Goroutines and Channels

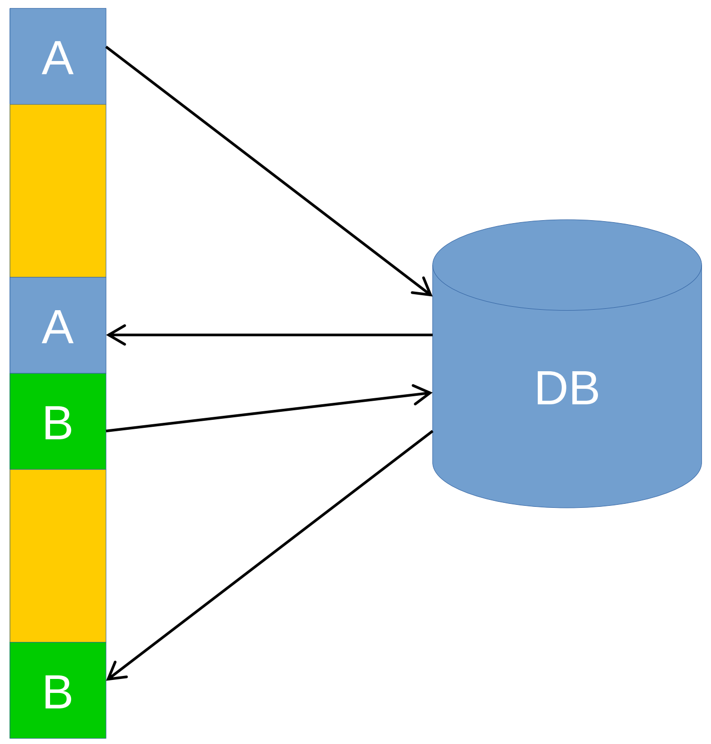
Goroutines, channels, parallel loops, select, goroutines cancelation

Where to Find The Code and Materials?

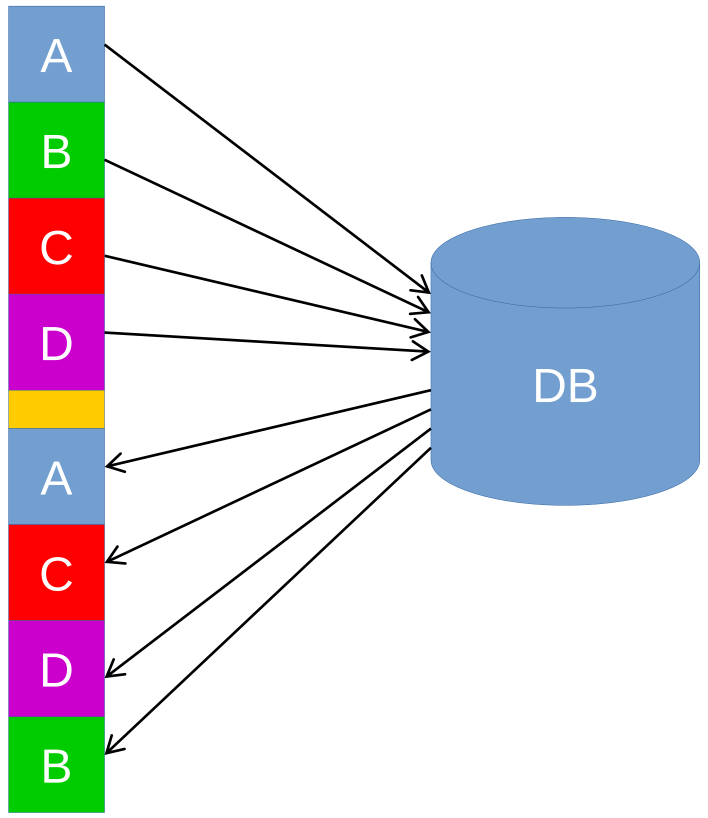
https://github.com/iproduct/coursegopro

Synchronous vs. Asynchronous IO

Synchronous



Asynchronous



Blocking vs. Non-blocking

- Blocking concurrency – uses **Mut**ual **Ex**clusion primitives (aka **Locks**) to prevent threads from simultaneously accessing/modifying the same resource
- Non-blocking concurrency does not make use of locks.
- One of the most advantageous feature of non-blocking vs. blocking is that, threads does not have to be suspended/waken up by the OS. Such overhead can amount to 1ms to a few 10ms, so removing this can be a big performance gain. In java for example, it also means that you can choose to use non-fair locking, which can have much more system throughput than fair-locking.

