Golang

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Goals

- Understand Go architecture and memory model
- Write idiomatic, concurrent Go programs
- Build modular and testable packages
- Use Go for systems, networking, and microservice development
- Implement secure, resilient microservices using external packages and patterns
- Use **GitHub Copilot** effectively for code suggestions, testing, refactoring, and documentation

Software Requirements

- 🛠️ **1. Operating System Requirements**
- Go is **cross-platform** and runs on all major OSes:
- **Linux** (x86_64, ARM64, PPC64, etc.)
- **Windows** (x86_64, ARM64)
- **macOS** (Intel & Apple Silicon)
- Other supported OS/architectures: FreeBSD, OpenBSD, NetBSD, Solaris
- 👉 Officially supported platforms: https://go.dev/dl/

Software Requirements

2. Go Compiler / SDK

- Download from go.dev/dl
- Current stable (as of 2025): **Go 1.23**
- Installation includes:
  - Go compiler (go)
  - Go tools (gofmt, godoc, etc.)
  - Standard library

System requirements (approx.):

- Disk space: **200–300 MB**
- Memory: minimum **2 GB RAM** (for builds)

Software Requirements

📁 3. Environment Variables

- GOROOT → Points to Go installation path (usually auto-set).
- GOPATH → Workspace directory for Go projects (default = $HOME/go).
- PATH → Must include $GOROOT/bin and $GOPATH/bin.

Software Requirements

Example (Linux/macOS – `~/.bashrc`):

```bash
export GOROOT=/usr/local/go
export GOPATH=$HOME/go
export PATH=$PATH:$GOROOT/bin:$GOPATH/bin
```

On Windows (PowerShell profile):

```powershell
$env:GOROOT="C:\Go"
$env:GOPATH="$env:USERPROFILE\go"
$env:PATH+=";$env:GOROOT\bin;$env:GOPATH\bin"
```

Software Requirements

📦 4. Build Tools & Dependency Management

- **Go Modules (go mod)** → official dependency management.
  - Initialize: go mod init myapp
  - Add deps: go get github.com/gin-gonic/gin
- No need for external build tools (like Maven/Gradle); Go handles builds with go build.

Software Requirements

🧪 5. Testing & Quality Tools

- go test → built-in unit testing.go
- lint → style checker (optional).go
- vet → static analysis.go
- fmt → auto-formatting (included in Go).

Software Requirements

- 💻 **6. IDE / Editors**
- **VS Code** (with Go plugin by Google)
- **GoLand (JetBrains)** – commercial, powerful
- Vim/Neovim, Sublime, Atom (plugins available)

Software Requirements

- **7. Optional Tools for Advanced Development**
  - Docker → containerize Go apps.
  - Git → version control for Go modules.
  - Task runners like make or Taskfile (cross-platform).
  - Profiling tools: pprof (comes with Go).

Software Requirements

- 🔐 **8. Security & Networking**
  - TLS libraries are in the Go standard library (crypto/tls).
  - For REST APIs → frameworks like Gin, Echo, Fiber.
  - For gRPC → google.golang.org/grpc.

Golang

- **Go (Golang)** is an **open-source, statically typed, compiled language** created at **Google in 2007** (publicly released in 2009).
- Designed by **Robert Griesemer, Rob Pike, and Ken Thompson** (Unix/C pioneers).
- Purpose: a language that combines the **simplicity of scripting languages** with the **performance and safety of compiled languages like C/C++**.

Key Goals of Go

- **Simplicity → minimal keywords, easy to learn.**
- **Performance → compiled, close to C speed.**
- **Concurrency → first-class support with goroutines & channels.**
- **Portability → cross-platform, built-in toolchain.**
- **Productivity → batteries-included standard library, fast builds.**

Introduction

- Go is a programming language that was born out of frustration at Google.
- Developers continually had to pick a language that executed efficiently but took a long time to compile, or to pick a language that was easy to program but ran inefficiently in production.
- Go was designed to have all three available at the same time: fast compilation, ease of programming, and efficient execution in production.

Main Features

- **Compiled & Fast** → produces standalone binaries, no external runtime.
- **Statically Typed** → type-checked at compile time.
- **Garbage Collected** → automatic memory management.
- **Concurrency** → lightweight threads (goroutines) + communication (channels).
- **Cross-Platform** → Linux, Windows, macOS, FreeBSD, ARM, etc.
- **Rich Standard Library** → networking, web, crypto, JSON, testing.
- **Built-in Tools** → go build, go test, go fmt, go mod.

Where is Go used?

- **Cloud & Infrastructure** → Docker, Kubernetes, Terraform, Istio are written in Go.
- **Web APIs & Microservices** → Gin, Echo, Fiber frameworks.
- **DevOps Tools** → CLI tools (kubectl, Hugo, etc.).
- **Networking & Distributed Systems** → gRPC, NATS, etc.

Does Golang have a future?

- 🌟 **Why Go Has a Bright Future**
- **1. Backed by Google + Big Ecosystem**
- Created by Google engineers (Rob Pike, Ken Thompson, Robert Griesemer).
- Used internally at Google for massive-scale systems.
- Supported by major companies like **Uber, Netflix, Dropbox, Cloudflare, Twitch, PayPal**

Does Golang have a future?

- **2. Cloud-Native Standard**
- **Docker, Kubernetes, Terraform, Prometheus, Grafana** → all written in Go.
- Became the **de-facto language for DevOps, cloud-native, and container tooling**.
- Cloud providers (AWS, GCP, Azure) provide Go SDKs first-class.

Does Golang have a future?

- **3. Performance + Concurrency**
- Almost as fast as C/C++ but much simpler.
- **Goroutines + channels** make concurrency **easy & scalable**.
- Perfect for **microservices, streaming, and networking** workloads.

Does Golang have a future?

- **4. Developer Productivity**
  - Small language, easy to learn.
  - Built-in tooling (go fmt, go mod, go test).
  - No heavy runtime (like JVM or .NET).
  - Cross-compilation: build binaries for Linux, Windows, macOS, ARM in one command.

Does Golang have a future?

- **5. Growing Community & Libraries**
- Rich frameworks: **Gin, Echo, Fiber, Buffalo** for web APIs.
- Strong ecosystem: **gRPC, GraphQL, Kafka clients, ML packages, etc.**
- Active open-source contributions, Go conferences, and meetups worldwide.

Does Golang have a future?

- **6. Job Market & Demand**
- High demand for Go developers in **startups and large enterprises**.
- Particularly strong in roles like:
  - Cloud Engineer
  - Backend Developer
  - DevOps/SRE
  - Blockchain / Web3 engineer
- Salaries for Go developers are **competitive and often higher than average backend roles**.

Does Golang have a future?

- ⚖️ **Challenges / Limitations**
- Simpler than Java/C# → fewer built-in abstractions (deliberately minimal).
- Lacks **generics until Go 1.18** (now added, but still evolving).
- Not as mature in **GUI / Data Science / AI** compared to Python/Java.

Does Golang have a future?

- 🔮 **Future Outlook (2025 and beyond)**
- ✅ **Stable & growing**: Go 1.23 released, continuous evolution.
  ✅ **Native concurrency model** will remain unmatched for cloud workloads.
  ✅ **DevOps & cloud-native ecosystem** guarantees long-term adoption.
  ✅ **Generics (added in Go 1.18)** makes Go more flexible → more adoption for libraries & enterprise systems.
  ✅ **Enterprise adoption rising** → banks, fintechs, and SaaS companies increasingly adopting Go for performance + scalability.

Is Golang better than Python and C++?

Aspect	**Golang**	**C++**
Performance	Very fast, but not as low-level as C++.	✅ Extreme performance, direct memory control.
Complexity	✅ Simple syntax, minimal keywords.	❌ Complex (templates, pointers, manual memory).
Memory Management	Garbage collector (automatic).	Manual (more control, but harder).
Concurrency	✅ Built-in (goroutines, channels).	❌ Threads, mutexes → harder to manage.
Use Cases	Cloud services, networking, APIs, DevOps tools.	Game engines, OS kernels, embedded systems, high-performance computing.
Portability	Cross-platform builds with ease.	Cross-platform but build systems (CMake, etc.) add complexity.

Golang vs C and C++

Linux custom development

Requirement	C	C++	Go
Size requirements in devices	Lowest	Low (1.8MB more)	Low (2.1 MB more, however will increase with more binaries)
Setup requirements in Yocto	None	None	None
Buffer under/overflow protection	None	Little	Yes
Code reuse/sharing from CFEngine	Good	Easy (full backwards compatibility)	Can import C API
Automatic memory management	No	Available, but not enforced	Yes
Standard data containers	No	Yes	Yes
JSON	json-c	jsoncpp	Built-in
HTTP library	curl	curl	Built-in
SSL/TLS	OpenSSL	OpenSSL	Built-in (TLS is a part of crypto/tls package)*

Golang vs C and C++

Aspect	**Golang**	**C**
Level	High-level (modern, simplified).	Low-level (close to hardware).
Memory Management	✅ Garbage collector (automatic).	❌ Manual (malloc/free).
Performance	Very fast (close to C, but not equal).	✅ Extremely fast (baseline for systems programming).
Concurrency	✅ Built-in goroutines + channels.	❌ No native concurrency (threads via libraries like pthreads).
Complexity	✅ Simple, readable, small spec.	❌ More boilerplate, error-prone.
Use Cases	Cloud-native apps, servers, APIs, DevOps tools.	OS kernels, embedded systems, drivers, hardware-level programming.

Golang vs C Speed Comparison

- ⚡ **Go vs C — Speed Comparison**
- **1. Execution Speed**
- **C**:
  - Compiled directly to machine code, minimal runtime.
  - Extremely fast (baseline for systems programming).
  - No garbage collector → predictable performance.
- **Go**:
  - Also compiled to machine code.
  - Slightly slower than C due to **garbage collection (GC)** and runtime checks (e.g., array bounds, type safety).
  - Typically **10–30% slower** than optimized C in raw compute benchmarks.

Golang vs C Speed Comparison

- **3. Concurrency**
- **C**: Uses **threads + mutexes** (via pthreads). High performance, but complex to implement safely.
- **Go**: Built-in **goroutines + channels** → lightweight concurrency model.
  - Goroutines are much lighter than OS threads.
  - For concurrent workloads, Go can **outperform C in developer productivity** (but not raw speed).

Golang vs C Speed Comparison

- **4. Compilation Speed**
- **C**: Slow for large projects (complex toolchains, headers, linking).
- **Go**: Designed for **very fast compilation** (great for microservices and CI/CD).

Golang vs C Speed Comparison

Task	**C**	**Go**
Raw math (loops, arrays)	✅ Fastest	~10–20% slower
String handling	Fast (manual)	Slightly slower, but safer
Concurrency (100k tasks)	Heavy (threads, more RAM)	✅ Goroutines scale easily
Memory usage	Very efficient	Higher (due to GC + runtime)
Compilation time	Slower on big projects	✅ Much faster

Golang vs C Speed Comparison

- ✅ **When to Choose**
- **C** → When absolute maximum performance and full hardware control is required (OS kernels, embedded, drivers, real-time systems).
- **Go** → When you need **near-C speed** but with **simplicity, concurrency, safety, and developer productivity** (APIs, cloud-native apps, microservices, servers).

Golang vs C and C++

GO OS / GO ARCH	amd64	386	arm	arm64	ppc64le	ppc64	mips64le	mips64	mipsle
aix						X			
android	X	X	X	X					
darwin	X			X					
dragonfly	X								
freebsd	X	X	X						
illumos				X					
ios				X					
js									
linux	X	X	X	X	X	X	X	X	X
netbsd	X	X	X						
openbsd	X	X	X	X					
plan9	X	X	X						
solaris	X								
windows	X	X	X	X					

Golang

- Golang has many advantages over other programming languages.
  - Golang has an easy learning curve
  - Go codes are easily readable. Over and above, an easy-to-use tool
  - Golang has good documentation, which will support developers significantly.
  - It compiles and executes codes at speed
  - Golang is portable. It means that it will work on all platforms
  - It has automatic garbage collection
  - It performs independent error handling
  - Golang reduces runtime errors and dependencies.
  - It has good memory safety and management
  - Golang supports scalability
  - It has a large user community.

Golang vs Python

Aspect	**Golang (Go)**	**Python**
Type System	✅ Statically typed (type-checked at compile time).	❌ Dynamically typed (checked at runtime).
Speed	✅ Compiled → much faster, close to C.	❌ Interpreted → slower (5–30x slower than Go).
Concurrency	✅ First-class support (goroutines, channels).	❌ Limited (Global Interpreter Lock / GIL restricts true parallelism).
Ease of Learning	Simple, small spec, easy to learn.	Even simpler, beginner-friendly.
Ecosystem	Strong for **cloud, APIs, microservices, DevOps tools**.	✅ Huge ecosystem → **AI, ML, Data Science, Web frameworks, scripting**.
Use Cases	Cloud-native apps, APIs, microservices, networking, CLI tools.	Data science, machine learning, scripting, automation, web apps (Django/Flask).

Golang vs Python

Memory Management	Garbage collected, efficient.	Garbage collected, but slower.
Syntax	C-like, minimalistic.	Very readable, English-like.
Community	Large, growing fast (DevOps, cloud).	Massive (data science, academia, startups, enterprises).
Deployment	Produces a **single binary**, easy deployment (no runtime needed).	Needs Python runtime + dependencies (can be tricky in production).

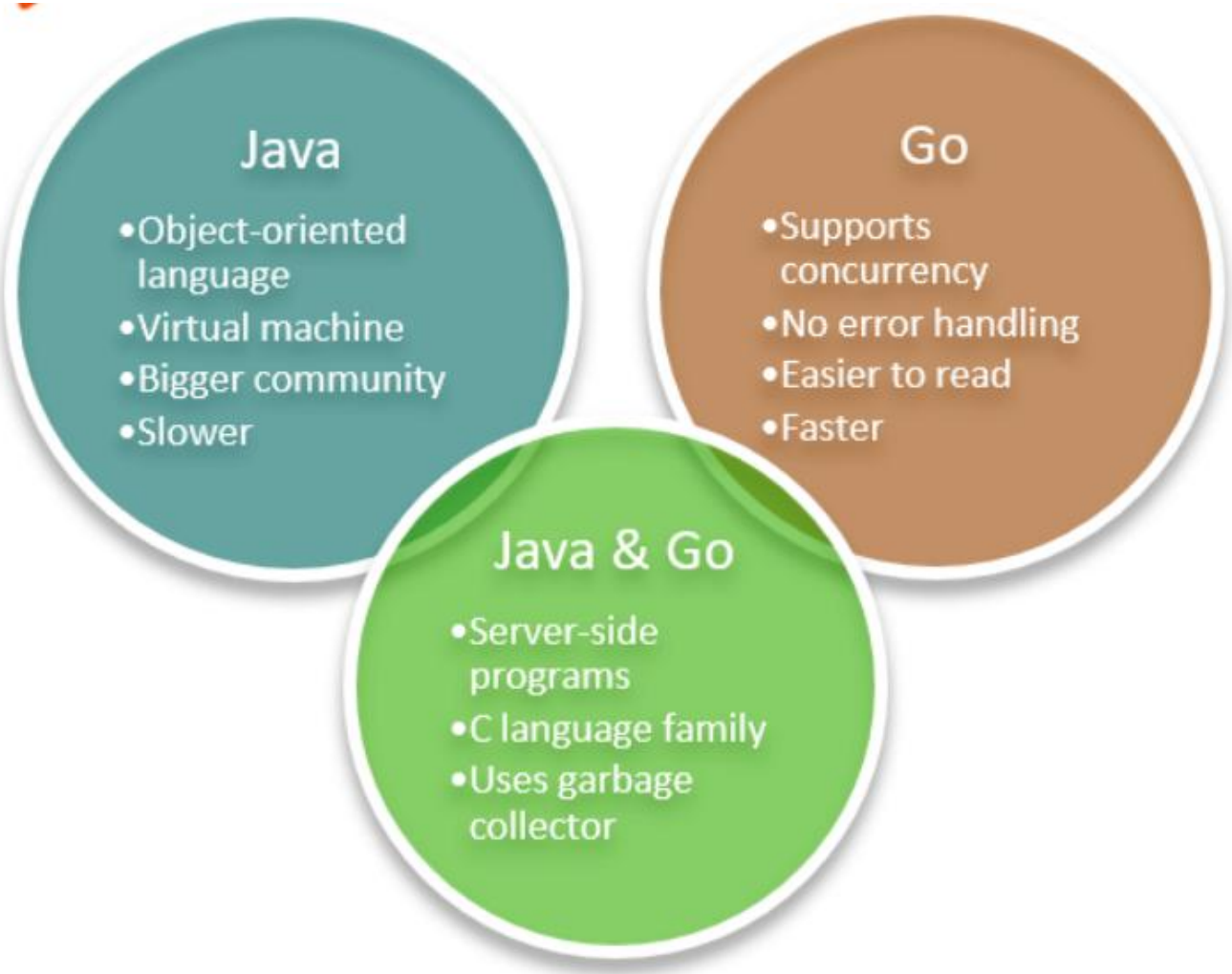
Golang vs Python

- 🔑 **Key Strengths**
- ✅ **Go**
- Fast, compiled, efficient concurrency → great for **microservices & cloud infrastructure**.
- Produces static binaries → easy to ship in Docker/K8s.
- Used by **Docker, Kubernetes, Terraform, Prometheus**.
- ✅ **Python**
- Huge ecosystem for **AI/ML, data science, scientific computing**.
- Super beginner-friendly.
- Widely used in **automation, scripting, web apps, prototyping**.

Where To Use

Domain	Best Choice
Microservices, APIs, Cloud, DevOps tools	**Go**
Machine Learning, AI, Data Science, Scripting	**Python**
General-purpose scripting & automation	**Python**
High-performance concurrent servers	**Go**

Golang vs Java



Golang vs Java

Aspect	**Golang (Go)**	**Java**
Type System	✅ Statically typed, simple	✅ Statically typed, object-oriented
Performance	✅ Compiled to native machine code → very fast, low overhead	Runs on **JVM**, slightly slower but still high-performance with JIT optimizations
Concurrency	✅ Built-in with **goroutines** and **channels** (lightweight, scalable)	Threads, executors, and CompletableFuture; powerful but heavier
Memory Management	Garbage collected, lightweight runtime	Garbage collected (mature GC, multiple strategies)
Ease of Learning	Small language spec, easy for beginners	Rich and verbose, larger learning curve
Ecosystem	Strong for **cloud-native, DevOps, microservices**	✅ Massive ecosystem (enterprise apps, Android, Spring, Hadoop, banking/finance)

Golang vs Java

Tooling	Built-in: go build, go test, go fmt, go mod	✅ Mature ecosystem: Maven, Gradle, JUnit, IntelliJ, Spring Boot
Deployment	✅ Single binary, easy to deploy in containers	Requires JVM; container-friendly but heavier
Community	Growing (cloud-native, startups, infra tools)	✅ Huge, decades-old, enterprise-backed
Use Cases	Cloud apps, APIs, microservices, DevOps tools (Docker, K8s, Terraform)	Enterprise apps, Android apps, banking systems, large-scale backends

Golang vs Java

- 🔑 **Key Strengths**
- ✅ **Go**
- Designed for **simplicity and concurrency**.
- Tiny runtime, fast startup, static binary → perfect for **containers & microservices**.
- Used in **Kubernetes, Docker, Prometheus, Terraform**.
- Great fit for **startups and modern cloud infrastructure**.
- ✅ **Java**
- Rich **enterprise ecosystem** (Spring Boot, Hibernate, Kafka, Spark).
- JVM portability → runs everywhere.
- Highly optimized for long-running enterprise apps.
- Used in **banks, telecom, big data, Android, large-scale enterprise software**.

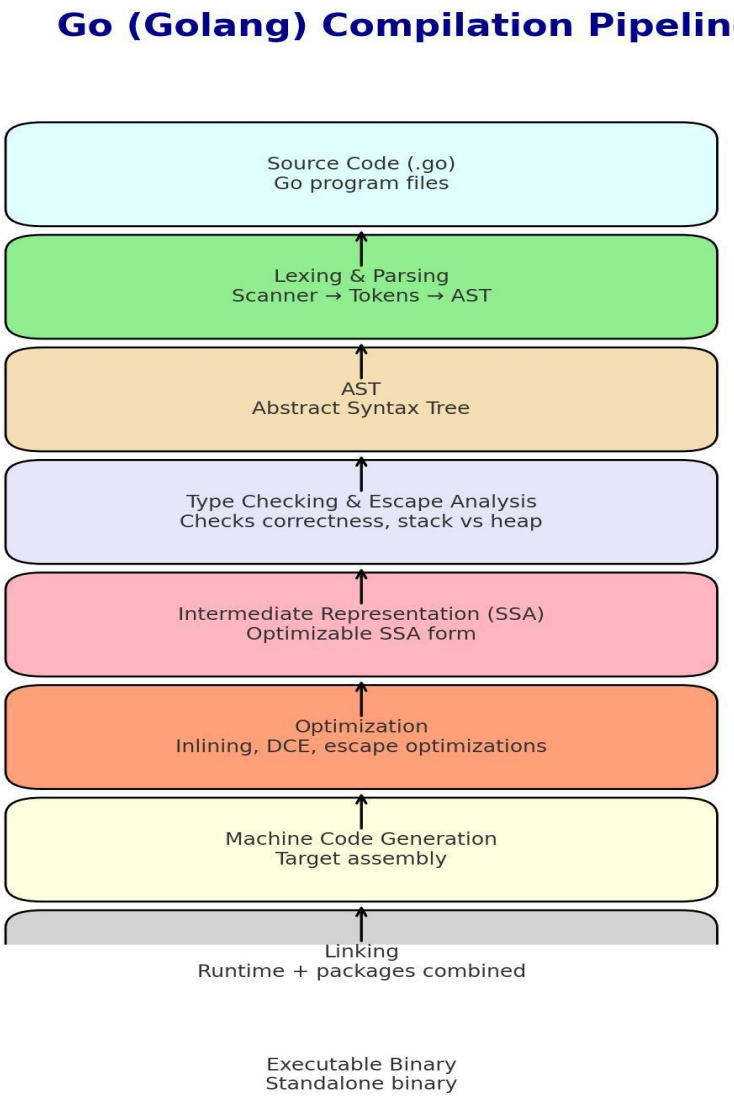
Golang vs Java - 📊 When to Use

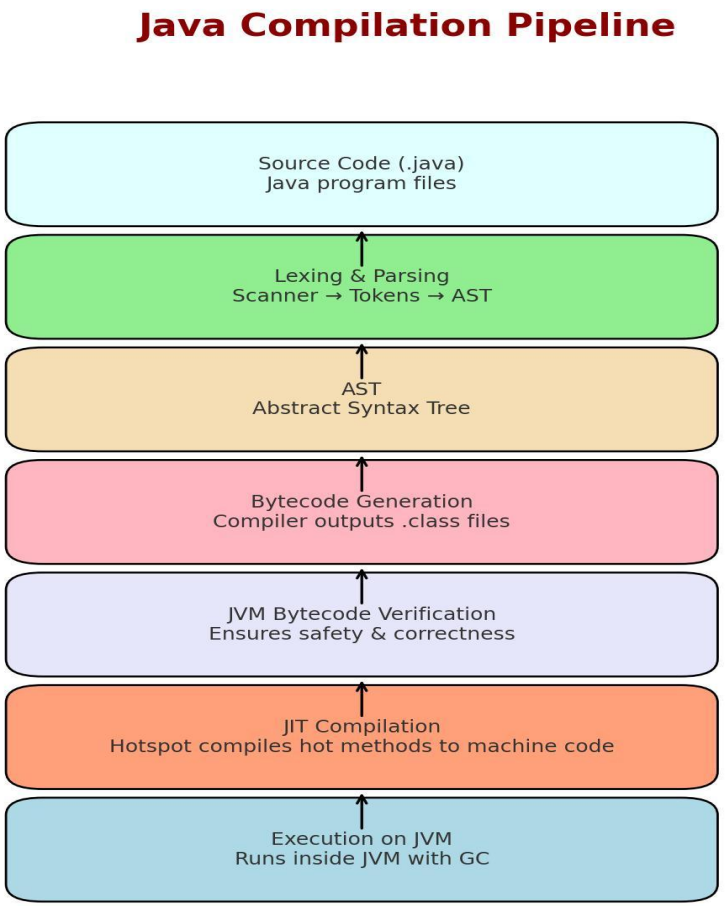
Domain	Best Choice
Cloud-native microservices, DevOps tools, APIs	**Go**
Enterprise software, banking, legacy systems	**Java**
Android apps	**Java/Kotlin**
Infrastructure (K8s, Docker, Terraform)	**Go**
Big Data (Spark, Hadoop, Kafka ecosystem)	**Java**

Golang vs Java

- ✅ **Verdict**
- **Go** → Simplicity, concurrency, cloud-native tooling. Best for **modern microservices** and **DevOps platforms**.
- **Java** → Stability, ecosystem, enterprise adoption. Best for **large-scale enterprise applications, finance, Android, and big data**.
- 👉 Many companies actually **use both**:
- **Go** for cloud infrastructure and high-performance APIs.
- **Java** for business logic-heavy enterprise systems.

Golang Compilation Model





Golang Compilation Process

⚡ Go Compilation Steps

1. Source Code (.go files)

- You write Go code in .go files.
- Organized into **packages** (each folder = a package).

Golang Compilation Process

- **2. Lexing (Tokenization)**
- The **scanner (lexer)** reads your code and breaks it into tokens: keywords, identifiers, literals, operators.
- Example:

```go
x := 42
```

→ Tokens: `IDENT(x)`, `:=`, `NUMBER(42)`

Golang Compilation Process

- **3. Parsing**
- Tokens are structured into an **AST (Abstract Syntax Tree)**.
- AST represents the program in tree form (functions, variables, control flow).

Golang Compilation Process

- **4. Type Checking & Escape Analysis**
- Compiler checks types (static typing).
- **Escape Analysis** decides:
  - If variable stays on **stack** (fast, no GC).
  - Or must be placed on **heap** (managed by GC).

Golang Compilation Process

- **5. Intermediate Representation (SSA)**
- Go compiler converts code into **Static Single Assignment (SSA)** form.
- Easier to optimize: constant folding, inlining, dead-code elimination, etc.

Golang Compilation Process

- **6. Optimization**
- Performs code optimizations:
  - Inline functions
  - Remove dead code
  - Optimize memory allocations (stack vs heap)

Golang Compilation Process

- **7. Machine Code Generation**
- Compiler backend generates **architecture-specific assembly** (x86, ARM, etc.).
- Uses **Plan 9 assembler syntax** internally.

Golang Compilation Process

- **8. Linking**
- Links:
  - Your program's machine code
  - Go runtime (scheduler, GC, etc.)
  - Standard library packages
- Produces a **single executable binary** (static by default).

Golang Compilation Process

- **9. Executable Binary**
- Final output = **self-contained binary** (no JVM or interpreter).
- Easy to deploy (great for Docker, Kubernetes).

Golang Compilation Process

- ✅ Example

```bash
go build main.go
```

Produces `main` (Linux/macOS) or `main.exe` (Windows).

```bash
./main
```

Runs directly — no external runtime needed.

Golang Compilation Process

- ✅ Example

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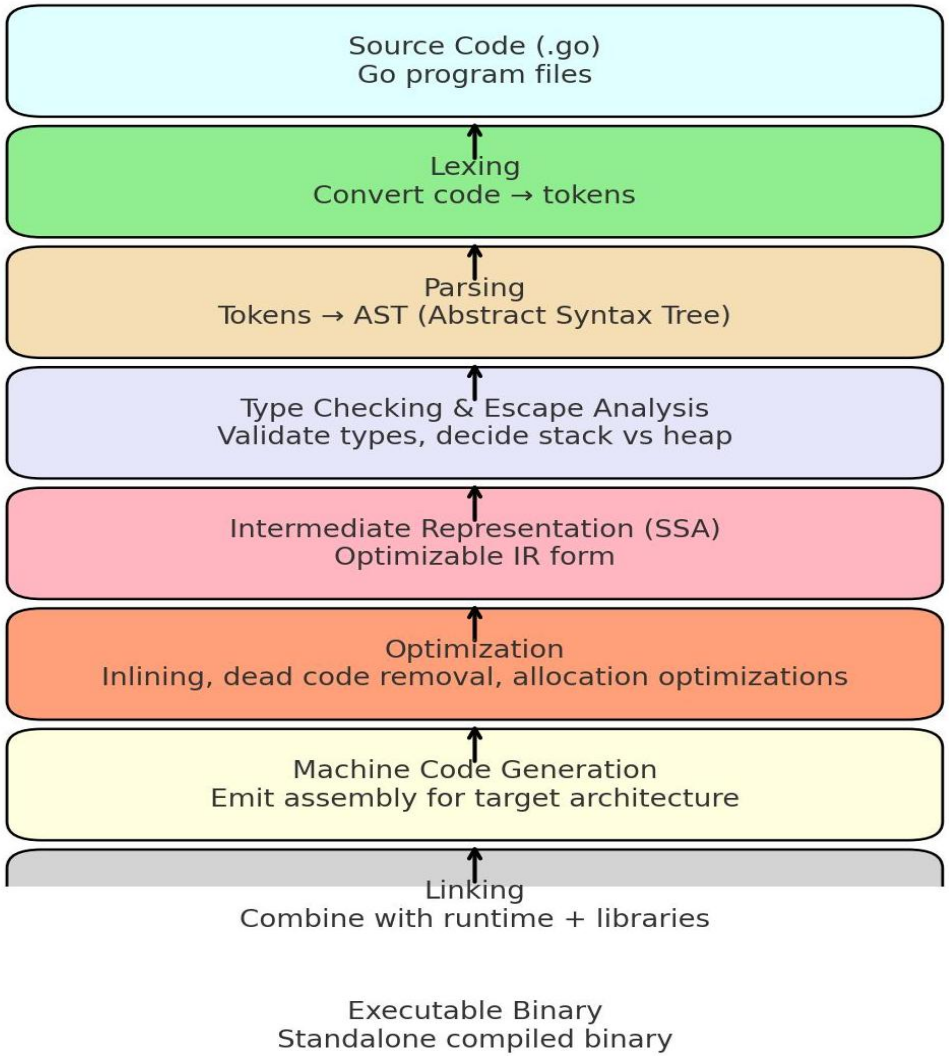
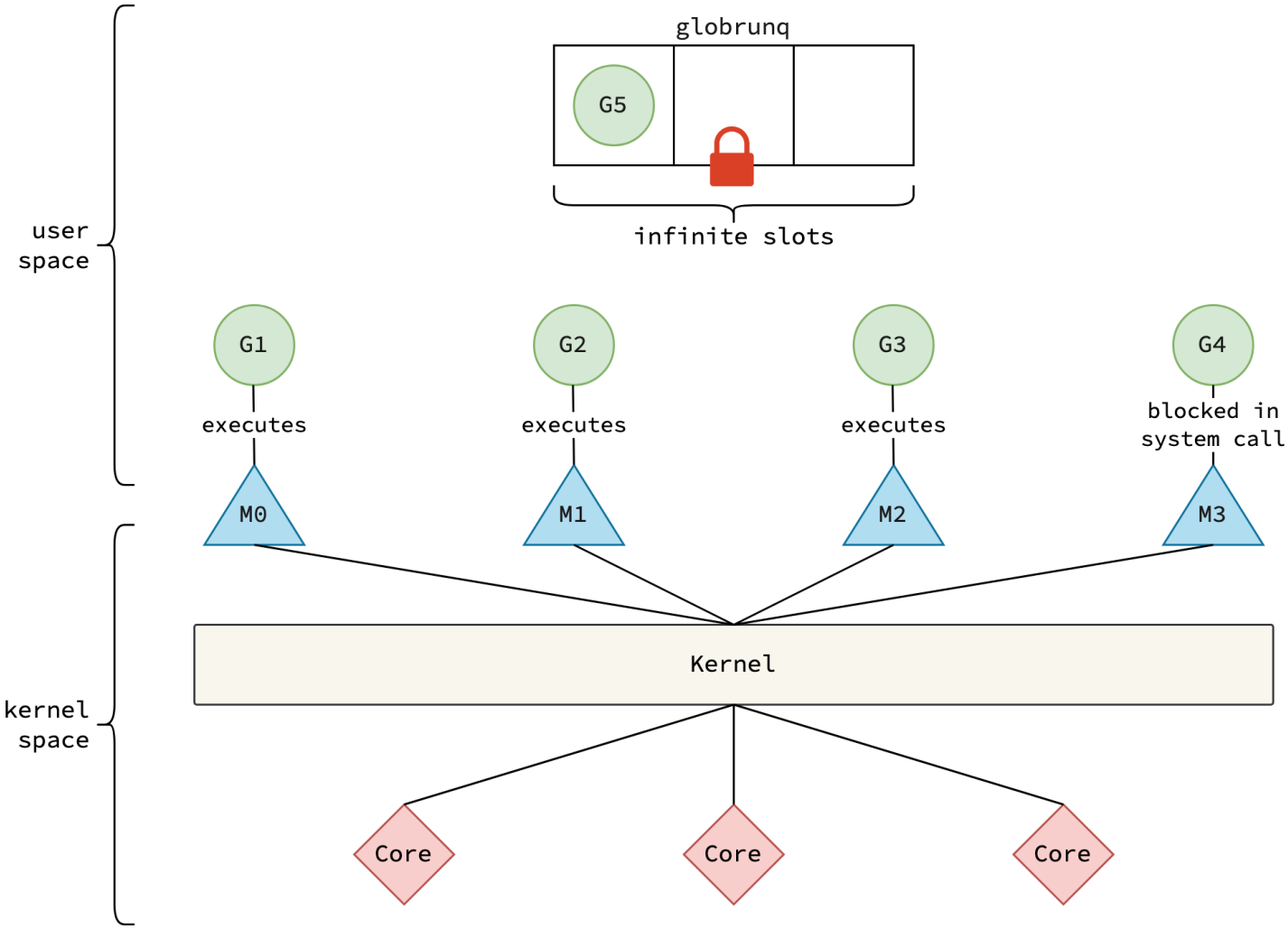
Golang Compilation Process



Go Scheduler



Go Scheduler

- **G (Goroutines)** → lightweight, user-space threads.
- **M (Machine/OS Threads)** → actual OS threads managed by kernel.
- **P (Processor, not shown here)** → logical schedulers that bind goroutines (G) to threads (M).
- **Kernel** → maps M's to physical CPU cores.
- **Global Run Queue (globrunq)** → holds goroutines waiting for execution.

