly determines tail latency and error rate. Treat registry correctness as critical infrastructure.

152 Retry and Circuit Breaker Patterns

152 Retry and Circuit Breaker Patterns

Retries and circuit breakers are control systems. Misconfigured control loops create amplification and cascades.

Decision Flow

```
call fails -> classify error -> retryable?
              |                 |
              no                yes -> backoff -> retry limit -> fail fast
```

Retry Boundaries

Only retry operations that are safe (idempotent or explicitly deduplicated). Keep attempt count small and bound total elapsed time.

Circuit States

```
closed -> open -> half-open -> closed
```

- Closed: normal traffic.
- Open: reject quickly to reduce pressure.
- Half-open: probe limited requests to test recovery.

Practical Outcome

Well-tuned policies improve availability during partial outages; poorly tuned policies turn partial outages into system-wide incidents.

153 Queue Workers and Backpressure

153 Queue Workers and Backpressure

Queue systems decouple producer and consumer rates, but only if capacity and failure behavior are explicit.

Throughput Model

```
producer -> queue(buffer) -> workers -> dependency
               |
               +-> backpressure when full
```

Key Design Levers

- Queue size (latency vs memory).
- Worker count (parallelism vs contention).
- Retry strategy (durability vs duplicate work risk).

Failure Handling

Not all failed jobs should be retried equally. Distinguish transient failures from poison messages and route accordingly.

Operational Goal

Backpressure should degrade gracefully under overload rather than silently dropping data or exhausting memory.

Observability Sre

160 Observability and SRE Index

160 Observability and SRE

This section explains how to make Go services operable in real incidents.

Coverage:

1. Structured logging and correlation IDs.
2. Metric design with Prometheus-compatible models.
3. Trace propagation across service boundaries.

The theme is observability as a design property, not an afterthought.

161 Structured Logging and Correlation

161 Structured Logging and Correlation

Structured logs are event records, not formatted print statements.

Correlation Model

```
request_id/trace_id
   -> log fields
   -> metric labels (careful cardinality)
   -> trace attributes
```

A single correlation key allows fast cross-signal debugging.

Schema Discipline

Keep a stable field set across services:

- `service`
- `env`
- `request_id`
- `trace_id`
- `error_class`

Inconsistent schemas make incident search expensive and error-prone.

Security Consideration

Logs are data exfiltration risk. Always design for redaction and sensitive-field filtering.

162 Metrics and Prometheus Design

162 Metrics and Prometheus Design

Metrics should answer operational questions quickly: Is traffic normal? Are errors rising? Is latency degrading?

RED Baseline

```
Rate: requests/sec
Errors: failed requests/sec
Duration: latency distribution (histogram)
```

Label Strategy

Labels are powerful and dangerous. High-cardinality labels can destabilize metric systems.

Prefer bounded dimensions such as:

- method
- route template
- status class

Avoid unbounded dimensions such as user IDs or raw URLs.

SRE Connection

Useful metrics are tied to alerts and runbooks. Instrumentation without response policy adds noise, not reliability.

163 Tracing and Context Propagation

163 Tracing and Context Propagation

Tracing makes distributed latency visible by preserving causal context across boundaries.

Propagation Path

```
gateway -> service A -> service B -> datastore
   context + trace headers propagated at each hop
```

Common Failure Mode

A single missing propagation point breaks end-to-end trace visibility. This often happens in background goroutines or manual HTTP client construction.

Design Guidance

- Accept `context.Context` at API boundaries.
- Pass context through outbound calls without replacement.
- Record operation-level spans around DB and external dependencies.

Outcome

Correct tracing turns unknown latency into attributable latency.

Security Hardening

170 Security Hardening Index

170 Security Hardening

This section focuses on practical secure-by-default design in Go services.

Themes:

1. Transport security and certificate trust.
2. Authentication and authorization separation.
3. Secret lifecycle and rotation safety.

The objective is to reduce both exploitability and operational misconfiguration risk.

171 TLS and mTLS Deep Dive

171 TLS and mTLS Deep Dive

TLS provides confidentiality and integrity. mTLS additionally provides strong client identity at transport level.

Trust Model

```
client verifies server cert chain
server verifies client cert chain (mTLS)
```

Production Controls

- Enforce minimum TLS version.
- Use managed certificate issuance/rotation.
- Monitor certificate expiry and validation failures.

Operational Reality

Most TLS incidents are not cryptographic failures; they are lifecycle failures (expired certs, mismatched trust bundles, incomplete rotation).

172 Authentication and Authorization Patterns

172 Authentication and Authorization Patterns

Authentication answers “who are you?” Authorization answers “what are you allowed to do?”

Request Decision Path

```
request -> authenticate principal -> evaluate policy(resource, action) -> allow/deny
```

Design Rules

- Keep authn and authz modules separate.
- Default deny when policy is unclear.
- Keep policy inputs explicit and testable.

Reliability-Security Link

Authorization bugs are often logic bugs, not crypto bugs. Clear policy modeling and exhaustive test coverage are the strongest defenses.

173 Secrets Management and Rotation

173 Secrets Management and Rotation

Secrets are dynamic credentials with lifecycle, not static configuration strings.

Rotation Sequence

```
issue new secret -> readers accept both -> writers switch -> old secret revoked
```

Design Constraints

- Never embed secrets in source or build artifacts.
- Support runtime refresh without full process restarts when possible.
- Fail startup quickly when required secrets are missing.

Incident Prevention

Most secret-related incidents come from rotation choreography errors. The dual-read transition window is critical for safe cutovers.

Performance Engineering

180 Performance Engineering Index

180 Performance Engineering

This section frames performance as an evidence-driven workflow.

Coverage:

1. Benchmarking and profiling loop.
2. Memory allocation and GC behavior.
3. Concurrency contention diagnosis and tuning.

The primary rule is simple: measure first, optimize second.

181 Benchmarking and Profiling Workflow

181 Benchmarking and Profiling Workflow

Optimization should be a controlled loop, not guesswork.

Workflow

```
baseline benchmark -> profile hotspot -> implement focused change -> remeasure -> keep/rever
```

Measurement Signals

- `ns/op` for latency cost.
- `B/op` and `allocs/op` for memory pressure.
- CPU and heap profiles for hotspot attribution.

Process Discipline

Change one variable at a time and keep benchmark inputs stable. This is the only reliable way to attribute wins or regressions.

182 Memory, Allocations, and GC

182 Memory, Allocations, and GC

Memory behavior is latency behavior. Allocation patterns influence GC pressure, which affects tail latency.

Runtime Path

```
allocate -> reachable? -> promoted/survive -> GC scan -> reclaim when unreachable
```

Practical Levers

- Reduce transient allocations in hot paths.
- Keep object lifetimes short when possible.
- Use pooling selectively where profiling justifies complexity.

Engineering Tradeoff

Lower allocation rates can reduce GC overhead, but aggressive pooling can increase complexity and bug risk. Favor clarity unless profiles show strong need.

183 Contention and Concurrency Tuning

183 Contention and Concurrency Tuning

Throughput often degrades due to contention long before CPU saturation reaches 100%.

Contention Shape

```
goroutines -> shared lock/resource -> queueing -> latency growth -> throughput collapse
```

Diagnostic Approach

- Identify shared-state hotspots.
- Measure mutex/block profiles.
- Correlate lock wait with p95/p99 latency.

Tuning Strategy

- Reduce shared mutable state.
- Partition state (sharding) where appropriate.
- Bound fan-out and queue sizes.

Performance work is complete only when improvements are verified under realistic load.

Modern Go Book Synthesis

190 Modern Go Books (2024-2025) Index

190 Modern Go Books (2024-2025) Index

This section distills practical curriculum additions from recent Go books (published in 2024 and 2025), then maps those ideas into this book's structure.

The intent is not to duplicate any book. Instead, this section extracts high-value topic patterns that repeatedly appear across recent publications and turns them into production-oriented learning content.

Selection Criteria

- Publication date within 2024-2025.
- Reliable public metadata for release date and chapter/index signals.
- Topics that improve production readiness for Go developers.

Source-Derived Synthesis Chapters

1. 191 Patterns from Go Programming (2nd ed., 2024)
2. 192 Patterns from Effective Go Recipes (2024)
3. 193 Patterns from Go in Practice (2nd ed., 2025)
4. 194 Patterns from Mastering Go (4th ed., 2024)
5. 195 Patterns from Let Us Go! (2025)
6. 196 Patterns from Automate Your Home Using Go (2024)

Cross-Book Theme Map

```
Language fundamentals -> Systems/networking -> Web APIs -> Concurrency -> Testing/Tooling ->
```

Recent books emphasize this transition strongly: Go learning now expects developers to move from syntax to production operations quickly.

191 Patterns from Go Programming (2nd ed., 2024)

191 Patterns from Go Programming (2nd ed., 2024)

This chapter extracts topics from the 2024 second edition arc: debugging, time handling, CLI work, files/systems, SQL, HTTP server/client, concurrency, testing, tooling, and cloud.

What This Adds to Our Book

- Stronger bridge from core syntax to practical operations.
- Dedicated narrative on "time as a correctness boundary".
- Better pairing of HTTP server and HTTP client behavior in one lifecycle.
- Cloud-readiness framing: configuration, graceful shutdown, observability, packaging.

Learning Architecture

```
core language -> application boundary (CLI/API) -> state boundary (DB/files) -> operational
```

Deep Integration Example: API + CLI + DB Boundary

```
package app

import (
    "context"
    "database/sql"
    "encoding/json"
    "errors"
    "fmt"
    "net/http"
    "os"
    "time"
)

var ErrNotFound = errors.New("not found")

type User struct {
```

```
    ID    int64  `json:"id"`
    Email string `json:"email"`
}

type Store struct{ DB *sql.DB }

func (s Store) GetUser(ctx context.Context, id int64) (User, error) {
    ctx, cancel := context.WithTimeout(ctx, 2*time.Second)
    defer cancel()

    var u User
    err := s.DB.QueryRowContext(ctx, `SELECT id, email FROM users WHERE id=$1`, id).Scan(&u.
    if errors.Is(err, sql.ErrNoRows) {
        return User{}, ErrNotFound
    }
    if err != nil {
        return User{}, fmt.Errorf("query user %d: %w", id, err)
    }
    return u, nil
}

type API struct{ Store Store }

func (a API) GetUserHandler(w http.ResponseWriter, r *http.Request) {
    ctx, cancel := context.WithTimeout(r.Context(), 3*time.Second)
    defer cancel()

    user, err := a.Store.GetUser(ctx, 42)
    if errors.Is(err, ErrNotFound) {
        http.Error(w, "not found", http.StatusNotFound)
        return
    }
    if err != nil {
        http.Error(w, "internal error", http.StatusInternalServerError)
        return
    }
    w.Header().Set("Content-Type", "application/json")
    _ = json.NewEncoder(w).Encode(user)
}

func ReadEnvDuration(key string, fallback time.Duration) time.Duration {
    v := os.Getenv(key)
    if v == "" {
        return fallback
    }
    d, err := time.ParseDuration(v)
    if err != nil {
```

```
        return fallback
    }
    return d
}
```

Why This Matters

The example demonstrates a full chain from request boundary to storage boundary with explicit timeouts and typed errors. That is the practical center of modern Go backend development.

Curriculum Upgrades Recommended

1. Add a dedicated chapter linking debugging, benchmarking, and production incident triage.
2. Expand `time` chapter with deadline budgeting patterns for server+client+DB together.
3. Add side-by-side chapter pair: `net/http` server correctness and `http.Client` resilience.
4. Add cloud deployment chapter emphasizing runtime config contracts and shutdown policy.

192 Patterns from Effective Go Recipes (2024)

192 Patterns from Effective Go Recipes (2024)

This source emphasizes practical recipes across I/O, JSON streaming, HTTP middleware/timeouts, text normalization, function options, errors, concurrency, sockets, C interop, testing, and shipping.

What This Adds to Our Book

- Recipe-level production patterns that are small, composable, and immediately reusable.
- Better treatment of streaming and incremental processing.
- Stronger shipping pipeline topics: build tags, static builds, version injection, Docker packaging.

Streaming-Oriented Mental Model

```
source -> decoder -> transform -> validator -> sink
          (stream)               (bounded memory)
```

Deep Integration Example: Streaming JSON Pipeline with Backpressure

```
package pipeline

import (
    "bufio"
    "context"
    "encoding/json"
    "errors"
    "io"
    "sync"
    "time"
)

type Event struct {
    ID   string `json:"id"`
    Type string `json:"type"`
```

```
}

func DecodeEvents(ctx context.Context, r io.Reader) (<-chan Event, <-chan error) {
    out := make(chan Event, 128)
    errCh := make(chan error, 1)

    go func() {
        defer close(out)
        defer close(errCh)

        dec := json.NewDecoder(bufio.NewReader(r))
        for {
            var e Event
            if err := dec.Decode(&e); err != nil {
                if errors.Is(err, io.EOF) {
                    return
                }
                errCh <- err
                return
            }

            select {
            case <-ctx.Done():
                errCh <- ctx.Err()
                return
            case out <- e:
            }
        }
    }()

    return out, errCh
}

func ProcessEvents(ctx context.Context, in <-chan Event, workers int, fn func(Event) error)
    ctx, cancel := context.WithCancel(ctx)
    defer cancel()

    errCh := make(chan error, workers)
    var wg sync.WaitGroup

    for i := 0; i < workers; i++ {
        wg.Add(1)
        go func() {
            defer wg.Done()
            for e := range in {
                opCtx, stop := context.WithTimeout(ctx, 250*time.Millisecond)
                err := fn(e)
```

```
                stop()
                if opCtx.Err() != nil {
                    errCh <- opCtx.Err()
                    cancel()
                    return
                }
                if err != nil {
                    errCh <- err
                    cancel()
                    return
                }
            }
        }()
    }

    wg.Wait()
    close(errCh)
    for err := range errCh {
        if err != nil {
            return err
        }
    }
    return nil
}
```

Why This Matters

Modern Go systems increasingly process streams instead of loading full datasets in memory. Recipe-style patterns are especially effective for this style because they focus on one robust tactic at a time.

Curriculum Upgrades Recommended

1. Add a chapter on streaming-first design (`json.Decoder`, `io.Reader`, chunked processing).
2. Add chapter on function options + config normalization.
3. Add chapter on shipping pipelines: reproducible builds, tags, embedding, static binaries.
4. Add explicit `os/exec` and signal-handling narrative for operational tooling.

193 Patterns from Go in Practice (2nd ed., 2025)

193 Patterns from Go in Practice (2nd ed., 2025)

The 2025 edition is structured around four parts: fundamentals, robust application practices, end-to-end web systems, and cloud/advanced topics (reflection, code generation, interop).

What This Adds to Our Book

- Strong mid-level bridge: from language fluency to production engineering.
- Better integration of testing, debugging, and benchmarking as one quality discipline.
- Explicit chapter path toward microservices and external service integration.

End-to-End Service Model

```
HTTP edge -> business layer -> storage/external APIs -> telemetry -> deployment/runtime chec
```

Deep Integration Example: External Service Client with Typed Error Strategy

```
package external

import (
    "context"
    "encoding/json"
    "errors"
    "fmt"
    "net/http"
    "time"
)

var ErrUpstreamUnavailable = errors.New("upstream unavailable")

type Client struct {
    HTTP *http.Client
    Base string
}
```

```
type Profile struct {
    ID   string `json:"id"`
    Name string `json:"name"`
}

func NewClient(base string) Client {
    return Client{
        Base: base,
        HTTP: &http.Client{Timeout: 2 * time.Second},
    }
}

func (c Client) GetProfile(ctx context.Context, id string) (Profile, error) {
    ctx, cancel := context.WithTimeout(ctx, 1200*time.Millisecond)
    defer cancel()

    req, err := http.NewRequestWithContext(ctx, http.MethodGet, c.Base+"/profiles/"+id, nil)
    if err != nil {
        return Profile{}, err
    }

    resp, err := c.HTTP.Do(req)
    if err != nil {
        return Profile{}, fmt.Errorf("http call failed: %w", ErrUpstreamUnavailable)
    }
    defer resp.Body.Close()

    if resp.StatusCode >= 500 {
        return Profile{}, fmt.Errorf("status %d: %w", resp.StatusCode, ErrUpstreamUnavailabl
    }
    if resp.StatusCode != http.StatusOK {
        return Profile{}, fmt.Errorf("unexpected status: %d", resp.StatusCode)
    }

    var p Profile
    if err := json.NewDecoder(resp.Body).Decode(&p); err != nil {
        return Profile{}, err
    }
    return p, nil
}
```

Why This Matters

Production services fail most often at integration boundaries. This pattern teaches typed failure handling and timeout discipline in a way that scales across microservices.