Non-blocking Concurrency

- In computer science, an algorithm is called **non-blocking** if failure or suspension of any thread cannot cause failure or suspension of another thread;[1] for some operations, these algorithms provide a useful alternative to traditional blocking implementations. A non-blocking algorithm is **lock-free** if there is guaranteed system-wide progress, and **wait-free** if there is also guaranteed per-thread progress. "Non-blocking" was used as a synonym for "lock-free" in the literature until the introduction of obstruction-freedom in 2003.
- It has been shown that widely available atomic *conditional* primitives, CAS and LL/SC, cannot provide starvation-free implementations of many common data structures without memory costs growing linearly in the number of threads.

[Wikipedia]

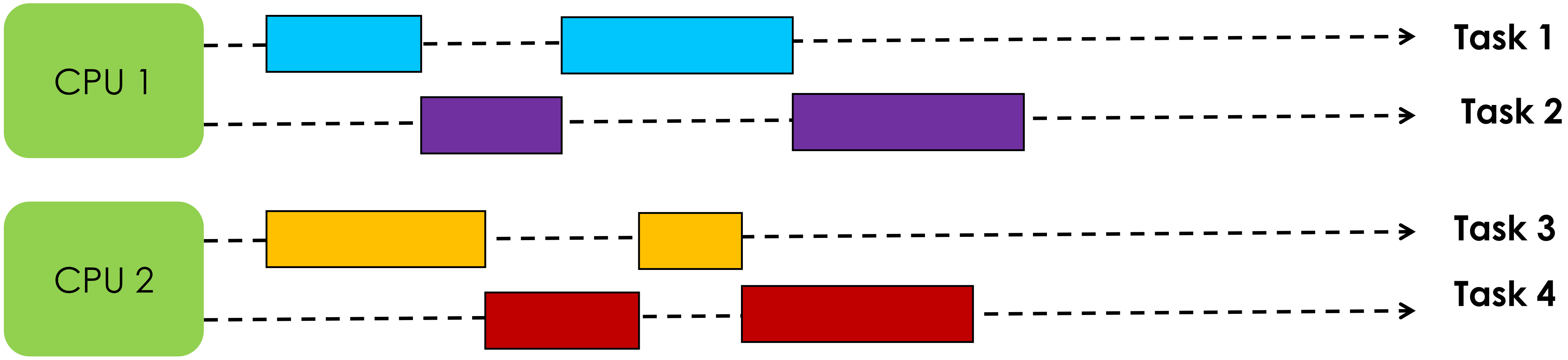
Concurrency vs. Parallelism

Question:

What is the difference between concurrency and parallelism?

Concurrency vs. Parallelism

- Concurrency refers to how a single CPU can make progress on multiple tasks seemingly at the same time (AKA concurrently).
- Parallelism allows an application to parallelize the execution of a single task - typically by splitting the task up into subtasks which can be completed in parallel.



Scalability Problem

- Scalability is the ability of a program to handle growing workloads.
- One way in which programs can scale is parallelism: if we want to process a large chunk of data, we describe its processing as a sequence of transforms on a stream, and by setting it to parallel we ask multiple processing cores to process the parts of the task simultaneously.
- The problem is that the processes and threads, the OS supported units of concurrency, cannot match the scale of the application domain's natural units of concurrency — a session, an HTTP request, or a database transactional operation.
- A server can handle upward of a million concurrent open sockets, yet the operating system cannot efficiently handle more than a few thousand active threads. So it becomes a mapping problem - M:N

Why are OS Threads Heavy?

- Universal – represent all languages and types of workloads
- Can be suspended and resumed - this requires preserving its state, which includes the instruction pointer, as well as all of the local computation data, stored on the stack.
- The stack should be quite large, because we can not assume constraints in advance.
- Because the OS kernel must schedule all types of threads that behave very differently it terms of processing and blocking — some serving HTTP requests, others playing videos => its scheduler must be all-encompassing, and not optimized.