Go Scheduler

- **G (Goroutine)**: the lightweight task that runs your Go function.
  In the image: G1–G4 are running/blocked; G5 is waiting.
- **M (Machine / OS thread)**: actual OS thread that executes code in user space.
  In the image: M0–M3 are the OS threads.
- **Kernel**: schedules **threads** (M) onto CPU **cores**.
- **Global run queue (globrunq)**: shared queue holding runnable goroutines when they're not on a local queue. In the image, G5 sits here.
- **User space vs kernel space**: goroutines and the Go runtime run in user space; syscalls and thread scheduling happen in kernel space.

Go Memory Architecture

- 🧠 **Go Memory Architecture (Internal)**
- At a high level, Go's memory system is built around:
- **Heap** → for dynamically allocated objects.
- **Stack** → for function calls and local variables.
- **Garbage Collector (GC)** → manages heap, reclaims unused memory.
- **Allocator (mcache, mcentral, mheap)** → highly optimized for concurrency.

1 Stack

- Each **goroutine** has its **own stack**.
- Starts small (~2 KB) and **grows/shrinks dynamically** (unlike C, which is fixed ~1 MB per thread).
- Stores:
  - Local variables
  - Function call frames
  - Return addresses
- No GC overhead for stack memory (reclaimed automatically when a goroutine ends).

2. Heap

- Shared memory pool for long-lived objects (like slices, maps, interfaces, closures).
- Allocations happen when data **escape's** function scope → determined by **escape analysis**.

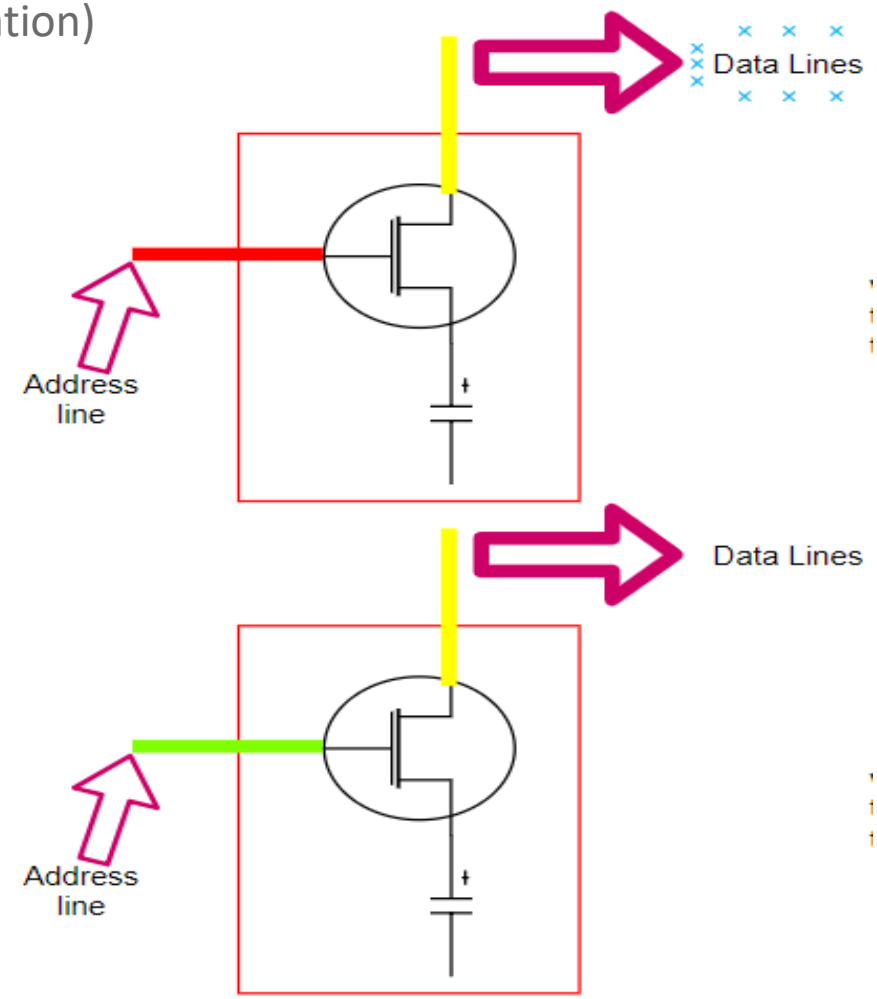
  - Example:

```go
func foo() *int {
    x := 42
    return &x // escapes → heap
}
```

- Heap is divided into **spans (pages)** → optimized for small allocations.

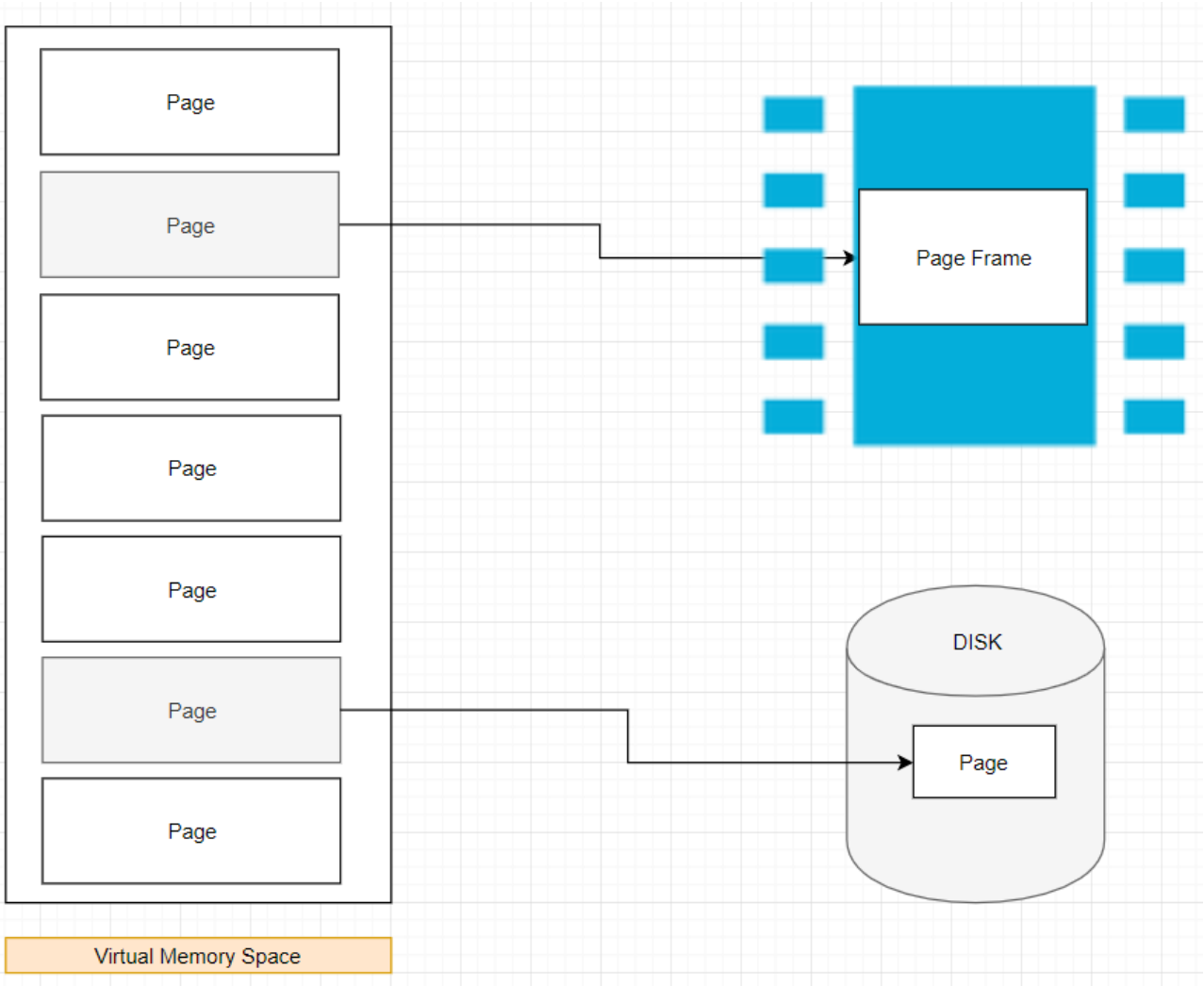
Physical and Virtual Memory

A simple illustration of a Physical Memory Cell (Not an exact representation)



Physical and Virtual Memory

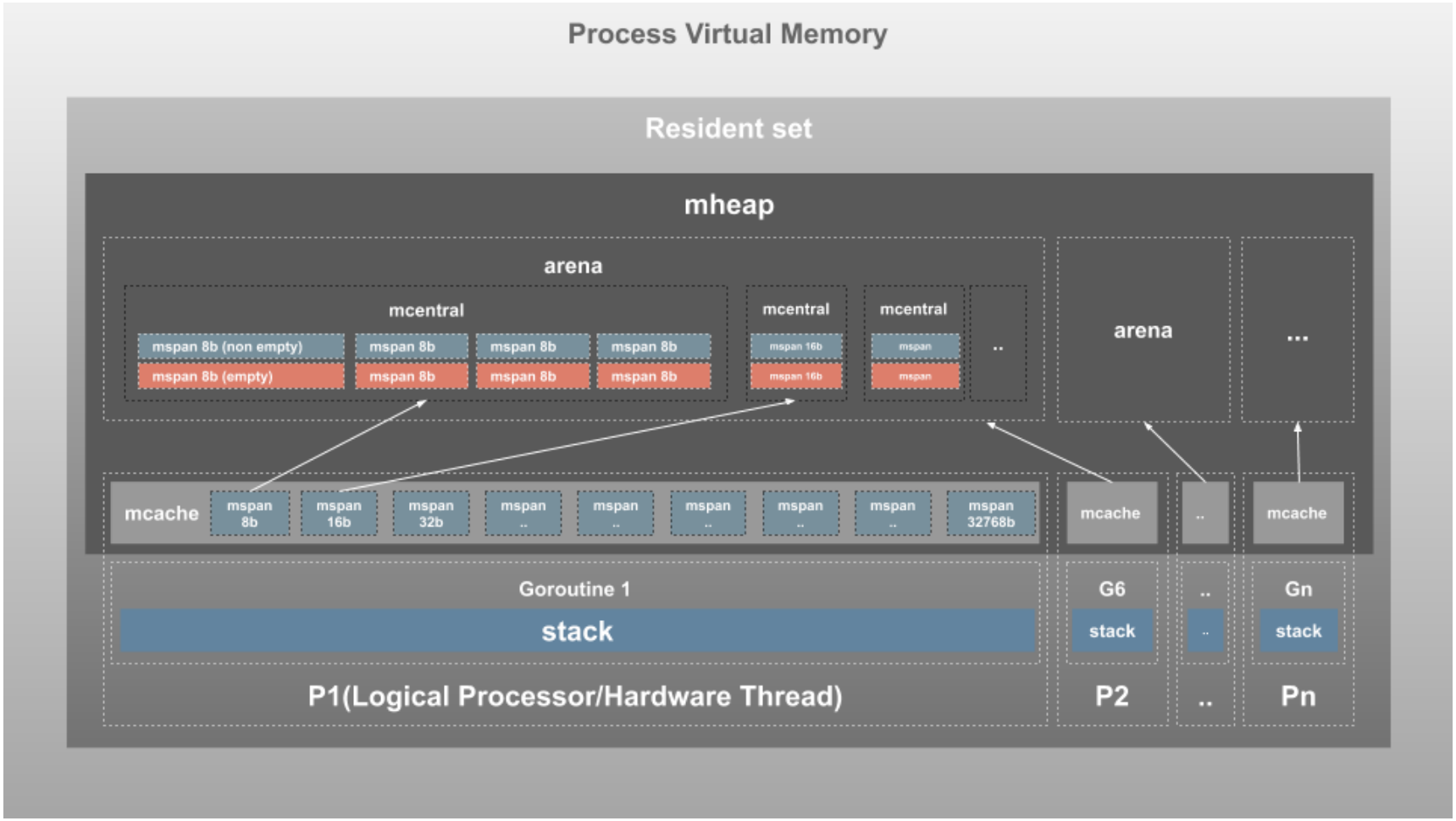
As the size of physical RAM is limited, so Each Process runs in its own memory sandbox — “virtual address space,” known as **Virtual Memory.**



Resident Set

- Each Go program process is allocated some virtual memory by the Operating System(OS), this is the total memory that the process has access to.
- The actual memory that is used within the virtual memory is called **Resident Set**.

Process Virtual Memory

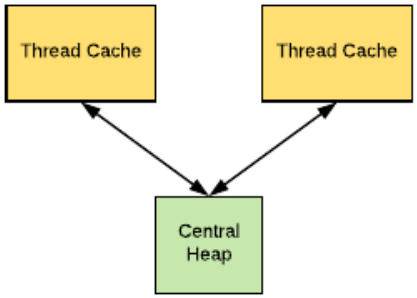


Process Virtual Memory


```
Page Heap (global pool of pages)
    ↓
mheap (global heap manager)
    ↓
mcentral (per size class)
    ↓
mspan (metadata describing span)
    ↓
mcache (per-P local cache of spans)
    ↓
Goroutines
```

TMalloc

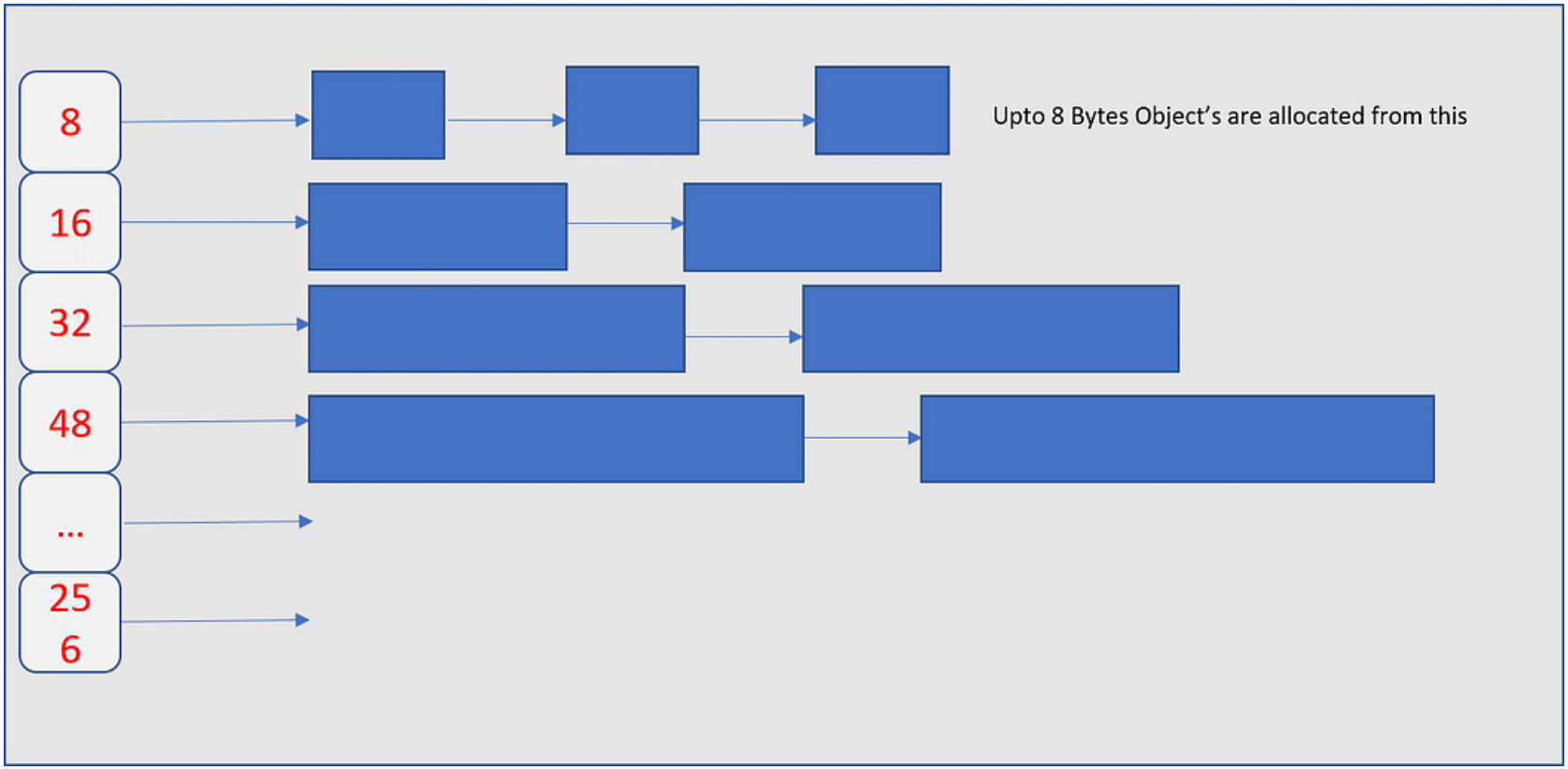
- 🌟 **What is tcmalloc?**
- **tcmalloc = Thread-Caching Malloc**, originally from Google.
- It's a **high-performance memory allocator** designed to reduce contention between threads when allocating and freeing memory.
- Go's runtime **memory allocator (mcache → mcentral → mheap)** is heavily inspired by tcmalloc's ideas.



Core Principles of tcmalloc

1. **Per-thread caches (thread-local freelists)**
   - Each thread has a small cache of objects of various sizes.
   - Allocation from this cache = **lock-free, O(1)**.
   - Frees go back into the thread's cache first.
2. **Size classes**
   - Objects are grouped into **size classes** (8B, 16B, 32B, ... up to a cutoff).
   - Each cache entry corresponds to a size class.
3. **Central free lists**
   - When a thread's cache runs empty/full, it fetches/releases a **batch** of objects from/to a central free list.
   - This reduces contention because lock acquisition happens **per batch**, not per allocation.
4. **Page heap (global heap)**
   - Large allocations (e.g., >32KB) bypass caches and go directly to the global heap.
   - The central free list itself gets memory from the **page heap**, which is managed in terms of pages (usually 8KB or multiples).

Core Principles of tcmalloc



Thread Cache (Each Thread gets this Thread Local Thread Cache)

Page Heap

- The heap managed by TCMalloc consists of a collection of pages, **where a set of consecutive pages can be represented by span**.
- When allocated Object is larger than 32K, Pages Heap is used for allocation.

Page Heap How it Works

1. **Page as a unit**
   - Memory is managed in pages (e.g., 8 KB).
   - Large objects take multiple contiguous pages.
2. **Span allocation**
   - The page heap carves memory into **spans** (contiguous groups of pages).
   - Each span is represented by an `mspan` (metadata struct).
   - Spans are then subdivided into objects of the same **size class**.
3. **Free lists**
   - Page heap maintains lists of **free spans** of various sizes.
   - When an `mcentral` needs more memory, it asks the page heap for a span.
4. **Large allocations**
   - If an allocation >32 KB, Go bypasses size classes and directly requests a **large span** from the page heap.
5. **Garbage Collection interaction**
   - The page heap interacts with the GC:
     - GC marks/free memory → freed spans go back to the page heap.
     - Reused later by other size classes.

mheap

- 🧩 **What is mheap?**
- **mheap = global heap manager** in Go's runtime.
- It manages the **entire heap space**, which is requested from the **Page Heap (OS memory)**.
- Acts as the **central authority** that hands out spans to **mcentral**.
- Works closely with the **garbage collector** to recycle freed memory

mheap

- ⚙️ **Role of mheap**
- Allocates **spans** (contiguous groups of pages).
- Maintains lists of **free spans** by size.
- Handles **large object allocations** directly (bypassing size classes).
- Interacts with **GC** to reclaim unused spans.
- Supplies spans to **mcentral** when its free list runs empty.

mheap

🔄 **mheap Lifecycle**

1.Initialization

- At runtime start, mheap is initialized.
- Gets memory from the OS (via mmap/sbrk).

2.Span allocation

- When mcentral needs more spans, it requests from mheap.
- mheap finds a suitable free span (or requests more pages from OS).

3.Large objects (>32 KB)

- Allocated directly by mheap, bypassing mcentral/mcache.
- Uses multiple contiguous pages.

4.Garbage Collection

- During GC, spans are marked/swept.
- Freed spans are returned to mheap’s free lists.

mcentral

What is mcentral?

- **mcentral** is a **per-size-class central cache of spans**.
- Each **size class** (e.g., 8B, 16B, 32B, … up to 32KB) has its own mcentral.
- It sits between **mheap** (global heap) and **mcaches** (per-P local caches).
- Purpose: to hand out spans to mcache when they run empty.

mcentral

- ⚙️ **Role of mcentral**
- Manages **free spans** for a particular size class.
- Maintains two linked lists of spans:
  - **Empty list** → spans currently being used (some objects still allocated).
  - **Non-empty list** → spans with free objects available.
- Allocates spans to **mcache** in batches.
- Returns spans back to **mheap** when completely free.

mcentral

🔄 How mcentral Works

1.mcache request

- When a goroutine needs memory, it asks its **mcache**.
- If mcache is empty → it requests a new span from mcentral.

2.Serving spans

- mcentral finds a span in its **non-empty list**.
- Hands the span over to the requesting mcache.

3.Replenishment from mheap

- If mcentral has no non-empty spans, it requests a fresh span from **mheap**.

4.Returning spans

- When a span is completely freed (all objects unused), mcentral returns it to mheap.

mspan

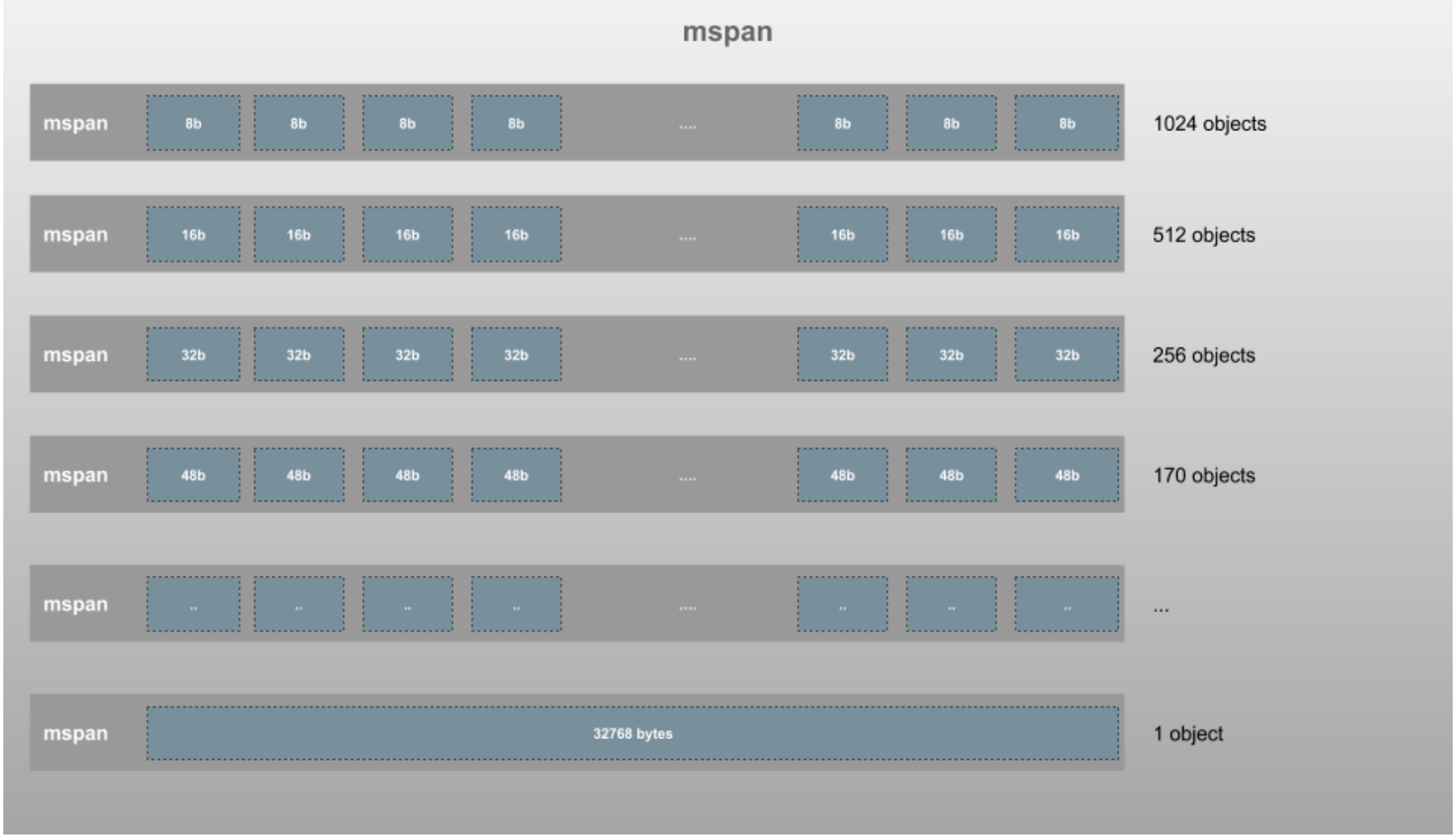
- 🧩 **What is mspan?**
- An **mspan** is the **metadata structure** that describes a **span** (a contiguous chunk of memory from the heap).
- Spans are the unit of allocation inside Go’s runtime.
- Every span is made up of one or more **pages** (default page = 8 KB).

mspan

🔄 Lifecycle of an mspan

1. **Created by mheap** → when mcentral requests memory.
2. **Assigned to size class** → span is subdivided into objects of fixed size.
3. **Used by mcache** → goroutines allocate objects from this span.
4. **GC interaction** → gcmarkBits used to mark live objects.
5. **Freed** → when all objects are free, span is returned to mcentral (and possibly to mheap).

mspan


mspan
mspan
8b
8b
8b
8b
....
8b
8b
8b
1024 objects
mspan
16b
16b
16b
16b
....
16b
16b
16b
512 objects
mspan
32b
32b
32b
32b
....
32b
32b
32b
256 objects
mspan
48b
48b
48b
48b
....
48b
48b
48b
170 objects
mspan
..
..
..
..
....
..
..
..
...
mspan
32768 bytes
1 object

Arena

- 🧩 **What is an Arena in Go?**
- An **Arena** is a **large contiguous region of virtual memory** reserved by the Go runtime to serve as the heap.
- The heap is divided into **arenas**, and each arena is further divided into **pages** (default: 8 KB).
- Arenas are managed by the **mheap**, which carves them into spans for allocation.
- 👉 You can think of arenas as **big chunks of memory** grabbed from the OS that Go slices into smaller pieces.

Arena

Arena Characteristics

- Size: typically, **64 MB** per arena on 64-bit systems.
- Alignment: arenas are aligned in memory for efficient indexing.
- Indexed by a global **heapArena array**.
- Each arena is subdivided into:
  - **Pages** (8 KB each).
  - **Spans** (group of one or more pages, tracked by an mspan).

Arena

- 🔄 **Arena Lifecycle**
- **Heap Growth**
  - If mheap cannot satisfy a request, it asks the OS for more memory.
  - A new **arena** is mapped into the process address space.
- **Span Carving**
  - mheap divides arenas into spans and assigns them to size classes.
- **Allocation**
  - Goroutines allocate from mcache → spans → pages inside an arena.
- **Garbage Collection**
  - GC reclaims unused objects.
  - Freed spans can be reused within the same arena.

Arena in the Allocation Hierarchy


```
OS (mmap/sbrk)
   ↓
Arena (64 MB)
   ↓
Pages (8 KB each)
   ↓
Spans (1+ pages, tracked by mspan)
   ↓
mcentral / mcache
   ↓
Goroutines
```

mcache

- 🧩 **What is mcache?**
- **mcache = per-P (per-processor) memory cache** in Go's allocator.
- Each **P** (from the Go scheduler's **G-M-P model**) owns one **mcache**.
- It's where **goroutines actually allocate memory from** most of the time.
- Designed to be **lock-free, fast, and local**, avoiding global contention.

mcache

Role of mcache

- Stores **spans** (from mcentral), one span per size class.
- Each span provides many objects of the same size.
- When a goroutine needs memory:
  1. If a span for that size class exists in mcache and has free slots → allocate immediately (fast path).
  2. If span is exhausted → refill from **mcentral** (slower path).

mcache

- 🔄 **How mcache Works**
- **Fast Allocation**
  - Goroutine allocates memory.
  - mcache picks a slot from its current span → O(1), no locks.
- **Refill (Slow Path)**
  - If current span is exhausted:
    - mcache requests a new span from **mcentral**.
    - If mcentral is empty → mcentral requests from **mheap**.
- **Return Spans**
  - When a span is fully freed (all objects unused), it's returned to **mcentral**.

3. Hierarchy

- 3 **Allocator Hierarchy**
- Go uses a **hierarchical memory allocator** inspired by **tcmalloc**:
- **mheap** → Global heap, managed by GC.
- **mcentral** → Manages spans (groups of objects of same size class).
- **mcache (per-P cache)** → Thread-local cache for each processor (P in Go scheduler).
  - Reduces lock contention by letting goroutines allocate from local caches.

Go Internal Memory Allocator Concepts

1 mheap

- The **global heap** managed by the Go runtime.
- Represents the **entire memory region** used for dynamic allocations.
- Divided into **spans** (continuous memory blocks).
- Managed by the **garbage collector (GC)**.
- Central allocator of memory, but expensive to access directly (locks required).

👉 Rarely allocated from directly. Instead, goroutines use **mcache** (per P-thread cache) which pulls memory from mcentral → mheap.

Go Internal Memory Allocator Concepts

2 mspan

- An mspan is a **descriptor (metadata)** for a block of memory in the heap.
- Each span represents a **contiguous region of memory** divided into objects of the same size class.
- Keeps track of:
  - Which objects are allocated vs free (bitmap).
  - The **size class** (e.g., 8B, 16B, 32B, …).
  - Links to free lists for fast allocation.
- Helps the allocator quickly find free space for an object of a given size.