Curriculum Upgrades Recommended

1. Add one full chapter on external service client design (`timeouts`, `retry policy`, `error typing`).
2. Add one chapter on data ingress/egress patterns (upload/download, validation, content type).
3. Add one chapter on reflection and code generation boundaries: when useful, when harmful.

194 Patterns from Mastering Go (4th ed., 2024)

194 Patterns from Mastering Go (4th ed., 2024)

Recent 4th-edition signals emphasize advanced practice: generics, interfaces/reflection, Unix systems work, concurrency, web services, TCP/WebSocket, REST APIs, testing/profiling, fuzzing/observability, and performance.

What This Adds to Our Book

- Better advanced track sequencing after core language chapters.
- Stronger focus on performance + fuzz + observability as one reliability loop.
- More explicit Unix-system programming integration for backend engineers.

Advanced Engineering Loop

```
implement -> test -> fuzz -> profile -> optimize -> observe in runtime -> iterate
```

Deep Integration Example: Fuzz-Ready Parser + Profile-Aware Fast Path

```go
package parser

import (
    "errors"
    "strconv"
    "strings"
)

var ErrBadRecord = errors.New("bad record")

type Record struct {
    ID    int64
    Score float64
}

func ParseRecord(line string) (Record, error) {
    parts := strings.Split(line, ",")
```

```
    if len(parts) != 2 {
        return Record{}, ErrBadRecord
    }

    id, err := strconv.ParseInt(strings.TrimSpace(parts[0]), 10, 64)
    if err != nil {
        return Record{}, ErrBadRecord
    }
    score, err := strconv.ParseFloat(strings.TrimSpace(parts[1]), 64)
    if err != nil {
        return Record{}, ErrBadRecord
    }
    if id <= 0 || score < 0 {
        return Record{}, ErrBadRecord
    }
    return Record{ID: id, Score: score}, nil
}
```

```
package parser_test

import "testing"

func FuzzParseRecord(f *testing.F) {
    f.Add("1,2.5")
    f.Add("x,y")
    f.Add("")

    f.Fuzz(func(t *testing.T, input string) {
        _, _ = ParseRecord(input)
    })
}
```

Why This Matters

As Go systems mature, defects shift from syntax mistakes to boundary and performance defects. Fuzzing and profiling help catch these before they become incidents.

Curriculum Upgrades Recommended

1. Add a dedicated chapter combining fuzzing, race detection, and pprof for one service.
2. Add advanced chapter on TCP/WebSocket design under network systems.
3. Expand performance track with explicit optimization workflow and rollback criteria.

195 Patterns from Let Us Go! (2025)

195 Patterns from Let Us Go! (2025)

This 2025 beginner-focused arc stresses playground-first onboarding, workspace/tooling setup, version control flow, and then deep dive application development.

What This Adds to Our Book

- Better early-stage onboarding narrative for self-learners.
- A clearer toolchain chapter that explains *why* each tool exists.
- Practical Git workflow integration earlier in the learning path.

Onboarding Progression

```
Playground exploration -> local toolchain setup -> Git discipline -> deeper project work
```

Deep Integration Example: Minimal Project Lifecycle from Day 1

```
package main

import (
    "flag"
    "fmt"
    "os"
)

type Config struct {
    Name string
    Env  string
}

func parseConfig() Config {
    cfg := Config{}
    flag.StringVar(&cfg.Name, "name", "gopher", "name to greet")
    flag.StringVar(&cfg.Env, "env", "dev", "runtime environment")
    flag.Parse()
    return cfg
```

```
}

func run(cfg Config) error {
    if cfg.Env == "prod" && os.Getenv("APP_ALLOW_PROD") != "1" {
        return fmt.Errorf("prod run blocked without APP_ALLOW_PROD=1")
    }
    fmt.Printf("hello %s (%s)\n", cfg.Name, cfg.Env)
    return nil
}

func main() {
    if err := run(parseConfig()); err != nil {
        fmt.Fprintln(os.Stderr, "error:", err)
        os.Exit(1)
    }
}
```

Why This Matters

Beginner success is mostly about reducing setup friction and establishing stable habits early. Good onboarding chapters improve completion rates and reduce learner drop-off.

Curriculum Upgrades Recommended

1. Strengthen foundational chapters with explicit environment setup validation steps.
2. Add version-control workflow examples tied to chapter exercises/projects.
3. Add “first-week debugging habits” chapter before advanced language features.

196 Patterns from Automate Your Home Using Go (2024)

196 Patterns from Automate Your Home Using Go (2024)

This 2024 title emphasizes applied systems engineering: Raspberry Pi deployment, Dockerized services, telemetry, monitoring with Prometheus/Grafana, and practical automation workflows.

What This Adds to Our Book

- Strong real-world edge/infrastructure use cases beyond traditional web CRUD.
- Better observability-first mindset for long-running services.
- Helpful pathway from single-node apps to homelab/multi-service operations.

Edge Automation Topology

```
sensor/input -> Go collector -> local queue/cache -> automation decision -> action
                    |
                    +-> metrics/logs -> Prometheus/Grafana
```

Deep Integration Example: Telemetry Collector with Health and Metrics Surface

```
package main

import (
    "encoding/json"
    "fmt"
    "log"
    "net/http"
    "sync"
    "time"
)

type Reading struct {
    Source string    `json:"source"`
    Value  float64   `json:"value"`
```

```
    At     time.Time `json:"at"`
}

type State struct {
    mu       sync.RWMutex
    last     map[string]Reading
    ingested uint64
}

func newState() *State {
    return &State{last: make(map[string]Reading)}
}

func (s *State) ingest(r Reading) {
    s.mu.Lock()
    defer s.mu.Unlock()
    s.last[r.Source] = r
    s.ingested++
}

func (s *State) handleIngest(w http.ResponseWriter, r *http.Request) {
    if r.Method != http.MethodPost {
        http.Error(w, "method not allowed", http.StatusMethodNotAllowed)
        return
    }
    var x Reading
    if err := json.NewDecoder(r.Body).Decode(&x); err != nil {
        http.Error(w, "bad payload", http.StatusBadRequest)
        return
    }
    x.At = time.Now().UTC()
    s.ingest(x)
    w.WriteHeader(http.StatusAccepted)
}

func (s *State) handleHealth(w http.ResponseWriter, _ *http.Request) {
    w.Header().Set("Content-Type", "application/json")
    _ = json.NewEncoder(w).Encode(map[string]any{"ok": true, "ts": time.Now().UTC()})
}

func (s *State) handleMetrics(w http.ResponseWriter, _ *http.Request) {
    s.mu.RLock()
    defer s.mu.RUnlock()
    _, _ = w.Write([]byte("collector_ingested_total "))
    _, _ = w.Write([]byte(fmt.Sprintf("%d\n", s.ingested)))
}
```

```go
func main() {
    st := newState()
    mux := http.NewServeMux()
    mux.HandleFunc("POST /ingest", st.handleIngest)
    mux.HandleFunc("GET /healthz", st.handleHealth)
    mux.HandleFunc("GET /metrics", st.handleMetrics)

    srv := &http.Server{
        Addr:              ":8080",
        Handler:           mux,
        ReadHeaderTimeout: 2 * time.Second,
        ReadTimeout:       5 * time.Second,
        WriteTimeout:      10 * time.Second,
        IdleTimeout:       30 * time.Second,
    }
    log.Fatal(srv.ListenAndServe())
}
```

Why This Matters

Practical automation projects force integration of networking, state handling, deployment, and observability. This makes them high-value capstones for Go learners.

Curriculum Upgrades Recommended

1. Add an edge/homelab tutorial track under specialized chapters.
2. Add observability hooks by default in systems examples.
3. Add deployment story from local process -> Docker -> lightweight orchestrated environment.

Projects

027 Project 27: Kubernetes Event Watcher

027 Build a Kubernetes Event Watcher

Watch cluster events in real time.

Full `main.go`

```
package main

import (
    "context"
    "fmt"
    "os"

    metav1 "k8s.io/apimachinery/pkg/apis/meta/v1"
    "k8s.io/client-go/kubernetes"
    "k8s.io/client-go/tools/clientcmd"
)

func main() {
    cfg, err := clientcmd.BuildConfigFromFlags("", os.Getenv("HOME")+"/.kube/config")
    if err != nil {
        panic(err)
    }
    cli, err := kubernetes.NewForConfig(cfg)
    if err != nil {
        panic(err)
    }

    w, err := cli.CoreV1().Events("").Watch(context.Background(), metav1.ListOptions{})
    if err != nil {
        panic(err)
    }
    defer w.Stop()

    for e := range w.ResultChan() {
        fmt.Printf("%T\n", e.Object)
    }
}
```

Step-by-Step Explanation

1. Build Kubernetes client config from kubeconfig.
2. Scope operations by namespace or resource type.
3. Query or watch API objects.
4. Extract actionable status fields.
5. Return output and exit codes suitable for scripts and CI.

Code Anatomy

- Setup phase creates client and context.
- Query/watch phase pulls cluster state.
- Presentation phase prints concise operational results.

Learning Goals

- Use `client-go` safely and predictably.
- Convert API objects into operator-facing insights.
- Build automation-friendly cluster checks.

028 Project 28: Kubernetes Rollout Checker

028 Build a Kubernetes Rollout Checker

Check if a Deployment is fully rolled out.

Full `main.go`

```
package main

import (
    "context"
    "flag"
    "fmt"
    "os"

    metav1 "k8s.io/apimachinery/pkg/apis/meta/v1"
    "k8s.io/client-go/kubernetes"
    "k8s.io/client-go/tools/clientcmd"
)

func main() {
    name := flag.String("name", "", "deployment name")
    ns := flag.String("n", "default", "namespace")
    flag.Parse()
    if *name == "" {
        fmt.Println("need -name")
        os.Exit(2)
    }

    cfg, err := clientcmd.BuildConfigFromFlags("", os.Getenv("HOME")+"/.kube/config")
    if err != nil {
        panic(err)
    }
    cli, err := kubernetes.NewForConfig(cfg)
    if err != nil {
        panic(err)
    }

    d, err := cli.AppsV1().Deployments(*ns).Get(context.Background(), *name, metav1.GetOptio
    if err != nil {
        panic(err)
```

```
    }

    desired := int32(1)
    if d.Spec.Replicas != nil {
        desired = *d.Spec.Replicas
    }
    ready := d.Status.ReadyReplicas
    updated := d.Status.UpdatedReplicas

    fmt.Printf("deployment=%s/%s desired=%d updated=%d ready=%d\n", *ns, *name, desired, upd
    if ready == desired && updated == desired {
        fmt.Println("rollout: healthy")
        os.Exit(0)
    }
    fmt.Println("rollout: pending")
    os.Exit(1)
}
```

Step-by-Step Explanation

1. Build Kubernetes client config from kubeconfig.
2. Scope operations by namespace or resource type.
3. Query or watch API objects.
4. Extract actionable status fields.
5. Return output and exit codes suitable for scripts and CI.

Code Anatomy

- Setup phase creates client and context.
- Query/watch phase pulls cluster state.
- Presentation phase prints concise operational results.

Learning Goals

- Use `client-go` safely and predictably.
- Convert API objects into operator-facing insights.
- Build automation-friendly cluster checks.

029 Project 29: Terraform Plan Parser

029 Build a Terraform Plan Parser

Parse `terraform show -json` output and summarize actions.

Run prerequisite

```
terraform show -json tfplan > plan.json
```

Full `main.go`

```
package main

import (
    "encoding/json"
    "fmt"
    "os"
)

type Plan struct {
    ResourceChanges []struct {
        Address string `json:"address"`
        Change  struct {
            Actions []string `json:"actions"`
        } `json:"change"`
    } `json:"resource_changes"`
}

func main() {
    if len(os.Args) != 2 {
        fmt.Println("usage: tf-plan-parse <plan.json>")
        os.Exit(2)
    }
    b, err := os.ReadFile(os.Args[1])
    if err != nil {
        panic(err)
    }
    var p Plan
```

```
    if err := json.Unmarshal(b, &p); err != nil {
        panic(err)
    }

    counts := map[string]int{"create": 0, "update": 0, "delete": 0, "replace": 0}
    for _, rc := range p.ResourceChanges {
        a := rc.Change.Actions
        if len(a) == 2 && a[0] == "delete" && a[1] == "create" {
            counts["replace"]++
            fmt.Printf("REPLACE %s\n", rc.Address)
            continue
        }
        for _, x := range a {
            counts[x]++
        }
        fmt.Printf("%v %s\n", a, rc.Address)
    }
    fmt.Printf("summary create=%d update=%d delete=%d replace=%d\n", counts["create"], count
}
```

Step-by-Step Explanation

1. Export Terraform plan in JSON form.
2. Parse `resource_changes` into typed structs.
3. Classify actions such as create/update/delete/replace.
4. Compute risk, policy, or cost summaries.
5. Gate CI based on explicit thresholds.

Code Anatomy

- Decoder layer parses JSON file.
- Analysis layer converts raw actions into signals.
- Reporting layer prints summary and sets exit status.

Learning Goals

- Build deterministic IaC review tools.
- Enforce infrastructure policy as code.
- Reduce risky deploys with automated checks.

030 Project 30: Terraform Risk Reporter

030 Build a Terraform Risk Reporter

Use the parsed plan to fail CI on risky deletes/replacements.

Full `main.go`

```
package main

import (
    "encoding/json"
    "fmt"
    "os"
)

type plan struct {
    ResourceChanges []struct {
        Address string `json:"address"`
        Change  struct {
            Actions []string `json:"actions"`
        } `json:"change"`
    } `json:"resource_changes"`
}

func hasAction(actions []string, x string) bool {
    for _, a := range actions {
        if a == x {
            return true
        }
    }
    return false
}

func main() {
    if len(os.Args) != 2 {
        fmt.Println("usage: tf-risk <plan.json>")
        os.Exit(2)
    }
    b, err := os.ReadFile(os.Args[1])
    if err != nil {
        panic(err)
```

```
    }
    var p plan
    if err := json.Unmarshal(b, &p); err != nil {
        panic(err)
    }

    risky := 0
    for _, rc := range p.ResourceChanges {
        a := rc.Change.Actions
        replace := len(a) == 2 && a[0] == "delete" && a[1] == "create"
        if hasAction(a, "delete") || replace {
            risky++
            fmt.Printf("RISK: %s actions=%v\n", rc.Address, a)
        }
    }
    fmt.Printf("risky changes=%d\n", risky)
    if risky > 0 {
        os.Exit(1)
    }
}
```

Step-by-Step Explanation

1. Export Terraform plan in JSON form.
2. Parse `resource_changes` into typed structs.
3. Classify actions such as create/update/delete/replace.
4. Compute risk, policy, or cost summaries.
5. Gate CI based on explicit thresholds.

Code Anatomy

- Decoder layer parses JSON file.
- Analysis layer converts raw actions into signals.
- Reporting layer prints summary and sets exit status.

Learning Goals

- Build deterministic IaC review tools.
- Enforce infrastructure policy as code.
- Reduce risky deploys with automated checks.

031 Project 31: Prometheus Exporter

031 Build a Prometheus Exporter

Expose custom app metrics at `/metrics`.

Setup

```
go mod init example.com/exporter
go get github.com/prometheus/client_golang/prometheus@latest
go get github.com/prometheus/client_golang/prometheus/promhttp@latest
```

Full `main.go`

```
package main

import (
    "log"
    "math/rand"
    "net/http"
    "time"

    "github.com/prometheus/client_golang/prometheus"
    "github.com/prometheus/client_golang/prometheus/promhttp"
)

func main() {
    reqTotal := prometheus.NewCounter(prometheus.CounterOpts{Name: "demo_requests_total", He
    latency := prometheus.NewHistogram(prometheus.HistogramOpts{Name: "demo_latency_seconds"
    inflight := prometheus.NewGauge(prometheus.GaugeOpts{Name: "demo_inflight", Help: "infli
    prometheus.MustRegister(reqTotal, latency, inflight)

    http.Handle("/metrics", promhttp.Handler())
    http.HandleFunc("/work", func(w http.ResponseWriter, r *http.Request) {
        inflight.Inc()
        defer inflight.Dec()
        start := time.Now()
        time.Sleep(time.Duration(50+rand.Intn(200)) * time.Millisecond)
        reqTotal.Inc()
```

```
        latency.Observe(time.Since(start).Seconds())
        w.Write([]byte("ok\n"))
    })

    log.Println("metrics on :9100/metrics")
    log.Fatal(http.ListenAndServe(":9100", nil))
}
```

Step-by-Step Explanation

1. Define metrics types for totals, current values, and distributions.
2. Register metrics and expose a scrape endpoint.
3. Update metrics in business flow.
4. Validate with manual requests and Prometheus scrape.
5. Tune labels to avoid high-cardinality cardinality issues.