Solutions To Thread Scalability Problem

- Because threads are costly to create, we pool them -> but we must pay the price: leaking thread-local data and a complex cancellation protocol.
- Thread pooling is coarse grained – not enough threads for all tasks.
- So instead of blocking the thread, the task should return the thread to the pool while it is waiting for some external event, such as a response from a database or a service, or any other activity that would block it.
- The task is no longer bound to a single thread for its entire execution.
- Proliferation of asynchronous APIs, from Noide.js to NIO in Java, to the many "reactive" libraries (Reactive Extensions - Rx, etc.) => intrusive, all-encompassing frameworks, even basic control flow, like loops and try/catch, need to be reconstructed in "reactive" DSLs, supporting classes with hundreds of methods.

What Color is Your Function?
[http://journal.stuffwithstuff.com/2015/02/01/what-color-is-your-function/]

- Synchronous functions return values, async ones do not and instead invoke callbacks.
- Synchronous functions give their result as a return value, async functions give it by invoking a callback you pass to it.
- You can't call an async function from a synchronous one because you won't be able to determine the result until the async one completes later.
- Async functions don't compose in expressions because of the callbacks, have different error-handling.
- Node's whole idea is that the core libs are all asynchronous. (Though they did dial that back and start adding ___Sync() versions of a lot functions.)

Async/Await in JS (and some other languages)

- Cooperative scheduling points are marked explicitly with await => scalable synchronous code – but we mark it as async – a bit of confusing!
- Solves the context issue by introducing a new kind of context that is like thread but is incompatible with threads – one blocks and the other returns some sort of Promise - you can not easily mix sync and async code.

Right-Sized Concurrency

- If we could make threads lighter, we could have more of them, and can use them as intended:
  1. to directly represent domain units of concurrency;
  2. by virtualizing scarce computational resources;
  3. hiding the complexity of managing those resources.
- Example: Goroutines, Erlang
- creating and blocking goroutines is cheap
- Managed by the Golang runtime, and scheduled cooperatively unlike the existing threads of OS.

How Are Goroutines Better?

- The goroutines make use of a stack, so it can represent execution state more compactly.
- Control over execution by optimized scheduler;
- Millions of goroutines => every unit of concurrency in the application domain can be represented by its own goroutine
- Just spawn a new goroutine, one per task.
- Example: HTTP request - a new goroutine is already spawned to handle it, but now, in the course of handling the request, you want to simultaneously query a database, and issue outgoing requests to three other services? No problem: spawn more goroutines.

How Are Goroutines Better?

- You need to wait for something to happen without wasting precious resources – forget about callbacks or reactive stream chaining – just block!
- Write straightforward, boring code.
- Goroutines preserve all the benefits threads give us are preserved by : control flow, exception context; only the runtime cost in footprint and performance is gone!

Welcome Goroutines!

Goroutines and channels

A Long Computation ...

Let’s have an example computation:

```
func main() {
	compute("compute!")
}

func compute(msg string) {
	for i := 0; ; i++ {
		fmt.Println(msg, i)
		time.Sleep(1 * time.Second)
	}
}
```

Let’s make it less boring …

Let’s introduce some randomness:

```
func main() {
		compute2("compute!")
}
func compute2(msg string) {
		for i := 0; ; i++ {
				fmt.Println(msg, i)
				time.Sleep(time.Duration(rand.Intn(1000)) * time.Millisecond)
		}
}
```