Go Internal Memory Allocator Concepts

3 span

- A **unit of allocation** on the heap.
- Backed by an mspan (the metadata).
- Groups together multiple objects of the same size.
- Allocations smaller than 32KB come from spans, sized by **size classes**.
- For large objects (>32KB), Go allocates a dedicated span directly from mheap.

Go Internal Memory Allocator Concepts

Goroutine → mcache (local, per-P) → mcentral (shared per size class) → mheap (global)

- **mcache: per-processor cache, lock-free, fastest allocation.**
- **mcentral: manages a pool of mspans for a given size class, shared across processors.**
- **mheap: global allocator, fallback when mcentral is empty.**

Go memory usage (Stack vs Heap)

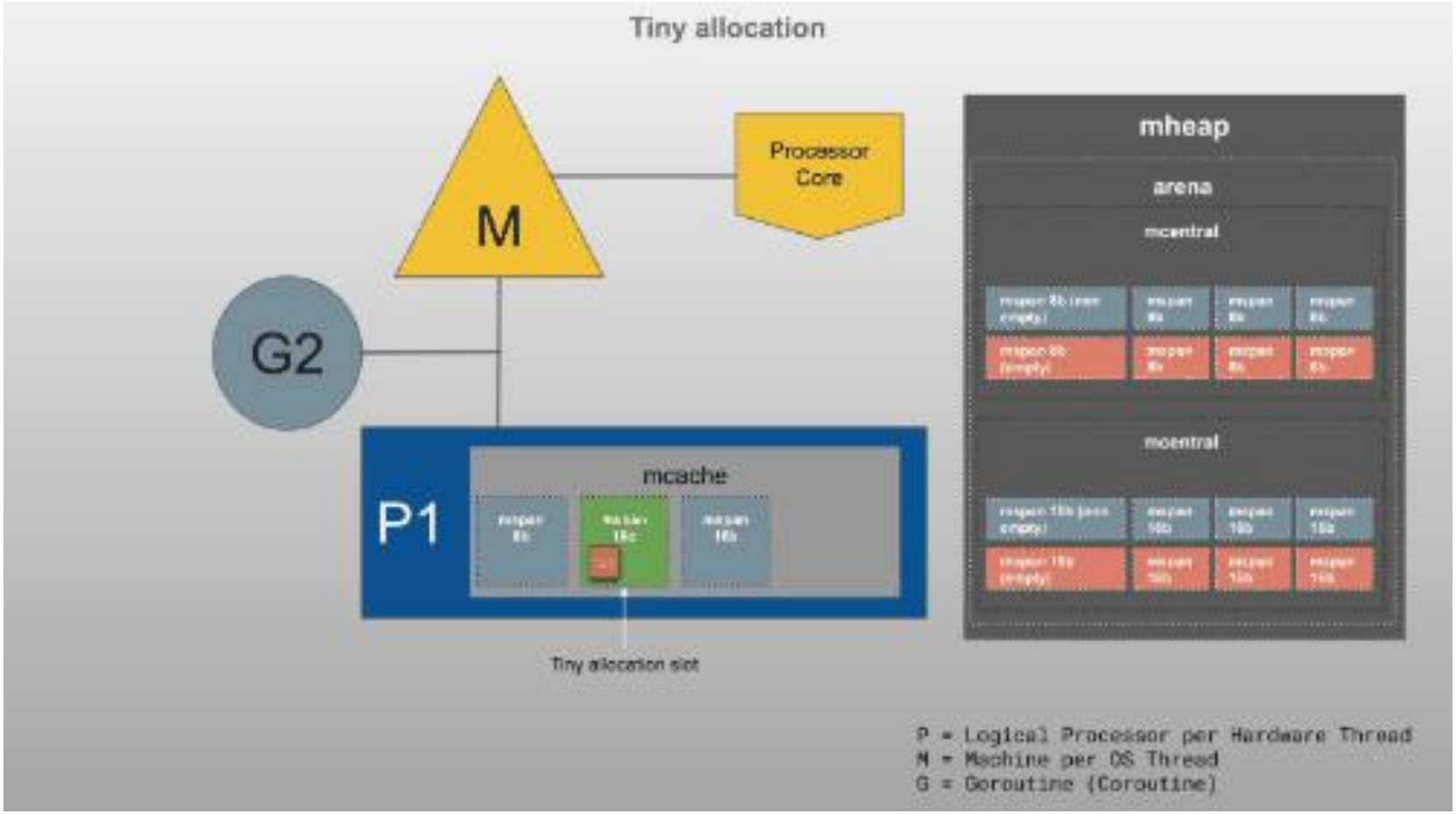
- Main function is kept in a “main frame” on the Stack
- Every function call is added to the stack memory as a frame-block
- All static variables including arguments and the return value is saved within the function frame-block on the Stack
- All static values regardless of type are stored directly on the Stack. This applies to global scope as well
- All dynamic types are created on the Heap and is referenced from the Stack using Stack pointers. Objects of size less than 32Kb go to the mcache of the P. This applies to global scope as well

Go memory usage (Stack vs Heap)

- The struct with static data is kept on the stack until any dynamic value is added at that point the struct is moved to the heap
- Functions called from the current function is pushed on top of the Stack
- When a function returns its frame is removed from the Stack
- Once the main process is complete, the objects on the Heap do not have any more pointers from Stack and becomes orphan

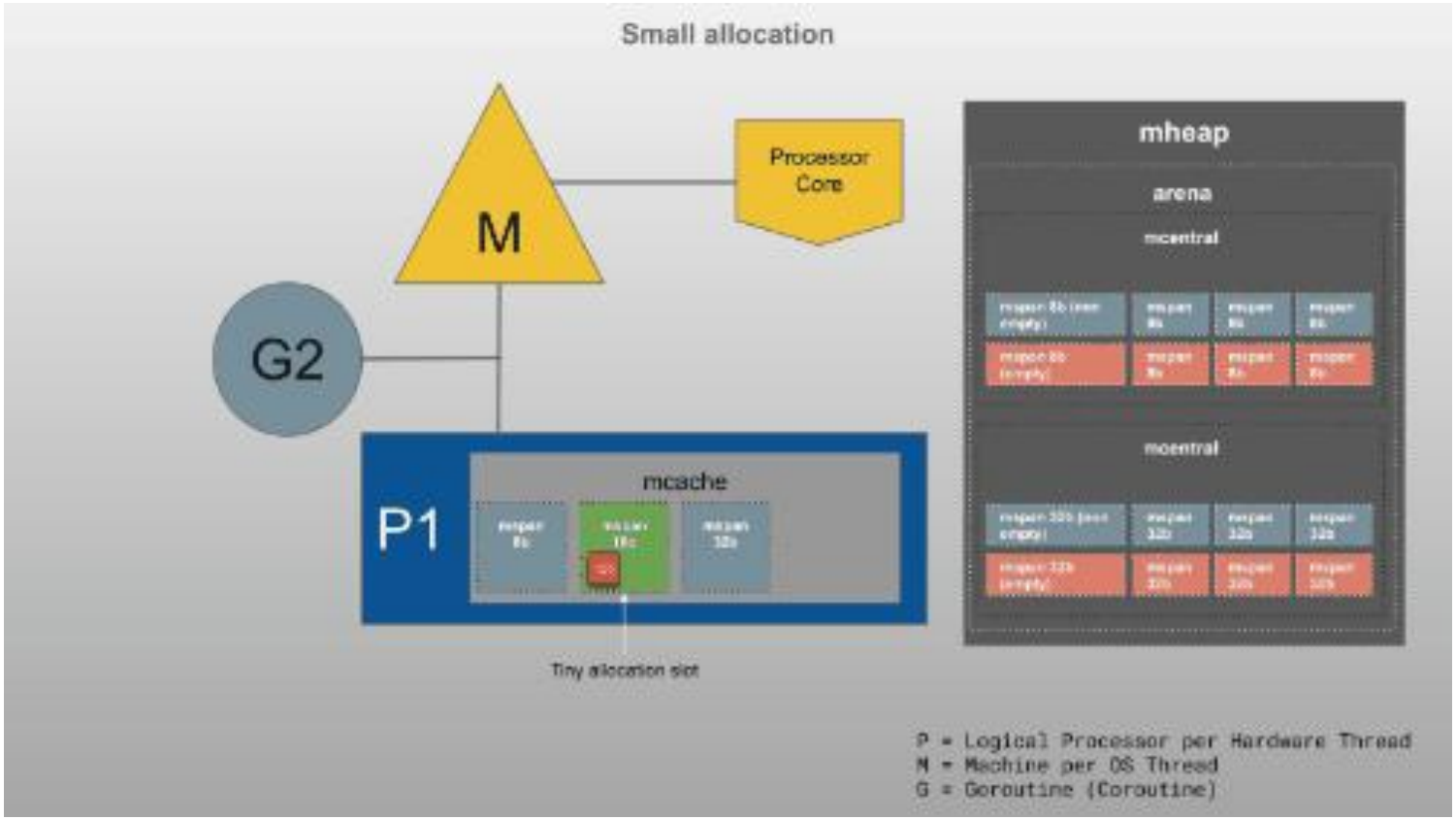
Memory Allocation

Tiny(size < 16B): Objects of size less than 16 bytes are allocated using the mcache's tiny allocator. This is efficient and multiple tiny allocations are done on a single 16-byte block.



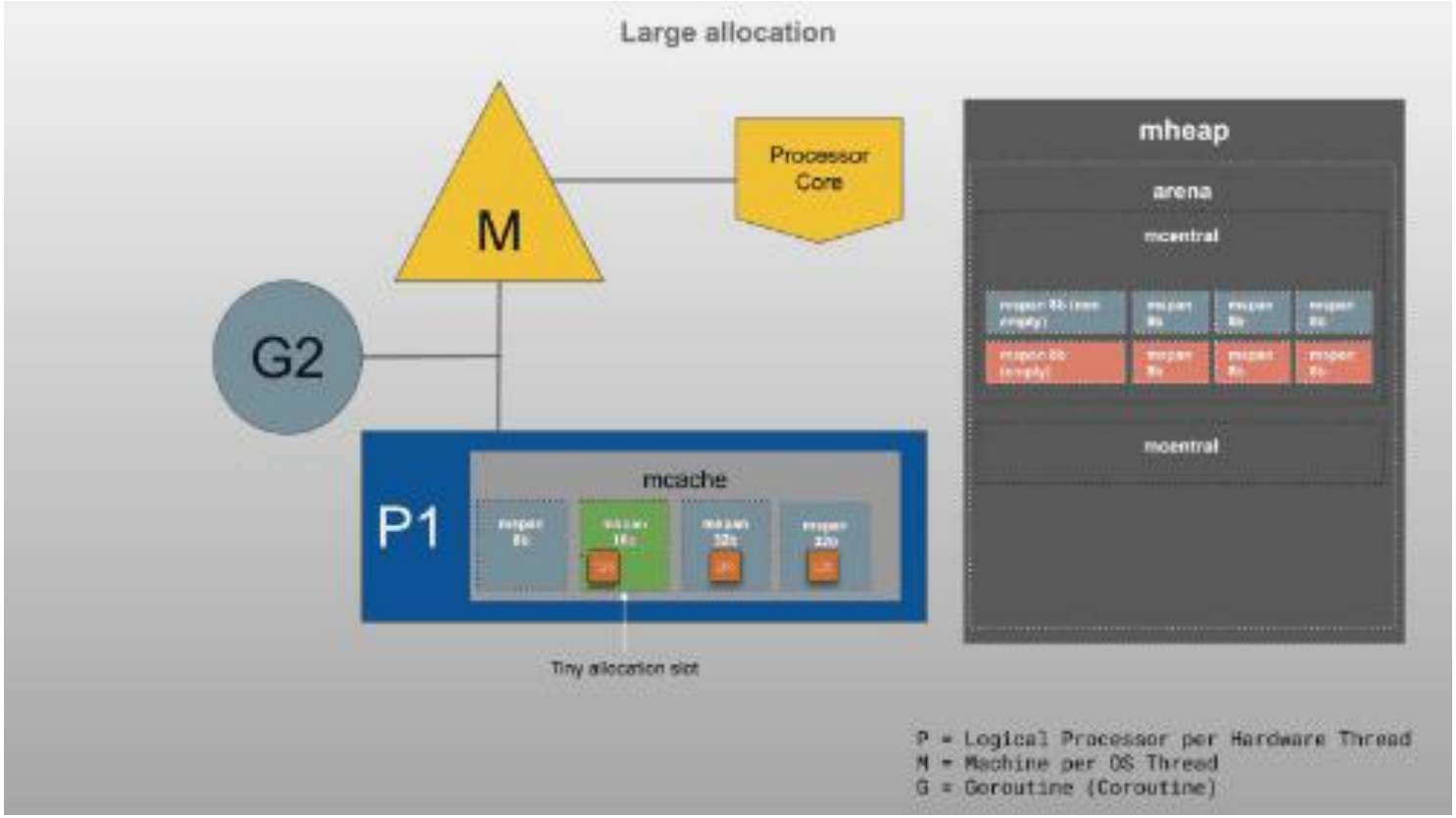
Memory Allocation

Small(size 16B ~ 32KB): Objects of size between 16 bytes and 32 Kilobytes are allocated on the corresponding size class(mspan) on mcache of the P where the G is running.



Memory Allocation

Large(size > 32KB): Objects of size greater than 32 kilobytes are allocated directly on the corresponding size class of mheap. If the mheap is empty or has no page runs large enough then it allocates a new group of pages (at least 1MB) from the OS.



4. Garbage Collector (GC)

- **Garbage Collector (GC)**
- Go uses a **non-generational, concurrent, tri-color, mark-and-sweep GC**.
- Improvements in Go 1.5+ made GC **low-latency (~<1ms pauses)**.
- Process:
  - **Mark phase** → traverse object graph, mark reachable objects.
  - **Sweep phase** → free unmarked objects.
  - Runs concurrently with goroutines (not fully stop-the-world).
- Modern Go GC is tuned for **low latency (<100 µs per MB allocated)** rather than max throughput.

GC

- Mark Setup (Stop the world): When GC starts, the collector turns on write barriers so that data integrity can be maintained during the next concurrent phase.
- This step needs a very small pause as every running Goroutine is paused to enable this and then continues.

GC

- Marking (Concurrent): Once write barriers are turned on the actual marking process is started in parallel to the application using 25% of the available CPU capacity.
- The corresponding Ps are reserved until marking is complete.
- This is done using dedicated Goroutines. Here the GC marks values in the heap that is alive(referenced from the Stack of any active Goroutines).
- When collection takes longer the process may employ active Goroutine from application to assist in the marking process. this is called Mark Assist.
- .

GC

- Mark Termination (Stop the world): Once marking is done every active Goroutine is paused and write barriers are turned off and clean up tasks are started. The GC also calculates the next GC goal here. Once this is done the reserved Ps are released back to the application.
- Sweeping (Concurrent): Once the collection is done and allocations are attempted, the sweeping process starts to reclaim memory from the heap that is not marked alive. The amount of memory swept is synchronous to the amount being allocated.

5. Analysis

- 5️⃣ **Escape Analysis**
- Compiler decides if a variable lives on **stack** (fast, no GC) or **heap** (needs GC).
- Example:

```
go

func main() {
    x := 42
    fmt.Println(x) // stays on stack
}
```

  - If a variable **escapes** function scope → allocated on heap.
  - Run with:

```
bash

go build -gcflags=-m main.go
```

6. Layout

- 6️⃣ **Memory Layout in Process**
- **A Go program's memory layout typically looks like this:**

```
+-----------------------------+
|  Text (compiled code)       |
+-----------------------------+
|  Global/Static variables    |
+-----------------------------+
|  Heap (dynamic allocations) |
|    - Managed by GC          |
+-----------------------------+
|  Stack (per goroutine)      |
|    - Function calls, locals |
+-----------------------------+
```

7. Concurrency & Memory

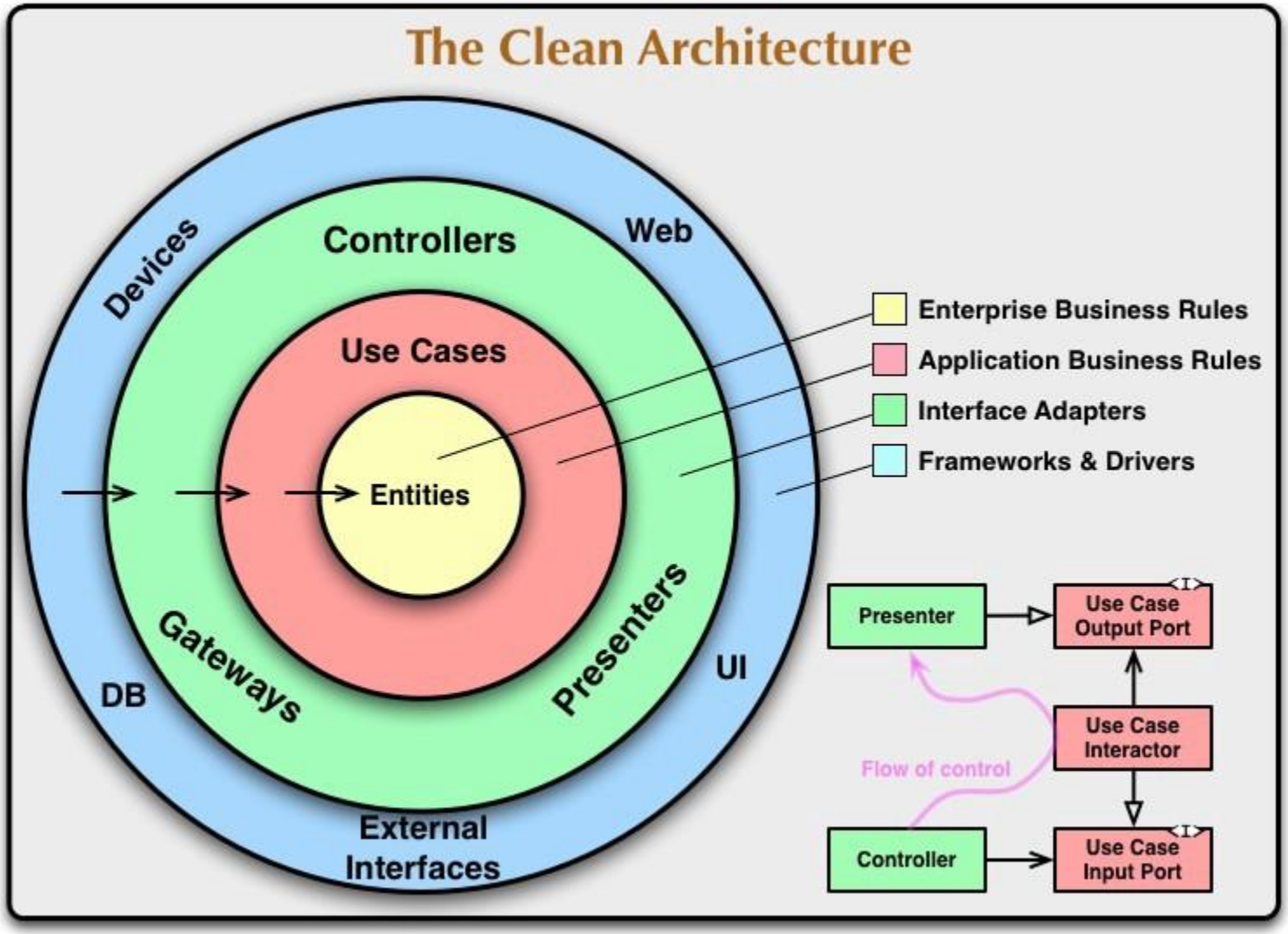
- 7 **Concurrency & Memory**
- Each goroutine’s stack is independent → no data races unless explicitly shared.
- Shared data (maps, slices, channels) lives on heap → needs synchronization (mutexes, channels).
- Scheduler (M:N model) + allocator design makes **millions of goroutines possible**.

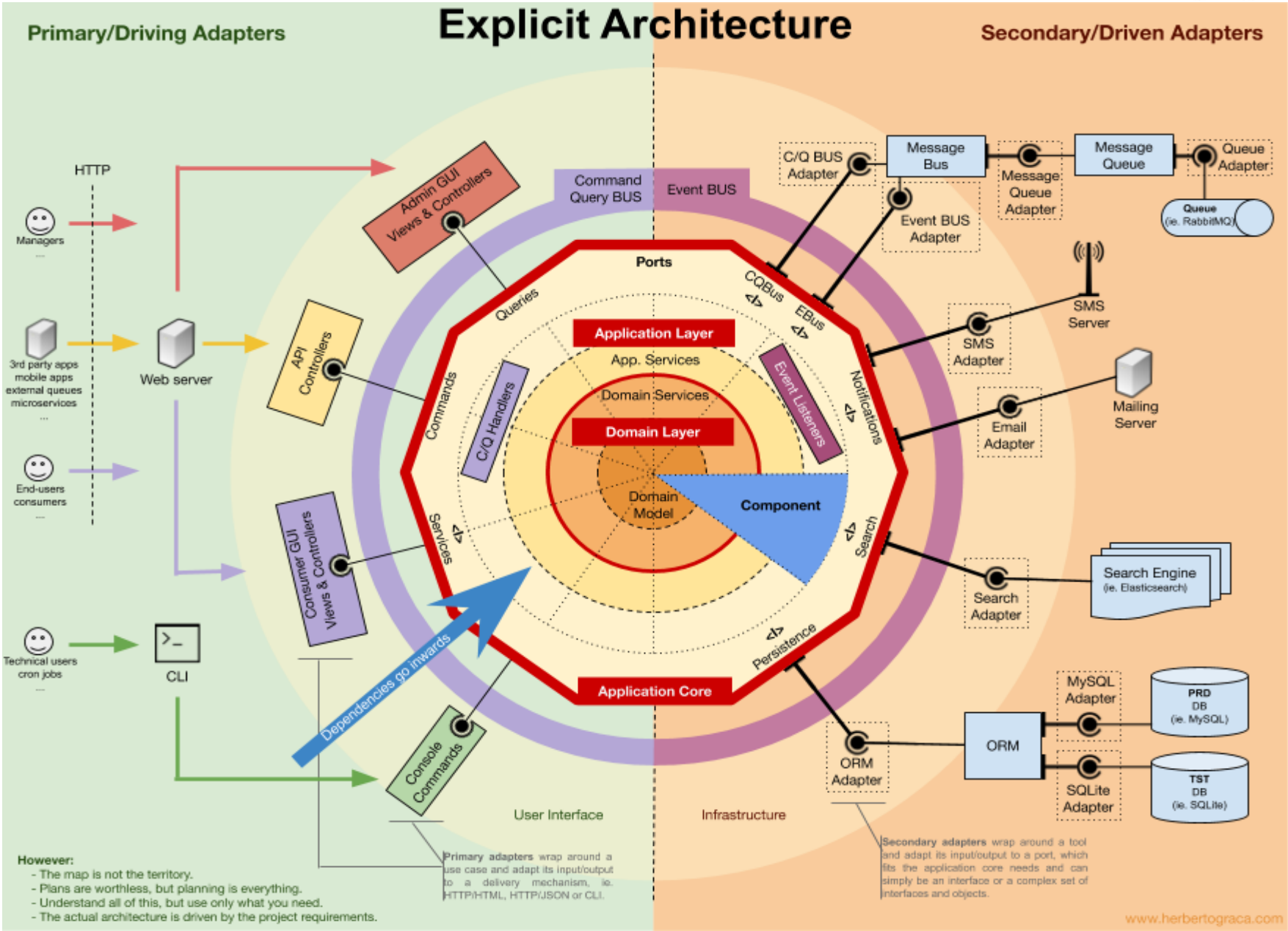
✅ Key Takeaways

- **Stack = fast, auto-managed** per goroutine.
- **Heap = global, GC-managed** for long-lived/shared data.
- **Allocator = mcache/mcentral/mheap** for low-latency allocations.
- **GC = concurrent, tri-color, low-pause** → keeps latency low.
- **Escape Analysis** decides heap vs stack allocation.

What is Clean Architecture?

- Popularized by Robert C. Martin (Uncle Bob).
- Organizes code into **layers with clear boundaries**.
- Rule: **Inner layers shouldn’t depend on outer layers**.
- Goal: keep **business rules (core logic)** independent from details (DB, HTTP, frameworks).


The Clean Architecture
Devices
Controllers
Web
Use Cases
Entities
Gateways
Presenters
DB
UI
External
Interfaces
Enterprise Business Rules
Application Business Rules
Interface Adapters
Frameworks & Drivers
Presenter
Use Case
Output Port
Use Case
Interactor
Flow of control
Controller
Use Case
Input Port


Explicit Architecture
Primary/Driving Adapters
Secondary/Driven Adapters
HTTP
Managers
3rd party apps
mobile apps
external queues
microservices
End-users
consumers
Technical users
cron jobs
Web server
CLI
Admin GUI
Views & Controllers
API
Controllers
Consumer GUI
Views & Controllers
Console
Commands
Command
Query BUS
Event BUS
Ports
Queries
Commands
Application Layer
App. Services
Domain Services
Domain Layer
Domain
Model
Component
C/Q Handlers
Event Listeners
CQBus
EBus
Notifications
Services
Search
Persistence
Application Core
Dependencies go inwards
User Interface
Infrastructure
C/Q BUS
Adapter
Message
Bus
Message
Queue
Adapter
Message
Queue
Queue
Adapter
Queue
(ie. RabbitMQ)
Event BUS
Adapter
SMS
Server
SMS
Adapter
Mailing
Server
Email
Adapter
Search Engine
(ie. Elasticsearch)
Search
Adapter
MySQL
Adapter
PRD
DB
(ie. MySQL)
ORM
ORM
Adapter
SQLite
Adapter
TST
DB
(ie. SQLite)
However:
- The map is not the territory.
- Plans are worthless, but planning is everything.
- Understand all of this, but use only what you need.
- The actual architecture is driven by the project requirements.
Primary adapters wrap around a use case and adapt its input/output to a delivery mechanism, ie. HTTP/HTML, HTTP/JSON or CLI.
Secondary adapters wrap around a tool and adapt its input/output to a port, which fits the application core needs and can simply be an interface or a complex set of interfaces and objects.
www.herbertograca.com

Go Questions

How do we run the code in our project?

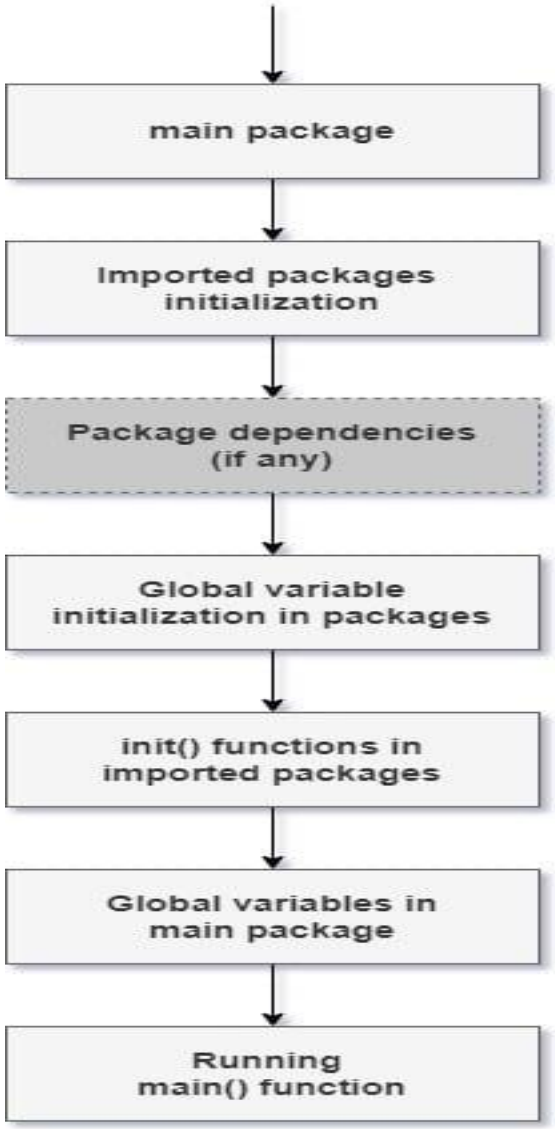
What does '*package main*' mean?

What does '*import "fmt"*' mean?

What's that '*func*' thing?

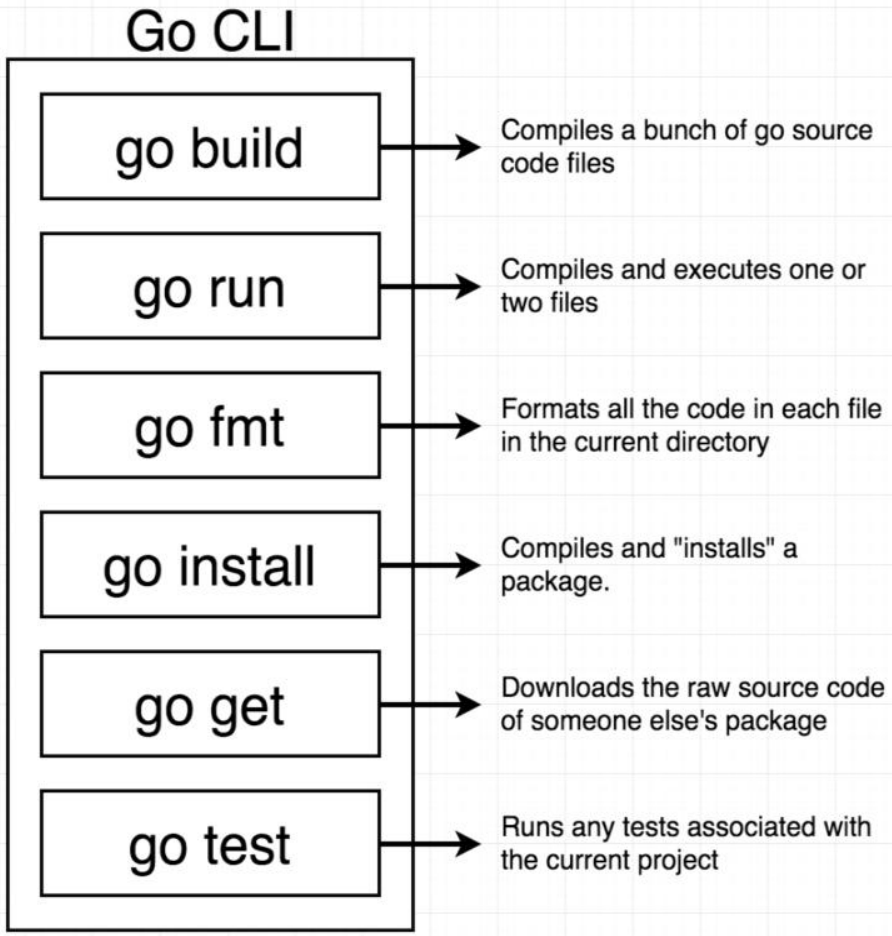
How is the main.go file organized?

Go Order Of Invocation



Go Compile and Run

How do we run the code in our project?



What is a Go Module?

📦 What is a Go Module?

- A **module** is a collection of Go packages stored in a file tree with a go.mod file at the root.
- The go.mod file defines:
  - The module path (usually a repo URL or project name).
  - The Go version.
  - The dependencies and their versions.

Since Go 1.16, modules are the **default** (replacing GOPATH-based workflow).