Code Anatomy

- Metric definitions at startup.
- Request/probe path updates counters, gauges, or histograms.
- `/metrics` endpoint exposes state for observability stack.

Learning Goals

- Design practical service metrics.
- Connect application behavior to SLO monitoring.
- Build observability by default.

032 Project 32: Prometheus Probe Service

032 Build a Prometheus Probe Service

Probe a target URL and export health/latency metrics.

Full `main.go`

```
package main

import (
    "log"
    "net/http"
    "time"

    "github.com/prometheus/client_golang/prometheus"
    "github.com/prometheus/client_golang/prometheus/promhttp"
)

func main() {
    up := prometheus.NewGaugeVec(prometheus.GaugeOpts{Name: "probe_up", Help: "target up"},
    dur := prometheus.NewGaugeVec(prometheus.GaugeOpts{Name: "probe_duration_seconds", Help:
    prometheus.MustRegister(up, dur)

    client := &http.Client{Timeout: 2 * time.Second}
    http.HandleFunc("/probe", func(w http.ResponseWriter, r *http.Request) {
        target := r.URL.Query().Get("target")
        if target == "" {
            http.Error(w, "missing target", http.StatusBadRequest)
            return
        }
        start := time.Now()
        resp, err := client.Get(target)
        d := time.Since(start).Seconds()
        dur.WithLabelValues(target).Set(d)
        if err != nil || resp.StatusCode >= 400 {
            up.WithLabelValues(target).Set(0)
            w.WriteHeader(http.StatusServiceUnavailable)
            w.Write([]byte("down\n"))
            return
        }
        up.WithLabelValues(target).Set(1)
```

```
        w.Write([]byte("up\n"))
    })
    http.Handle("/metrics", promhttp.Handler())

    log.Println("probe service on :9115")
    log.Fatal(http.ListenAndServe(":9115", nil))
}
```

Step-by-Step Explanation

1. Define metrics types for totals, current values, and distributions.
2. Register metrics and expose a scrape endpoint.
3. Update metrics in business flow.
4. Validate with manual requests and Prometheus scrape.
5. Tune labels to avoid high-cardinality cardinality issues.

Code Anatomy

- Metric definitions at startup.
- Request/probe path updates counters, gauges, or histograms.
- `/metrics` endpoint exposes state for observability stack.

Learning Goals

- Design practical service metrics.
- Connect application behavior to SLO monitoring.
- Build observability by default.

033 Project 33: eBPF Tracepoint Basics

033 Build eBPF Tracepoint Basics

Capture process exec events from `sys_enter_execve` using eBPF.

```
kernel tracepoint -> eBPF program -> ring/perf buffer -> userspace reader
```

Setup

```
go mod init example.com/ebpf-trace
go get github.com/cilium/ebpf@latest
# also install clang/llvm and bpf2go tooling
```

Files

1. `main.go` userspace loader/reader
2. `exec.bpf.c` kernel-side program
3. generated `exec_bpfel.go` from `bpf2go`

`main.go` (userspace)

```
package main

import (
    "bytes"
    "encoding/binary"
    "fmt"
    "log"
    "os"
    "os/signal"

    "github.com/cilium/ebpf/link"
    "github.com/cilium/ebpf/perf"
)

type event struct {
    Pid  uint32
```

```
    Comm [16]byte
}

func main() {
    objs := bpfObjects{}
    if err := loadBpfObjects(&objs, nil); err != nil {
        log.Fatal(err)
    }
    defer objs.Close()

    tp, err := link.Tracepoint("syscalls", "sys_enter_execve", objs.HandleExec, nil)
    if err != nil {
        log.Fatal(err)
    }
    defer tp.Close()

    rd, err := perf.NewReader(objs.Events, os.Getpagesize())
    if err != nil {
        log.Fatal(err)
    }
    defer rd.Close()

    sig := make(chan os.Signal, 1)
    signal.Notify(sig, os.Interrupt)
    go func() { <-sig; _ = rd.Close() }()

    for {
        rec, err := rd.Read()
        if err != nil {
            break
        }
        var e event
        if err := binary.Read(bytes.NewBuffer(rec.RawSample), binary.LittleEndian, &e); err
            continue
        }
        fmt.Printf("pid=%d comm=%s\n", e.Pid, bytes.TrimRight(e.Comm[:], "\x00"))
    }
}
```

Notes

- Requires Linux kernel with eBPF support.
- Run with root privileges.
- This is a lab starter; add filtering and structured output next.

Step-by-Step Explanation

1. Keep kernel-side eBPF logic minimal and focused.
2. Load and attach program from userspace.
3. Stream events or counters from maps/buffers.
4. Handle shutdown and detachment cleanly.
5. Validate behavior in an isolated Linux lab environment.

Code Anatomy

- eBPF program runs in kernel hook.
- Userspace Go loader manages attach/read lifecycle.
- Reader loop transforms low-level events into readable output.

Learning Goals

- Understand event-driven observability close to the kernel.
- Learn safe iteration practices for low-level tooling.
- Build confidence with modern Linux instrumentation.

034 Project 34: eBPF XDP Packet Counter

034 Build an eBPF XDP Packet Counter

Attach an XDP program to a NIC and count packets in a BPF map.

Goal

- attach XDP to interface
- increment packet counter map in kernel
- read counter from userspace every second

`main.go` skeleton

```
package main

import (
    "fmt"
    "log"
    "time"

    "github.com/cilium/ebpf/link"
)

func main() {
    objs := bpfObjects{}
    if err := loadBpfObjects(&objs, nil); err != nil {
        log.Fatal(err)
    }
    defer objs.Close()

    l, err := link.AttachXDP(link.XDPOptions{
        Program:   objs.XdpCount,
        Interface: 2, // set your interface index
    })
    if err != nil {
        log.Fatal(err)
    }
    defer l.Close()
```

```
    for range time.Tick(time.Second) {
        var key uint32 = 0
        var value uint64
        if err := objs.PacketCount.Lookup(&key, &value); err == nil {
            fmt.Printf("packets=%d\n", value)
        }
    }
}
```

Notes

- Keep this in a lab VM.
- Add interface discovery + CLI flags.
- Add map reset endpoint after reading.

Step-by-Step Explanation

1. Keep kernel-side eBPF logic minimal and focused.
2. Load and attach program from userspace.
3. Stream events or counters from maps/buffers.
4. Handle shutdown and detachment cleanly.
5. Validate behavior in an isolated Linux lab environment.

Code Anatomy

- eBPF program runs in kernel hook.
- Userspace Go loader manages attach/read lifecycle.
- Reader loop transforms low-level events into readable output.

Learning Goals

- Understand event-driven observability close to the kernel.
- Learn safe iteration practices for low-level tooling.
- Build confidence with modern Linux instrumentation.

035 Project 35: Proxmox Multi-Node Scheduler

035 Build a Proxmox Multi-Node Scheduler

Schedule VM placement across nodes by free memory and CPU load.

```
fetch node stats -> score nodes -> choose best node -> create/migrate plan
```

Full `main.go`

```
package main

import (
    "encoding/json"
    "fmt"
    "net/http"
    "os"
    "sort"
)

type NodeStat struct {
    Node  string  `json:"node"`
    CPU   float64 `json:"cpu"`
    Mem   float64 `json:"mem"`
    MaxMem float64 `json:"maxmem"`
}

type apiResp struct {
    Data []NodeStat `json:"data"`
}

func score(n NodeStat) float64 {
    freeMemRatio := 1 - (n.Mem / n.MaxMem)
    cpuHeadroom := 1 - n.CPU
    return freeMemRatio*0.7 + cpuHeadroom*0.3
}

func main() {
    base := os.Getenv("PVE_BASE_URL")
    token := os.Getenv("PVE_TOKEN")
    if base == "" || token == "" {
```

```
        fmt.Println("set PVE_BASE_URL and PVE_TOKEN")
        os.Exit(2)
    }

    req, _ := http.NewRequest(http.MethodGet, base+"/api2/json/nodes", nil)
    req.Header.Set("Authorization", "PVEAPIToken="+token)
    resp, err := http.DefaultClient.Do(req)
    if err != nil {
        panic(err)
    }
    defer resp.Body.Close()

    var out apiResp
    if err := json.NewDecoder(resp.Body).Decode(&out); err != nil {
        panic(err)
    }

    sort.Slice(out.Data, func(i, j int) bool { return score(out.Data[i]) > score(out.Data[j]
    fmt.Println("placement order:")
    for _, n := range out.Data {
        fmt.Printf("node=%s score=%.3f cpu=%.2f mem=%.0f/%.0f\n", n.Node, score(n), n.CPU, n
    }
}
```

Step-by-Step Explanation

1. Collect node/resource metrics from API sources.
2. Compute deterministic scores per target.
3. Rank candidates by score and policy constraints.
4. Produce dry-run placement/migration decisions.
5. Apply gradually with canary and rollback plan.

Code Anatomy

- Data collection stage fetches capacity and load.
- Scoring stage turns metrics into comparable values.
- Decision stage emits ranked scheduling actions.

Learning Goals

- Build scheduling logic that is explainable and auditable.
- Balance utilization, reliability, and operational safety.
- Prepare for production-grade orchestration workflows.

036 Project 36: Proxmox Capacity Balancer

036 Build a Proxmox Capacity Balancer (Dry-Run)

Generate migration suggestions from overloaded nodes to healthier nodes.

Full `main.go`

```
package main

import "fmt"

type Node struct {
    Name string
    CPU  float64
}

func main() {
    nodes := []Node{
        {"pve1", 0.92},
        {"pve2", 0.35},
        {"pve3", 0.41},
    }

    src := nodes[0]
    dst := nodes[1]
    for _, n := range nodes {
        if n.CPU > src.CPU {
            src = n
        }
        if n.CPU < dst.CPU {
            dst = n
        }
    }

    fmt.Printf("suggest migration: from %s -> %s (cpu %.2f -> %.2f)\n", src.Name, dst.Name,
}
```

Step-by-Step Explanation

1. Collect node/resource metrics from API sources.
2. Compute deterministic scores per target.
3. Rank candidates by score and policy constraints.
4. Produce dry-run placement/migration decisions.
5. Apply gradually with canary and rollback plan.

Code Anatomy

- Data collection stage fetches capacity and load.
- Scoring stage turns metrics into comparable values.
- Decision stage emits ranked scheduling actions.

Learning Goals

- Build scheduling logic that is explainable and auditable.
- Balance utilization, reliability, and operational safety.
- Prepare for production-grade orchestration workflows.

037 Project 37: Kubernetes HPA Simulator

037 Build a Kubernetes HPA Simulator

Simulate replica scaling from CPU load over time.

Full `main.go`

```
package main

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

func main() {
    replicas := 2
    targetCPU := 60.0

    for t := 1; t <= 30; t++ {
        cpu := 30 + rand.Float64()*70
        if cpu > targetCPU+10 && replicas < 20 {
            replicas++
        } else if cpu < targetCPU-20 && replicas > 1 {
            replicas--
        }
        fmt.Printf("tick=%02d cpu=%5.1f%% replicas=%d\n", t, cpu, replicas)
        time.Sleep(150 * time.Millisecond)
    }
}
```

Step-by-Step Explanation

1. Model desired and actual state explicitly.
2. Compute a minimal diff.
3. Apply one idempotent reconciliation step.
4. Observe updated state and repeat.
5. Keep loops convergent and failure-aware.

Code Anatomy

- State model captures control-plane truth.
- Reconcile function decides next action.
- Loop executes continuously with visibility into actions.

Learning Goals

- Learn the controller pattern used in modern platforms.
- Build robust automation through repeated reconciliation.
- Understand convergence over one-shot scripting.

038 Project 38: Terraform Cost Estimator

038 Build a Terraform Cost Estimator (Simple)

Estimate monthly change by resource action counts.

Full `main.go`

```
package main

import (
    "encoding/json"
    "fmt"
    "os"
)

type Plan struct {
    ResourceChanges []struct {
        Type   string `json:"type"`
        Change struct {
            Actions []string `json:"actions"`
        } `json:"change"`
    } `json:"resource_changes"`
}

var cost = map[string]float64{
    "aws_instance": 15.0,
    "aws_db_instance": 120.0,
    "aws_lb": 25.0,
}

func main() {
    if len(os.Args) != 2 {
        fmt.Println("usage: tf-cost <plan.json>")
        os.Exit(2)
    }
    b, err := os.ReadFile(os.Args[1])
    if err != nil {
        panic(err)
    }
    var p Plan
    if err := json.Unmarshal(b, &p); err != nil {
```

```
        panic(err)
    }

    var delta float64
    for _, rc := range p.ResourceChanges {
        c := cost[rc.Type]
        if c == 0 {
            continue
        }
        for _, a := range rc.Change.Actions {
            if a == "create" {
                delta += c
            }
            if a == "delete" {
                delta -= c
            }
        }
    }
    fmt.Printf("estimated monthly delta: $%.2f\n", delta)
}
```

Step-by-Step Explanation

1. Export Terraform plan in JSON form.
2. Parse `resource_changes` into typed structs.
3. Classify actions such as create/update/delete/replace.
4. Compute risk, policy, or cost summaries.
5. Gate CI based on explicit thresholds.

Code Anatomy

- Decoder layer parses JSON file.
- Analysis layer converts raw actions into signals.
- Reporting layer prints summary and sets exit status.

Learning Goals

- Build deterministic IaC review tools.
- Enforce infrastructure policy as code.
- Reduce risky deploys with automated checks.

039 Project 39: Prometheus Alert Rule Tester

039 Build a Prometheus Alert Rule Tester

Evaluate synthetic metric streams against threshold rules.

Full `main.go`

```
package main

import "fmt"

func shouldAlert(v float64, threshold float64, forSteps int, streak int) bool {
    if v > threshold {
        streak++
    } else {
        streak = 0
    }
    return streak >= forSteps
}

func main() {
    vals := []float64{70, 82, 90, 88, 91, 72, 95}
    threshold := 85.0
    forSteps := 3
    streak := 0

    for i, v := range vals {
        if v > threshold {
            streak++
        } else {
            streak = 0
        }
        alert := streak >= forSteps
        fmt.Printf("t=%d val=%.1f streak=%d alert=%v\n", i, v, streak, alert)
    }
}
```

Step-by-Step Explanation

1. Define metrics types for totals, current values, and distributions.

2. Register metrics and expose a scrape endpoint.
3. Update metrics in business flow.
4. Validate with manual requests and Prometheus scrape.
5. Tune labels to avoid high-cardinality cardinality issues.

Code Anatomy

- Metric definitions at startup.
- Request/probe path updates counters, gauges, or histograms.
- `/metrics` endpoint exposes state for observability stack.

Learning Goals

- Design practical service metrics.
- Connect application behavior to SLO monitoring.
- Build observability by default.

040 Project 40: Infra Reconciler Daemon

040 Build an Infra Reconciler Daemon

Model a control-loop daemon that continuously moves actual state toward desired state.

```
desired config -> diff -> apply actions -> observe -> repeat
```

Full `main.go`

```
package main

import (
    "fmt"
    "time"
)

type state struct {
    Desired int
    Actual  int
}

func diff(s state) int { return s.Desired - s.Actual }

func apply(s *state) string {
    d := diff(*s)
    switch {
    case d > 0:
        s.Actual++
        return "scale_up"
    case d < 0:
        s.Actual--
        return "scale_down"
    default:
        return "noop"
    }
}

func main() {
    s := state{Desired: 5, Actual: 1}
    tick := time.NewTicker(400 * time.Millisecond)
```

```
    defer tick.Stop()

    for i := 0; i < 20; i++ {
        <-tick.C
        action := apply(&s)
        fmt.Printf("tick=%02d desired=%d actual=%d action=%s\n", i, s.Desired, s.Actual, act
        if i == 10 {
            s.Desired = 3
        }
    }
}
```

Step-by-Step Explanation

1. Model desired and actual state explicitly.
2. Compute a minimal diff.
3. Apply one idempotent reconciliation step.
4. Observe updated state and repeat.
5. Keep loops convergent and failure-aware.

Code Anatomy

- State model captures control-plane truth.
- Reconcile function decides next action.
- Loop executes continuously with visibility into actions.

Learning Goals

- Learn the controller pattern used in modern platforms.
- Build robust automation through repeated reconciliation.
- Understand convergence over one-shot scripting.

000 Projects Index

000 Projects: Build Real Software

This section is hands-on. Each chapter is a complete project with runnable code and a step-by-step breakdown.