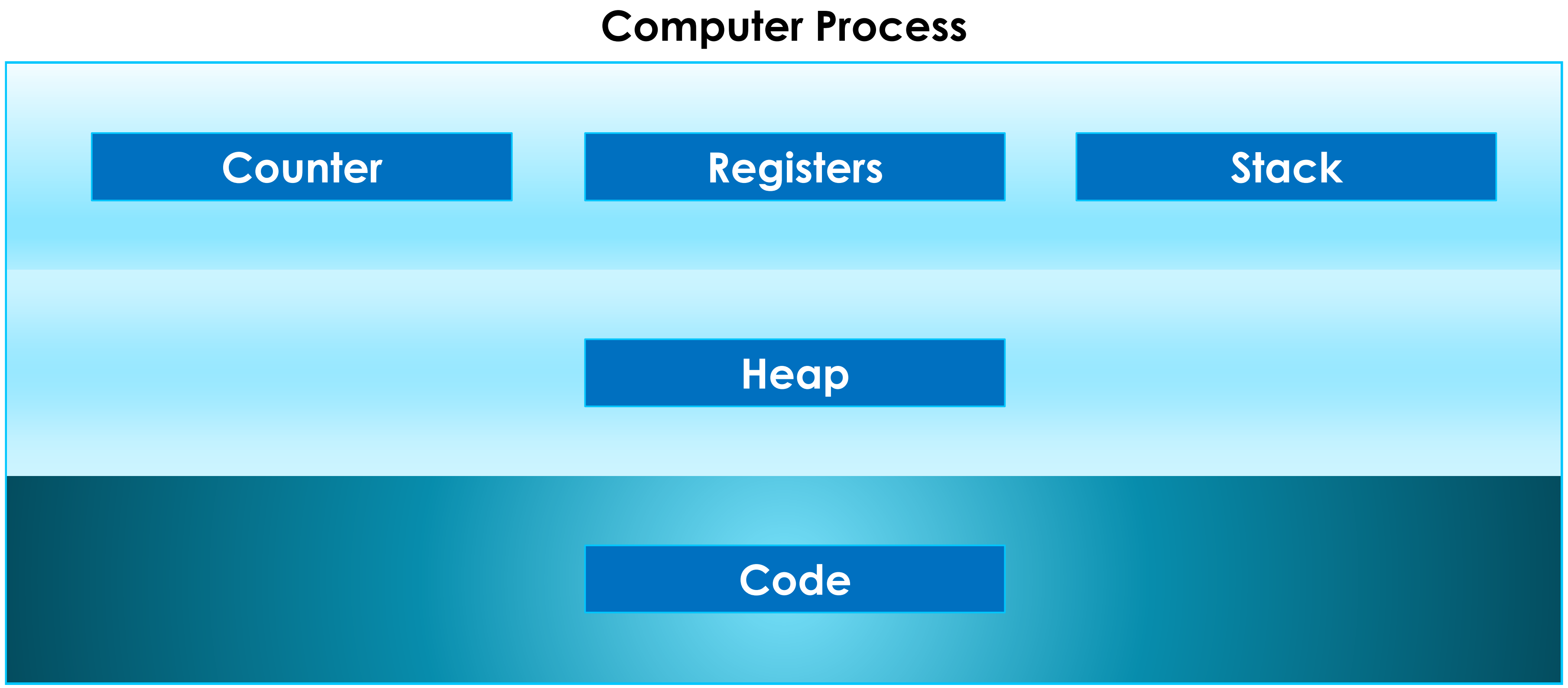
But why should we wait it?

Let’s compute in separate goroutine:

```
func main() {
	go compute3("compute!")
	time.Sleep(5 * time.Second)
}
func compute3(msg string) {
	rand.Seed(time.Now().UnixNano())
	for i := 0; ; i++ {
		fmt.Println(msg, i)
		time.Sleep(time.Duration(rand.Intn(1000)) * time.Millisecond)
	}
}
```