🛠 Step 1: Create a new module

- 🛠 Step 1: Create a new module

Inside your project folder:

```bash
mkdir myapp
cd myapp
go mod init myapp
```

This creates a `go.mod` file:

```
go

module myapp

go 1.22
```

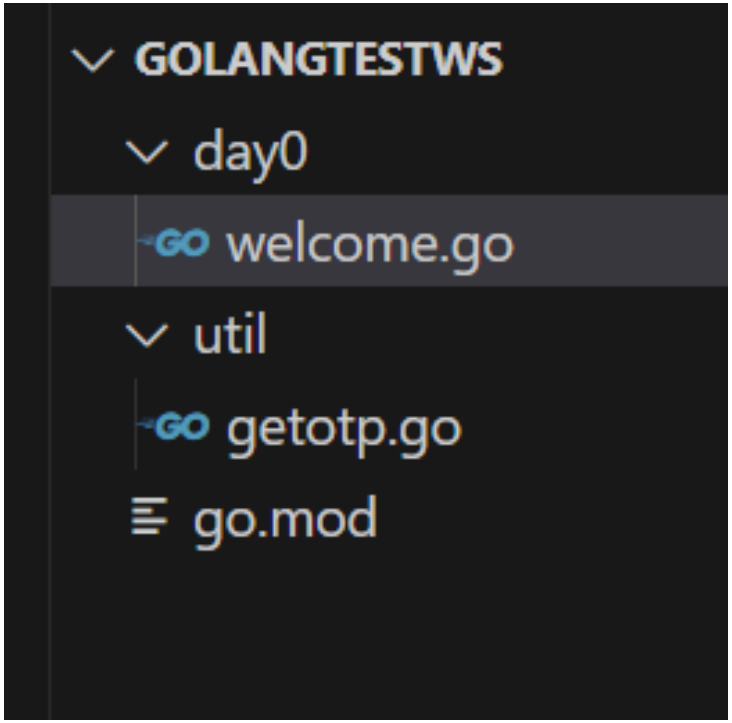
🛠 Step 2: Add code and local packages

- In Go, **a package is a collection of source files in the same directory that are compiled together**.
- Every Go program is made up of packages.
- The entry point is always the main package (with a main() function).

📂 Package structure example

```
go

myapp/
 ├── go.mod
 ├── main.go           // package main
 └── greetings/
     └── greetings.go  // package greetings
```

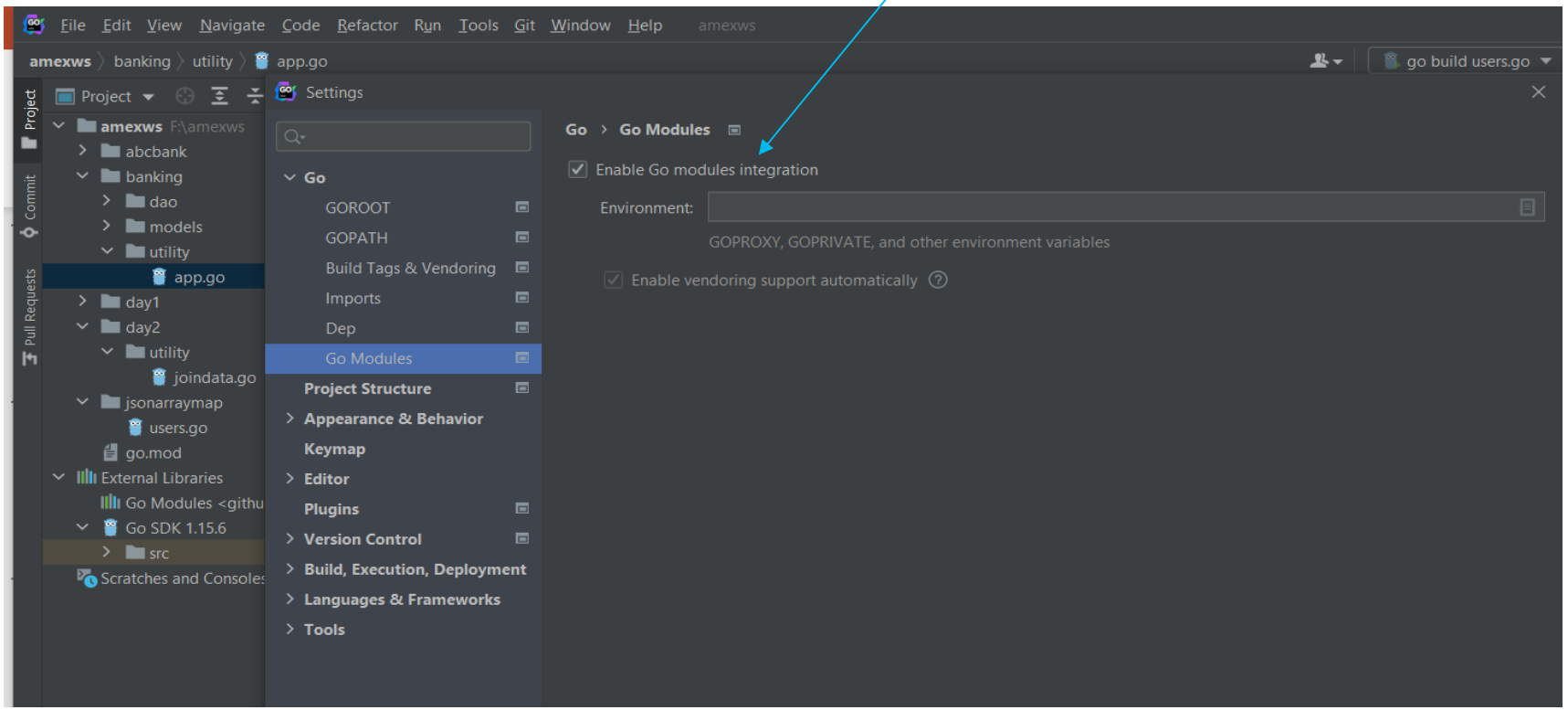
Go Packages



Go mod init github.com/eswaribala/gitlangtestws
#from root go to day0 folder
Go run .

Go mod in Goland

- Go mod init github.com/amexws/abcbank
- Set File settings Go mod preferences enable integration

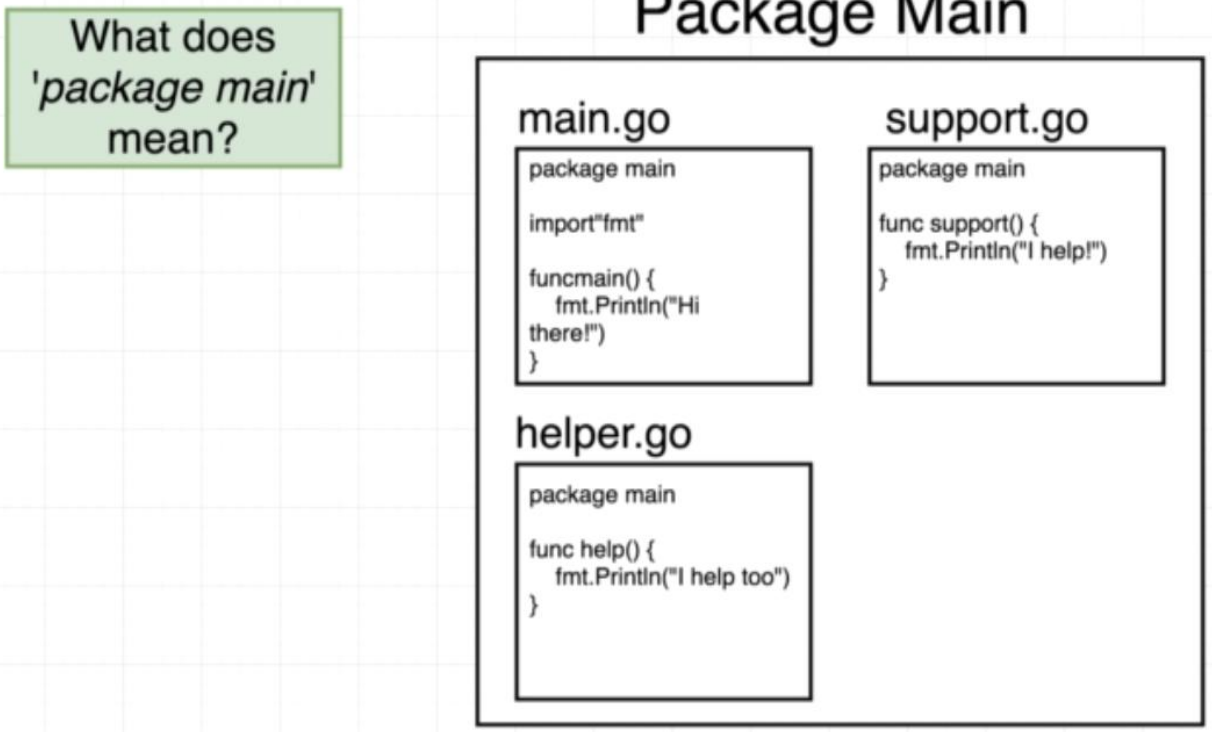


Key rules about packages

🔑 **Key rules about packages**

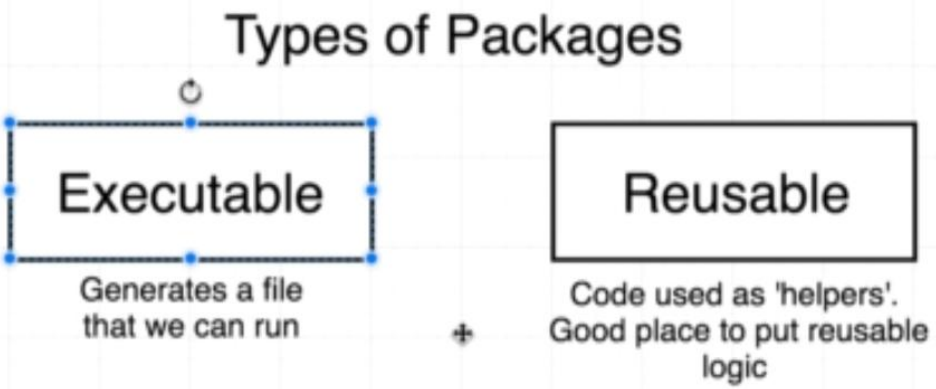
1. **Package name = directory name** (usually).
   - All files in a directory must have the same package statement.
2. **Exported vs unexported**:
   - Identifiers starting with an **uppercase letter** are exported (public).
   - Lowercase = private to the package.
3. **Main package**:
   - package main with a func main() is the entry point.
4. **Imports**:
   - Standard library: import "fmt"
   - External: import "github.com/google/uuid"
   - Local: relative to module name in go.mod.

What does package main mean



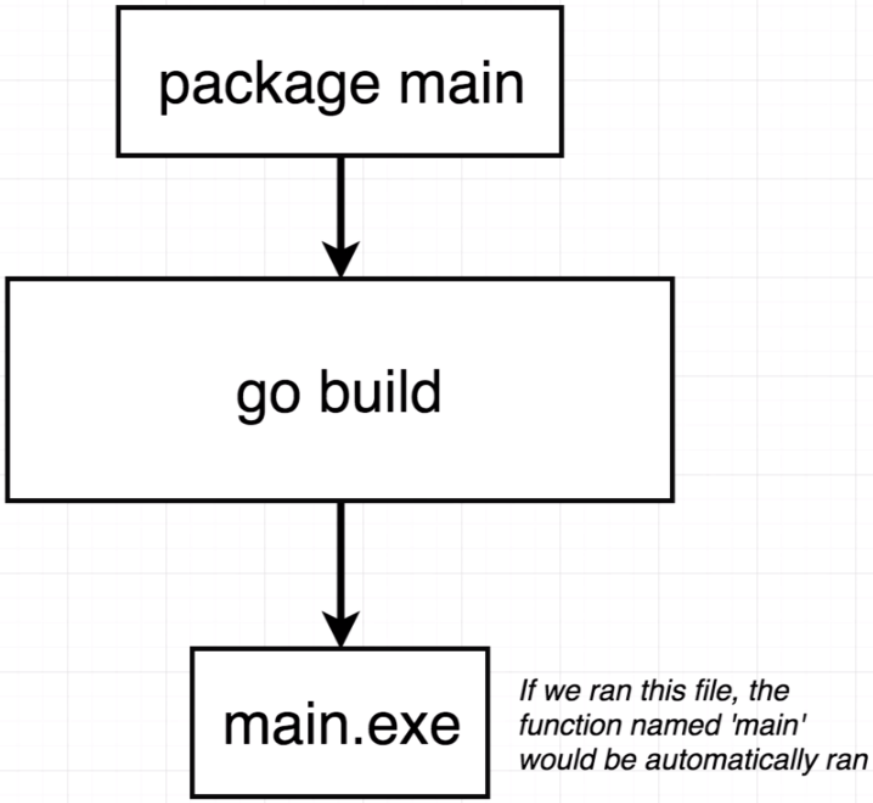
Types of packages

What does '*package main*' mean?



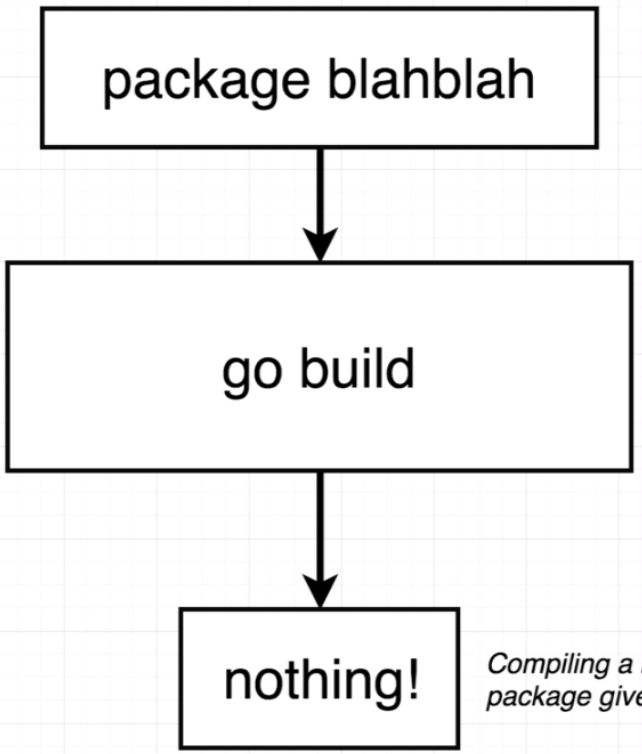
Go Package Main

What does '*package main*' mean?



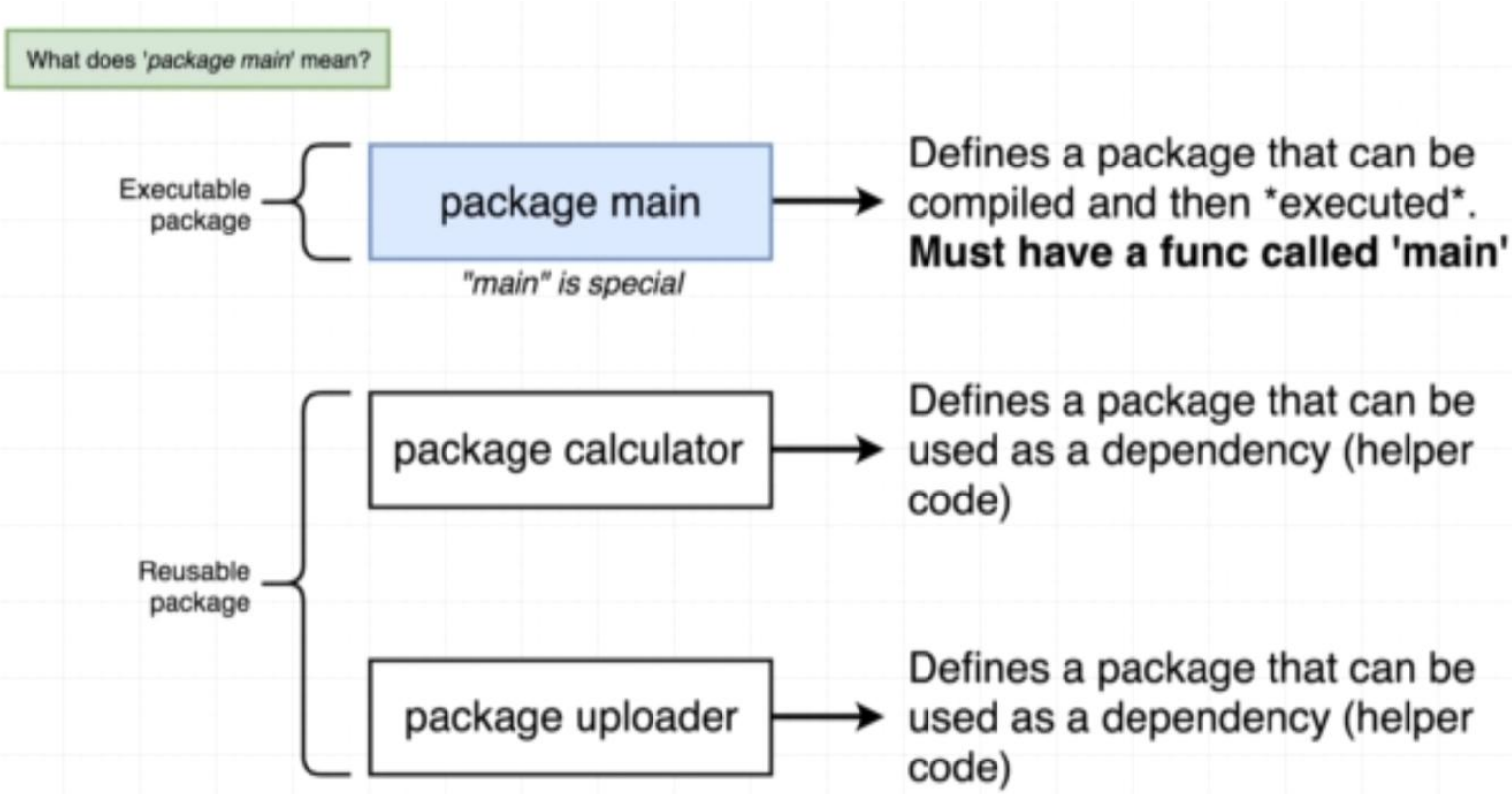
Go Packages

What does '*package main*' mean?



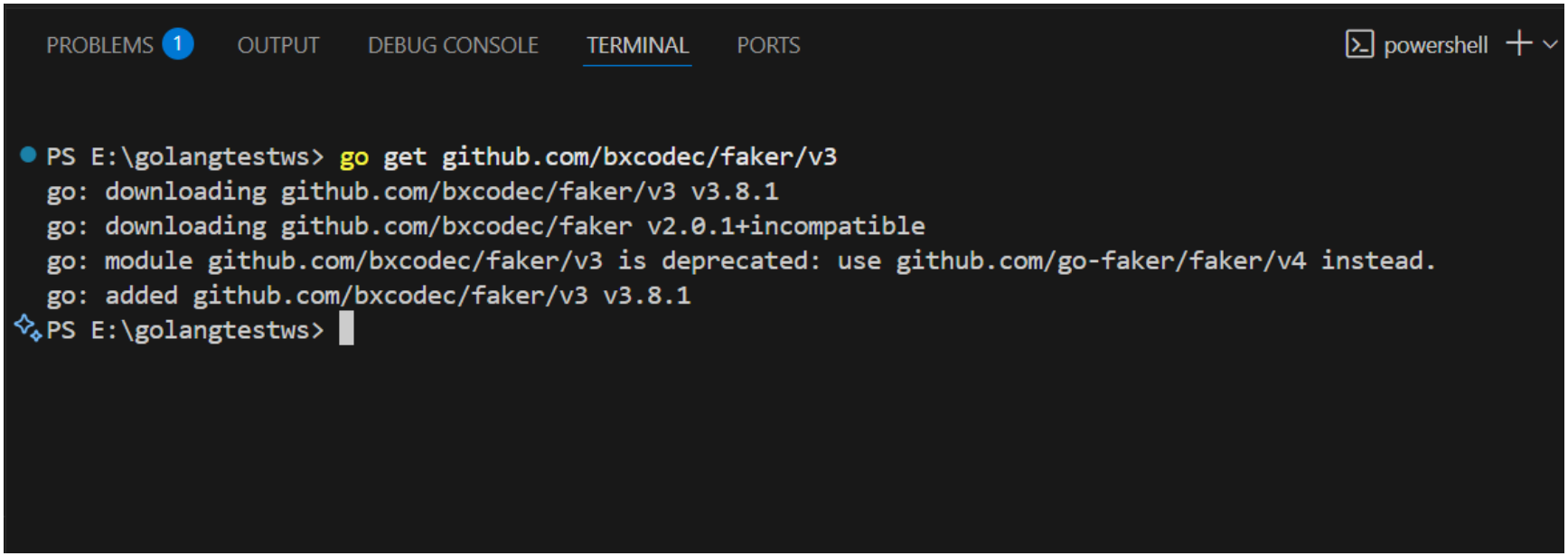
Compiling a non-main package gives

Multi Module GO



External Packages

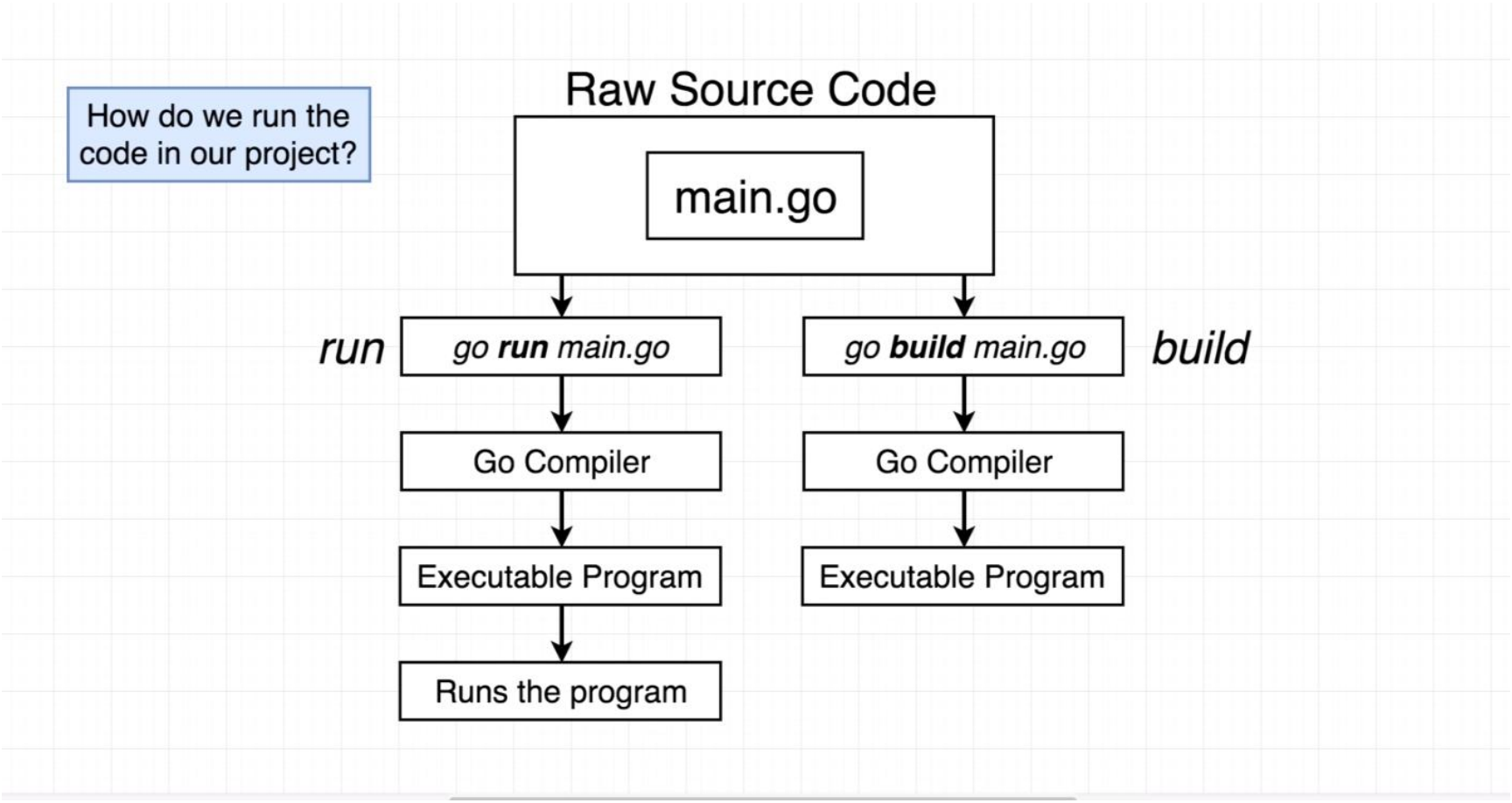
- go get github.com/bxcodec/faker/v3



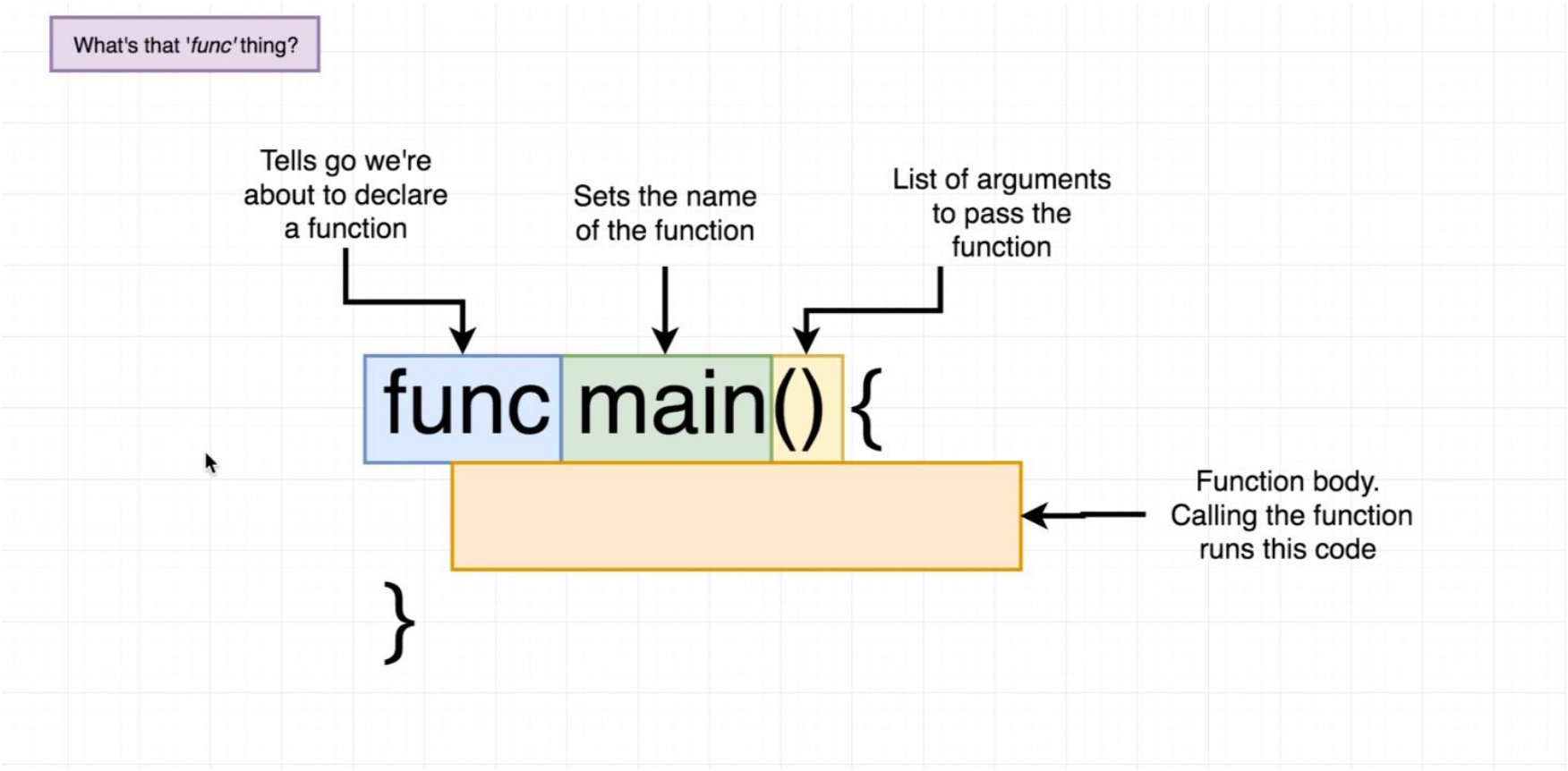
External Packages


```go
package main

import (
    "fmt"

    "github.com/bxcodec/faker/v3"
)

func GenerateNamesArray() {
    var names [5]string
    for i := 0; i < len(names); i++ {
        names[i] = faker.Name()
    }
    fmt.Println(names)
}
```

Go Compilation Process



Go Main Structure



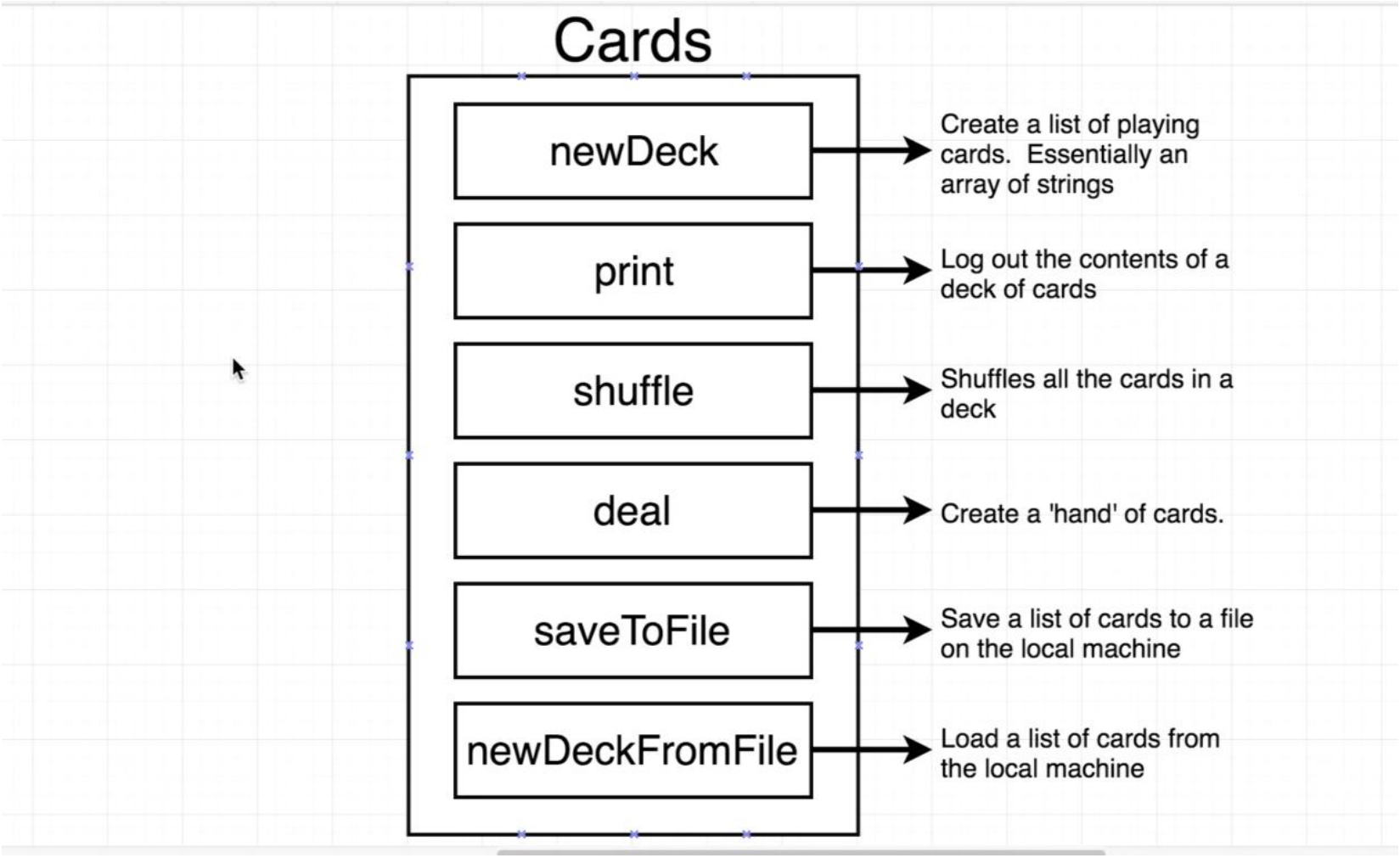
Go Main Structure

How is the main.go file organized?