How To Use These Projects

1. Read the architecture diagram.
2. Type the code yourself first.
3. Run it.
4. Break it intentionally.
5. Add one extension before moving to the next project.

```
Learning loop

read -> build -> run -> debug -> extend -> repeat
```

Project Path (Beginner -> Advanced)

1. CLI Ping Tool
2. URL Shortener API
3. Concurrent Log Analyzer
4. File Integrity Checker
5. Concurrent Port Scanner
6. Mini Job Runner
7. Linux `ls` Clone
8. Linux `cat` Clone
9. Linux `grep` Clone
10. Linux `tail -f` Clone
11. Linux `du` Clone
12. Linux `find` Clone
13. Linux `wc` Clone
14. HTTP Load Tester
15. TUI System Monitor
16. Proxmox TUI Manager
17. SSH Remote Orchestrator
18. Go Workout: 200 Ten-Minute Exercises
19. Linux ps-lite
20. KV HTTP Store

21. WebSocket Chat
22. Log Shipper CLI
23. Proxmox Batch Operations CLI
24. Controller Pattern Simulator
25. Resource Index + 150 More Ideas
26. Kubernetes Pod Lister
27. Kubernetes Event Watcher
28. Kubernetes Rollout Checker
29. Terraform Plan Parser
30. Terraform Risk Reporter
31. Prometheus Exporter
32. Prometheus Probe Service
33. eBPF Tracepoint Basics
34. eBPF XDP Packet Counter
35. Proxmox Multi-Node Scheduler
36. Proxmox Capacity Balancer
37. Kubernetes HPA Simulator
38. Terraform Cost Estimator
39. Prometheus Alert Rule Tester
40. Infra Reconciler Daemon

What You Will Practice

- CLI flags and argument parsing
- Networking and HTTP servers
- Goroutines, channels, and worker pools
- File I/O and hashing
- Error handling and retries
- Production-friendly project structure

Step-by-Step Explanation

1. Pick a small set of exercises by track.
2. Timebox each attempt to ten minutes.
3. Record one takeaway and one weakness after each exercise.
4. Revisit chapter references when blocked.
5. Re-solve selected problems from memory weekly.

Learning Goals

- Build consistency, not one-time intensity.
- Improve retrieval and transfer of Go patterns.
- Progress from syntax fluency to engineering fluency.

001 Project 1: CLI Ping Tool

001 Build a CLI Ping Tool (TCP Ping)

We will build a portable ping tool using the standard library. It measures round-trip time by opening a TCP connection.

Why TCP Ping?

Classic ICMP ping needs raw socket permissions. TCP ping works as a normal user and is enough for most app/network diagnostics.

```
CLI flow

input host -> resolve DNS -> connect N times -> record RTT -> print stats
```

Step 1: Create the Module

```
mkdir goping && cd goping
go mod init example.com/goping
```

Step 2: Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "math"
    "net"
    "os"
    "time"
)

type result struct {
    ok  bool
    rtt time.Duration
    err error
```

```
}

func tcpPing(host, port string, timeout time.Duration) result {
    start := time.Now()
    conn, err := net.DialTimeout("tcp", net.JoinHostPort(host, port), timeout)
    if err != nil {
        return result{ok: false, err: err}
    }
    _ = conn.Close()
    return result{ok: true, rtt: time.Since(start)}
}

func main() {
    count := flag.Int("c", 4, "number of probes")
    interval := flag.Duration("i", 1*time.Second, "interval between probes")
    timeout := flag.Duration("t", 2*time.Second, "connection timeout")
    port := flag.String("p", "443", "tcp port to probe")
    flag.Parse()

    if flag.NArg() != 1 {
        fmt.Println("usage: goping [flags] <host>")
        flag.PrintDefaults()
        os.Exit(2)
    }

    host := flag.Arg(0)
    ips, err := net.LookupIP(host)
    if err != nil || len(ips) == 0 {
        fmt.Fprintf(os.Stderr, "resolve failed: %v\n", err)
        os.Exit(1)
    }

    fmt.Printf("PING %s (%s) over TCP:%s\n", host, ips[0].String(), *port)

    var sent, recv int
    var minRTT time.Duration = time.Hour
    var maxRTT time.Duration
    var sumRTT time.Duration

    for i := 1; i <= *count; i++ {
        sent++
        r := tcpPing(host, *port, *timeout)
        if r.ok {
            recv++
            if r.rtt < minRTT {
                minRTT = r.rtt
            }
```

```
            if r.rtt > maxRTT {
                maxRTT = r.rtt
            }
            sumRTT += r.rtt
            fmt.Printf("%d: connected time=%v\n", i, r.rtt)
        } else {
            fmt.Printf("%d: timeout/error: %v\n", i, r.err)
        }

        if i < *count {
            time.Sleep(*interval)
        }
    }

    loss := float64(sent-recv) / float64(sent) * 100
    avg := time.Duration(0)
    if recv > 0 {
        avg = sumRTT / time.Duration(recv)
    } else {
        minRTT = 0
    }

    stdDev := time.Duration(0)
    if recv > 1 {
        // Quick second pass estimate from avg not stored per sample.
        // Keep simple for CLI output consistency.
        _ = math.Sqrt(1)
    }

    fmt.Println("--- stats ---")
    fmt.Printf("%d probes sent, %d received, %.1f%% loss\n", sent, recv, loss)
    fmt.Printf("rtt min/avg/max = %v/%v/%v\n", minRTT, avg, maxRTT)
    _ = stdDev
}
```

Step 3: Run

```
go run . google.com
go run . -c 10 -i 500ms -t 1s -p 443 cloudflare.com
```

What to Extend

1. Add per-IP probing when DNS returns multiple addresses.

2. Add JSON output (`-json`) for scripting.
3. Track jitter by storing all RTT samples.

Step-by-Step Explanation

1. Parse probe flags and validate host input.
2. Resolve DNS and print target IP for transparency.
3. Dial TCP with timeout for each probe.
4. Measure latency and aggregate min/avg/max.
5. Print packet loss and summary stats.

Code Anatomy

- `tcpPing` performs one probe and returns a typed result.
- Main loop controls pacing and collects metrics.
- Final summary computes packet loss and latency profile.

Learning Goals

- Network diagnostics with standard library only.
- Timeouts and resilient error reporting.
- Building practical CLI observability tools.

002 Project 2: URL Shortener API

002 Build a URL Shortener API

You will build a small HTTP service with two endpoints:

- `POST /shorten` -> create short URL
- `GET /:code` -> redirect to original URL

```
Request flow

client -> POST /shorten -> store (code -> url) -> return short URL
client -> GET /abc123  -> lookup code -> 302 redirect
```

Full `main.go`

```
package main

import (
    "crypto/rand"
    "encoding/base64"
    "encoding/json"
    "fmt"
    "log"
    "net/http"
    "net/url"
    "strings"
    "sync"
)

type store struct {
    mu   sync.RWMutex
    data map[string]string
}

type shortenRequest struct {
    URL string `json:"url"`
}

type shortenResponse struct {
    Code string `json:"code"`
```

```
    URL  string `json:"short_url"`
}

func newCode(n int) string {
    b := make([]byte, n)
    if _, err := rand.Read(b); err != nil {
        panic(err)
    }
    return strings.TrimRight(base64.RawURLEncoding.EncodeToString(b), "=")
}

func main() {
    s := &store{data: make(map[string]string)}
    mux := http.NewServeMux()

    mux.HandleFunc("POST /shorten", func(w http.ResponseWriter, r *http.Request) {
        var req shortenRequest
        if err := json.NewDecoder(r.Body).Decode(&req); err != nil {
            http.Error(w, "invalid json", http.StatusBadRequest)
            return
        }

        u, err := url.ParseRequestURI(req.URL)
        if err != nil || u.Scheme == "" || u.Host == "" {
            http.Error(w, "invalid url", http.StatusBadRequest)
            return
        }

        code := newCode(5)
        s.mu.Lock()
        s.data[code] = req.URL
        s.mu.Unlock()

        resp := shortenResponse{
            Code: code,
            URL:  fmt.Sprintf("http://%s/%s", r.Host, code),
        }
        w.Header().Set("Content-Type", "application/json")
        _ = json.NewEncoder(w).Encode(resp)
    })

    mux.HandleFunc("GET /{code}", func(w http.ResponseWriter, r *http.Request) {
        code := r.PathValue("code")
        s.mu.RLock()
        longURL, ok := s.data[code]
        s.mu.RUnlock()
        if !ok {
```

```
            http.NotFound(w, r)
            return
        }
        http.Redirect(w, r, longURL, http.StatusFound)
    })

    log.Println("listening on :8080")
    log.Fatal(http.ListenAndServe(":8080", mux))
}
```

Run and Test

```
go run .

curl -s -X POST localhost:8080/shorten \
  -H 'content-type: application/json' \
  -d '{"url":"https://go.dev/doc/"}'

curl -i localhost:8080/<code-from-response>
```

What to Extend

1. Persistent storage (BoltDB/Postgres).
2. Expiry timestamps.
3. Rate limiting middleware.

Step-by-Step Explanation

1. Define request and response contracts first.
2. Validate inbound input before doing any state changes.
3. Keep handler logic short and move reusable logic into helper functions.
4. Add timeouts and clear error paths.
5. Return consistent responses and status codes.

Code Anatomy

- Handlers parse input, call domain logic, write response.
- Shared state uses synchronization where needed.
- Transport concerns stay separate from business rules.

Learning Goals

- Build reliable service endpoints in Go.
- Understand API ergonomics and operational safety.
- Prepare code structure for tests and persistence later.

003 Project 3: Concurrent Log Analyzer

003 Build a Concurrent Log Analyzer

This CLI reads a log file and counts log levels using a worker pool.

```
file -> producer -> jobs channel -> N workers -> partial counts -> merge -> report
```

Full `main.go`

```
package main

import (
    "bufio"
    "flag"
    "fmt"
    "os"
    "runtime"
    "strings"
    "sync"
)

func worker(lines <-chan string, out chan<- map[string]int, wg *sync.WaitGroup) {
    defer wg.Done()
    local := map[string]int{"INFO": 0, "WARN": 0, "ERROR": 0, "DEBUG": 0}
    for line := range lines {
        for level := range local {
            if strings.Contains(line, level) {
                local[level]++
            }
        }
    }
    out <- local
}

func main() {
    workers := flag.Int("w", runtime.NumCPU(), "worker count")
    flag.Parse()
    if flag.NArg() != 1 {
        fmt.Println("usage: log-analyzer [-w N] <file>")
        os.Exit(2)
```

```
    }

    f, err := os.Open(flag.Arg(0))
    if err != nil {
        fmt.Fprintf(os.Stderr, "open failed: %v\n", err)
        os.Exit(1)
    }
    defer f.Close()

    jobs := make(chan string, 1024)
    partials := make(chan map[string]int, *workers)
    var wg sync.WaitGroup

    for i := 0; i < *workers; i++ {
        wg.Add(1)
        go worker(jobs, partials, &wg)
    }

    scanner := bufio.NewScanner(f)
    for scanner.Scan() {
        jobs <- scanner.Text()
    }
    close(jobs)
    if err := scanner.Err(); err != nil {
        fmt.Fprintf(os.Stderr, "scan error: %v\n", err)
        os.Exit(1)
    }

    wg.Wait()
    close(partials)

    total := map[string]int{"INFO": 0, "WARN": 0, "ERROR": 0, "DEBUG": 0}
    for p := range partials {
        for k, v := range p {
            total[k] += v
        }
    }

    fmt.Println("Log Summary")
    fmt.Printf("INFO:  %d\n", total["INFO"])
    fmt.Printf("WARN:  %d\n", total["WARN"])
    fmt.Printf("ERROR: %d\n", total["ERROR"])
    fmt.Printf("DEBUG: %d\n", total["DEBUG"])
}
```

Run

```
go run . -w 8 app.log
```

What to Extend

1. Add JSON output mode.
2. Add per-service breakdown.
3. Add top-N error messages.

Step-by-Step Explanation

1. Model jobs, workers, and outputs explicitly.
2. Bound concurrency using worker pools and buffered channels.
3. Use `sync.WaitGroup` for lifecycle control.
4. Aggregate worker results in one place.
5. Verify behavior under both normal and failure paths.

Code Anatomy

- Producer pushes jobs into a channel.
- Workers consume jobs and emit results.
- Aggregator merges results and prints summary.

Learning Goals

- Build leak-free goroutine patterns.
- Balance throughput and resource limits.
- Understand fan-out/fan-in architecture.

004 Project 4: File Integrity Checker

004 Build a File Integrity Checker

This CLI calculates SHA-256 checksums and verifies files against a manifest.

```
manifest mode: file -> hash -> write "hash path"
verify mode:   read manifest -> re-hash files -> compare -> report
```

Full `main.go`

```
package main

import (
    "bufio"
    "crypto/sha256"
    "encoding/hex"
    "flag"
    "fmt"
    "io"
    "os"
    "path/filepath"
    "strings"
)

func hashFile(path string) (string, error) {
    f, err := os.Open(path)
    if err != nil {
        return "", err
    }
    defer f.Close()

    h := sha256.New()
    if _, err := io.Copy(h, f); err != nil {
        return "", err
    }
    return hex.EncodeToString(h.Sum(nil)), nil
}

func createManifest(root, out string) error {
    mf, err := os.Create(out)
```

```
    if err != nil {
        return err
    }
    defer mf.Close()

    return filepath.WalkDir(root, func(path string, d os.DirEntry, err error) error {
        if err != nil {
            return err
        }
        if d.IsDir() {
            return nil
        }
        h, err := hashFile(path)
        if err != nil {
            return err
        }
        _, err = fmt.Fprintf(mf, "%s  %s\n", h, path)
        return err
    })
}

func verifyManifest(path string) error {
    f, err := os.Open(path)
    if err != nil {
        return err
    }
    defer f.Close()

    s := bufio.NewScanner(f)
    failed := 0
    for s.Scan() {
        line := s.Text()
        parts := strings.SplitN(line, "  ", 2)
        if len(parts) != 2 {
            return fmt.Errorf("bad line: %q", line)
        }
        expected, filePath := parts[0], parts[1]
        got, err := hashFile(filePath)
        if err != nil || got != expected {
            failed++
            fmt.Printf("FAIL %s\n", filePath)
        } else {
            fmt.Printf("OK   %s\n", filePath)
        }
    }
    if err := s.Err(); err != nil {
        return err
```

```
    }
    if failed > 0 {
        return fmt.Errorf("%d file(s) failed verification", failed)
    }
    return nil
}

func main() {
    mode := flag.String("mode", "manifest", "manifest|verify")
    root := flag.String("root", ".", "root directory for manifest mode")
    manifest := flag.String("manifest", "checksums.txt", "manifest path")
    flag.Parse()

    var err error
    switch *mode {
    case "manifest":
        err = createManifest(*root, *manifest)
    case "verify":
        err = verifyManifest(*manifest)
    default:
        err = fmt.Errorf("unknown mode: %s", *mode)
    }

    if err != nil {
        fmt.Fprintln(os.Stderr, "error:", err)
        os.Exit(1)
    }
}
```

Run

```
go run . -mode manifest -root ./data -manifest checksums.txt
go run . -mode verify -manifest checksums.txt
```

What to Extend

1. Support ignore patterns (`.git`, `node_modules`).
2. Output machine-readable JSON reports.
3. Add optional HMAC signing for manifest authenticity.

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

005 Project 5: Concurrent Port Scanner

005 Build a Concurrent Port Scanner

This CLI scans a host across a port range using a bounded worker pool.

```
ports range -> jobs channel -> workers dial tcp -> open ports channel -> sorted output
```

Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "net"
    "os"
    "sort"
    "sync"
    "time"
)

func scan(host string, timeout time.Duration, jobs <-chan int, openPorts chan<- int, wg *syn
    defer wg.Done()
    for p := range jobs {
        addr := fmt.Sprintf("%s:%d", host, p)
        conn, err := net.DialTimeout("tcp", addr, timeout)
        if err == nil {
            _ = conn.Close()
            openPorts <- p
        }
    }
}

func main() {
    host := flag.String("host", "127.0.0.1", "target host")
    from := flag.Int("from", 1, "start port")
    to := flag.Int("to", 1024, "end port")
    workers := flag.Int("w", 200, "worker count")
    timeout := flag.Duration("t", 300*time.Millisecond, "dial timeout")
    flag.Parse()
```

```
    if *from < 1 || *to > 65535 || *from > *to {
        fmt.Fprintln(os.Stderr, "invalid port range")
        os.Exit(2)
    }

    jobs := make(chan int, *workers)
    openPorts := make(chan int, 1024)
    var wg sync.WaitGroup

    for i := 0; i < *workers; i++ {
        wg.Add(1)
        go scan(*host, *timeout, jobs, openPorts, &wg)
    }

    go func() {
        for p := *from; p <= *to; p++ {
            jobs <- p
        }
        close(jobs)
        wg.Wait()
        close(openPorts)
    }()

    var open []int
    for p := range openPorts {
        open = append(open, p)
    }
    sort.Ints(open)

    fmt.Printf("open ports on %s:\n", *host)
    for _, p := range open {
        fmt.Println(p)
    }
}
```

Run

```
go run . -host scanme.nmap.org -from 1 -to 2000 -w 300 -t 200ms
```

What to Extend

1. CIDR support for scanning multiple hosts.
2. Banner grabbing for open ports.

3. Rate limiting to avoid overwhelming targets.

Step-by-Step Explanation

1. Model jobs, workers, and outputs explicitly.
2. Bound concurrency using worker pools and buffered channels.
3. Use `sync.WaitGroup` for lifecycle control.
4. Aggregate worker results in one place.
5. Verify behavior under both normal and failure paths.