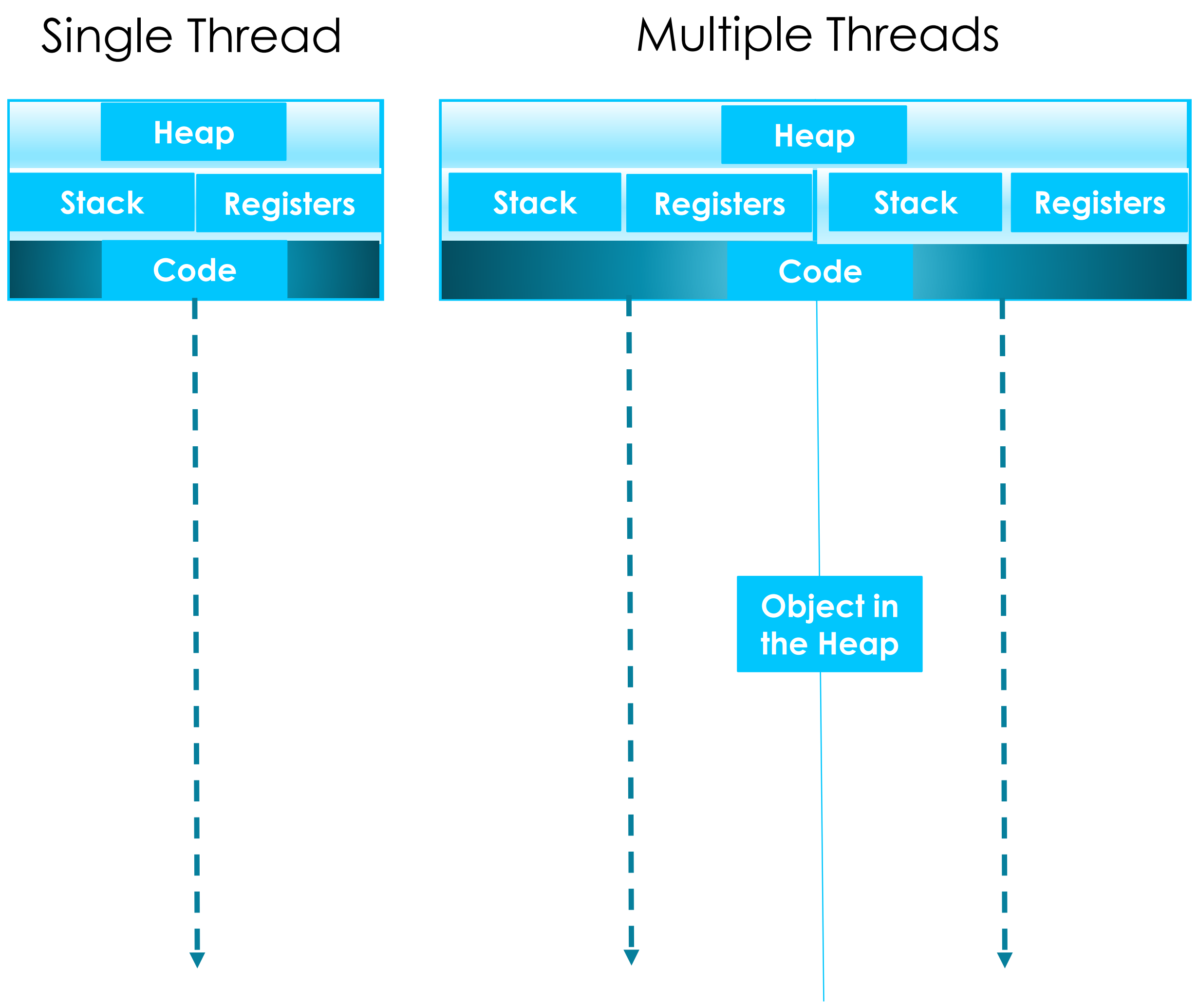
When main goroutine completes all other goroutines stop.

Concurrency Approaches: Processes



Threads

- There can be many threads in the same process
- The threads can access the shared memory
- This means that the global objects can be accessed by all threads
- Provided by the OS
- Cheaper to create than processes
- Some languages expose them directly other hide them behind a level of abstraction



Goroutines

- They are executed independently from the main function
- Can be hundreds of thousands of them – the initial stack can be as low as 2KB
- The goroutines stack can grow dynamically as needed
- In Golang there is a smart scheduler that can map goroutines to OS threads
- Goroutines follow the idea of Communicating sequential processes of Hoare

But why should we bother: concurrency problems

If we access the same memory from two threads/ goroutines, than we have a race! Lets see this pseudo-code:

```
int i = 0

thread1 { i++ }
thread2 { i++ }

wait { thread1 } { thread2 }
print i
```

What will be the result of the computation?

Critical Sections

- We provide Mutual Exclusion between different threads accessing the same resource concurrently
- There are many ways to implement Mutual Exclusion
- In Golang there are sync.Mutex, sync.RWMutex, atomic operations, semaphores, error groups (structured concurrency), concurrent hash maps, etc.
- And the message passing using Channels of course :)