`package main`	*Package declaration*
`import "fmt"`	*Import other packages that we need*

`func main() {`
`  fmt.Println("hi there")`
`}`
	Declare functions, tell Go to do things

Go Use case


Cards
newDeck
Create a list of playing cards. Essentially an array of strings
print
Log out the contents of a deck of cards
shuffle
Shuffles all the cards in a deck
deal
Create a 'hand' of cards.
saveToFile
Save a list of cards to a file on the local machine
newDeckFromFile
Load a list of cards from the local machine

Golang Structure

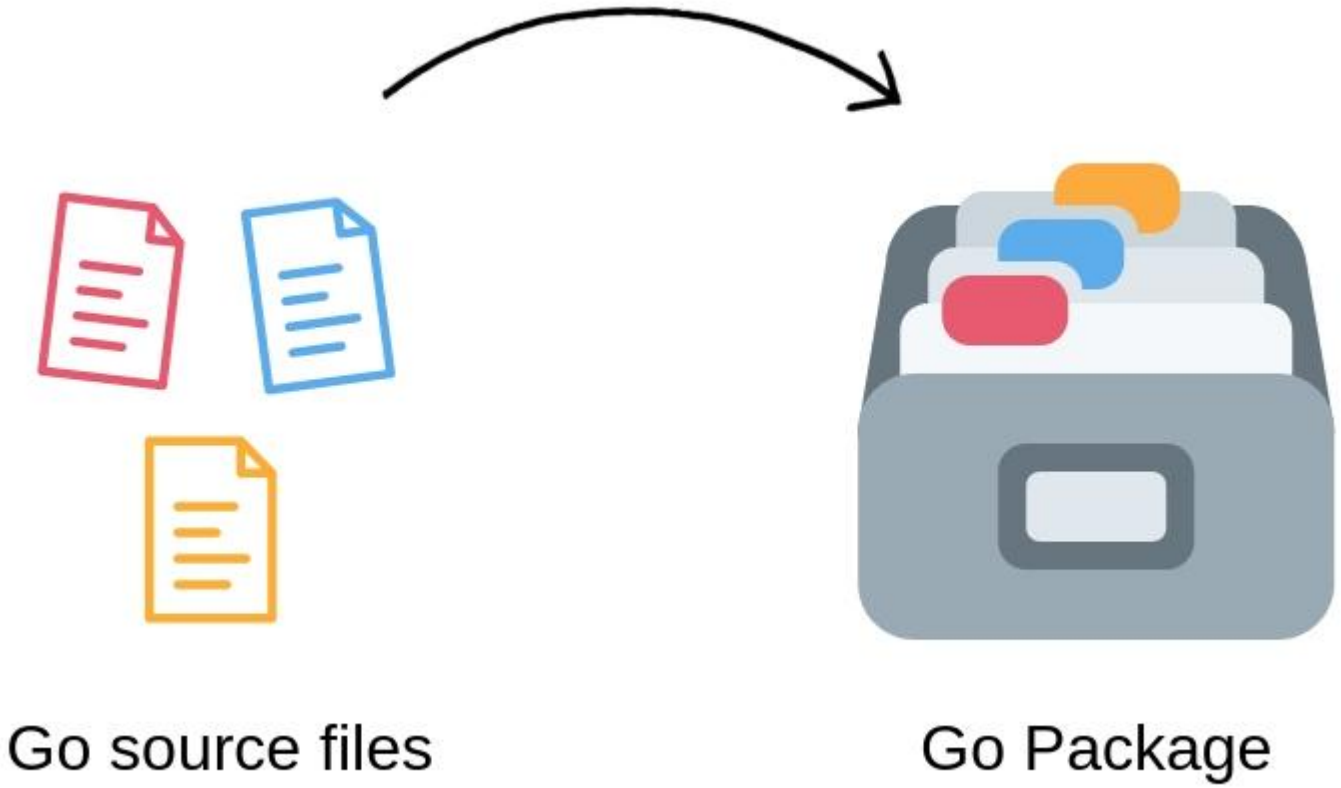
- Every Go Program Contains the following Parts

  - Declaration of Packages
  - Package Importing
  - Functions
  - Variables
  - Expression and Statements
  - Comments

Golang Execution Steps

- Step1) Write the Go Program in a Text Editor.
- Step2) Save the program with ".go" as the program file extension.
- Step3) Go to command Prompt.
- Step4) In the command prompt, we have to open the directory where we have saved our Program.
- Step5) After opening the directory, we have to open our file and click enter to compile our code.
- Step6) If no errors are present in our code, then our program is executed, and the following output is displayed:

Packages



Packages – Standard Libraries

1. Core / Language Support

- `fmt` → formatted I/O (`fmt.Println`, `fmt.Sprintf`)
- `errors` → error handling (`errors.New`, `errors.Is`)
- `strconv` → string ↔ numeric conversions
- `strings` → string manipulation
- `unicode`, `unicode/utf8` → Unicode runes, UTF-8 encoding
- `reflect` → runtime reflection
- `unsafe` → low-level pointer operations

Packages – Standard Libraries

2. I/O and Files

- `os` → operating system interface (files, env vars, process)
- `io` → basic I/O primitives (`Reader`, `Writer`)
- `io/ioutil` → old helpers (deprecated in favor of `os` and `io`)
- `bufio` → buffered I/O
- `path`, `path/filepath` → path handling (Unix-style and OS-native)
- `embed` → embedding static files into binaries

Packages – Standard Libraries

3. Time and Dates

- `time` → time, duration, timers, tickers
- `context` → request-scoped cancellation, deadlines

---

4. Math

- `math` → floating-point math
- `math/rand` → pseudo-random numbers
- `crypto/rand` → secure random numbers
- `math/big` → arbitrary-precision integers and floats
- `math/cmplx` → complex number math

Packages – Standard Libraries

5. Networking & Internet

- `net` → TCP/UDP sockets, DNS
- `net/http` → HTTP client/server
- `net/url` → URL parsing
- `net/mail` → parsing email headers
- `net/smtp` → sending email
- `html`, `html/template` → escaping, templating

Packages – Standard Libraries

6. Data Encoding / Decoding

- `encoding/json` → JSON encode/decode
- `encoding/xml` → XML encode/decode
- `encoding/csv` → CSV reader/writer
- `encoding/base64`, `hex`, `binary` → encodings
- `compress/gzip`, `zlib`, `flate` → compression
- `archive/zip`, `tar` → archive formats

Packages – Standard Libraries

7. Cryptography & Security

- `crypto` → common interfaces
- `crypto/sha256`, `sha512`, `md5` → hashing
- `crypto/hmac` → HMAC signatures
- `crypto/aes`, `des`, `rsa`, `ecdsa`, `ed25519` → encryption/signatures
- `crypto/tls` → TLS (SSL)
- `crypto/x509` → certificates

8. Concurrency / Sync

- `sync` → mutexes, waitgroups
- `sync/atomic` → low-level atomic ops
- `runtime` → goroutine and GC info
- `runtime/debug` → debugging
- `runtime/pprof` → profiling

Packages – Standard Libraries

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Packages – Standard Libraries

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- `runtime` → goroutine and GC info
- `runtime/debug` → debugging
- `runtime/pprof` → profiling

9. Testing

- `testing` → unit tests (`go test`)
- `testing/quick` → randomized property testing
- `net/http/httptest` → HTTP test servers

Your First Program


```
package main

import "fmt"

// this is a comment

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

package main

- This is known as a “package declaration”.
- Every Go program must start with a package declaration.
- Packages are Go's way of organizing and reusing code.
- There are two types of Go programs: executables and libraries.
- **Executable** applications are the kinds of programs that we can run directly from the terminal. (in Windows they end with .exe)
- **Libraries** are collections of code that we package together so that we can use them in other programs.

Packages and imports Every Go


```
package main

func main() {
        print("Hello, World!\n")
}
```

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

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

Code Location


```
import "github.com/mattetti/goRailsYourself/crypto"
```

```
$ go get github.com/mattetti/goRailsYourself/crypto
```

Import fmt

- The import keyword is how we include code from other packages to use with our program.
- The fmt package (shorthand for format) implements formatting for input and output.

Fmt package

📦 `fmt` Package Overview

Common functions

- **Printing**
  - `fmt.Print()` → print values
  - `fmt.Println()` → print values + newline
  - `fmt.Printf(format, args...)` → C-style formatted output
- **Formatting (return as string)**
  - `fmt.Sprint()`
  - `fmt.Sprintln()`
  - `fmt.Sprintf(format, args...)`
- **Input**
  - `fmt.Scan()`, `fmt.Scanf()`, `fmt.Scanln()` → read from `os.Stdin`

Fmt package

Verb	Meaning (for Printf / Sprintf)
%v	default format (any value)
%+v	include field names for structs
%#v	Go syntax representation
%T	type of the value
%d	decimal integer
%b	binary integer
%x / %X	hex integer (lower/upper)
%f	float decimal
%e / %E	scientific notation
%t	boolean
%s	string
%q	quoted string
%p	pointer (address)

Fmt package


```go
// Print / Println
fmt.Print("Hello")            // Hello
fmt.Println("Go", 2025)       // Go 2025

// Printf with format verbs
n := 42
fmt.Printf("Decimal: %d\n", n)     // Decimal: 42
fmt.Printf("Binary: %b\n", n)      // Binary: 101010
fmt.Printf("Hex: %x\n", n)         // Hex: 2a

// Floats
f := 3.14159
fmt.Printf("Float: %.2f\n", f)     // Float: 3.14

// Strings
s := "golang"
fmt.Printf("String: %s\n", s)      // String: golang
fmt.Printf("Quoted: %q\n", s)      // Quoted: "golang"

// Structs
u := User{"Alice", 30}
fmt.Printf("Default: %v\n", u)     // {Alice 30}
fmt.Printf("With fields: %+v\n", u) // {Name:Alice Age:30}
fmt.Printf("Go syntax: %#v\n", u) // main.User{Name:"Alice", Age:30}
fmt.Printf("Type: %T\n", u)        // main.User

// Sprint -> returns string
msg := fmt.Sprintf("Hi %s, age %d", u.Name, u.Age)
fmt.Println(msg)                   // Hi Alice, age 30
```

How To Write Comments in Go


```
// This is a comment


/*
Everything here
will be considered
a block comment
*/
```

Naming Variables: Rules and Style

- The naming of variables is quite flexible, but there are some rules to keep in mind:
- Variable names must only be one word (as in no spaces).
- Variable names must be made up of only letters, numbers, and underscores (_).
- Variable names cannot begin with a number.

Valid	Invalid	Why Invalid
`userName`	`user-name`	Hyphens are not permitted
`name4`	`4name`	Cannot begin with a number
`user`	`$user`	Cannot use symbols
`userName`	`user name`	Cannot be more than one word

Global and Local Variables


```
package main

import "fmt"


var g = "global"

func printLocal() {
    l := "local"
    fmt.Println(l)
}

func main() {
    printLocal()
    fmt.Println(g)
}
```

Data Types

Category	Type(s)	Example Declaration	Example Value	Zero Value
Boolean	bool	var b bool = true	true, false	false
Integer (signed)	int, int8, int16, int32 (rune), int64	var x int32 = -42	-42	0
Integer (unsigned)	uint, uint8 (byte), uint16, uint32, uint64, uintptr	var y uint16 = 500	500	0
Float	float32, float64	var pi float64 = 3.1415	3.1415	0.0
Complex	complex64, complex128	z := complex(2, 3)	(2+3i)	0+0i

Data Types

String	string	name := "GoLang"	"GoLang"	"" (empty string)
Pointer	*T	var p *int	pointer to int	nil
Array	[N]T	var arr [3]int = [3]int{1,2,3}	[1 2 3]	[0 0 0]
Slice	[]T	s := []int{1,2,3}	[1 2 3]	nil
Map	map[K]V	m := map[string]int{"Alice":25}	map[Alice:25]	nil
Struct	struct {}	type P struct {Name string}	P{Name:"Bob"}	field zero-values
Interface	interface{} or custom	var i interface{} = 42	42	nil
Function	func	var f func(int) int	function reference	nil
Channel	chan T	c := make(chan int)	channel reference	nil

Data Types

Data Type	Range
uint8	0 to 255
uint16	0 to 65535
uint32	0 to 4294967295
uint64	0 to 18446744073709551615

Data Type	Range
int8	-128 to 127
int16	-32768 to 32767
int32	-2147483648 to 2147483647
int64	-9223372036854775808 to 9223372036854775808

Data Types

Go has the following architecture-independent integer types:

```
uint8       unsigned  8-bit integers (0 to 255)
uint16      unsigned 16-bit integers (0 to 65535)
uint32      unsigned 32-bit integers (0 to 4294967295)
uint64      unsigned 64-bit integers (0 to 18446744073709551615)
int8        signed  8-bit integers (-128 to 127)
int16       signed 16-bit integers (-32768 to 32767)
int32       signed 32-bit integers (-2147483648 to 2147483647)
int64       signed 64-bit integers (-9223372036854775808 to 9223372036854775807)
```

Floats and complex numbers also come in varying sizes:

```
float32     IEEE-754 32-bit floating-point numbers
float64     IEEE-754 64-bit floating-point numbers
complex64   complex numbers with float32 real and imaginary parts
complex128  complex numbers with float64 real and imaginary parts
```

There are also a couple of alias number types, which assign useful names to specific data types:

```
byte        alias for uint8
rune        alias for int32
```

Data Types


```
uint     unsigned, either 32 or 64 bits
int      signed, either 32 or 64 bits
uintptr  unsigned integer large enough to store the uninterpreted bits of a pointer value
```

Keywords

break	default	func	interface	select
case	defer	go	map	struct
chan	else	goto	package	switch
const	fallthrough	If	range	type
continue	for	import	return	var

Variables & inferred typing

The var statement declares a list of variables with the type declared last.

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

Or even

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

Variables & inferred typing

Variables can also be declared one by one:

```
var name      string
var age       int
var location string
```

A var declaration can include initializers, one per variable.

```
var (
        name      string = "Prince Oberyn"
        age       int    =  32
        location string = "Dorne"
)
```

If an initializer is present, the type can be omitted, the variable will take the type of the initializer (inferred typing).

```
var (
        name      = "Prince Oberyn"
        age       =  32
        location = "Dorne"
)
```

Variables & inferred typing

You can also initialize variables on the same line:

```
var (
        name, location, age = "Prince Oberyn", "Dorne", 32
)
```

Inside a function, the := short assignment statement can be used in place of a var declaration with implicit type.

```
func main() {
        name, location := "Prince Oberyn", "Dorne"
        age := 32
        fmt.Printf("%s (%d) of %s", name, age, location)
}
```

A variable can contain any type, including functions:

```
func main() {
        action := func() {
                //doing something
        }
        action()
}
```

Constants


```
const Pi = 3.14
const (
        StatusOK                   = 200
        StatusCreated              = 201
        StatusAccepted             = 202
        StatusNonAuthoritativeInfo = 203
        StatusNoContent            = 204
        StatusResetContent         = 205
        StatusPartialContent       = 206
)
```

```
const (
        Pi     = 3.14
        Truth  = false
        Big    = 1 << 62
        Small  = Big >> 61
)

func main() {
        const Greeting = ""
        fmt.Println(Greeting)
        fmt.Println(Pi)
        fmt.Println(Truth)
        fmt.Println(Big)
}
```

Basic Types


```
package main

import (
        "fmt"
        "math/cmplx"
)

var (
        goIsFun bool       = true
        maxInt  uint64     = 1<<64 - 1
        complex complex128 = cmplx.Sqrt(-5 + 12i)
)

func main() {
        const f = "%T(%v)\n"
        fmt.Printf(f, goIsFun, goIsFun)
        fmt.Printf(f, maxInt, maxInt)
        fmt.Printf(f, complex, complex)
}
```

```
bool(true)
uint64(18446744073709551615)
complex128((2+3i))
```

Type conversion

The expression `T(v)` converts the value `v` to the type `T`. Some numeric conversions:

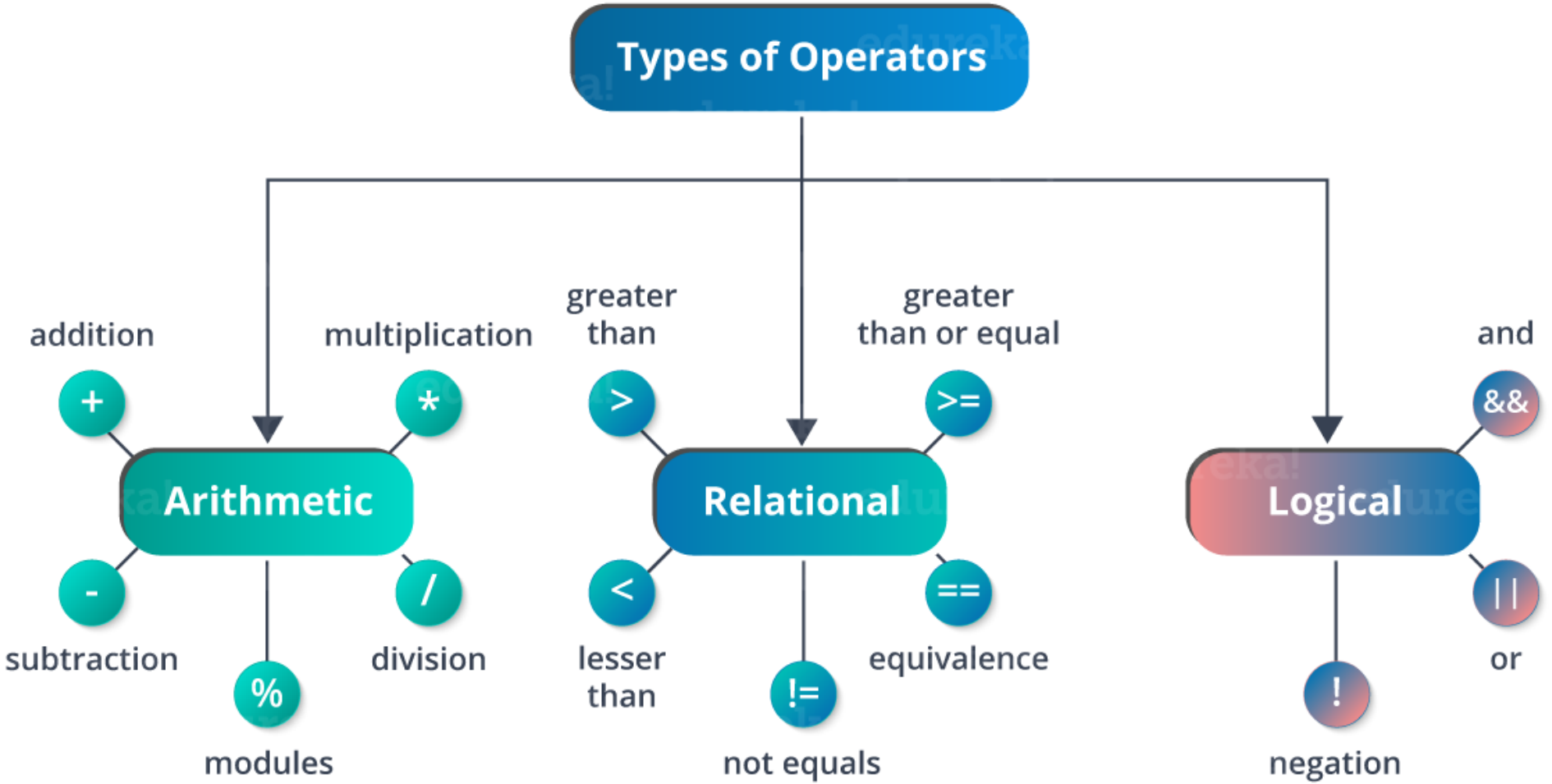
```
var i int = 42
var f float64 = float64(i)
var u uint = uint(f)
```

```
b := 125.0
c := 390.8

fmt.Println(int(b))
fmt.Println(int(c))
```

```
package main

import (
    "fmt"
    "strconv"
)

func main() {
    a := strconv.Itoa(12)
    fmt.Printf("%q\n", a)
}
```

```
a := "not a number"
b, err := strconv.Atoi(a)
fmt.Println(b)
fmt.Println(err)
```

Operators


Types of Operators
Arithmetic
addition
+
multiplication
*
subtraction
-
division
/
modules
%
Relational
greater than
>
greater than or equal
>=
lesser than
<
not equals
!=
equivalence
==
Logical
and
&&
or
||
negation
!

Array

📦 Arrays in Go

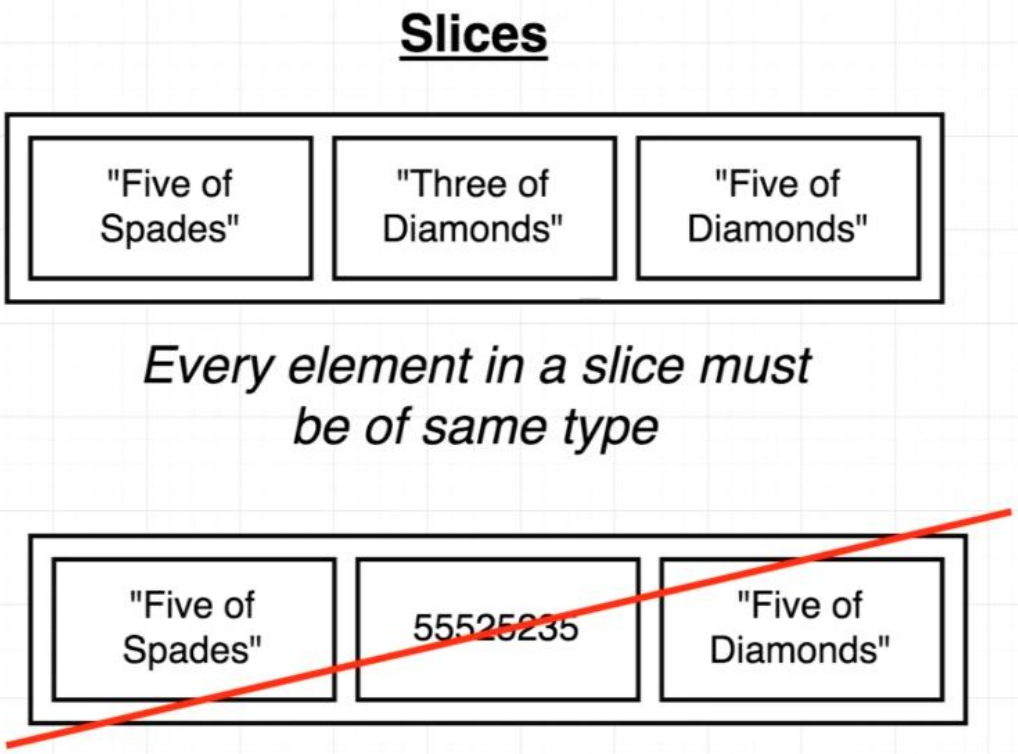
🔹 Definition

• An **array** is a **fixed-length** sequence of elements of the same type.

• Length is part of the type ([5]int is not the same as [10]int).

•var arr [3]int // array of 3 ints, initialized to [0 0 0]

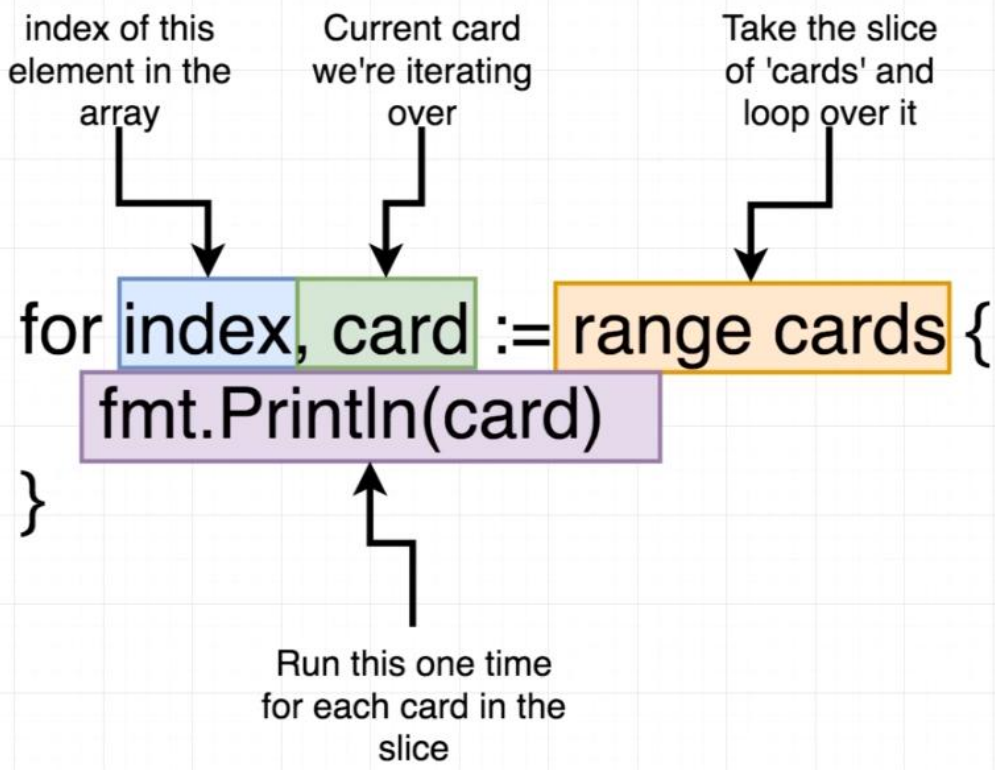
Array


Slices
"Five of Spades"
"Three of Diamonds"
"Five of Diamonds"
Every element in a slice must be of same type
"Five of Spades"
55525235
"Five of Diamonds"

Array


```go
import "fmt"

func main() {
    cards := []string{"Ace of Diamonds", newCard()}
    cards = append(cards, "Six of Spades")