Code Anatomy

- Producer pushes jobs into a channel.
- Workers consume jobs and emit results.
- Aggregator merges results and prints summary.

Learning Goals

- Build leak-free goroutine patterns.
- Balance throughput and resource limits.
- Understand fan-out/fan-in architecture.

006 Project 6: Mini Job Runner

006 Build a Mini Job Runner with Retries

This project builds a small in-process job runner with retries and backoff.

```
enqueue jobs -> workers pick jobs -> run handler -> retry on failure -> final status
```

Full `main.go`

```
package main

import (
    "context"
    "errors"
    "fmt"
    "math/rand"
    "sync"
    "time"
)

type Job struct {
    ID       int
    Payload  string
    Attempts int
}

type Runner struct {
    workers int
    maxTry  int
    jobs    chan Job
}

func NewRunner(workers, maxTry, queueSize int) *Runner {
    return &Runner{
        workers: workers,
        maxTry:  maxTry,
        jobs:    make(chan Job, queueSize),
    }
}
```

```
func (r *Runner) Enqueue(j Job) {
    r.jobs <- j
}

func process(ctx context.Context, j Job) error {
    select {
    case <-ctx.Done():
        return ctx.Err()
    case <-time.After(100 * time.Millisecond):
        // simulate intermittent failure
        if rand.Intn(3) == 0 {
            return errors.New("temporary failure")
        }
        fmt.Printf("job %d ok payload=%q\n", j.ID, j.Payload)
        return nil
    }
}

func (r *Runner) Start(ctx context.Context) {
    var wg sync.WaitGroup
    for w := 1; w <= r.workers; w++ {
        wg.Add(1)
        go func(workerID int) {
            defer wg.Done()
            for {
                select {
                case <-ctx.Done():
                    return
                case j, ok := <-r.jobs:
                    if !ok {
                        return
                    }

                    err := process(ctx, j)
                    if err == nil {
                        continue
                    }

                    j.Attempts++
                    if j.Attempts < r.maxTry {
                        backoff := time.Duration(j.Attempts*200) * time.Millisecond
                        time.AfterFunc(backoff, func() { r.Enqueue(j) })
                        fmt.Printf("worker=%d retry job=%d attempt=%d err=%v\n", workerID, j
                    } else {
                        fmt.Printf("worker=%d dead-letter job=%d err=%v\n", workerID, j.ID,
                    }
                }
```

```
            }
        }(w)
    }

    wg.Wait()
}

func (r *Runner) Stop() {
    close(r.jobs)
}

func main() {
    rand.Seed(time.Now().UnixNano())
    ctx, cancel := context.WithTimeout(context.Background(), 5*time.Second)
    defer cancel()

    r := NewRunner(4, 4, 64)
    for i := 1; i <= 20; i++ {
        r.Enqueue(Job{ID: i, Payload: fmt.Sprintf("task-%d", i)})
    }

    go func() {
        <-ctx.Done()
        r.Stop()
    }()

    r.Start(ctx)
}
```

Run

```
go run .
```

What to Extend

1. Persistent queue storage.
2. Dead-letter queue file.
3. Metrics endpoint (`/metrics`) with processing stats.

Step-by-Step Explanation

1. Model jobs, workers, and outputs explicitly.

2. Bound concurrency using worker pools and buffered channels.
3. Use `sync.WaitGroup` for lifecycle control.
4. Aggregate worker results in one place.
5. Verify behavior under both normal and failure paths.

Code Anatomy

- Producer pushes jobs into a channel.
- Workers consume jobs and emit results.
- Aggregator merges results and prints summary.

Learning Goals

- Build leak-free goroutine patterns.
- Balance throughput and resource limits.
- Understand fan-out/fan-in architecture.

007 Project 7: Build an ls Clone

007 Build an `ls` Clone

This project builds a practical `ls`-style CLI with flags for hidden files, long format, and sorting.

```
path -> read entries -> filter -> sort -> format -> print
```

Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "io/fs"
    "os"
    "path/filepath"
    "sort"
    "strings"
    "time"
)

type item struct {
    Name string
    Info fs.FileInfo
}

func main() {
    showAll := flag.Bool("a", false, "show hidden files")
    longFmt := flag.Bool("l", false, "long listing format")
    sortBy := flag.String("sort", "name", "name|size|time")
    flag.Parse()

    path := "."
    if flag.NArg() > 0 {
        path = flag.Arg(0)
    }

    entries, err := os.ReadDir(path)
    if err != nil {
```

```
        fmt.Fprintf(os.Stderr, "read dir failed: %v\n", err)
        os.Exit(1)
    }

    var items []item
    for _, e := range entries {
        name := e.Name()
        if !*showAll && strings.HasPrefix(name, ".") {
            continue
        }
        info, err := e.Info()
        if err != nil {
            continue
        }
        items = append(items, item{Name: name, Info: info})
    }

    sort.Slice(items, func(i, j int) bool {
        switch *sortBy {
        case "size":
            return items[i].Info.Size() < items[j].Info.Size()
        case "time":
            return items[i].Info.ModTime().Before(items[j].Info.ModTime())
        default:
            return strings.ToLower(items[i].Name) < strings.ToLower(items[j].Name)
        }
    })

    for _, it := range items {
        if *longFmt {
            mode := it.Info.Mode().String()
            sz := it.Info.Size()
            mod := it.Info.ModTime().Format(time.DateTime)
            name := it.Name
            if it.Info.IsDir() {
                name += string(filepath.Separator)
            }
            fmt.Printf("%s %10d %s %s\n", mode, sz, mod, name)
        } else {
            fmt.Println(it.Name)
        }
    }
}
```

Run

```
go run .
go run . -a -l -sort size /var/log
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

008 Project 8: Build a cat Clone

008 Build a `cat` Clone

Create a streaming file printer with line numbers and optional end-of-line markers.

```
stdin/files -> scanner -> transform lines -> stdout
```

Full `main.go`

```
package main

import (
    "bufio"
    "flag"
    "fmt"
    "io"
    "os"
)

func cat(r io.Reader, number, showEnds bool, start int) (int, error) {
    s := bufio.NewScanner(r)
    lineNo := start
    for s.Scan() {
        line := s.Text()
        if showEnds {
            line += "$"
        }
        if number {
            fmt.Printf("%6d\t%s\n", lineNo, line)
            lineNo++
        } else {
            fmt.Println(line)
        }
    }
    return lineNo, s.Err()
}

func main() {
    number := flag.Bool("n", false, "number output lines")
    showEnds := flag.Bool("E", false, "show $ at end of line")
```

```
    flag.Parse()

    lineNo := 1
    if flag.NArg() == 0 {
        if _, err := cat(os.Stdin, *number, *showEnds, lineNo); err != nil {
            fmt.Fprintln(os.Stderr, err)
            os.Exit(1)
        }
        return
    }

    for _, path := range flag.Args() {
        f, err := os.Open(path)
        if err != nil {
            fmt.Fprintf(os.Stderr, "%s: %v\n", path, err)
            continue
        }
        var n int
        n, err = cat(f, *number, *showEnds, lineNo)
        _ = f.Close()
        if err != nil {
            fmt.Fprintf(os.Stderr, "%s: %v\n", path, err)
        }
        lineNo = n
    }
}
```

Run

```
go run . file.txt
go run . -n -E file1.txt file2.txt
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
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Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

009 Project 9: Build a grep Clone

009 Build a `grep` Clone

Search text with regex, case-insensitive mode, and line numbers.

```
files -> scan line by line -> regex match -> print matches
```

Full `main.go`

```
package main

import (
    "bufio"
    "flag"
    "fmt"
    "os"
    "regexp"
)

func grepFile(path string, re *regexp.Regexp, showLineNo bool) error {
    f, err := os.Open(path)
    if err != nil {
        return err
    }
    defer f.Close()

    s := bufio.NewScanner(f)
    lineNo := 0
    for s.Scan() {
        lineNo++
        line := s.Text()
        if re.MatchString(line) {
            if showLineNo {
                fmt.Printf("%s:%d:%s\n", path, lineNo, line)
            } else {
                fmt.Printf("%s:%s\n", path, line)
            }
        }
    }
    return s.Err()
```

```
}

func main() {
    ignoreCase := flag.Bool("i", false, "ignore case")
    showLineNo := flag.Bool("n", false, "show line number")
    flag.Parse()

    if flag.NArg() < 2 {
        fmt.Fprintln(os.Stderr, "usage: ggrep [flags] <pattern> <file...>")
        os.Exit(2)
    }

    pattern := flag.Arg(0)
    if *ignoreCase {
        pattern = "(?i)" + pattern
    }
    re, err := regexp.Compile(pattern)
    if err != nil {
        fmt.Fprintln(os.Stderr, "invalid regex:", err)
        os.Exit(2)
    }

    for _, file := range flag.Args()[1:] {
        if err := grepFile(file, re, *showLineNo); err != nil {
            fmt.Fprintf(os.Stderr, "%s: %v\n", file, err)
        }
    }
}
```

Run

```
go run . error app.log
go run . -i -n "timeout|refused" *.log
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

010 Project 10: Build a tail -f Clone

010 Build a `tail -f` Clone

Read last N lines and follow appended content.

```
open file -> ring buffer last N -> print -> poll size growth -> print new data
```

Full `main.go`

```
package main

import (
    "bufio"
    "flag"
    "fmt"
    "io"
    "os"
    "time"
)

func lastNLines(path string, n int) ([]string, error) {
    f, err := os.Open(path)
    if err != nil {
        return nil, err
    }
    defer f.Close()

    buf := make([]string, 0, n)
    s := bufio.NewScanner(f)
    for s.Scan() {
        if len(buf) == n {
            copy(buf, buf[1:])
            buf[n-1] = s.Text()
        } else {
            buf = append(buf, s.Text())
        }
    }
    return buf, s.Err()
}
```

```
func follow(path string, offset int64) error {
    f, err := os.Open(path)
    if err != nil {
        return err
    }
    defer f.Close()

    if _, err := f.Seek(offset, io.SeekStart); err != nil {
        return err
    }

    for {
        _, _ = io.Copy(os.Stdout, f)
        time.Sleep(500 * time.Millisecond)
    }
}

func main() {
    n := flag.Int("n", 10, "show last n lines")
    followMode := flag.Bool("f", false, "follow file")
    flag.Parse()

    if flag.NArg() != 1 {
        fmt.Fprintln(os.Stderr, "usage: gtail [-n N] [-f] <file>")
        os.Exit(2)
    }

    path := flag.Arg(0)
    lines, err := lastNLines(path, *n)
    if err != nil {
        fmt.Fprintln(os.Stderr, err)
        os.Exit(1)
    }
    for _, line := range lines {
        fmt.Println(line)
    }

    if *followMode {
        st, err := os.Stat(path)
        if err != nil {
            fmt.Fprintln(os.Stderr, err)
            os.Exit(1)
        }
        if err := follow(path, st.Size()); err != nil {
            fmt.Fprintln(os.Stderr, err)
            os.Exit(1)
        }
```

```
    }
}
```

Run

```
go run . -n 50 app.log
go run . -n 20 -f app.log
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

011 Project 11: Build a du Clone

011 Build a `du` Clone

Calculate recursive directory size and print human-readable output.

```
dir walk -> sum file sizes -> print per path + total
```

Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "io/fs"
    "os"
    "path/filepath"
)

func human(n int64) string {
    units := []string{"B", "KB", "MB", "GB", "TB"}
    v := float64(n)
    i := 0
    for v >= 1024 && i < len(units)-1 {
        v /= 1024
        i++
    }
    return fmt.Sprintf("%.1f%s", v, units[i])
}

func dirSize(root string) (int64, error) {
    var total int64
    err := filepath.WalkDir(root, func(path string, d fs.DirEntry, err error) error {
        if err != nil {
            return nil
        }
        if d.IsDir() {
            return nil
        }
        info, err := d.Info()
```

```
        if err != nil {
            return nil
        }
        total += info.Size()
        return nil
    })
    return total, err
}

func main() {
    humanFmt := flag.Bool("h", true, "human readable")
    flag.Parse()

    args := flag.Args()
    if len(args) == 0 {
        args = []string{"."}
    }

    var grand int64
    for _, p := range args {
        sz, err := dirSize(p)
        if err != nil {
            fmt.Fprintf(os.Stderr, "%s: %v\n", p, err)
            continue
        }
        grand += sz
        if *humanFmt {
            fmt.Printf("%8s  %s\n", human(sz), p)
        } else {
            fmt.Printf("%8d  %s\n", sz, p)
        }
    }

    if len(args) > 1 {
        if *humanFmt {
            fmt.Printf("%8s  total\n", human(grand))
        } else {
            fmt.Printf("%8d  total\n", grand)
        }
    }
}
```

Run

```
go run . -h /var/log /tmp
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

012 Project 12: Build a find Clone

012 Build a `find` Clone

Search recursively by name pattern, type, and min size.

```
walk tree -> filter (name/type/size) -> print matching paths
```

Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "io/fs"
    "os"
    "path/filepath"
    "strings"
)

func main() {
    name := flag.String("name", "", "substring to match in filename")
    typeFlag := flag.String("type", "", "f=file d=dir")
    minSize := flag.Int64("min-size", 0, "minimum file size in bytes")
    flag.Parse()

    root := "."
    if flag.NArg() > 0 {
        root = flag.Arg(0)
    }

    err := filepath.WalkDir(root, func(path string, d fs.DirEntry, err error) error {
        if err != nil {
            return nil
        }
        base := filepath.Base(path)
        if *name != "" && !strings.Contains(strings.ToLower(base), strings.ToLower(*name)) {
            return nil
        }
```

```
        if *typeFlag == "f" && d.IsDir() {
            return nil
        }
        if *typeFlag == "d" && !d.IsDir() {
            return nil
        }

        if *minSize > 0 && !d.IsDir() {
            info, err := d.Info()
            if err != nil || info.Size() < *minSize {
                return nil
            }
        }

        fmt.Println(path)
        return nil
    })
    if err != nil {
        fmt.Fprintln(os.Stderr, err)
        os.Exit(1)
    }
}
```

Run

```
go run . /etc -name conf -type f
go run . . -name log -min-size 1048576
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

013 Project 13: Build a wc Clone

013 Build a `wc` Clone

Count lines, words, and bytes across files.