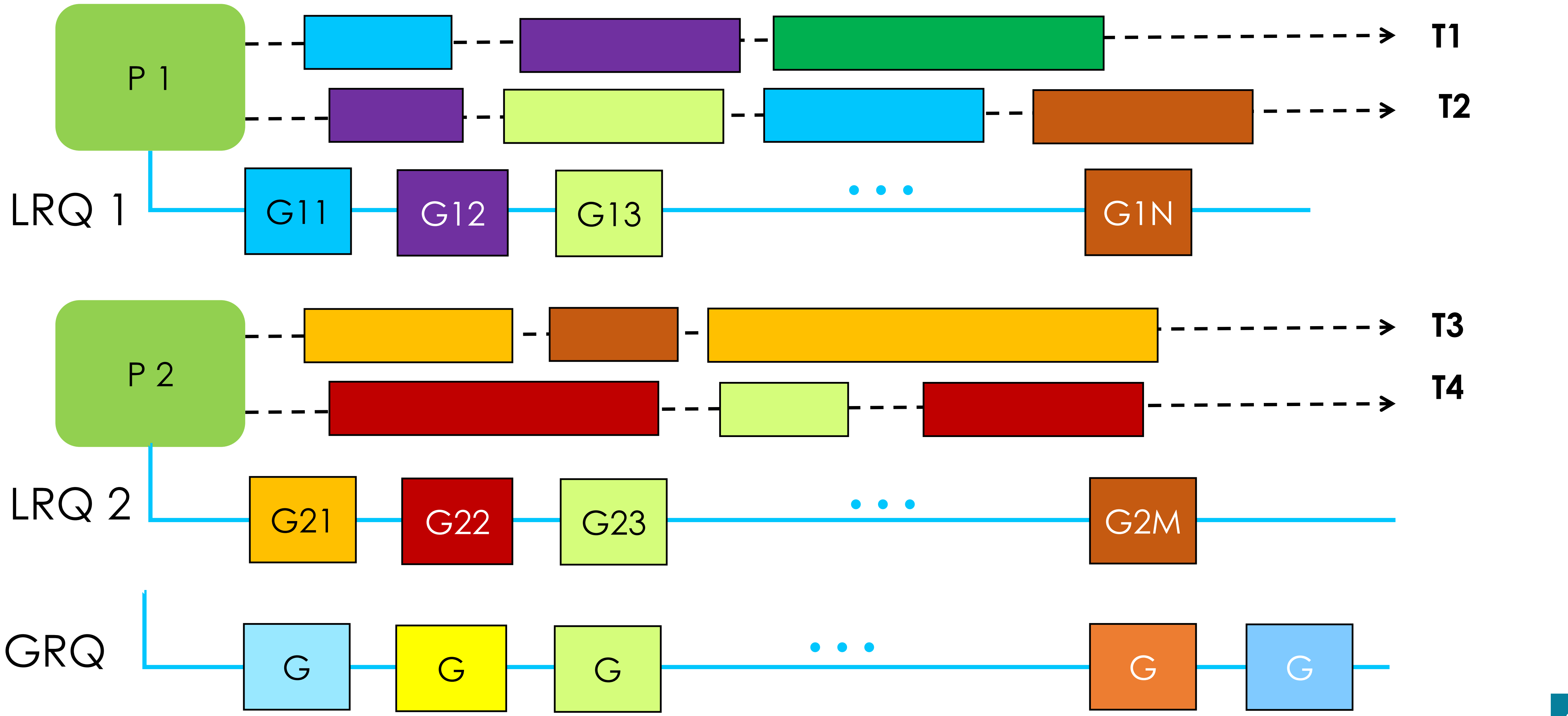
Share by communicating vs. Communicate by sharing

We can use Mutex / Atomic primitives for mutual exclusion between goroutines as in other languages, but in most cases it happens to be simpler and more obvious to handle data to other goroutines using channels.