    for i, card := range cards {
        fmt.Println(i, card)
    }
}

func newCard() string {
    return "Five of Diamonds"
}
```

Array


index of this element in the array
Current card we're iterating over
Take the slice of 'cards' and loop over it
for index, card := range cards {
fmt.Println(card)
}
Run this one time for each card in the slice

Array

Question 3:

How do we iterate through each element in a slice and print out its value?

- ○
```
colors := []string{"Red", "Yellow", "Blue"}
for value in colors {
   fmt.Println(value)
}
```

- ○
```
colors := []string{"Red", "Yellow", "Blue"}
colors.forEach(func(value, index) {
   fmt.Println(value)
})
```

- ○
```
colors := []string{"Red", "Yellow", "Blue"}
for index, color := colors {
   fmt.Println(index, color)
}
```

- ◉
```
colors := []string{"Red", "Yellow", "Blue"}
for index, color := range colors {
   fmt.Println(index, color)
}
```

Arrays

- Define Array
  - *[capacity]data_type{element_values}*
  - *[4]string{"blue coral", "staghorn coral", "pillar coral", "elkhorn coral"}*

- `coral := [4]string{"blue coral", "staghorn coral", "pillar coral", "elkhorn coral”}`
- `fmt.Println(coral)`

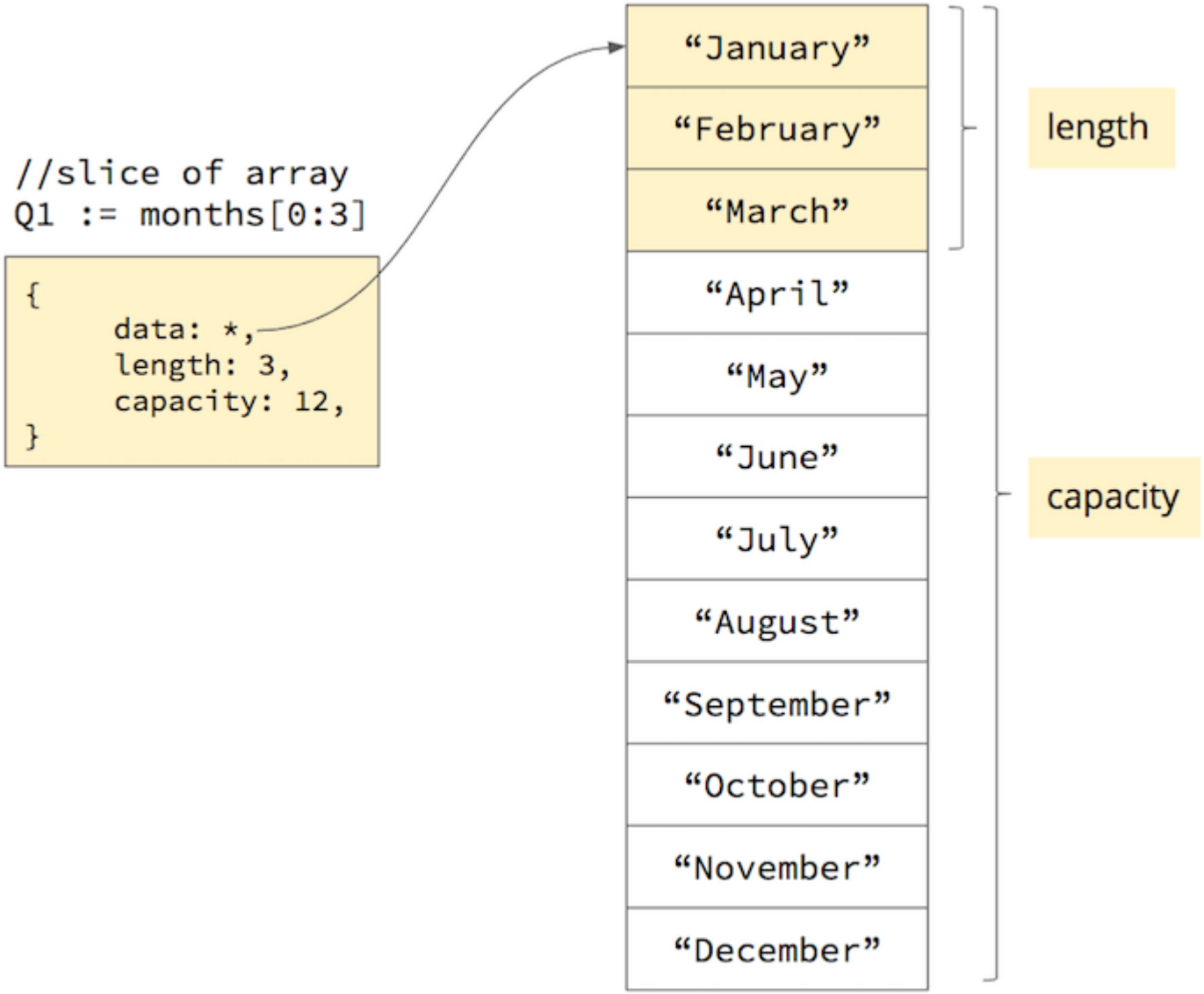
Arrays

- var myArray1 = [3]int // will be filled with so called zero values, for integers: 0
- var myArray2 = [5]int{1,2,3,4,5} // number of values between { } can not be larger than size (ofc)
- var myArray3 = […]int{1,2,3,4} // the compiler will count the array elements for you

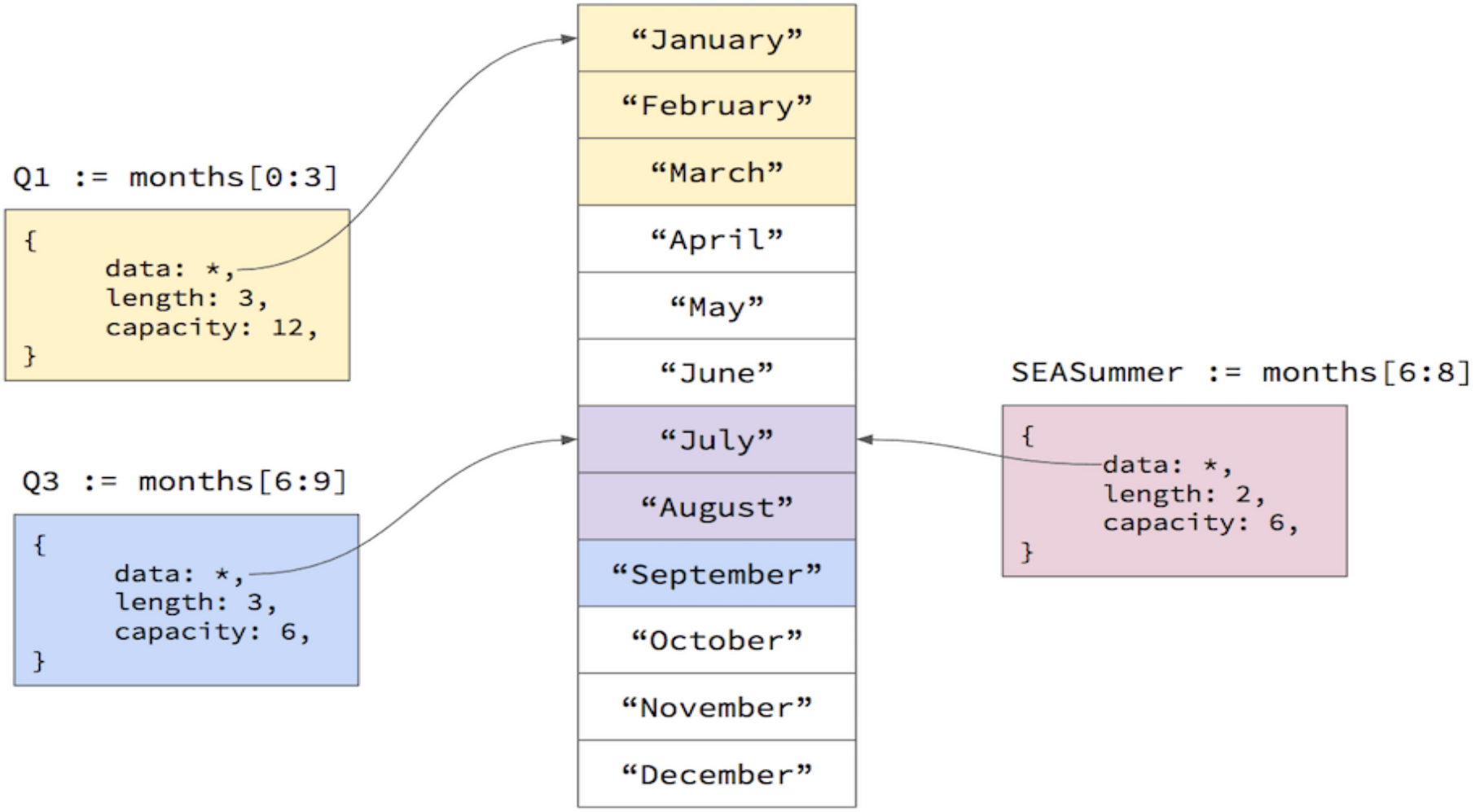
Arrays

- ar variable_name [SIZE1][SIZE2]…[SIZEN] variable_type
- a := [3][4]int{
- {0, 1, 2, 3} , // initializers for row indexed by 0
- {4, 5, 6, 7} , // initializers for row indexed by 1 */
- {8, 9, 10, 11} // initializers for row indexed by 2
- }

Slices


//slice of array
Q1 := months[0:3]
{
data: *,
length: 3,
capacity: 12,
}
“January”
“February”
“March”
“April”
“May”
“June”
“July”
“August”
“September”
“October”
“November”
“December”
length
capacity

Slices


Q1 := months[0:3]
{
data: *,
length: 3,
capacity: 12,
}
Q3 := months[6:9]
{
data: *,
length: 3,
capacity: 6,
}
"January"
"February"
"March"
"April"
"May"
"June"
"July"
"August"
"September"
"October"
"November"
"December"
SEASummer := months[6:8]
{
data: *,
length: 2,
capacity: 6,
}

Creating slices

- From an existing array
- We already stated slices are an abstraction over the array, so let's grab a slice from an array.
- myArray := [10]int{0,1,2,3,4,5,6,7,8,9} // firstly we need an array to make the slice out of
- mySlice1 := myArray[1:5] // slice from 1st up to 5th element, so [1 2 3 4]
- mySlice2 := mySlice1[0:2] slicing a slice
  // [1 2]

Creating slices

- var mySlice3 := make([]int, 4, 4) // mySlice has lenght and capacity 5, and it’s filled with zero values for int, so it's [0 0 0 0]
- mySlice5 := make([]int, 2, 4) // now it's [0 0 nil nil]
- // but be aware that nil
- // values don't print, so
- // when printed it will be
- // just [0 0]

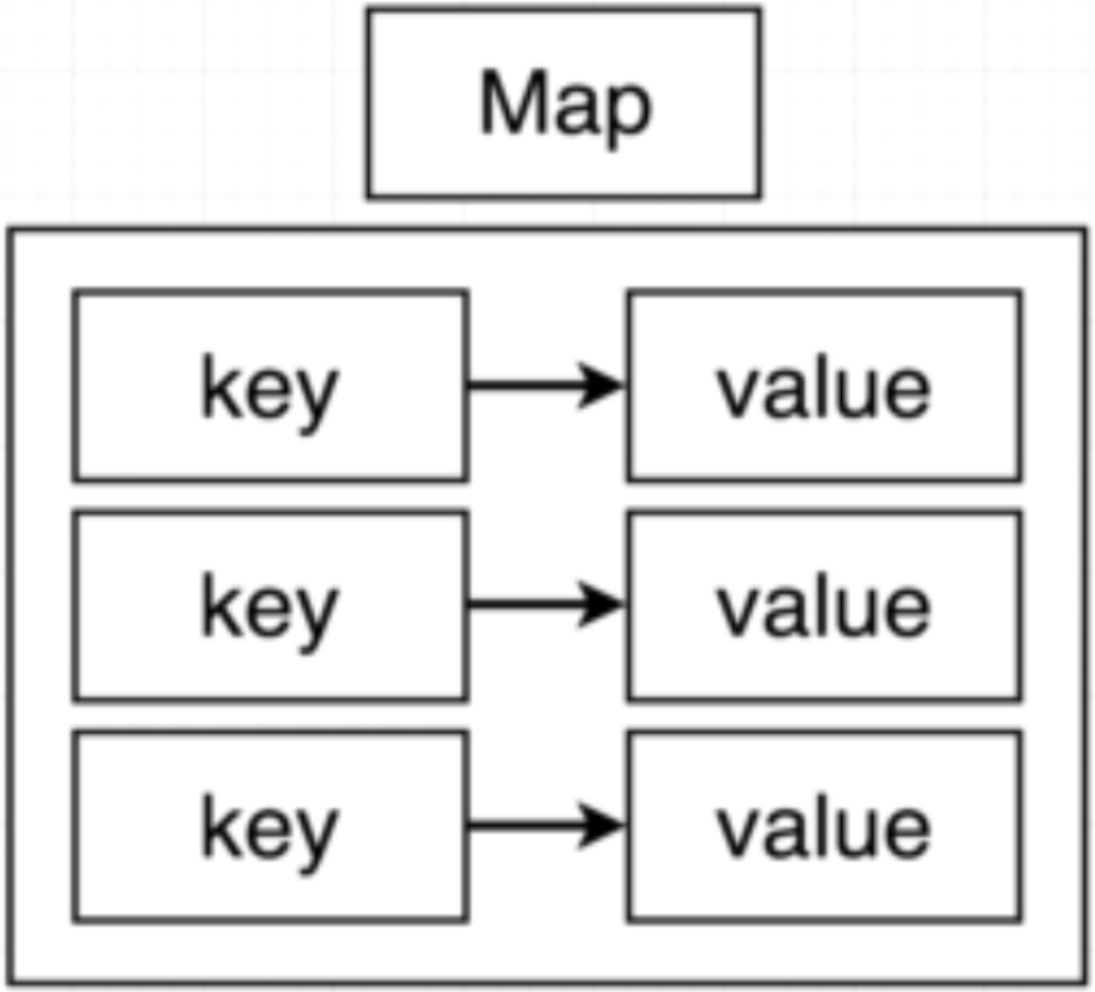
Arrays


```
regNos :=make([]int32,100)
//Assign values
for r:=range regNos{
regNos[r] = rand.Int31n(1000)
        }
//print values
for index, val := range regNos{
        fmt.Printf("%d = %d\n", index, val)
}
```

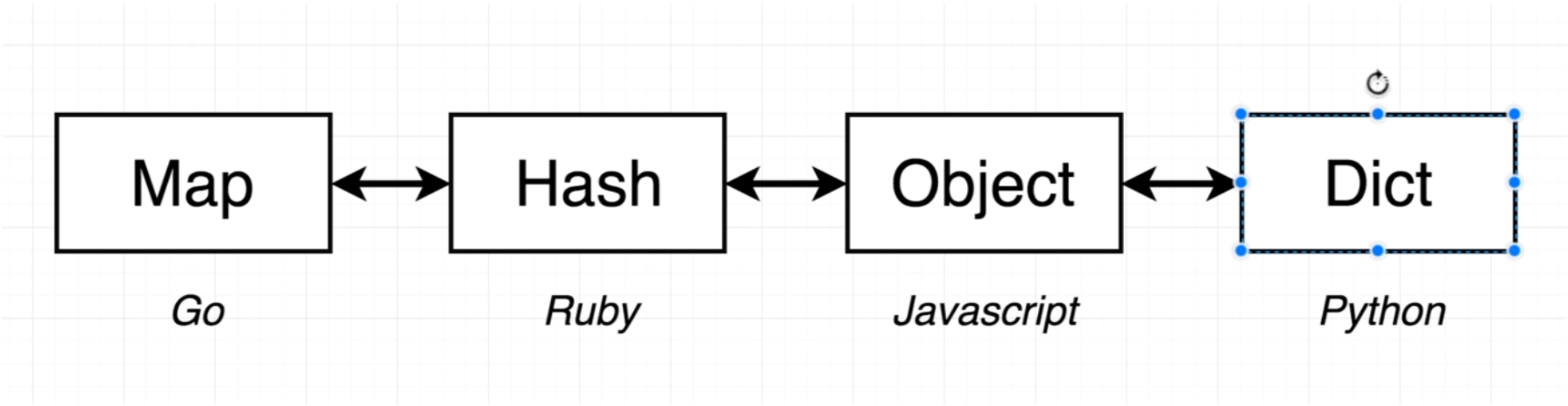
Map

- A map maps keys to values.
- The zero value of a map is nil. A nil map has no keys, nor can keys be added.
- The make function returns a map of the given type, initialized and ready for use.

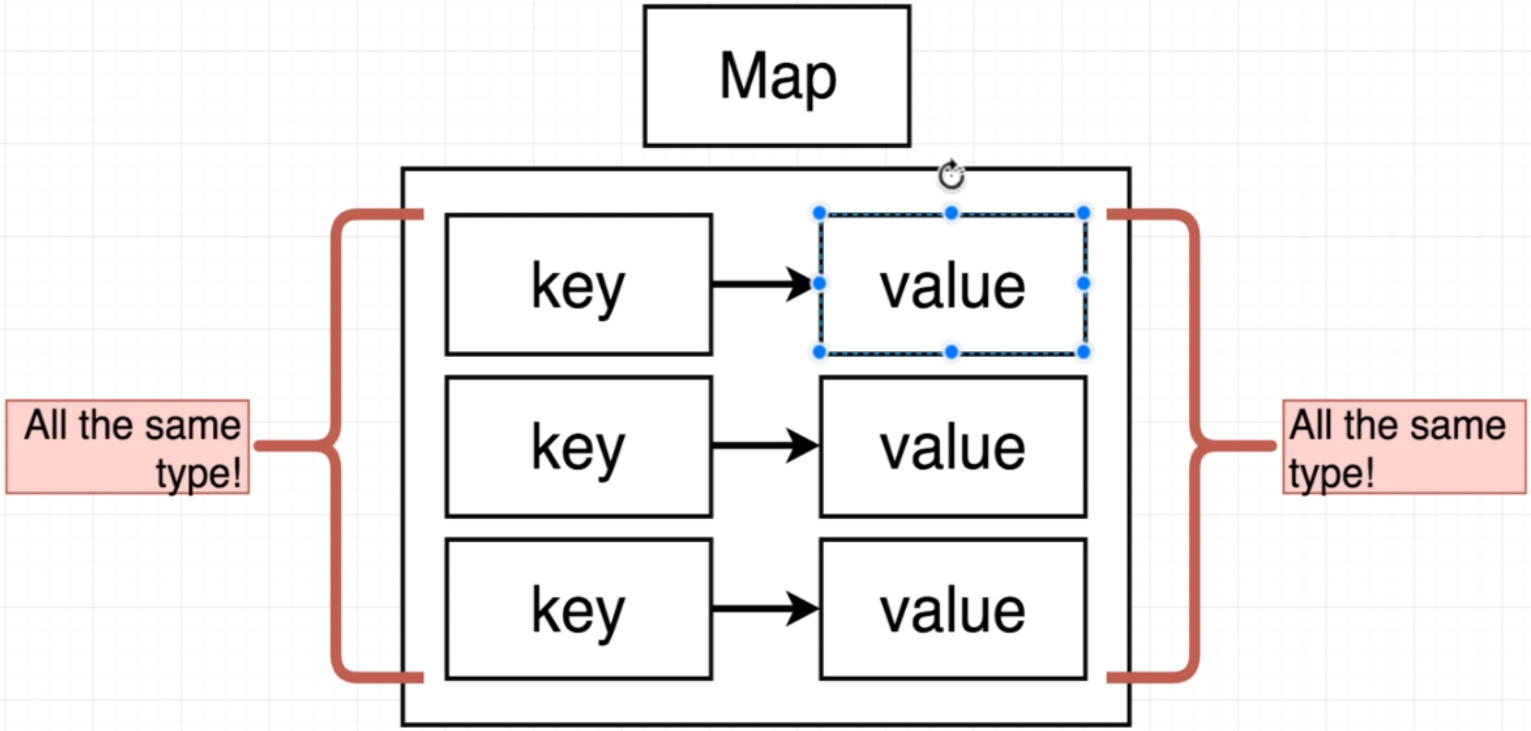
Map



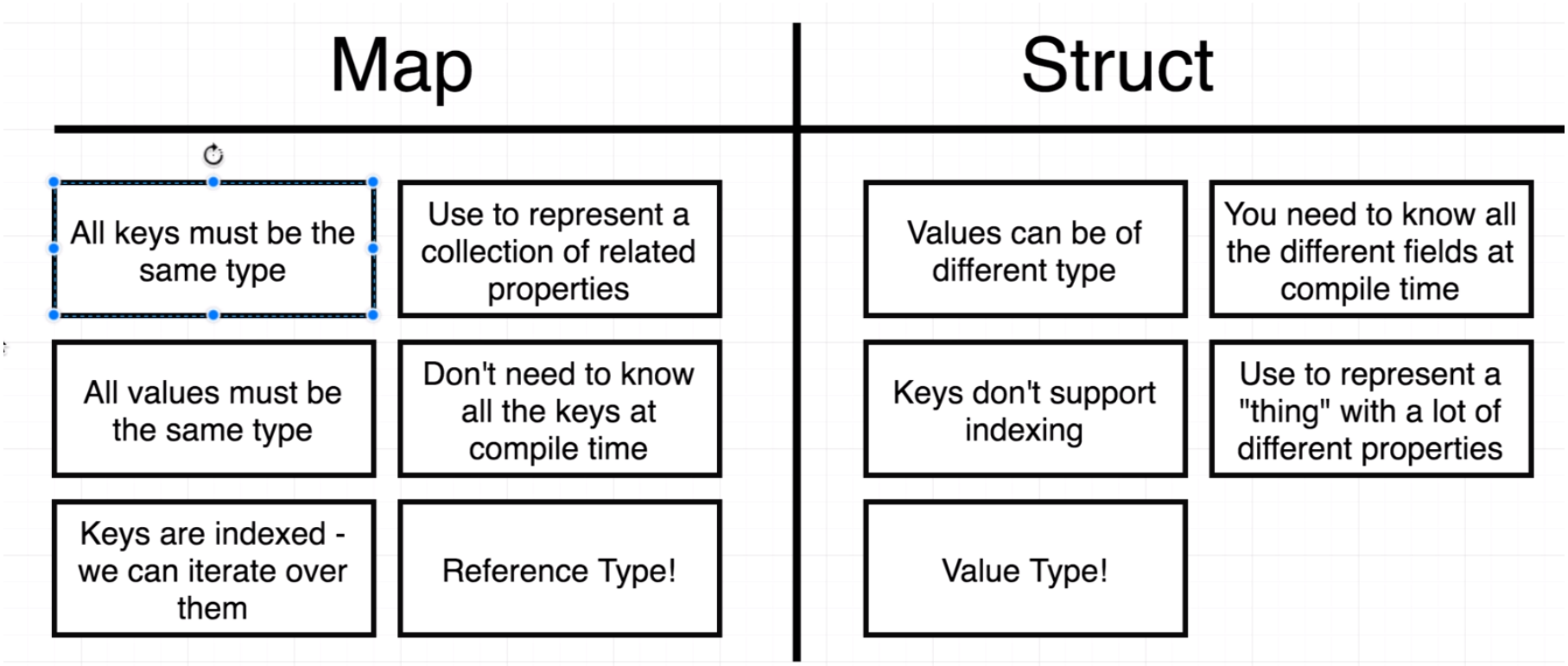
Map



Map

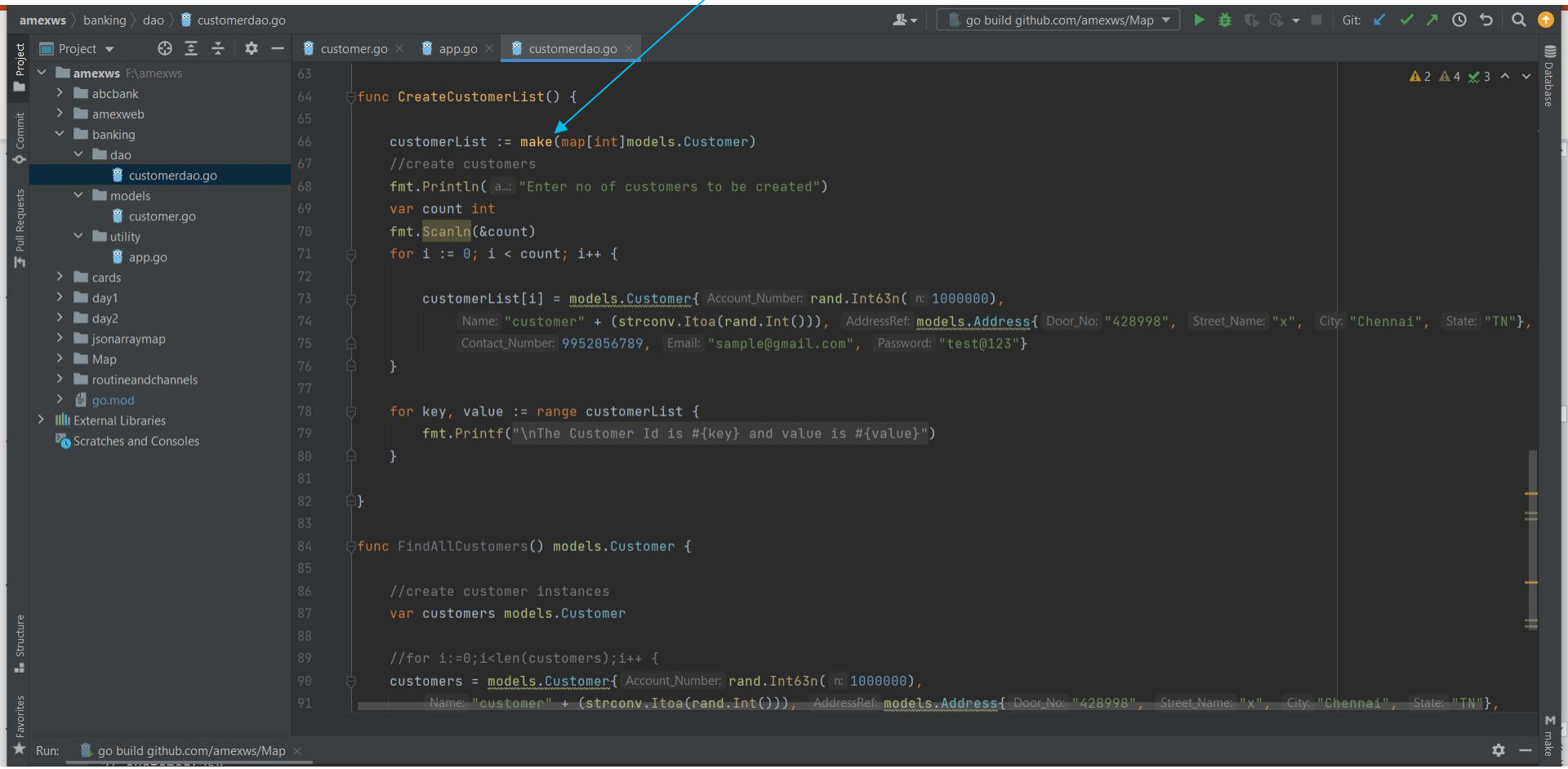

Map
key
value
key
value
key
value
All the same type!
All the same type!

Map


Map
Struct
All keys must be the same type
Use to represent a collection of related properties
All values must be the same type
Don't need to know all the keys at compile time
Keys are indexed - we can iterate over them
Reference Type!
Values can be of different type
You need to know all the different fields at compile time
Keys don't support indexing
Use to represent a "thing" with a lot of different properties
Value Type!

Map

Dynamic map (int,customer)



Map

- In Go, a **map** is a built-in data type that associates **keys** with **values.**

Declaring a Map

```go
// Method 1: Using make
m := make(map[string]int)

// Method 2: Using map literal
n := map[string]string{
    "foo": "bar",
    "baz": "qux",
}
```

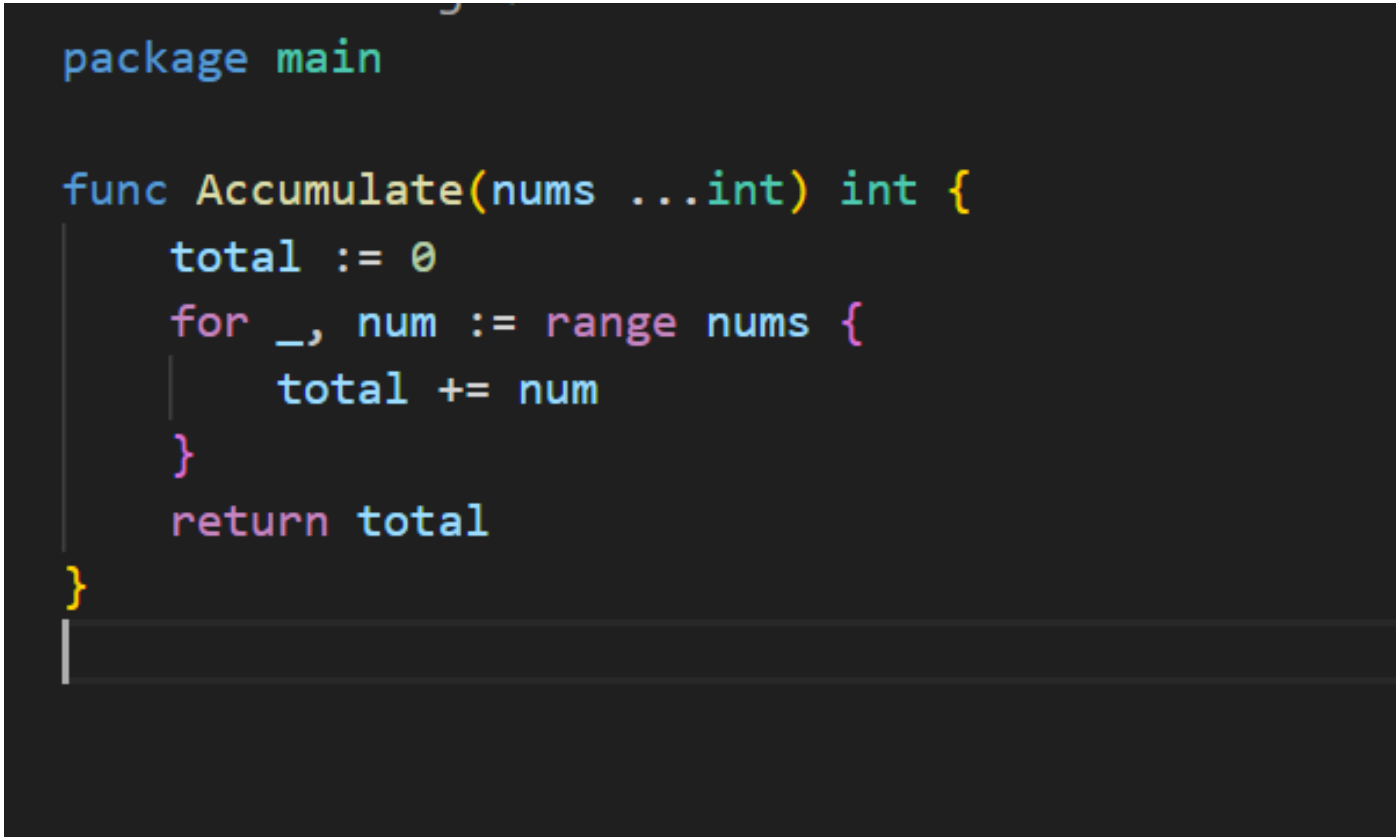
Map


```go
// Create an empty map
numbers := make(map[int]string)

// Assign values in a loop
for i := 1; i <= 5; i++ {
    numbers[i] = fmt.Sprintf("Value-%d", i)
}

// Print the map
for k, v := range numbers {
    fmt.Println(k, "=>", v)
}
```

Map

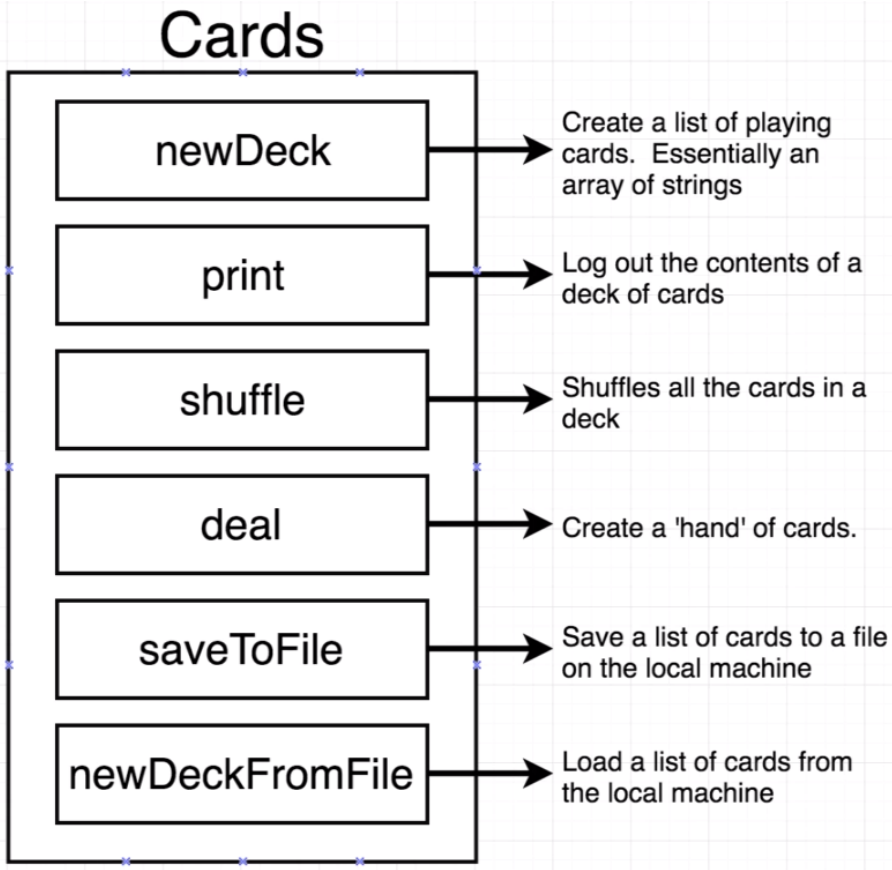
```
func GenCustomer() {
        customers[i] = faker.FirstName()
    }
    fmt.Println("Length of map:", len(customers))
    for k, v := range customers {
        println(k, v)
    }
    //delete(customers, 10)
    // Remove customers with ID < 50
    for k := range customers {
        if k < 50 {
            delete(customers, k)
        }
    }

    fmt.Println("Length of map:", len(customers))
}
```

Variadic Function

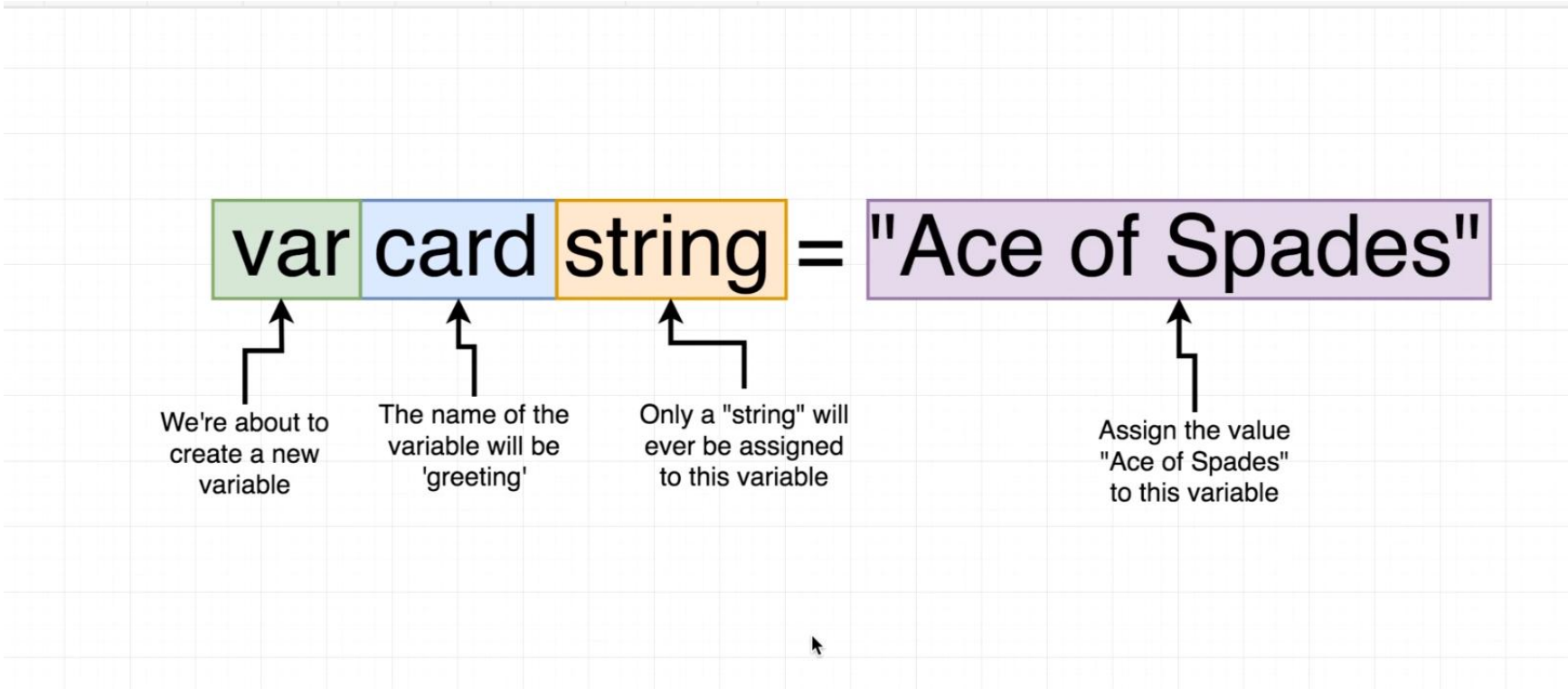