```
file -> scanner/read -> count L/W/B -> per file + total
```

Full `main.go`

```
package main

import (
    "bufio"
    "flag"
    "fmt"
    "io"
    "os"
    "unicode"
)

type counts struct {
    lines int
    words int
    bytes int
}

func countReader(r io.Reader) (counts, error) {
    var c counts
    s := bufio.NewScanner(r)
    for s.Scan() {
        line := s.Text()
        c.lines++
        c.bytes += len(line) + 1
        inWord := false
        for _, ch := range line {
            if unicode.IsSpace(ch) {
                inWord = false
                continue
            }
            if !inWord {
```

```
                c.words++
                inWord = true
            }
        }
    }
    return c, s.Err()
}

func main() {
    flag.Parse()
    if flag.NArg() == 0 {
        c, err := countReader(os.Stdin)
        if err != nil {
            fmt.Fprintln(os.Stderr, err)
            os.Exit(1)
        }
        fmt.Printf("%8d %8d %8d\n", c.lines, c.words, c.bytes)
        return
    }

    var total counts
    for _, path := range flag.Args() {
        f, err := os.Open(path)
        if err != nil {
            fmt.Fprintf(os.Stderr, "%s: %v\n", path, err)
            continue
        }
        c, err := countReader(f)
        _ = f.Close()
        if err != nil {
            fmt.Fprintf(os.Stderr, "%s: %v\n", path, err)
            continue
        }
        total.lines += c.lines
        total.words += c.words
        total.bytes += c.bytes
        fmt.Printf("%8d %8d %8d %s\n", c.lines, c.words, c.bytes, path)
    }
    if flag.NArg() > 1 {
        fmt.Printf("%8d %8d %8d total\n", total.lines, total.words, total.bytes)
    }
}
```

Run

```
go run . README.md
go run . *.qmd
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

014 Project 14: HTTP Load Tester

014 Build an HTTP Load Tester

Generate concurrent requests and report throughput and latency.

```
N workers -> request loop -> result channel -> aggregate metrics
```

Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "net/http"
    "os"
    "sync"
    "time"
)

type result struct {
    ok  bool
    dur time.Duration
}

func main() {
    url := flag.String("url", "http://localhost:8080/health", "target URL")
    concurrency := flag.Int("c", 20, "concurrent workers")
    requests := flag.Int("n", 500, "total requests")
    timeout := flag.Duration("t", 3*time.Second, "request timeout")
    flag.Parse()

    client := &http.Client{Timeout: *timeout}
    results := make(chan result, *requests)

    start := time.Now()
    var wg sync.WaitGroup
    jobs := make(chan struct{}, *requests)
    for i := 0; i < *requests; i++ {
        jobs <- struct{}{}
```

```
    }
    close(jobs)

    for w := 0; w < *concurrency; w++ {
        wg.Add(1)
        go func() {
            defer wg.Done()
            for range jobs {
                t0 := time.Now()
                resp, err := client.Get(*url)
                d := time.Since(t0)
                if err != nil {
                    results <- result{ok: false, dur: d}
                    continue
                }
                _ = resp.Body.Close()
                results <- result{ok: resp.StatusCode < 500, dur: d}
            }
        }()
    }

    wg.Wait()
    close(results)

    var okCount int
    var min, max, sum time.Duration
    min = 1<<63 - 1
    for r := range results {
        if r.ok {
            okCount++
        }
        if r.dur < min {
            min = r.dur
        }
        if r.dur > max {
            max = r.dur
        }
        sum += r.dur
    }

    elapsed := time.Since(start)
    avg := time.Duration(int64(sum) / int64(*requests))
    rps := float64(*requests) / elapsed.Seconds()

    fmt.Printf("target: %s\n", *url)
    fmt.Printf("requests: %d, success: %d, failed: %d\n", *requests, okCount, *requests-okCo
```

```
    fmt.Printf("latency min/avg/max: %v/%v/%v\n", min, avg, max)
    fmt.Printf("elapsed: %v, throughput: %.2f req/s\n", elapsed, rps)

    if okCount == 0 {
        os.Exit(1)
    }
}
```

Run

```
go run . -url http://localhost:8080/health -c 50 -n 5000
```

Step-by-Step Explanation

1. Model jobs, workers, and outputs explicitly.
2. Bound concurrency using worker pools and buffered channels.
3. Use `sync.WaitGroup` for lifecycle control.
4. Aggregate worker results in one place.
5. Verify behavior under both normal and failure paths.

Code Anatomy

- Producer pushes jobs into a channel.
- Workers consume jobs and emit results.
- Aggregator merges results and prints summary.

Learning Goals

- Build leak-free goroutine patterns.
- Balance throughput and resource limits.
- Understand fan-out/fan-in architecture.

015 Project 15: TUI System Monitor

015 Build a TUI System Monitor

Create a live terminal UI for CPU, memory, and goroutine stats using Bubble Tea + gopsutil.

```
ticker -> collect metrics -> update model -> render tui frame
```

Setup

```
go mod init example.com/gotop
go get github.com/charmbracelet/bubbletea@latest
go get github.com/charmbracelet/lipgloss@latest
go get github.com/shirou/gopsutil/v4/cpu@latest
go get github.com/shirou/gopsutil/v4/mem@latest
```

Full `main.go`

```
package main

import (
    "fmt"
    "runtime"
    "time"

    tea "github.com/charmbracelet/bubbletea"
    "github.com/charmbracelet/lipgloss"
    "github.com/shirou/gopsutil/v4/cpu"
    "github.com/shirou/gopsutil/v4/mem"
)

type tickMsg struct{}

type sample struct {
    cpuPct   float64
    memPct   float64
    gorCount int
    ts       time.Time
}
```

```
type model struct {
    last sample
    err  error
}

func tickCmd() tea.Cmd {
    return tea.Tick(1*time.Second, func(time.Time) tea.Msg { return tickMsg{} })
}

func (m model) Init() tea.Cmd { return tickCmd() }

func (m model) Update(msg tea.Msg) (tea.Model, tea.Cmd) {
    switch msg := msg.(type) {
    case tea.KeyMsg:
        if msg.String() == "q" || msg.String() == "ctrl+c" {
            return m, tea.Quit
        }
    case tickMsg:
        cp, err := cpu.Percent(0, false)
        if err != nil || len(cp) == 0 {
            m.err = err
            return m, tickCmd()
        }
        vm, err := mem.VirtualMemory()
        if err != nil {
            m.err = err
            return m, tickCmd()
        }
        m.last = sample{
            cpuPct:   cp[0],
            memPct:   vm.UsedPercent,
            gorCount: runtime.NumGoroutine(),
            ts:       time.Now(),
        }
        m.err = nil
        return m, tickCmd()
    }
    return m, nil
}

func (m model) View() string {
    title := lipgloss.NewStyle().Bold(true).Foreground(lipgloss.Color("86")).Render("GoTop -
    if m.err != nil {
        return fmt.Sprintf("%s\n\nerror: %v\n\npress q to quit\n", title, m.err)
    }
    return fmt.Sprintf(
```

```
        "%s\n\nCPU:        %6.2f%%\nMemory:     %6.2f%%\nGoroutines: %d\nUpdated:    %s\n\np
        title,
        m.last.cpuPct,
        m.last.memPct,
        m.last.gorCount,
        m.last.ts.Format(time.TimeOnly),
    )
}

func main() {
    p := tea.NewProgram(model{})
    if _, err := p.Run(); err != nil {
        panic(err)
    }
}
```

Run

```
go run .
```

Step-by-Step Explanation

1. Collect node/resource metrics from API sources.
2. Compute deterministic scores per target.
3. Rank candidates by score and policy constraints.
4. Produce dry-run placement/migration decisions.
5. Apply gradually with canary and rollback plan.

Code Anatomy

- Data collection stage fetches capacity and load.
- Scoring stage turns metrics into comparable values.
- Decision stage emits ranked scheduling actions.

Learning Goals

- Build scheduling logic that is explainable and auditable.
- Balance utilization, reliability, and operational safety.
- Prepare for production-grade orchestration workflows.

016 Project 16: Proxmox TUI Manager

016 Build a Proxmox TUI Manager

This project builds an advanced terminal UI that talks to Proxmox API.

Features: - list nodes - list QEMU VMs on selected node - start/stop VM - refresh state

```
TUI keypress -> API client -> Proxmox endpoint -> update model -> redraw UI
```

Setup

```
go mod init example.com/proxmox-tui
go get github.com/charmbracelet/bubbletea@latest
go get github.com/charmbracelet/lipgloss@latest
```

Set env vars:

```
export PVE_BASE_URL="https://proxmox.local:8006"
export PVE_TOKEN="user@pam!token=secret"
```

Full `main.go`

```
package main

import (
    "crypto/tls"
    "encoding/json"
    "fmt"
    "io"
    "net/http"
    "os"
    "strconv"
    "time"

    tea "github.com/charmbracelet/bubbletea"
    "github.com/charmbracelet/lipgloss"
)
```

```
type node struct {
    Node string `json:"node"`
}

type vm struct {
    VMID   int    `json:"vmid"`
    Name   string `json:"name"`
    Status string `json:"status"`
}

type apiResp[T any] struct {
    Data T `json:"data"`
}

type client struct {
    base string
    hc   *http.Client
}

func newClient(base string) *client {
    return &client{
        base: base,
        hc: &http.Client{Timeout: 8 * time.Second, Transport: &http.Transport{
            TLSClientConfig: &tls.Config{InsecureSkipVerify: true},
        }},
    }
}

func (c *client) do(method, path string, body io.Reader) (*http.Response, error) {
    req, err := http.NewRequest(method, c.base+path, body)
    if err != nil {
        return nil, err
    }
    req.Header.Set("Authorization", "PVEAPIToken="+os.Getenv("PVE_TOKEN"))
    return c.hc.Do(req)
}

func (c *client) listNodes() ([]node, error) {
    resp, err := c.do(http.MethodGet, "/api2/json/nodes", nil)
    if err != nil {
        return nil, err
    }
    defer resp.Body.Close()
    var out apiResp[[]node]
    if err := json.NewDecoder(resp.Body).Decode(&out); err != nil {
        return nil, err
    }
```

```
    return out.Data, nil
}

func (c *client) listVMs(nodeName string) ([]vm, error) {
    resp, err := c.do(http.MethodGet, "/api2/json/nodes/"+nodeName+"/qemu", nil)
    if err != nil {
        return nil, err
    }
    defer resp.Body.Close()
    var out apiResp[[]vm]
    if err := json.NewDecoder(resp.Body).Decode(&out); err != nil {
        return nil, err
    }
    return out.Data, nil
}

func (c *client) vmAction(nodeName string, vmid int, action string) error {
    resp, err := c.do(http.MethodPost, "/api2/json/nodes/"+nodeName+"/qemu/"+strconv.Itoa(vm
    if err != nil {
        return err
    }
    defer resp.Body.Close()
    if resp.StatusCode >= 300 {
        b, _ := io.ReadAll(resp.Body)
        return fmt.Errorf("action failed: %s", string(b))
    }
    return nil
}

type loadedMsg struct {
    nodes []node
    vms   []vm
    err   error
}

type actionMsg struct{ err error }

type model struct {
    cli    *client
    nodes  []node
    vms    []vm
    sel    int
    node   string
    status string
}

func loadCmd(c *client, n string) tea.Cmd {
```

```
    return func() tea.Msg {
        ns, err := c.listNodes()
        if err != nil {
            return loadedMsg{err: err}
        }
        nodeName := n
        if nodeName == "" && len(ns) > 0 {
            nodeName = ns[0].Node
        }
        vs, err := c.listVMs(nodeName)
        return loadedMsg{nodes: ns, vms: vs, err: err}
    }
}

func (m model) Init() tea.Cmd { return loadCmd(m.cli, "") }

func (m model) Update(msg tea.Msg) (tea.Model, tea.Cmd) {
    switch msg := msg.(type) {
    case tea.KeyMsg:
        switch msg.String() {
        case "q", "ctrl+c":
            return m, tea.Quit
        case "r":
            return m, loadCmd(m.cli, m.node)
        case "down", "j":
            if m.sel < len(m.vms)-1 {
                m.sel++
            }
        case "up", "k":
            if m.sel > 0 {
                m.sel--
            }
        case "s": // start
            if len(m.vms) == 0 {
                return m, nil
            }
            v := m.vms[m.sel]
            return m, func() tea.Msg { return actionMsg{err: m.cli.vmAction(m.node, v.VMID,
        case "x": // stop
            if len(m.vms) == 0 {
                return m, nil
            }
            v := m.vms[m.sel]
            return m, func() tea.Msg { return actionMsg{err: m.cli.vmAction(m.node, v.VMID,
        }
    case loadedMsg:
```

```
        if msg.err != nil {
            m.status = "load error: " + msg.err.Error()
            return m, nil
        }
        m.nodes = msg.nodes
        m.vms = msg.vms
        if m.node == "" && len(msg.nodes) > 0 {
            m.node = msg.nodes[0].Node
        }
        if m.sel >= len(m.vms) {
            m.sel = len(m.vms) - 1
            if m.sel < 0 {
                m.sel = 0
            }
        }
        m.status = "loaded"
    case actionMsg:
        if msg.err != nil {
            m.status = "action error: " + msg.err.Error()
            return m, nil
        }
        m.status = "action submitted"
        return m, loadCmd(m.cli, m.node)
    }
    return m, nil
}

func (m model) View() string {
    title := lipgloss.NewStyle().Bold(true).Foreground(lipgloss.Color("39")).Render("Proxmox
    s := title + "\n"
    s += fmt.Sprintf("node: %s | status: %s\n", m.node, m.status)
    s += "keys: j/k move | s start | x stop | r refresh | q quit\n\n"
    for i, v := range m.vms {
        cur := " "
        if i == m.sel {
            cur = ">"
        }
        s += fmt.Sprintf("%s vmid=%d name=%s status=%s\n", cur, v.VMID, v.Name, v.Status)
    }
    return s
}

func main() {
    base := os.Getenv("PVE_BASE_URL")
    if base == "" || os.Getenv("PVE_TOKEN") == "" {
        fmt.Println("set PVE_BASE_URL and PVE_TOKEN")
        os.Exit(2)
```

```
    }
    m := model{cli: newClient(base), status: "booting"}
    if _, err := tea.NewProgram(m).Run(); err != nil {
        panic(err)
    }
}
```

Run

```
go run .
```

Notes

- This sample uses `InsecureSkipVerify` for lab environments. Use proper TLS validation in production.
- Use API tokens with least privilege.

Step-by-Step Explanation

1. Collect node/resource metrics from API sources.
2. Compute deterministic scores per target.
3. Rank candidates by score and policy constraints.
4. Produce dry-run placement/migration decisions.
5. Apply gradually with canary and rollback plan.

Code Anatomy

- Data collection stage fetches capacity and load.
- Scoring stage turns metrics into comparable values.
- Decision stage emits ranked scheduling actions.

Learning Goals

- Build scheduling logic that is explainable and auditable.
- Balance utilization, reliability, and operational safety.
- Prepare for production-grade orchestration workflows.

017 Project 17: SSH Remote Orchestrator

017 Build an SSH Remote Orchestrator

Run commands on many hosts concurrently over SSH and aggregate results.

```
host list -> worker pool -> ssh exec per host -> collect stdout/stderr -> summary
```

Setup

```
go mod init example.com/gossh-orchestrator
go get golang.org/x/crypto/ssh@latest
```

Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "os"
    "strings"
    "sync"
    "time"

    "golang.org/x/crypto/ssh"
)

type result struct {
    host string
    out  string
    err  error
}

func run(host, user, keyPath, cmd string, timeout time.Duration) result {
    key, err := os.ReadFile(keyPath)
    if err != nil {
        return result{host: host, err: err}
    }
```

```
    signer, err := ssh.ParsePrivateKey(key)
    if err != nil {
        return result{host: host, err: err}
    }

    cfg := &ssh.ClientConfig{
        User:            user,
        Auth:            []ssh.AuthMethod{ssh.PublicKeys(signer)},
        HostKeyCallback: ssh.InsecureIgnoreHostKey(),
        Timeout:         timeout,
    }

    c, err := ssh.Dial("tcp", host+":22", cfg)
    if err != nil {
        return result{host: host, err: err}
    }
    defer c.Close()

    s, err := c.NewSession()
    if err != nil {
        return result{host: host, err: err}
    }
    defer s.Close()

    out, err := s.CombinedOutput(cmd)
    return result{host: host, out: string(out), err: err}
}

func main() {
    hostsArg := flag.String("hosts", "", "comma-separated host list")
    user := flag.String("user", "root", "ssh user")
    key := flag.String("key", os.Getenv("HOME")+"/.ssh/id_rsa", "private key path")
    cmd := flag.String("cmd", "uname -a", "command to run")
    workers := flag.Int("w", 10, "worker count")
    timeout := flag.Duration("t", 5*time.Second, "ssh timeout")
    flag.Parse()

    if *hostsArg == "" {
        fmt.Fprintln(os.Stderr, "provide -hosts")
        os.Exit(2)
    }
    hosts := strings.Split(*hostsArg, ",")

    jobs := make(chan string)
    results := make(chan result)
    var wg sync.WaitGroup
```

```
    for i := 0; i < *workers; i++ {
        wg.Add(1)
        go func() {
            defer wg.Done()
            for h := range jobs {
                results <- run(strings.TrimSpace(h), *user, *key, *cmd, *timeout)
            }
        }()
    }

    go func() {
        for _, h := range hosts {
            jobs <- h
        }
        close(jobs)
        wg.Wait()
        close(results)
    }()

    ok := 0
    for r := range results {
        if r.err != nil {
            fmt.Printf("[%s] ERROR: %v\n", r.host, r.err)
            continue
        }
        ok++
        fmt.Printf("[%s]\n%s\n", r.host, strings.TrimSpace(r.out))
    }
    fmt.Printf("done: %d/%d succeeded\n", ok, len(hosts))
}
```

Run

```
go run . -hosts "10.0.0.11,10.0.0.12" -user root -cmd "uptime"
```

Security Notes

- Replace `ssh.InsecureIgnoreHostKey` with known-hosts validation in production.
- Use dedicated restricted SSH keys for automation.

Step-by-Step Explanation

1. Model jobs, workers, and outputs explicitly.
2. Bound concurrency using worker pools and buffered channels.
3. Use `sync.WaitGroup` for lifecycle control.
4. Aggregate worker results in one place.
5. Verify behavior under both normal and failure paths.

Code Anatomy

- Producer pushes jobs into a channel.
- Workers consume jobs and emit results.
- Aggregator merges results and prints summary.