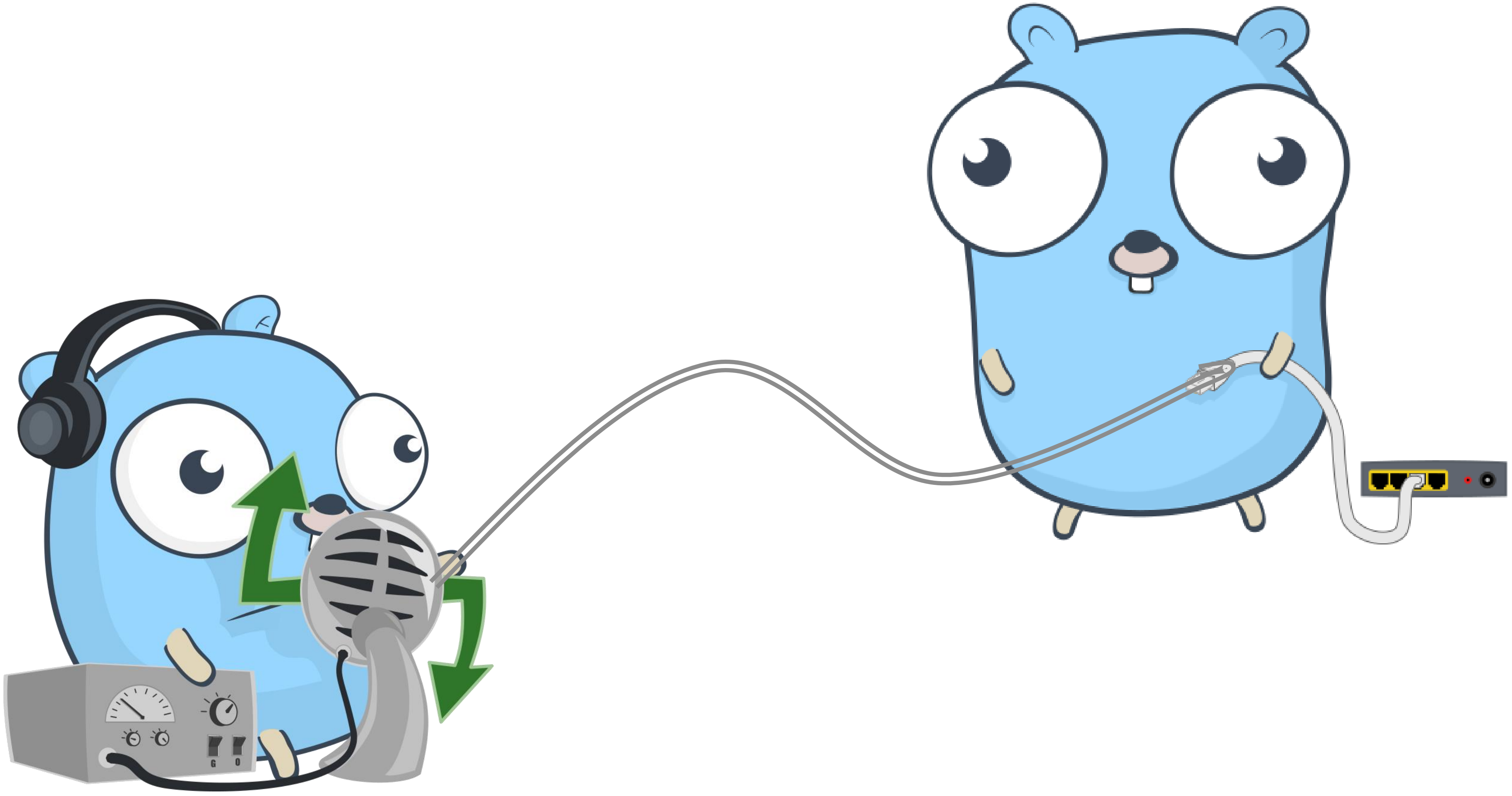
Goroutines Scheduling

GRQ – Global Run Queue **LRQ – Local Run Queue**

P – Processor T – Thread G – Goroutine



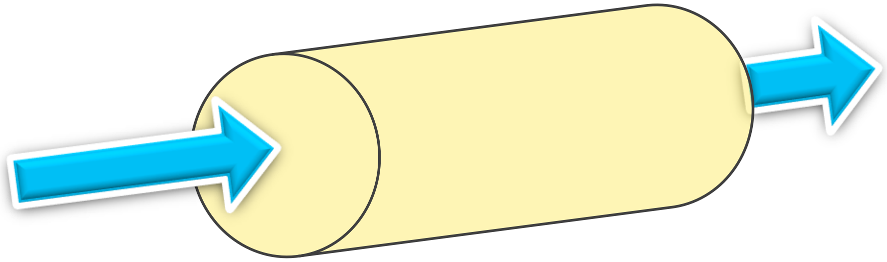
Channels



Channels

- Channels are Golang provided type used for communication between goroutines
- Like a pipeline in which the water can flow – but instead of water there are messages that are sent and received from different ends of the channel
- There is a special language support for channels in Go
- The channels in Go are typed – you should provide the type of messages that will be sent and received using this channel
- Can be created using **make**

```
stringChannel := make(chan string)
```