```go
package main

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

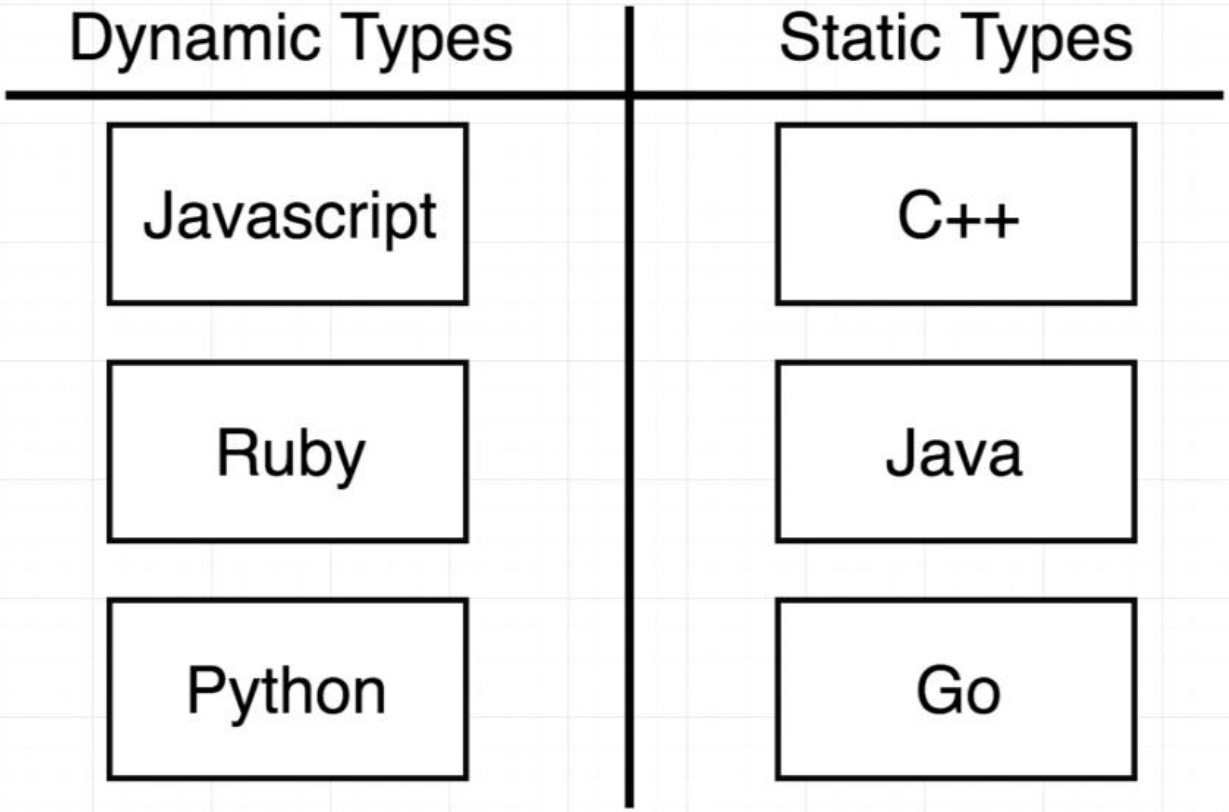
Use case


Cards
newDeck
print
shuffle
deal
saveToFile
newDeckFromFile
Create a list of playing cards. Essentially an array of strings
Log out the contents of a deck of cards
Shuffles all the cards in a deck
Create a 'hand' of cards.
Save a list of cards to a file on the local machine
Load a list of cards from the local machine

Use case


var card string = "Ace of Spades"
We're about to create a new variable
The name of the variable will be 'greeting'
Only a "string" will ever be assigned to this variable
Assign the value "Ace of Spades" to this variable

Use case


Dynamic Types
Static Types
Javascript
C++
Ruby
Java
Python
Go

Use case

Question 4:

Will the following code compile? Why or why not?

```
1  paperColor := "Green"
2  paperColor := "Blue"
```

- ○ Yes, because we are creating and assigning a value to the variable 'paperColor' twice.
- ◉ No, because a variable can only be initialized one time. In this case, the ':=' operator is being used to initialize 'paperColor' two times
- ○ No, because ':=' is not a valid operator

Use case

Question 6:

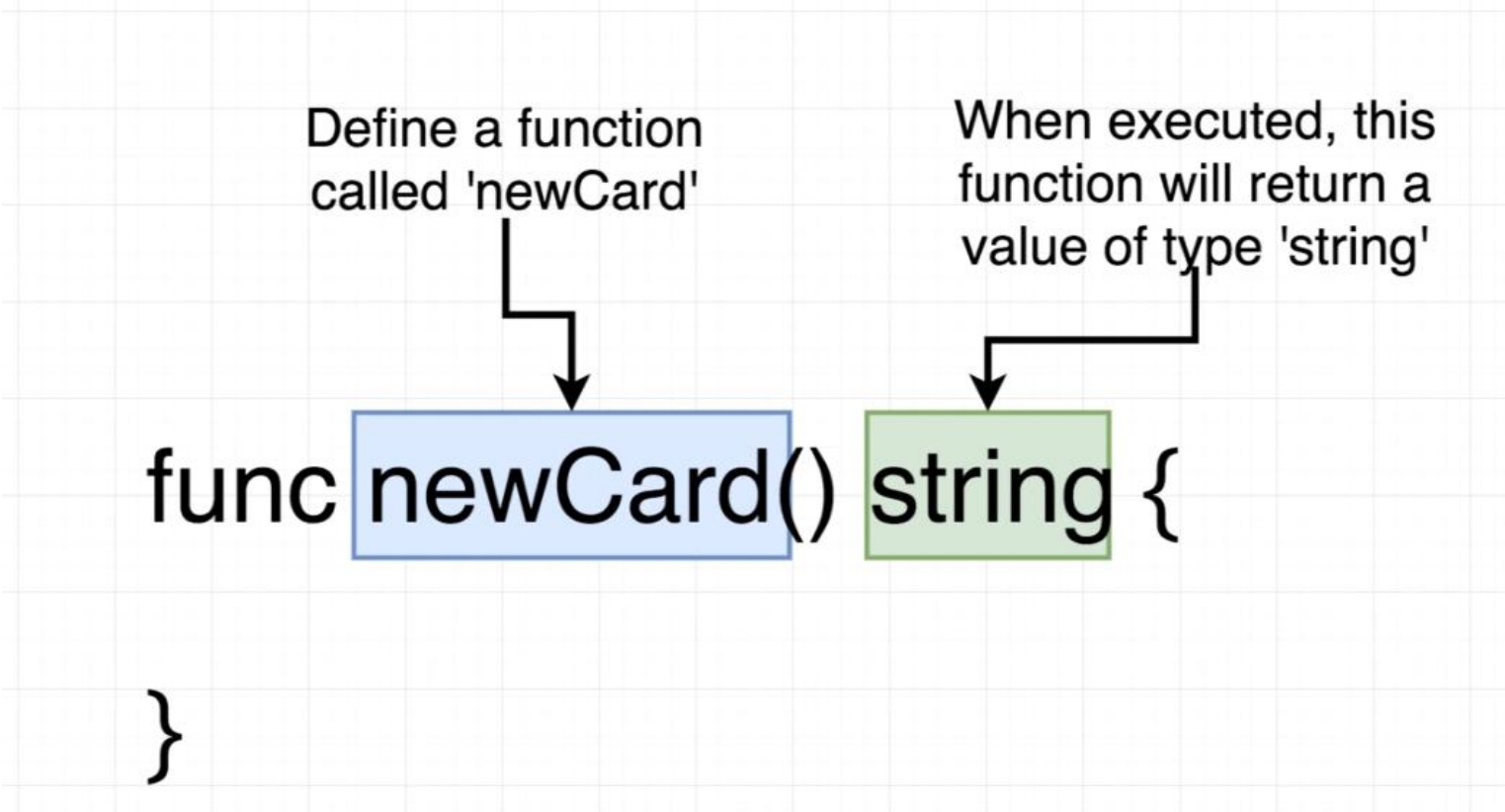
This might require a bit of experimentation on your end :). Remember that you can use the Go Playground at https://play.golang.org/ to quickly run a snippet of code.

Is the following code valid?

```
1  package main
2
3  import "fmt"
4
5  deckSize := 20
6
7  func main() {
8    fmt.Println(deckSize)
9  }
```

- ○ Yes
- ◉ No

Functions


Define a function called 'newCard'
When executed, this function will return a value of type 'string'
func newCard() string {
}

Understanding init in Go

- In Go, the predefined init() function sets off a piece of code to run before any other part of your package.
- This code will execute as soon as the package is imported.
- It can be used when you need your application to initialize in a specific state, such as when you have a specific configuration or set of resources with which your application needs to start.
- It is also used when importing a side effect, a technique used to set the state of a program by importing a specific package.

Understanding init in Go

- ◆ **What is init in Go?**
- init is a **special function** in Go that runs **automatically** before main().
- It is mainly used for **initialization logic** (setting defaults, connecting to configs, seeding random, etc.).
- You **cannot call init() explicitly**.

Understanding init in Go

1 Basic Example

```go
package main

import "fmt"

func init() {
    fmt.Println("Init function runs before main")
}

func main() {
    fmt.Println("Main function runs")
}
```

Output:

```pgsql
Init function runs before main
Main function runs
```

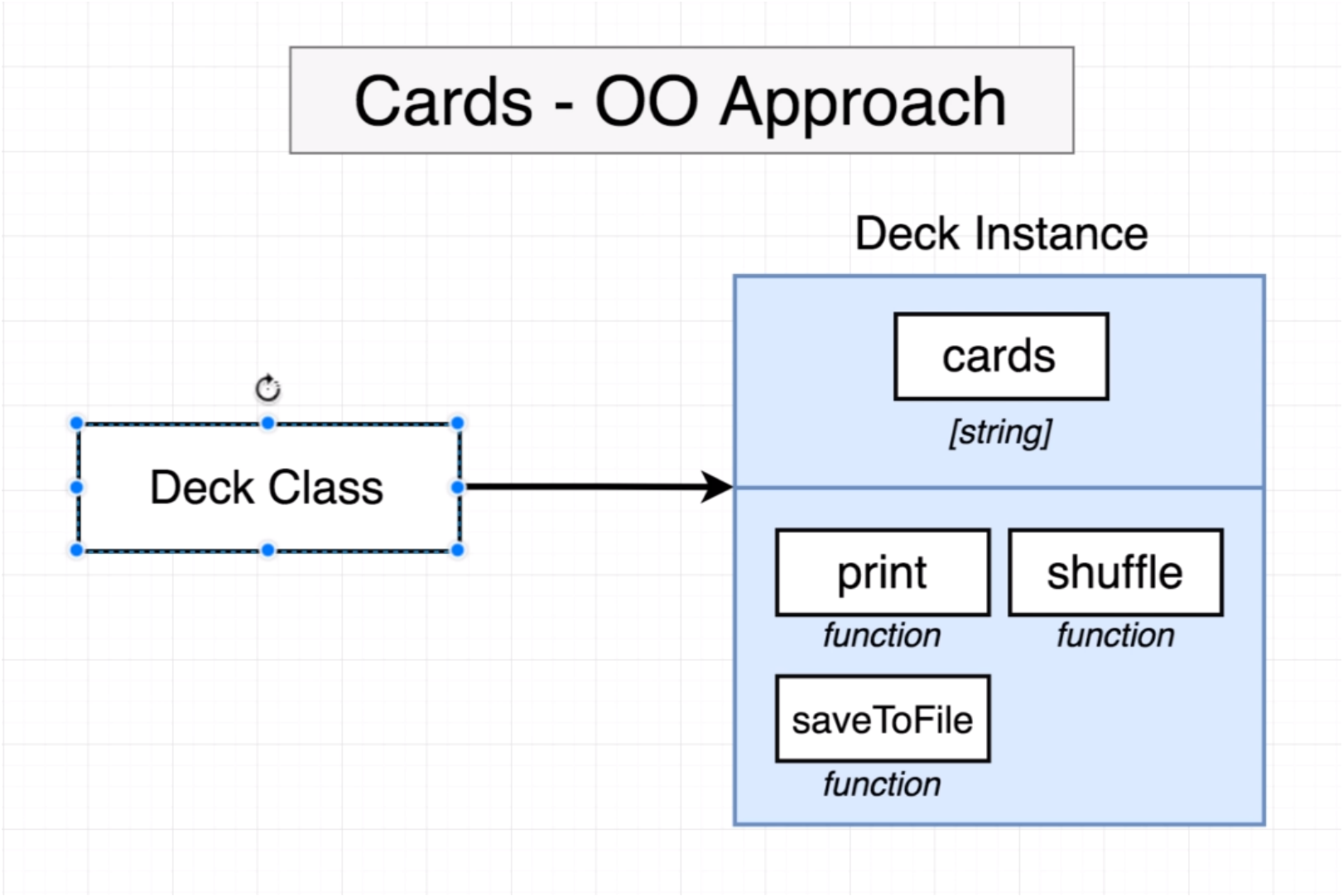
Understanding init in Go

2 Multiple `init` Functions

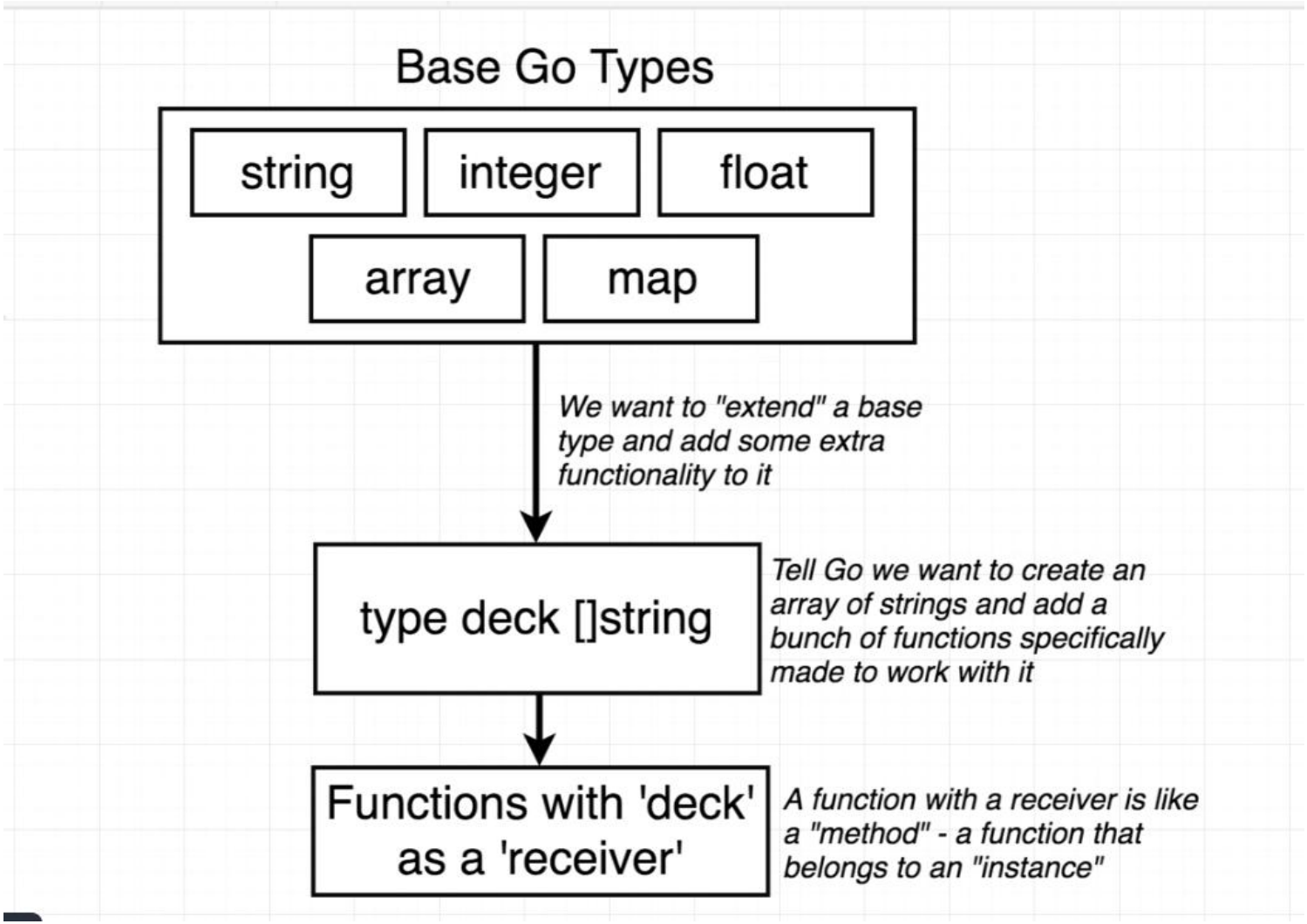
You can define **multiple** `init` **functions** in the same package (even in different files).
They all execute before `main`, in the order they appear **within the package**.

```
go

package main

import "fmt"

func init() {
    fmt.Println("First init")
}

func init() {
    fmt.Println("Second init")
}

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

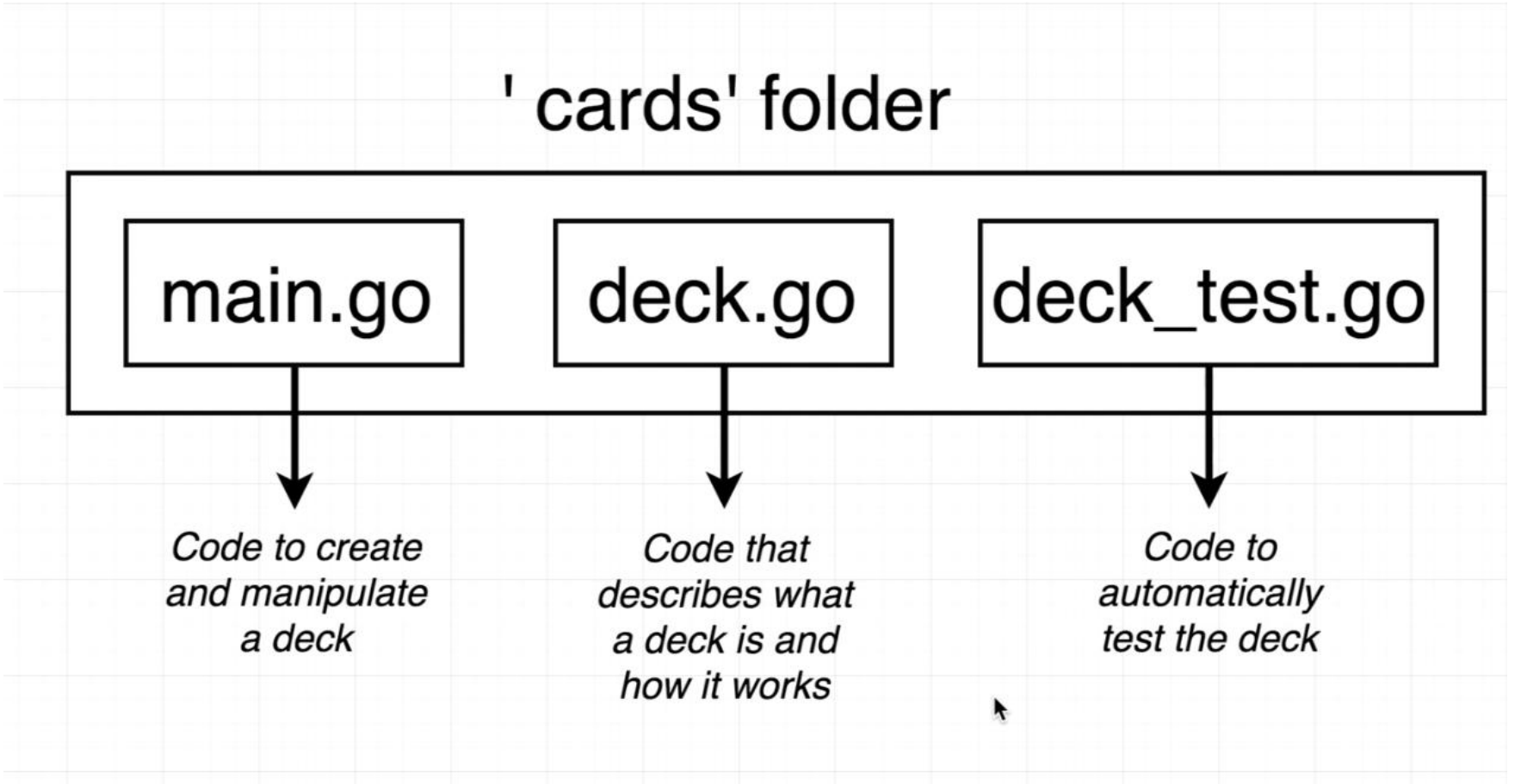
OO vs Go Structure



OO vs Go Structure



OO vs Go Structure



Custom Type

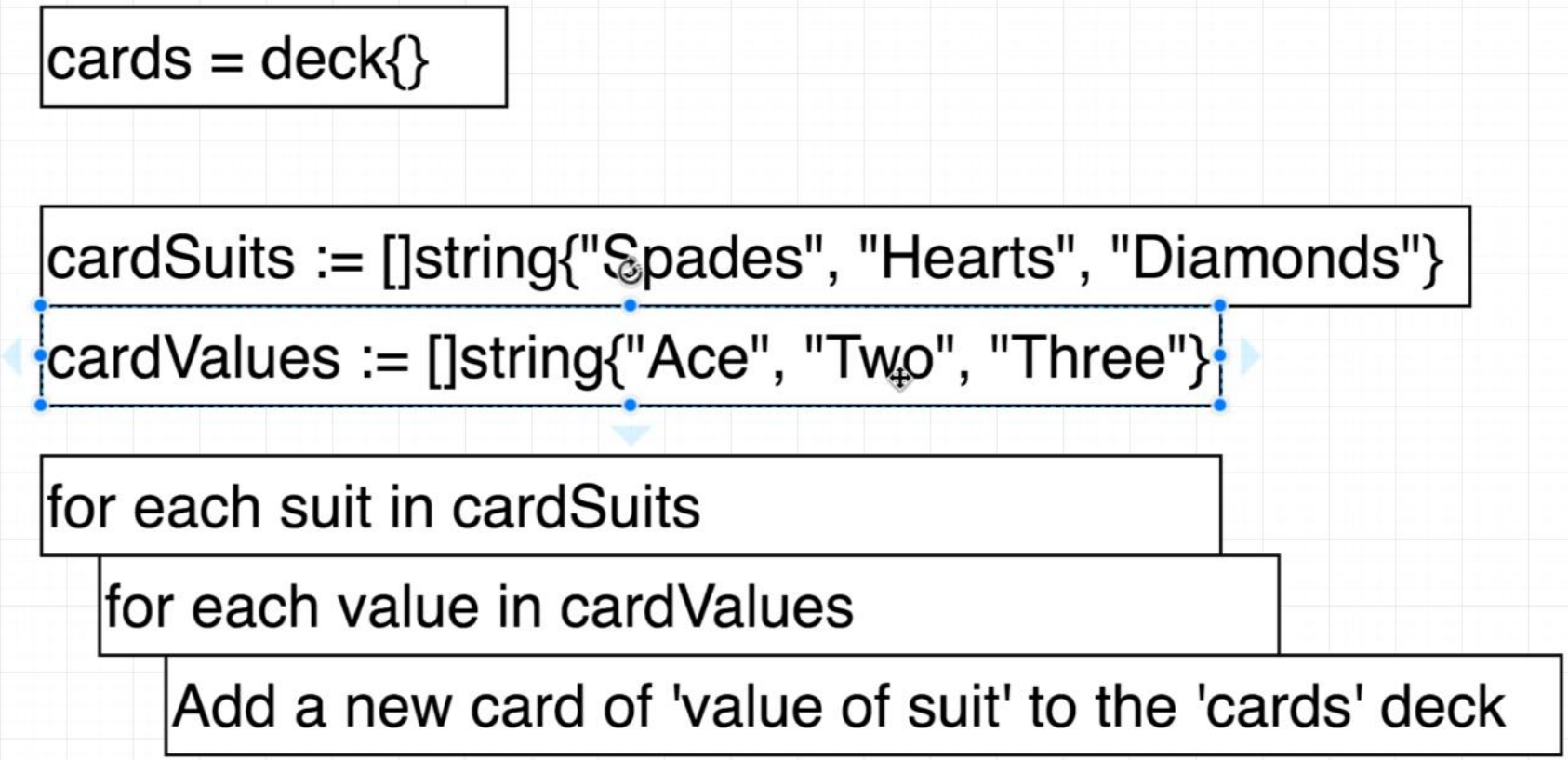

```go
package main

import "fmt"

// Define a custom type
type Age int

func main() {
    var a Age = 25
    fmt.Println("Age is:", a)
}
```

Custom Type

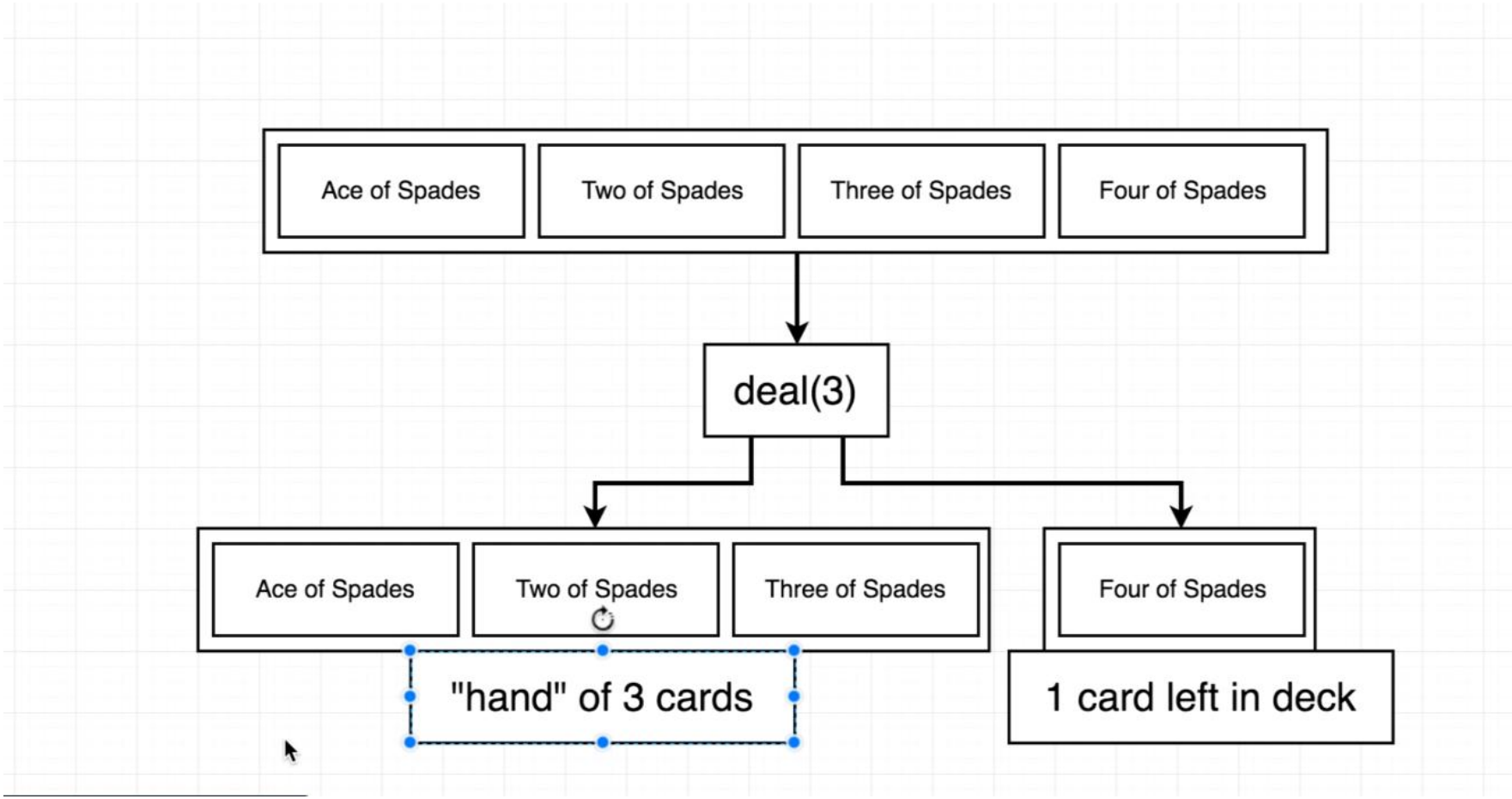
```
}

type min int
type max int

func main() {
    otp := util.GetOTP()
    fmt.Println("Your OTP is:", otp)
    // Print / Println
    fmt.Print("Hello")        // Hello
    fmt.Println("Go", 2025) // Go 2025
```

```
func GenId(minId min, maxId max) int {
    return rand.Intn(int(maxId)-int(minId)+1) + int(minId)
}
```

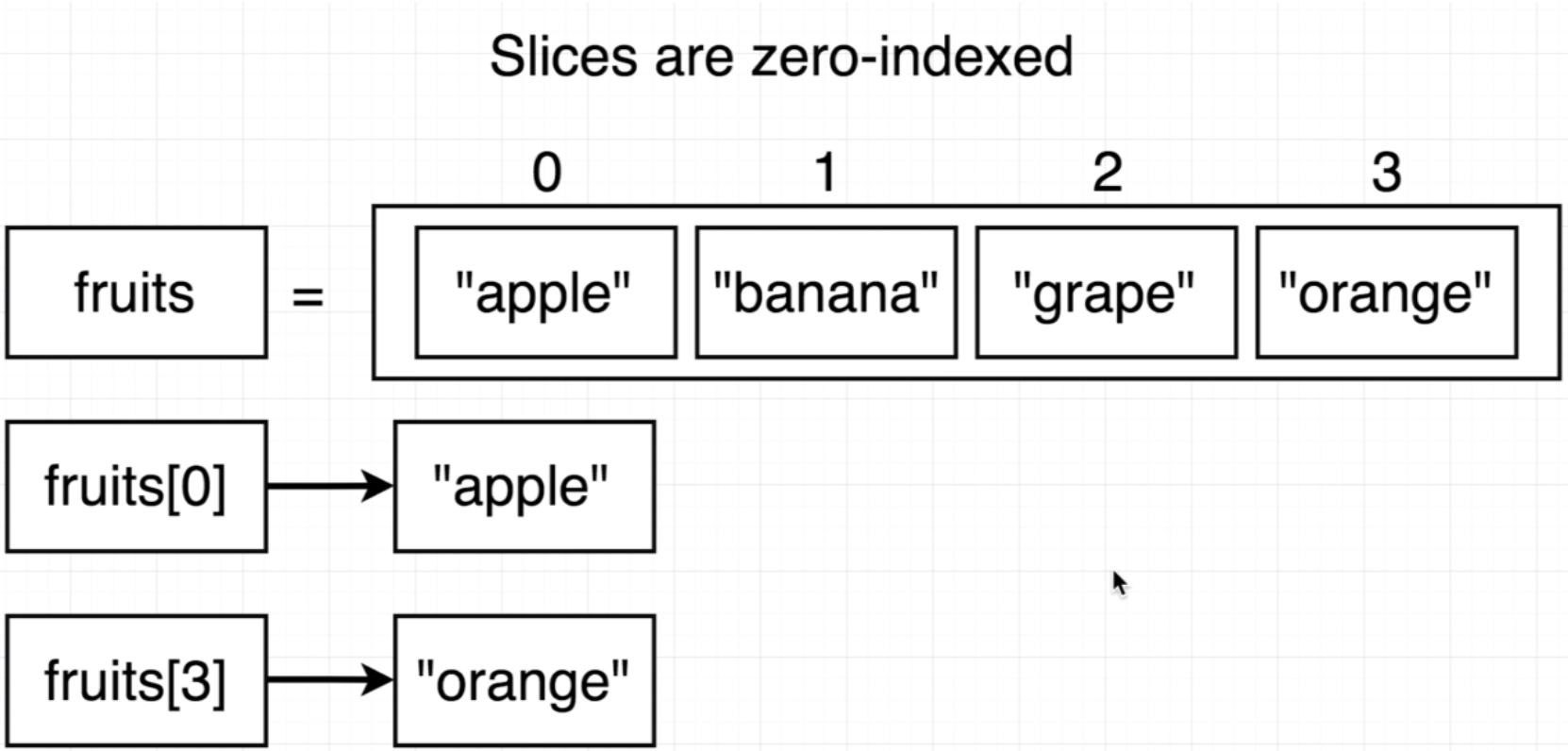
Case Study


cards = deck{}
cardSuits := []string{"Spades", "Hearts", "Diamonds"}
cardValues := []string{"Ace", "Two", "Three"}
for each suit in cardSuits
for each value in cardValues
Add a new card of 'value of suit' to the 'cards' deck

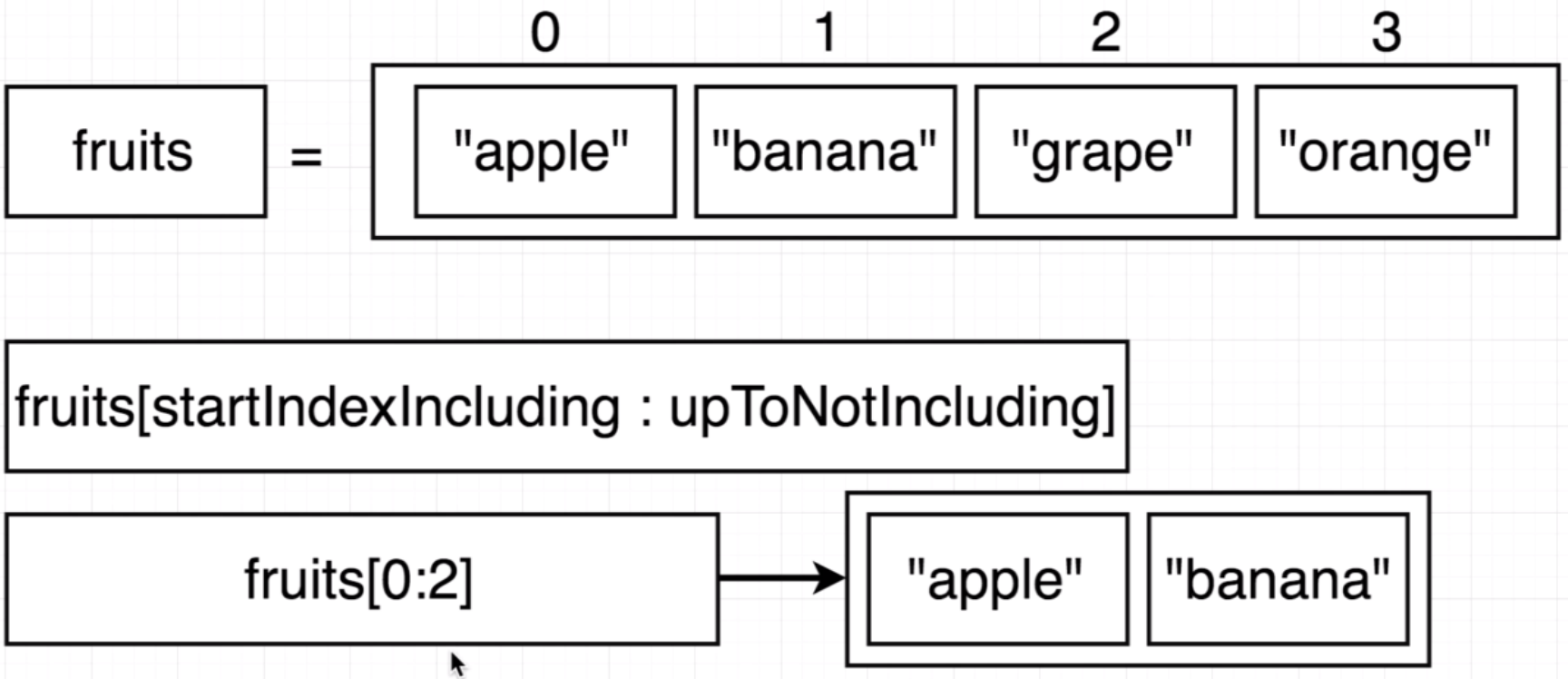
Case Study


Ace of Spades
Two of Spades
Three of Spades
Four of Spades
deal(3)
Ace of Spades
Two of Spades
Three of Spades
Four of Spades
"hand" of 3 cards
1 card left in deck

Case Study


Slices are zero-indexed
0
1
2
3
fruits
=
"apple"
"banana"
"grape"
"orange"
fruits[0]
"apple"
fruits[3]
"orange"

Case Study


0
1
2
3
fruits
=
"apple"
"banana"
"grape"
"orange"
fruits[startIndexIncluding : upToNotIncluding]
fruits[0:2]
"apple"
"banana"

Byte Slice

- In Go, []byte is a slice of bytes (uint8 values).
- Often used for strings, files, network data, etc.

1 Declaring a byte slice