Learning Goals

- Build leak-free goroutine patterns.
- Balance throughput and resource limits.
- Understand fan-out/fan-in architecture.

018 Project 18: Go Workout - 200 Ten-Minute Exercises

018 Go Workout: 200 Ten-Minute Exercises

This chapter uses a **short-exercise format** inspired by workout-style learning books: small tasks, tight scope, immediate practice.

How to Use

- Spend 10 minutes per exercise.
- Do not copy old answers.
- Prefer standard library first.
- After every 10 exercises, write a short reflection.

```
10-minute loop

read task -> code -> run -> test edge case -> note takeaway
```

Foundation Warmup (1-20)

1. Parse two integers from CLI args and print sum.
2. Parse `-name` flag and print greeting.
3. Build a `switch` on day number (1-7).
4. Convert Celsius to Fahrenheit with proper formatting.
5. Reverse a string safely for ASCII.
6. Count vowels in a string.
7. Find min/max in an `[]int`.
8. Remove duplicates from a slice.
9. Implement `contains([]string, string) bool`.
10. Build a frequency map for words in a sentence.
11. Sort a slice of ints ascending.
12. Sort a slice of structs by one field.
13. Write a function returning `(value, error)` for divide.
14. Use `defer` to time function execution.
15. Create a custom error type with context.
16. Marshal struct to JSON with tags.
17. Unmarshal JSON into struct and validate fields.
18. Read env var with fallback default.
19. Parse RFC3339 timestamp.
20. Format duration nicely (`1h2m3s`).

Files and CLI Tools (21-40)

21. Read file and print line count.
22. Read file and print byte count.
23. Read from stdin and uppercase output.
24. Build tiny `head -n` clone.
25. Build tiny `tail -n` clone.
26. Filter lines containing a substring.
27. Replace substring in each line and print.
28. Walk directory and count files.
29. Walk directory and sum file sizes.
30. Print top 10 largest files in a directory tree.
31. Build file extension counter (`.go`, `.md`, etc.).
32. Skip hidden files while walking.
33. Add `-json` output mode to a CLI tool.
34. Add `-quiet` and `-verbose` log levels.
35. Create a checksum (SHA-256) for one file.
36. Compare two files by checksum.
37. Build tiny `wc` (lines/words/bytes).
38. Build tiny `grep` with regex input.
39. Add case-insensitive flag to grep clone.
40. Print first match index and line number.

Structs, Methods, Interfaces (41-60)

41. Define `User` struct and constructor.
42. Add `String()` method to struct.
43. Add pointer receiver mutator method.
44. Add value receiver read-only method.
45. Implement small interface (`Runner`) with two types.
46. Compose two structs via embedding.
47. Resolve method name conflict in embedded structs.
48. Implement `io.Writer` that counts bytes.
49. Implement `io.Reader` over in-memory string.
50. Build a decorator function for timing any function.
51. Build `Option` pattern for server config.
52. Validate config and return combined error.
53. Compare two structs for equality constraints.
54. Parse CSV into typed struct slice.
55. Convert struct slice to map by key field.
56. Implement generic `Map` helper for slices.
57. Implement generic `Filter` helper.
58. Implement generic `Reduce` helper.
59. Create custom type alias with methods.
60. Add unit tests for all methods.

Errors and Reliability (61-80)

61. Wrap errors with `%w` across 3 layers.
62. Detect sentinel error with `errors.Is`.
63. Detect custom type with `errors.As`.
64. Build retry helper with max attempts.
65. Add exponential backoff to retry helper.
66. Add jitter to retry backoff.
67. Build circuit-breaker lite (open/close states).
68. Add timeout via `context.WithTimeout`.
69. Add cancellation via parent context.
70. Build `must` helper for internal tooling only.
71. Build panic recovery middleware for HTTP.
72. Capture stack trace on panic and log.
73. Return structured JSON error response.
74. Add error codes enum for API errors.
75. Validate all CLI input and fail fast.
76. Add dead-letter file for failed jobs.
77. Add graceful shutdown on SIGINT.
78. Add idempotency key check for commands.
79. Add bounded retries for network call.
80. Add fallback path when primary call fails.

Concurrency Basics (81-100)

81. Launch 5 goroutines and wait with `WaitGroup`.
82. Fan-out tasks to worker pool.
83. Fan-in results from workers.
84. Add context cancellation to worker pool.
85. Add timeout to a blocking goroutine.
86. Use buffered channel to smooth bursts.
87. Use unbuffered channel to enforce handoff.
88. Prevent goroutine leak on early return.
89. Build bounded semaphore using channel.
90. Merge two channels into one output.
91. Implement producer-consumer with backpressure.
92. Add `select` with timeout case.
93. Add `select` with default non-blocking case.
94. Protect shared map with mutex.
95. Replace mutex map with `sync.Map` and compare.
96. Use `sync.Once` for singleton init.
97. Use `sync.Cond` for queue notifications.
98. Build rate limiter with ticker.
99. Build token bucket limiter.
100. Profile goroutine count during load.

Networking and HTTP (101-120)

101. Build `/health` endpoint.
102. Add `/ready` endpoint with dependency check.
103. Parse query params safely.
104. Parse JSON request body with size limit.
105. Return JSON response helper function.
106. Add middleware for request logging.
107. Add middleware for panic recovery.
108. Add middleware for request ID.
109. Add middleware for timeout context.
110. Add simple in-memory rate limit middleware.
111. Build URL shortener `POST /shorten`.
112. Build URL shortener `GET /{code}` redirect.
113. Add TTL to short links.
114. Add short-link collision handling.
115. Add ETag support to one endpoint.
116. Add graceful server shutdown with context.
117. Build HTTP client with timeout + retries.
118. Build HTTP client with custom transport.
119. Add gzip compression middleware.
120. Benchmark one endpoint with your load tester.

Data and Persistence (121-140)

121. Use `encoding/csv` to read sample data.
122. Use `encoding/csv` to write report file.
123. Store key-value data in BoltDB (or bbolt).
124. Build repository interface over in-memory store.
125. Add file-backed repository implementation.
126. Add migration version field to data model.
127. Add optimistic locking field (`version`).
128. Add simple cache with TTL map.
129. Add cache invalidation on write.
130. Serialize map to JSON snapshot file.
131. Recover state from snapshot on startup.
132. Add periodic snapshot goroutine.
133. Add checksum to snapshot file.
134. Add snapshot restore validation.
135. Build append-only event log file.
136. Replay event log to rebuild state.
137. Add compaction command for old events.
138. Add corruption detection for events.
139. Add CLI export to CSV.
140. Add CLI import from CSV.

Testing Workout (141-160)

141. Write table-driven tests for parser.
142. Add subtests by category.
143. Add golden file test for CLI output.
144. Add benchmark with `b.Loop`.
145. Add benchmark with `-benchmem` analysis.
146. Add fuzz test for JSON decode path.
147. Add race test and fix discovered issue.
148. Add test helper for temporary fixture files.
149. Add `t.Cleanup` in all integration tests.
150. Use `httptest` for handler test.
151. Use `httptest.Server` for client test.
152. Use `testing/synctest` for flaky timer logic.
153. Add tests for retry backoff boundaries.
154. Add tests for context timeout path.
155. Add tests for panic recovery middleware.
156. Add tests for rate limiter edge case.
157. Add tests for short-link collision behavior.
158. Add tests for file checksum mismatch path.
159. Add integration test with build tag `integration`.
160. Add CI test command matrix in README.

Linux Tooling Track (161-180)

161. Extend `ls` clone with `-R` recursion.
162. Extend `ls` clone with colorized output.
163. Extend `cat` clone with `-T` tab markers.
164. Extend `grep` clone with invert match `-v`.
165. Extend `grep` clone with count-only `-c`.
166. Extend `tail` clone to handle file rotation.
167. Extend `du` clone with max depth flag.
168. Extend `find` clone with regex match mode.
169. Extend `wc` clone with rune count flag.
170. Build mini `xargs` clone.
171. Build mini `cut` clone.
172. Build mini `sort` clone.
173. Build mini `uniq` clone.
174. Build mini `tee` clone.
175. Build mini `which` clone.
176. Build mini `ps` clone using `/proc` (Linux).
177. Build mini `free` clone from `/proc/meminfo`.
178. Build mini `uptime` clone from `/proc/uptime`.
179. Build mini `df` clone using `syscall.Statfs`.
180. Build mini `watch` clone for repeated commands.

Advanced TUI and Infra Track (181-200)

181. Add CPU history sparkline to TUI monitor.
182. Add memory history sparkline to TUI monitor.
183. Add keybinding help modal in TUI.
184. Add theme toggle (light/dark terminal palette).
185. Add status bar with connection state.
186. Add periodic refresh ticker with pause key.
187. Add filtering by VM status in Proxmox TUI.
188. Add node selector screen in Proxmox TUI.
189. Add VM details pane in Proxmox TUI.
190. Add confirmation dialog before VM stop.
191. Add async action queue and progress states.
192. Add retry-on-429 for Proxmox API calls.
193. Add structured logs for every API request.
194. Add audit log file for start/stop actions.
195. Add SSH orchestrator output to JSON report.
196. Add SSH orchestrator parallel limit per subnet.
197. Add host reachability precheck before SSH.
198. Add rollout mode: canary then full batch.
199. Add rollback command set for failed rollout.
200. Build capstone: TUI panel that triggers SSH jobs and shows live results.

Chapter References in This Book

Use these while solving workouts:

- Foundations: `/Users/king/Workspace/Repos/books/books/Go/content/01-foundations`
- Core: `/Users/king/Workspace/Repos/books/books/Go/content/02-core`
- Concurrency: `/Users/king/Workspace/Repos/books/books/Go/content/07-concurrency-parallelism`
- Testing: `/Users/king/Workspace/Repos/books/books/Go/content/06-testing`
- Projects: `/Users/king/Workspace/Repos/books/books/Go/content/99-projects`

Step-by-Step Explanation

1. Pick a small set of exercises by track.
2. Timebox each attempt to ten minutes.
3. Record one takeaway and one weakness after each exercise.
4. Revisit chapter references when blocked.
5. Re-solve selected problems from memory weekly.

Learning Goals

- Build consistency, not one-time intensity.

- Improve retrieval and transfer of Go patterns.
- Progress from syntax fluency to engineering fluency.

019 Project 19: Linux ps-lite

019 Build a Linux ps-Lite Tool

Read process info from `/proc` and print a compact process table.

```
/proc -> parse /proc/<pid>/stat + comm -> rows -> sort by pid -> table
```

Full `main.go`

```
package main

import (
    "flag"
    "fmt"
    "os"
    "path/filepath"
    "sort"
    "strconv"
    "strings"
)

type proc struct {
    PID  int
    Comm string
    RSS  int64
    State string
}

func parseProc(pid int) (proc, error) {
    statPath := fmt.Sprintf("/proc/%d/stat", pid)
    b, err := os.ReadFile(statPath)
    if err != nil {
        return proc{}, err
    }
    parts := strings.Fields(string(b))
    if len(parts) < 24 {
        return proc{}, fmt.Errorf("short stat")
    }
    comm := strings.Trim(parts[1], "()")
    state := parts[2]
```

```
    rssPages, _ := strconv.ParseInt(parts[23], 10, 64)
    return proc{PID: pid, Comm: comm, State: state, RSS: rssPages * 4096}, nil
}

func main() {
    limit := flag.Int("n", 50, "max rows")
    flag.Parse()

    entries, err := os.ReadDir("/proc")
    if err != nil {
        fmt.Println("/proc unavailable (Linux only)")
        os.Exit(1)
    }

    var rows []proc
    for _, e := range entries {
        if !e.IsDir() {
            continue
        }
        pid, err := strconv.Atoi(e.Name())
        if err != nil {
            continue
        }
        p, err := parseProc(pid)
        if err == nil {
            rows = append(rows, p)
        }
    }

    sort.Slice(rows, func(i, j int) bool { return rows[i].PID < rows[j].PID })
    if *limit > len(rows) {
        *limit = len(rows)
    }

    fmt.Printf("%-8s %-4s %-10s %s\n", "PID", "S", "RSS(MB)", "COMM")
    for i := 0; i < *limit; i++ {
        r := rows[i]
        fmt.Printf("%-8d %-4s %-10.1f %s\n", r.PID, r.State, float64(r.RSS)/1024.0/1024.0, f
    }
}
```

Run

```
go run . -n 40
```

Step-by-Step Explanation

1. Parse command-line flags and validate inputs early.
2. Keep the core operation in a small, testable function.
3. Process data as a stream when possible to reduce memory use.
4. Print stable output and meaningful exit codes.
5. Add one extension feature and test edge cases.

Code Anatomy

- `main` handles flags, orchestration, and errors.
- Worker/helper functions hold business logic.
- Output section should be deterministic for scripting and CI usage.

Learning Goals

- Write composable Unix-style Go tools.
- Improve error messages and operator experience.
- Practice iterative improvement over one clear baseline.

020 Project 20: KV HTTP Store

020 Build a Key-Value HTTP Store

A production-style mini service with CRUD endpoints and periodic snapshot persistence.

```
HTTP API <-> in-memory map + mutex <-> snapshot.json
```

Full `main.go`

```
package main

import (
    "encoding/json"
    "log"
    "net/http"
    "os"
    "sync"
    "time"
)

type store struct {
    mu sync.RWMutex
    m  map[string]string
}

func (s *store) load(path string) {
    b, err := os.ReadFile(path)
    if err != nil {
        return
    }
    s.mu.Lock()
    defer s.mu.Unlock()
    _ = json.Unmarshal(b, &s.m)
}

func (s *store) save(path string) error {
    s.mu.RLock()
    defer s.mu.RUnlock()
    b, err := json.MarshalIndent(s.m, "", "  ")
    if err != nil {
```

```
        return err
    }
    return os.WriteFile(path, b, 0o644)
}

func main() {
    s := &store{m: map[string]string{}}
    snap := "snapshot.json"
    s.load(snap)

    go func() {
        t := time.NewTicker(10 * time.Second)
        defer t.Stop()
        for range t.C {
            _ = s.save(snap)
        }
    }()

    mux := http.NewServeMux()
    mux.HandleFunc("PUT /kv/{key}", func(w http.ResponseWriter, r *http.Request) {
        key := r.PathValue("key")
        var body struct{ Value string `json:"value"` }
        if err := json.NewDecoder(r.Body).Decode(&body); err != nil {
            http.Error(w, "bad json", http.StatusBadRequest)
            return
        }
        s.mu.Lock()
        s.m[key] = body.Value
        s.mu.Unlock()
        w.WriteHeader(http.StatusNoContent)
    })

    mux.HandleFunc("GET /kv/{key}", func(w http.ResponseWriter, r *http.Request) {
        key := r.PathValue("key")
        s.mu.RLock()
        v, ok := s.m[key]
        s.mu.RUnlock()
        if !ok {
            http.NotFound(w, r)
            return
        }
        _ = json.NewEncoder(w).Encode(map[string]string{"key": key, "value": v})
    })

    mux.HandleFunc("DELETE /kv/{key}", func(w http.ResponseWriter, r *http.Request) {
        key := r.PathValue("key")
        s.mu.Lock()
```

```
        delete(s.m, key)
        s.mu.Unlock()
        w.WriteHeader(http.StatusNoContent)
    })

    mux.HandleFunc("GET /kv", func(w http.ResponseWriter, r *http.Request) {
        s.mu.RLock()
        defer s.mu.RUnlock()
        _ = json.NewEncoder(w).Encode(s.m)
    })

    log.Println("listening :8081")
    log.Fatal(http.ListenAndServe(":8081", mux))
}
```

Run

```
go run .
curl -X PUT localhost:8081/kv/name -d '{"value":"king"}' -H 'content-type: application/json'
curl localhost:8081/kv/name
```

Step-by-Step Explanation

1. Define request and response contracts first.
2. Validate inbound input before doing any state changes.
3. Keep handler logic short and move reusable logic into helper functions.
4. Add timeouts and clear error paths.
5. Return consistent responses and status codes.

Code Anatomy

- Handlers parse input, call domain logic, write response.
- Shared state uses synchronization where needed.
- Transport concerns stay separate from business rules.

Learning Goals

- Build reliable service endpoints in Go.
- Understand API ergonomics and operational safety.
- Prepare code structure for tests and persistence later.

021 Project 21: WebSocket Chat

021 Build a WebSocket Chat Server

A minimal real-time chat backend with broadcast hub.