```go
var b []byte                // nil slice
b = []byte{65, 66, 67}      // slice with values
fmt.Println(b)              // [65 66 67]
fmt.Println(string(b))      // "ABC"
```

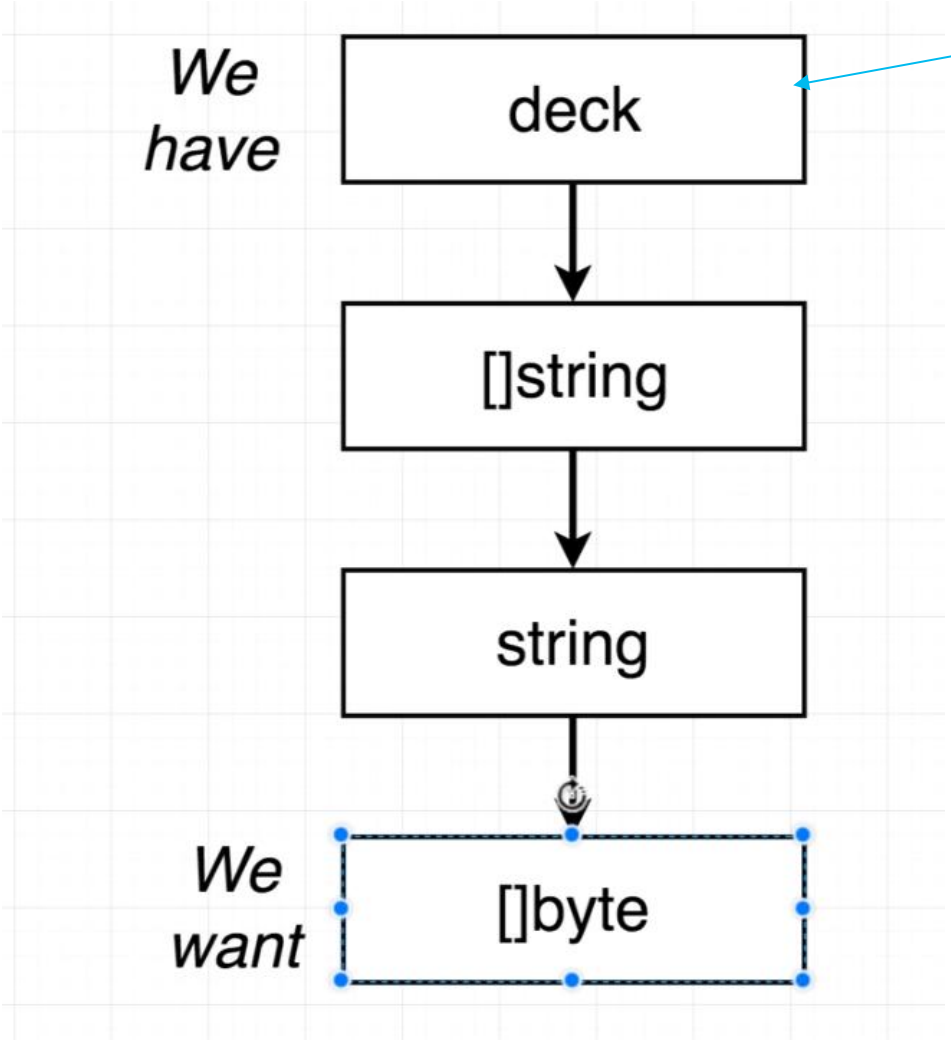
2 Converting string ↔ byte slice

```go
s := "Hello"
b := []byte(s)          // string → []byte
fmt.Println(b)          // [72 101 108 108 111]

s2 := string(b)         // []byte → string
fmt.Println(s2)         // Hello
```

Byte Slice


```go
import (
    "crypto/rand"
    "fmt"
)

func main() {
    b := make([]byte, 8)   // slice of 8 bytes
    _, err := rand.Read(b) // fills slice with random bytes
    if err != nil {
        panic(err)
    }
    fmt.Println("Random bytes:", b)
}
```

Byte Slice



Pointers

- ◆ **What is a pointer?**
- A pointer holds the **memory address** of a value.
- In Go, the type of a pointer is written with *T (pointer to type T).
- The & operator gives you the address of a variable.
- The * operator dereferences a pointer (gets the value at that address).

What is the need of the pointers?

- **1. Avoid Copying Large Data**
- By default, Go passes values **by copy**.
  If you pass a large struct or array to a function, it makes a full copy (expensive in memory & CPU).
- **2. Modify Values Inside Functions**
- Functions in Go normally work on copies.
  If you want a function to actually **modify the original**, you need a pointer.
- **3. Work with Structs Efficiently**
- Structs can be large; passing by pointer makes function calls cheaper and allows updates.

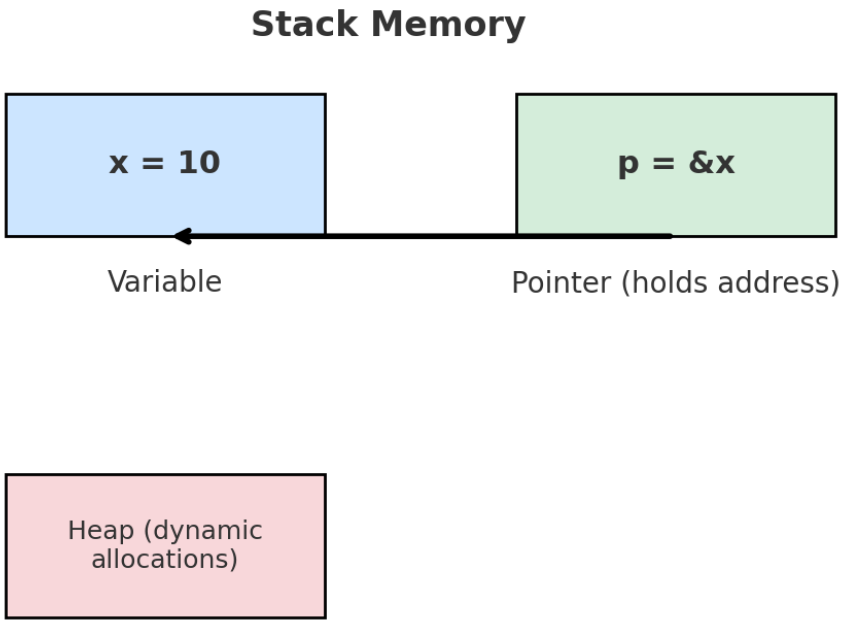
What is the need of the pointers?

- **4. Optional / Nil Values**
- Pointers let you represent “no value” with nil.

- **5. Share Data Between Functions**
- Pointers let multiple functions access & update the **same underlying data**, instead of working on copies.

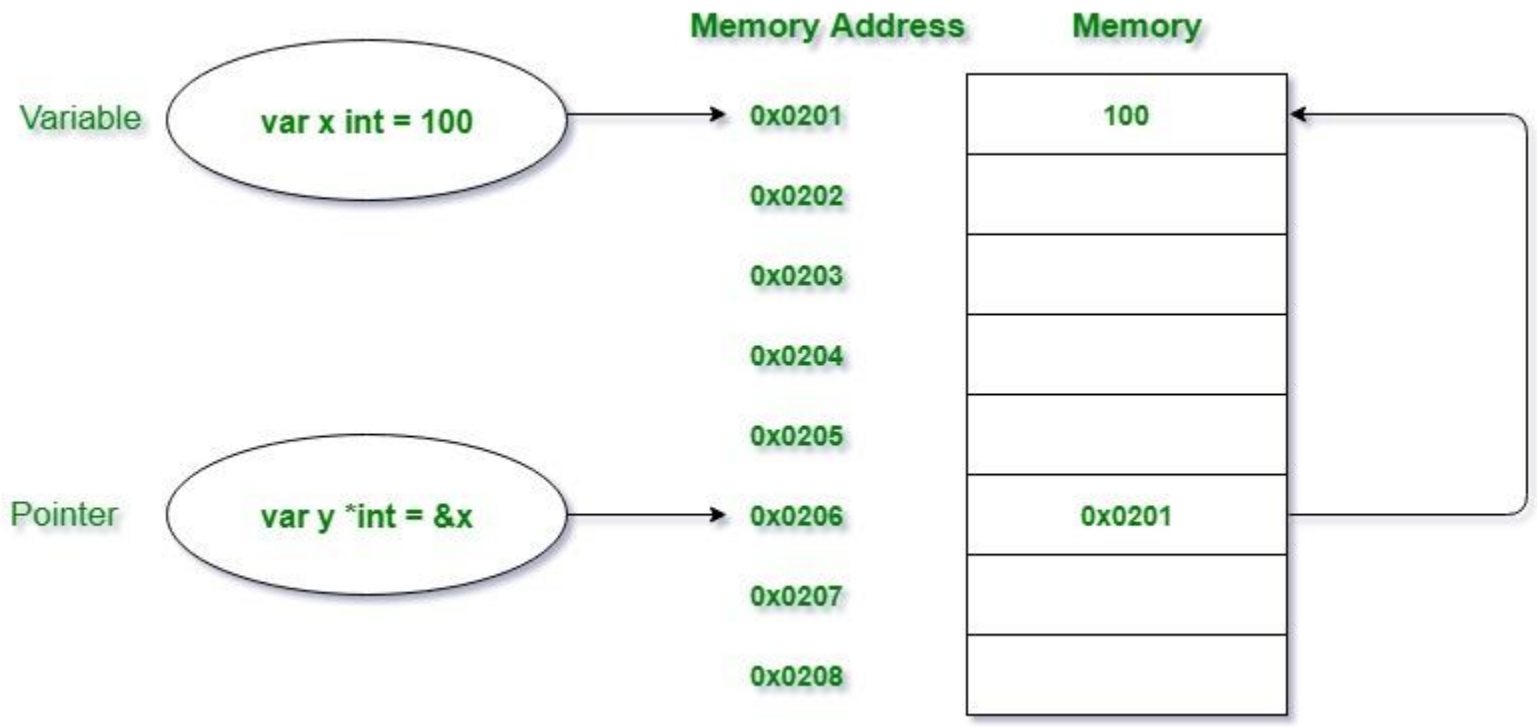
- **6. Under the Hood of Slices, Maps, Channels**
- Slices, maps, and channels in Go already **use pointers internally**.
- That’s why when you pass a slice/map/channel to a function, modifications are visible outside the function, **without explicit pointers**.

What is the need of the pointers?



- `x = 10` is stored directly in **stack memory**.
- `p = &x` is a **pointer** that stores the memory address of `x`.
- Dereferencing `*p` gives you the actual value (`10`).
- The **heap** (shown below) is where dynamically allocated values (via `new`, `make`, slices, maps, channels) live.

What is the need of the pointers?



Pointers

main.go

```
package main

import "fmt"

func main() {
    var creature string = "shark"
    var pointer *string = &creature

    fmt.Println("creature =", creature)
    fmt.Println("pointer =", pointer)
}
```

Structures

- **What is a Struct?**
- A **struct** is a collection of fields (variables) grouped together under one type.
  Think of it like a **class without methods** in other languages.

1 Declaring a Struct

```go
type Person struct {
    Name string
    Age  int
}
```

Structures

2 Creating Struct Instances

```go
p1 := Person{"Alice", 25}                // positional
p2 := Person{Name: "Bob", Age: 30}       // named fields
p3 := Person{Name: "Charlie"}            // Age defaults to 0
var p4 Person                            // empty struct with zero values

fmt.Println(p1, p2, p3, p4)
```

3 Accessing & Modifying Fields

```go
p := Person{Name: "Alice", Age: 25}
fmt.Println(p.Name) // Alice
p.Age = 26          // update field
```

Structures

4 Struct with Pointers

```go
func birthday(p *Person) {
    p.Age++ // modifies original
}

p := Person{"Alice", 25}
birthday(&p)
fmt.Println(p.Age) // 26
```

Structures

5 Struct with Methods

```go
func (v *Vehicle) Save() (bool, error) {
    vehicleMap[v.RegistrationNo] = v
    return true, nil
}
func (v *Vehicle) GetByID(id string) (*Vehicle, error) {
    if vehicle, exists := vehicleMap[id]; exists {
        return vehicle, nil
    }
    return nil, fmt.Errorf("vehicle not found")
}
func (v *Vehicle) GetAll() ([]*Vehicle, error) {
    vehicles := make([]*Vehicle, 0, len(vehicleMap))
    for _, vehicle := range vehicleMap {
        vehicles = append(vehicles, vehicle)
    }
    return vehicles, nil
}
func (v *Vehicle) Update(id string, color string) (*Vehicle, error) {
    if vehicle, exists := vehicleMap[id]; exists {
        vehicle.Color = color
        return vehicle, nil
    }
    return nil, fmt.Errorf("vehicle not found")
}
func (v *Vehicle) Delete(id string) (bool, error) {
    if _, exists := vehicleMap[id]; exists {
        delete(vehicleMap, id)
        return true, nil
```

Structures - Anonymous

- Why use anonymous structs?
- **1. One-off / throwaway models**
- If you need a data structure **only once**, it's wasteful to create a named type.

```
response := struct {
    Status string `json:"status"`
    Data   any    `json:"data"`
}{
    Status: "ok",
    Data:   "something",
}
```

This is common in **DTOs / API responses** — no need to define a full struct type.

Structures - Anonymous

- Why use anonymous structs?
- **2. Avoid clutter**
- If your domain already has many models, creating named types for small nested structs can bloat your codebase. Instead:

```
type Policy struct {
    ID   string
    Type string

    Coverage struct {   // no separate Coverage type needed
        MaxAmount  float64
        Deductible float64
    }
}
```

Here, `Coverage` exists **only inside Policy**, so we don't need to expose a separate type.

Structures - Anonymous

- Why use anonymous structs?
- **3. Encapsulation (locality of reference)**
  - By using anonymous structs inside a model:
  - You **signal** that the nested struct should not be reused elsewhere.
  - Keeps logic **tied closely** to the parent type.
  - For example, Policy.Holder only makes sense **inside Policy**, not as a standalone Holder type.

Structures - Anonymous

- Why use anonymous structs?
- **4. Quick prototyping**
- When you're just **testing an idea or writing quick code**, anonymous structs are faster than designing full models.
- **5. Anonymous fields (embedding)**
- You can embed a struct **without a field name**, promoting its fields:

```
type MotorClaim struct {
    Policy // anonymous embedded field
}
```

This lets you access `MotorClaim.Coverage` directly instead of `MotorClaim.Policy.Coverage`.

Structures - Anonymous

- ⚠️ **When NOT to use anonymous structs**
- When you need **reusability** (e.g., Customer used in many places).
- When you need **methods** on that type.
- When you want to export (public API).
- When clarity is more important than conciseness.

Structures - Anonymous

- ✨ **Rule of Thumb**
- 👉 Use **anonymous structs** when:
- Data structure is **short-lived, local, or tightly coupled**.
- It’s only relevant **inside one type or one function**.
- 👉 Use **named structs** when:
- You expect **reuse** across packages.
- You need **methods**.
- You want to share/export in APIs.

Structures - Anonymous


```go
// Policy model with anonymous struct fields
type Policy struct {
    ID   string
    Type string // "HEALTH", "MOTOR", etc.

    // Inline anonymous struct for coverage details
    Coverage struct {
        MaxAmount  float64
        Deductible float64
        Copay      float64
    }

    // Inline anonymous struct for policy holder
    Holder struct {
        ID   string
        Name string
        DOB  time.Time
    }

    // Inline anonymous struct for provider info
    Provider struct {
        ID   string
        Name string
    }
}
```

When to Use Which?

Scenario	Anonymous Struct ✅	Named Struct ✅
Data is used only once, local to a parent	✔	✘
You want to reduce boilerplate	✔	✘
You need reusability across multiple models	✘	✔
You want to attach methods	✘	✔
Public API (exported types)	✘	✔
Quick prototyping	✔	✘

Structures

7 Nested Structs

```go
type Address struct {
    City, Country string
}

type Employee struct {
    Name    string
    Address Address
}

e := Employee{
    Name: "John",
    Address: Address{City: "Paris", Country: "France"},
}
fmt.Println(e.Address.City) // Paris
```

Structures – Embedding like Inheritance


```go
// Base struct
type Policy struct {
    ID   string
    Type string
}

// Another base struct
type Audit struct {
    CreatedAt time.Time
    UpdatedAt time.Time
    Actor     string
}

// Child struct embeds Policy & Audit anonymously
type HealthClaim struct {
    Policy // embedded (anonymous field)
    Audit  // embedded

    ClaimID       string
    ClaimedAmount float64
    Status        string
}
```

Inline Structure


```
package main

import "fmt"

func main() {
    c := struct {
        Name string
        Type string
    }{
        Name: "Sammy",
        Type: "Shark",
    }
    fmt.Println(c.Name, "the", c.Type)
}
```

Methods in GO

func(reciver_name Type) method_name(parameter_list)(return_type){
// Code
}

```
type Creature struct {
    Name     string
    Greeting string
}

func (c Creature) Greet() {
    fmt.Printf("%s says %s", c.Name, c.Greeting)
}
```

Method vs Function

Feature	Function	Method
Receiver	❌ None	✅ Has a receiver (r Rectangle or r *Rectangle)
Tied to type	❌ Independent	✅ Belongs to a type (struct or custom type)
Call syntax	Add(3, 4)	rect.Area()
Use case	General-purpose logic	Behavior associated with a type (OOP-style)

Recursive Function

- ◆ **What is a recursive function?**
- A recursive function is a function that **calls itself** until a **base condition** is met.
  It’s useful for problems that can be broken down into smaller sub-problems (factorial, Fibonacci, tree traversal, etc.).

Recursive Function


```go
// LineItem represents one billed service, which may contain sub-services.
type LineItem struct {
    Code     string
    Amount   float64
    Children []*LineItem
}

// Recursive function to calculate total cost
func TotalCost(item *LineItem) float64 {
    if item == nil {
        return 0
    }
    total := item.Amount
    for _, child := range item.Children {
        total += TotalCost(child) // recursion here
    }
    return total
}
```

Anonymous Function

- ◆ **What is an Anonymous Function?**
- A function **without a name**.
- You can define it inline and assign it to a variable or call it immediately.
- Useful for **short logic**, **callbacks**, **goroutines**, etc.

Anonymous Function

1 Assign to a variable

```go
package main

import "fmt"

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

    fmt.Println(add(3, 4)) // 7
}
```

Anonymous Function

2 Immediate execution (IIFE: Immediately Invoked Function Expression)

```go
package main

import (
    "fmt"
    "time"
)

func main() {
    go func(amount float64) {
        if amount > 1000 {
            fmt.Println("⚠️ High-value transaction alert:", amount)
        }
    }(1500)

    time.Sleep(time.Second) // wait for goroutine
}
```

Anonymous Function

3 Anonymous function as goroutine

```go
package main

import (
    "fmt"
    "time"
)

func main() {
    go func(msg string) {
        fmt.Println("Hello,", msg)
    }("Banking User")

    time.Sleep(time.Second) // wait for goroutine
}
```

Anonymous Function

4 Passing anonymous function as argument

```go
package main

import "fmt"

func operate(a, b int, op func(int, int) int) int {
    return op(a, b)
}

func main() {
    sum := operate(10, 20, func(x, y int) int {
        return x + y
    })
    fmt.Println(sum) // 30
}
```

Anonymous Function

5 Closures (anonymous function capturing variables)

```go
package main

import "fmt"

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

func main() {
    next := counter()
    fmt.Println(next()) // 1
    fmt.Println(next()) // 2
    fmt.Println(next()) // 3
}
```

Here, the anonymous function **remembers the variable** `count` even after `counter()` has returned.

Anonymous Function


```go
package main

import "fmt"

func main() {
    rate := 0.05 // 5% interest

    applyInterest := func(balance float64) float64 {
        return balance * (1 + rate)
    }

    fmt.Println("New balance:", applyInterest(1000)) // 1050
}
```

Method with Pointer and Value

- Refer StructAuthorDemo

Interface

- In **Go**, an **interface** is a type that defines a set of methods but does not provide their implementation. Any struct (or type) that implements those methods *implicitly* satisfies the interface.

Interface

```go
type PatientInfo interface {
    ShowPatientInfo(newMail string)
    DisplayPatientInfo(newMail string)
}

// call by value
func (patient Patient) ShowPatientInfo(newMail string) {
    println("Patient Information:")
    println("First Name:", patient.FirstName)
    println("Last Name:", patient.LastName)
    println("Date of Birth:", patient.DOB.Day, "/", patient.DOB.Month, "/", patient.DOB.Year)
    patient.Email = newMail // Modifying the email field
    println("Email:", patient.Email)
    println("Phone:", patient.Phone)
}

//call by reference

func (patient *Patient) DisplayPatientInfo(newMail string) {
    println("Patient Information:")
    println("First Name:", patient.FirstName)
    println("Last Name:", patient.LastName)
    println("Date of Birth:", patient.DOB.Day, "/", patient.DOB.Month, "/", patient.DOB.Year)
    patient.Email = newMail // Modifying the email field
    println("Email:", patient.Email)
    println("Phone:", patient.Phone)
}
```

Interface

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

The simplicity of the `error` interface makes writing logging and metrics implementations much easier. Let's define a struct that represents a network problem:

```
type networkProblem struct {
        message string
        code    int
}
```

Then we can define an `Error()` method:

```
func (np networkProblem) Error() string {
        return fmt.Sprintf("network error! message: %s, code: %v", np.m
}
```

Interface


```
type Modify interface {
        changeName(name *string)
}

func receiveInterface(m Modify){
        var name string ="Parameswari"
        var ptrname *string=&name
        m.changeName(ptrname)
```

Interface

Interfaces are **not** generic types	*Other languages have 'generic' types - go (famously) does not.*
Interfaces are 'implicit'	*We don't manually have to say that our custom type satisfies some interface.*
Interfaces are a contract to help us manage types	*GARBAGE IN -> GARBAGE OUT. If our custom type's implementation of a function is broken then interfaces wont help us!*
Interfaces are tough. Step #1 is understanding how to read them	*Understand how to read interfaces in the standard lib. Writing your own interfaces is tough and requires experience*

Interface keys and slices


```
package main

import "fmt"
import "reflect"

func main() {
        data := []string{"one","two","three"}
        test(data)
        moredata := []int{1,2,3}
        test(moredata)
}

func test(t interface{}) {
        switch reflect.TypeOf(t).Kind() {
        case reflect.Slice:
                s := reflect.ValueOf(t)

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

Handling Errors

1. Returning and Checking Errors

```go
package main

import (
    "errors"
    "fmt"
)

func divide(a, b float64) (float64, error) {
    if b == 0 {
        return 0, errors.New("cannot divide by zero")
    }
    return a / b, nil
}

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

👉 Every call must check `err`.

Custom Error Message

2. Creating Custom Errors

```go
var ErrNotFound = errors.New("item not found")

func findItem(id int) (string, error) {
    if id != 1 {
        return "", ErrNotFound
    }
    return "Laptop", nil
}

func main() {
    item, err := findItem(2)
    if err != nil {
        if errors.Is(err, ErrNotFound) {
            fmt.Println("Custom Error:", err)
        }
        return
    }
    fmt.Println("Found:", item)
}
```

Wrapping Errors (Go 1.13+)

Use `fmt.Errorf` with `%w` to keep the original error for inspection.

```go
func readFile() error {
    // simulate error
    return errors.New("disk not found")
}

func processFile() error {
    err := readFile()
    if err != nil {
        return fmt.Errorf("processFile failed: %w", err)
    }
    return nil
}

func main() {
    err := processFile()
    if err != nil {
        fmt.Println("Error:", err)
    }
}
```

Error Nil


```
package main

import (
    "errors"
    "fmt"
)

func boom() error {
    return errors.New("barnacles")
}

func main() {
    err := boom()

    if err != nil {
        fmt.Println("An error occurred:", err)
        return
    }
    fmt.Println("Anchors away!")
}
```

Error Along Value


```
package main

import (
    "errors"
    "fmt"
    "strings"
)

func capitalize(name string) (string, error) {
    if name == "" {
        return "", errors.New("no name provided")
    }
    return strings.ToTitle(name), nil
}
```

Error Along Value


```
func main() {
    name, err := capitalize("sammy")
    if err != nil {
        fmt.Println("Could not capitalize:", err)
        return
    }


     fmt.Println("Capitalized name:", name)
}
```

Error Propagation

- Refer amexws error propagation

Handling Panics in Go

- Errors that a program encounters fall into two broad categories: those the programmer has anticipated and those the programmer has not.
- The error largely deal with errors that we expect as we are writing Go programs.
- The error interface even allows us to acknowledge the rare possibility of an error occurring from function calls, so we can respond appropriately in those situations.

Handling Panics in Go

- Panics fall into the second category of errors, which are unanticipated by the programmer.
- These unforeseen errors lead a program to spontaneously terminate and exit the running Go program.
- Common mistakes are often responsible for creating panics.

Handling Panics in Go

- There are certain operations in Go that automatically return panics and stop the program.
- Common operations include indexing an array beyond its capacity, performing type assertions, calling methods on nil pointers, incorrectly using mutexes, and attempting to work with closed channels.
- Most of these situations result from mistakes made while programming that the compiler has no ability to detect while compiling your program.
- Since panics include detail that is useful for resolving an issue, developers commonly use panics as an indication that they have made a mistake during a program's development.

Handling Panics in Go

```go
func safeDivide(a, b int) int {
    defer func() {
        if r := recover(); r != nil {
            fmt.Println("Recovered:", r)
        }
    }()

    return a / b // panic if b == 0
}

func main() {
    fmt.Println("Result:", safeDivide(10, 2)) // 5
    fmt.Println("Result:", safeDivide(10, 0)) // recovers instead of crashing
}
```

Panic and Recover in Go


```go
func riskyOperation() {
    defer func() {
        if r := recover(); r != nil {
            fmt.Println("Recovered from panic:", r)
        }
    }()
    panic("something went very wrong")
}

func main() {
    riskyOperation()
    fmt.Println("Program continues...")
}
```

Handling Panics in Go

- **Out of Bounds Panics**
- When you attempt to access an index beyond the length of a slice or the capacity of an array, the Go runtime will generate a panic.

```
func main() {
    names := []string{
        "lobster",
        "sea urchin",
        "sea cucumber",
    }
    fmt.Println("My favorite sea creature is:", names[len(names)])
}
```

Nil Receivers

- The Go programming language has pointers to refer to a specific instance of some type existing in the computer's memory at runtime.
- Pointers can assume the value nil indicating that they are not pointing at anything.
- When we attempt to call methods on a pointer that is nil, the Go runtime will generate a panic.

```
func main() {
    s := &Shark{"Sammy"}
    s = nil
    s.SayHello()
}
```

RealTime Examples


```go
func main() {
    data, err := os.ReadFile("missing.txt")
    if err != nil {
        if os.IsNotExist(err) {
            fmt.Println("File not found!")
        } else {
            fmt.Println("Other file error:", err)
        }
        return
    }
    fmt.Println("File content:", string(data))
}
```

Deferred Functions

- Our program may have resources that it must clean up properly, even while a panic is being processed by the runtime.
- Go allows you to defer the execution of a function call until its calling function has completed execution.
- Deferred functions run even in the presence of a panic and are used as a safety mechanism to guard against the chaotic nature of panics.
- Functions are deferred by calling them as usual, then prefixing the entire statement with the defer keyword, as in defer sayHello().

Deferred Function


```go
func main() {
    resp, err := http.Get("https://golang.org")
    if err != nil {
        fmt.Println("Network error:", err)
        return
    }
    defer resp.Body.Close()

    if resp.StatusCode != http.StatusOK {
        fmt.Printf("HTTP Error: %d %s\n", resp.StatusCode, resp.Status)
        return
    }

    body, err := io.ReadAll(resp.Body)
    if err != nil {
        fmt.Println("Error reading body:", err)
        return
    }
    fmt.Println("Response:", string(body[:100]), "...")
}
```

Deferred Function


```go
func main() {
    db, err := sql.Open("sqlite3", "test.db")
    if err != nil {
        panic(err)
    }
    defer db.Close()

    var name string
    err = db.QueryRow("SELECT name FROM users WHERE id = ?", 1).Scan(&name)
    if err != nil {
        if err == sql.ErrNoRows {
            fmt.Println("No record found")
        } else {
            fmt.Println("Query error:", err)
        }
        return
    }

    fmt.Println("User:", name)
}
```

Module Summary

- In this module we discussed
  - Go Modules
  - Goroutines
  - Go Tools