Setup

```
go mod init example.com/gochat
go get github.com/gorilla/websocket@latest
```

```
clients <-> ws hub <-> broadcast channel
```

Full `main.go`

```
package main

import (
    "log"
    "net/http"
    "sync"

    "github.com/gorilla/websocket"
)

var upgrader = websocket.Upgrader{CheckOrigin: func(r *http.Request) bool { return true }}

type hub struct {
    mu      sync.Mutex
    clients map[*websocket.Conn]struct{}
}

func (h *hub) add(c *websocket.Conn) {
    h.mu.Lock(); defer h.mu.Unlock()
    h.clients[c] = struct{}{}
}

func (h *hub) del(c *websocket.Conn) {
    h.mu.Lock(); defer h.mu.Unlock()
```

```
    delete(h.clients, c)
}

func (h *hub) broadcast(msg []byte) {
    h.mu.Lock(); defer h.mu.Unlock()
    for c := range h.clients {
        _ = c.WriteMessage(websocket.TextMessage, msg)
    }
}

func main() {
    h := &hub{clients: map[*websocket.Conn]struct{}{}}

    http.HandleFunc("/ws", func(w http.ResponseWriter, r *http.Request) {
        c, err := upgrader.Upgrade(w, r, nil)
        if err != nil {
            return
        }
        h.add(c)
        defer func() { h.del(c); _ = c.Close() }()

        for {
            _, msg, err := c.ReadMessage()
            if err != nil {
                return
            }
            h.broadcast(msg)
        }
    })

    log.Println("ws chat on :8090 /ws")
    log.Fatal(http.ListenAndServe(":8090", nil))
}
```

Run

```
go run .
# Connect from browser/websocket client to ws://localhost:8090/ws
```

Step-by-Step Explanation

1. Define request and response contracts first.
2. Validate inbound input before doing any state changes.
3. Keep handler logic short and move reusable logic into helper functions.

4. Add timeouts and clear error paths.
5. Return consistent responses and status codes.

Code Anatomy

- Handlers parse input, call domain logic, write response.
- Shared state uses synchronization where needed.
- Transport concerns stay separate from business rules.

Learning Goals

- Build reliable service endpoints in Go.
- Understand API ergonomics and operational safety.
- Prepare code structure for tests and persistence later.

022 Project 22: Log Shipper CLI

022 Build a Log Shipper CLI

Tail a file and POST new lines to an HTTP ingestion endpoint.

```
file tail -> line channel -> batch -> HTTP POST /ingest
```

Full `main.go`

```
package main

import (
    "bufio"
    "bytes"
    "encoding/json"
    "flag"
    "fmt"
    "io"
    "net/http"
    "os"
    "time"
)

func main() {
    file := flag.String("file", "app.log", "log file")
    endpoint := flag.String("endpoint", "http://localhost:8080/ingest", "ingest URL")
    flag.Parse()

    f, err := os.Open(*file)
    if err != nil {
        panic(err)
    }
    defer f.Close()

    _, _ = f.Seek(0, io.SeekEnd)
    r := bufio.NewReader(f)
    client := &http.Client{Timeout: 3 * time.Second}

    for {
        line, err := r.ReadString('\n')
```

```
        if err == io.EOF {
            time.Sleep(300 * time.Millisecond)
            continue
        }
        if err != nil {
            fmt.Println("read error:", err)
            continue
        }

        payload, _ := json.Marshal(map[string]any{
            "ts":   time.Now().Format(time.RFC3339Nano),
            "line": line,
        })

        resp, err := client.Post(*endpoint, "application/json", bytes.NewReader(payload))
        if err != nil {
            fmt.Println("post failed:", err)
            continue
        }
        _ = resp.Body.Close()
    }
}
```

Run

```
go run . -file app.log -endpoint http://localhost:8080/ingest
```

Step-by-Step Explanation

1. Define request and response contracts first.
2. Validate inbound input before doing any state changes.
3. Keep handler logic short and move reusable logic into helper functions.
4. Add timeouts and clear error paths.
5. Return consistent responses and status codes.

Code Anatomy

- Handlers parse input, call domain logic, write response.
- Shared state uses synchronization where needed.
- Transport concerns stay separate from business rules.

Learning Goals

- Build reliable service endpoints in Go.
- Understand API ergonomics and operational safety.
- Prepare code structure for tests and persistence later.

023 Project 23: Proxmox Batch Operations CLI

023 Build a Proxmox Batch CLI

Operate many VMs in one command (start/stop/reboot) using Proxmox API token auth.

```
parse vmid list -> concurrent API calls -> result summary
```

Full `main.go`

```
package main

import (
    "crypto/tls"
    "flag"
    "fmt"
    "net/http"
    "os"
    "strconv"
    "strings"
    "sync"
    "time"
)

func action(base, token, node string, vmid int, op string) error {
    hc := &http.Client{Timeout: 8 * time.Second, Transport: &http.Transport{
        TLSClientConfig: &tls.Config{InsecureSkipVerify: true},
    }}
    url := fmt.Sprintf("%s/api2/json/nodes/%s/qemu/%d/status/%s", base, node, vmid, op)
    req, _ := http.NewRequest(http.MethodPost, url, nil)
    req.Header.Set("Authorization", "PVEAPIToken="+token)
    resp, err := hc.Do(req)
    if err != nil {
        return err
    }
    defer resp.Body.Close()
    if resp.StatusCode >= 300 {
        return fmt.Errorf("status %d", resp.StatusCode)
    }
    return nil
}
```

```
func main() {
    base := flag.String("base", os.Getenv("PVE_BASE_URL"), "proxmox base url")
    token := flag.String("token", os.Getenv("PVE_TOKEN"), "api token")
    node := flag.String("node", "pve", "node name")
    op := flag.String("op", "start", "start|stop|reboot")
    ids := flag.String("ids", "", "comma list vmids")
    workers := flag.Int("w", 8, "parallel workers")
    flag.Parse()

    if *base == "" || *token == "" || *ids == "" {
        fmt.Println("need -base, -token, -ids")
        os.Exit(2)
    }

    jobs := make(chan int)
    var wg sync.WaitGroup
    for i := 0; i < *workers; i++ {
        wg.Add(1)
        go func() {
            defer wg.Done()
            for id := range jobs {
                err := action(*base, *token, *node, id, *op)
                if err != nil {
                    fmt.Printf("vm %d fail: %v\n", id, err)
                } else {
                    fmt.Printf("vm %d ok\n", id)
                }
            }
        }()
    }

    for _, s := range strings.Split(*ids, ",") {
        id, err := strconv.Atoi(strings.TrimSpace(s))
        if err == nil {
            jobs <- id
        }
    }
    close(jobs)
    wg.Wait()
}
```

Run

```
go run . -node pve -op start -ids 101,102,103
```

Step-by-Step Explanation

1. Model jobs, workers, and outputs explicitly.
2. Bound concurrency using worker pools and buffered channels.
3. Use `sync.WaitGroup` for lifecycle control.
4. Aggregate worker results in one place.
5. Verify behavior under both normal and failure paths.

Code Anatomy

- Producer pushes jobs into a channel.
- Workers consume jobs and emit results.
- Aggregator merges results and prints summary.

Learning Goals

- Build leak-free goroutine patterns.
- Balance throughput and resource limits.
- Understand fan-out/fan-in architecture.

024 Project 24: Controller Pattern Simulator

024 Build a Controller/Reconciler Simulator

Practice the Kubernetes-style reconciliation loop without Kubernetes dependencies.

```
desired state + actual state -> reconcile loop -> actions -> converge
```

Full `main.go`

```
package main

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

type State struct {
    DesiredReplicas int
    ActualReplicas  int
}

func reconcile(s *State) string {
    if s.ActualReplicas < s.DesiredReplicas {
        s.ActualReplicas++
        return "scale up"
    }
    if s.ActualReplicas > s.DesiredReplicas {
        s.ActualReplicas--
        return "scale down"
    }
    return "noop"
}

func main() {
    rand.Seed(time.Now().UnixNano())
    s := State{DesiredReplicas: 3, ActualReplicas: 0}

    for i := 0; i < 20; i++ {
        if rand.Intn(6) == 0 {
```

```
            // simulate external drift
            s.ActualReplicas += rand.Intn(3) - 1
            if s.ActualReplicas < 0 {
                s.ActualReplicas = 0
            }
        }
        action := reconcile(&s)
        fmt.Printf("tick=%02d desired=%d actual=%d action=%s\n", i, s.DesiredReplicas, s.Act
        time.Sleep(300 * time.Millisecond)
    }
}
```

Run

```
go run .
```

Step-by-Step Explanation

1. Model desired and actual state explicitly.
2. Compute a minimal diff.
3. Apply one idempotent reconciliation step.
4. Observe updated state and repeat.
5. Keep loops convergent and failure-aware.

Code Anatomy

- State model captures control-plane truth.
- Reconcile function decides next action.
- Loop executes continuously with visibility into actions.

Learning Goals

- Learn the controller pattern used in modern platforms.
- Build robust automation through repeated reconciliation.
- Understand convergence over one-shot scripting.

025 Project 25: Resource Index + 150 More Ideas

025 Resource Index and Project Idea Backlog

This chapter is a curated idea generator based on well-known Go learning resources and book/tutorial indexes.

Resource Anchors

1. Go by Example: gobyexample.com
2. Exercism Go Track (141 exercises): exercism.org/tracks/go
3. Exercism Go docs/testing: exercism.org/docs/tracks/go
4. Build Your Own X list: github.com/codecrafters-io/build-your-own-x
5. Awesome Go: github.com/uhub/awesome-go
6. Go by Example (book index/public page): simonandschuster.com/…/Go-by-Example

150 Additional Project Ideas

Linux CLI (1-30)

1. `chmod` helper wrapper with safety checks.
2. `chown` dry-run simulator.
3. `tree` command with depth filtering.
4. file deduplicator by checksum.
5. symlink verifier.
6. broken symlink cleaner.
7. directory watcher + action runner.
8. command history analyzer.
9. shell session recorder parser.
10. cron expression validator.
11. mini `top` clone.
12. mini `iotop` style estimator.
13. mini `netstat` parser.
14. mini `ss` parser.
15. process killer by regex.
16. zombie process detector.
17. service health checker.
18. journalctl filter wrapper.
19. colorized log viewer.
20. rotating file logger CLI.
21. backup snapshot tool.

22. rsync-like copy planner.
23. permission drift checker.
24. stale temp-file cleaner.
25. bulk rename utility.
26. grep over compressed files.
27. large-file splitter/merger.
28. file entropy scanner.
29. duplicate line remover.
30. path sanitizer utility.

Networking/Web (31-60)

31. DNS lookup CLI with JSON output.
32. TLS certificate inspector.
33. HTTP header security scanner.
34. simple API gateway with auth key.
35. reverse proxy with rate limit.
36. websocket event broadcaster.
37. webhook receiver with signature check.
38. link checker crawler.
39. HTTP cache proxy.
40. REST pagination helper.
41. OpenAPI schema diff checker.
42. JSON API contract tester.
43. API replay tool from HAR.
44. request signer (HMAC).
45. JWT issue/verify CLI.
46. OAuth device-flow sample app.
47. multipart upload service.
48. resumable upload protocol demo.
49. static site server with live reload.
50. image resize API.
51. URL metadata extractor.
52. API latency SLO dashboard backend.
53. HTTP retry middleware benchmark.
54. gRPC health check service.
55. gRPC proxy to REST bridge.
56. protobuf evolution checker.
57. distributed trace demo app.
58. log correlation ID middleware.
59. CORS policy validator.
60. synthetic uptime checker.

Data/Storage (61-90)

61. sqlite migration runner.

62. seed data loader CLI.
63. query timing profiler.
64. slow-query report generator.
65. CSV-to-SQL importer.
66. SQL-to-CSV exporter.
67. data masking utility.
68. pii scanner for CSV/JSON.
69. key rotation simulation tool.
70. append-only ledger store.
71. LSM-tree toy storage engine.
72. B-tree toy index.
73. bloom filter demo service.
74. write-ahead log simulator.
75. compaction strategy benchmark.
76. cache stampede protector demo.
77. id generator service (ksuid/ulid).
78. event sourcing sample.
79. CQRS read model projector.
80. dead letter queue consumer.
81. stream deduplication worker.
82. retention policy enforcer.
83. object storage sync tool.
84. folder-to-s3 mirror (mock).
85. schema migration drift detector.
86. JSON schema validator CLI.
87. XML-to-JSON converter.
88. parquet writer demo.
89. backup restore verifier.
90. data lineage tracer toy.

Concurrency/Systems (91-120)

91. pipeline backpressure simulator.
92. bounded queue benchmark.
93. lock contention visualizer.
94. goroutine leak detector wrapper.
95. worker auto-scaler simulation.
96. scheduler fairness simulator.
97. token bucket distributed simulation.
98. local message broker toy.
99. pub/sub with retries.
100. exactly-once semantics demo.
101. raft consensus toy model.
102. leader election simulator.
103. heartbeat failure detector.
104. distributed lock prototype.
105. partial failure injection tool.

106. chaos monkey for local services.
107. process supervisor.
108. service dependency graph parser.
109. config hot-reload framework.
110. plugin loader architecture demo.
111. dynamic rule engine toy.
112. policy-as-code evaluator.
113. command bus/event bus demo.
114. saga workflow simulator.
115. batch scheduler prototype.
116. resource quota enforcer.
117. cgroup stats reader (Linux).
118. seccomp profile inspector.
119. ptrace-based syscall tracer (toy).
120. mini container runtime PoC.

TUI/Infra/Platform (121-150)

121. TUI docker image browser.
122. TUI git commit explorer.
123. TUI log tail with filters.
124. TUI database query runner.
125. TUI feature-flag manager.
126. TUI release dashboard.
127. TUI CI pipeline monitor.
128. TUI Kubernetes pod viewer.
129. TUI helm values diff tool.
130. TUI terraform plan viewer.
131. Proxmox node capacity dashboard.
132. Proxmox VM template manager.
133. Proxmox snapshot orchestrator.
134. VM startup order manager.
135. host inventory manager.
136. SSH key rotation orchestrator.
137. parallel command runner with canary.
138. rollout status dashboard.
139. blue/green deployment simulator.
140. incident timeline builder.
141. SRE runbook executor CLI.
142. service dependency outage simulator.
143. alert noise reduction analyzer.
144. SLO burn-rate calculator.
145. policy compliance reporter.
146. artifact promotion workflow.
147. SBOM generator wrapper.
148. CVE triage dashboard.
149. secure secrets sync tool.

150. platform control plane toy app.

Suggested Build Order

1. Pick 10 CLI tasks.
2. Pick 5 network/API tasks.
3. Pick 5 concurrency/system tasks.
4. Pick 3 TUI/infra tasks.
5. Finish with one capstone controller + dashboard.

Step-by-Step Explanation

1. Pick a small set of exercises by track.
2. Timebox each attempt to ten minutes.
3. Record one takeaway and one weakness after each exercise.
4. Revisit chapter references when blocked.
5. Re-solve selected problems from memory weekly.

Learning Goals

- Build consistency, not one-time intensity.
- Improve retrieval and transfer of Go patterns.
- Progress from syntax fluency to engineering fluency.

026 Project 26: Kubernetes Pod Lister

026 Build a Kubernetes Pod Lister

List pods across namespaces using `client-go`.

Setup

```
go mod init example.com/k8s-pods
go get k8s.io/client-go@latest
```

Full `main.go`

```
package main

import (
    "context"
    "flag"
    "fmt"
    "os"

    metav1 "k8s.io/apimachinery/pkg/apis/meta/v1"
    "k8s.io/client-go/kubernetes"
    "k8s.io/client-go/tools/clientcmd"
)

func main() {
    kubeconfig := flag.String("kubeconfig", os.Getenv("HOME")+"/.kube/config", "kubeconfig p
    namespace := flag.String("n", "", "namespace (empty=all)")
    flag.Parse()

    cfg, err := clientcmd.BuildConfigFromFlags("", *kubeconfig)
    if err != nil {
        panic(err)
    }
    cli, err := kubernetes.NewForConfig(cfg)
    if err != nil {
        panic(err)
    }
```

```
    ns := *namespace
    if ns == "" {
        ns = metav1.NamespaceAll
    }
    pods, err := cli.CoreV1().Pods(ns).List(context.Background(), metav1.ListOptions{})
    if err != nil {
        panic(err)
    }

    for _, p := range pods.Items {
        fmt.Printf("%s/%s\t%s\t%s\n", p.Namespace, p.Name, p.Status.Phase, p.Spec.NodeName)
    }
}
```

Step-by-Step Explanation

1. Build Kubernetes client config from kubeconfig.
2. Scope operations by namespace or resource type.
3. Query or watch API objects.
4. Extract actionable status fields.
5. Return output and exit codes suitable for scripts and CI.

Code Anatomy

- Setup phase creates client and context.
- Query/watch phase pulls cluster state.
- Presentation phase prints concise operational results.

Learning Goals

- Use `client-go` safely and predictably.
- Convert API objects into operator-facing insights.
- Build automation-friendly cluster checks.