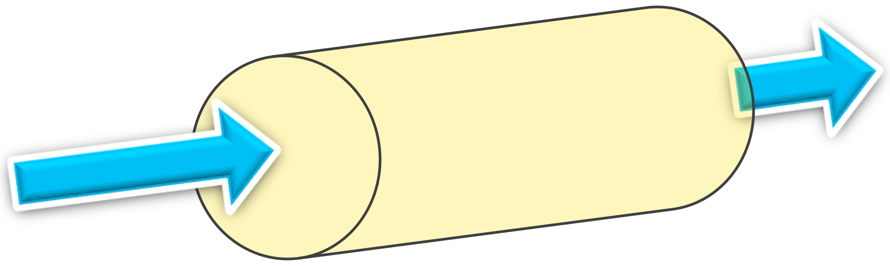


Types of Channels

- Channels can be buffered and non-buffered.
  By default they are non-buffered:

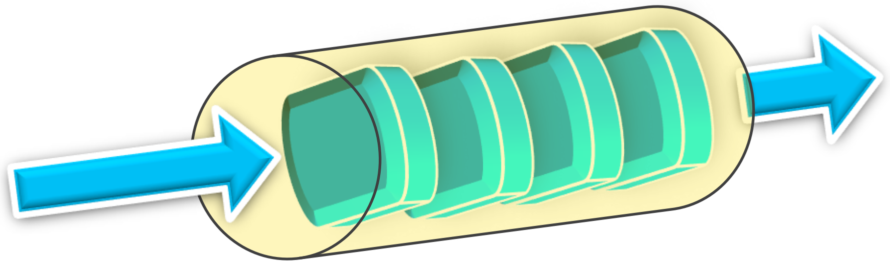
- Non - buffered channel

```
stringChannel := make(chan string)
```



- Buffered channel

```
ch := make(chan string, 4)
```



IO using channels

- You can send to a channel or receive from channel:

```
ch <- "hello"
read := <-ch
```

- Sending and receiving operations are done using the **<-** operator

  chan <- someValue - sends value to channel

  someVar = <-chan - receives a value from channel

- If the channel is non-buffered or if the buffer is full, the sending side can block until a value is read from the reading side
- If the channel is empty the receiving side can block until there is a value sent to the channel.
- The goroutine can block, but it is NOT blocking the OS thread behind it – the thread just continues to execute the next goroutine in LRQ/GRQ

Channels are first class objects in Go

- You can send channels as payload by using a channel:

```
c := make(chan chan int)
```

- Channels can be given as function arguments

```
func doSomething(input chan int) {
        // do something
}
```

- Channels can be returned as function results

```
func doSomethingElse() chan int {
        result := make(chan int)
        return result
}
```

Closing channels

- A channel can be closed using the builtin function **close**:

  ```
  close(ch)
  ```

- If closed, the channel can not be opened again
- Writing to a closed channel brings panic
- Reading from a closed channel never blocks
- You can continue reading from the reading side all the values if the channel is buffered.
- After that, the reading returns the zero value for the channel data type, and **false** as second result, if read as follows:

  ```
  someVar, ok = <-chan
  ```

Example – closing a channel

```
func main() {
        ch := make(chan string)
        go func() {
                for i := 0; i < 10; i++ {
                        ch <- fmt.Sprintf("Sending message number %d", i)
                }
                close(ch)
        }()
        var val string
        for ok := true; ok; {
                val, ok = <-ch
                fmt.Printf("Receiving: %#v, %#v\n", val, ok)
        }
        ch <- fmt.Sprintf("... but I have a question ...") // results in panic
}
```

Restricted channels

- The channels can be declared as read-only (**<-chan**) or write-only type (**chan<-**):

```
func randomFeed(count, maxVal int) <-chan int {
        ch := make(chan int)

        go func() {
                defer close(ch)
                for i := 0; i < count; i++ {
                        ch <- rand.Intn(maxVal)
                }
        }()
        return ch
}
```

```
func main() {
        intVals := randomFeed(5, 1000)
        for value := range intVals {
                fmt.Println(value)
        }
}
```

Range

Reading from channel until closed can be done most conveniently using **for - range**:

- The **range** blocks until new value is available or the channel is closed
- When the channel is closed the **for-range** loop exits:

```
intVals := randomFeed(5, 1000)
for value := range intVals {
        fmt.Println(value)
}
```

Deadlock

Deadlock happens if a group of goroutines can not continue to progress, because they are mutually waiting each other for something (e.g. to free a resource, or to write/read from channel). For example:

```
func main() {
		ch := make(chan int)
		ch <- 1
		fmt.Println(<-ch)
}
```

```
fatal error: all goroutines are asleep - deadlock!
goroutine 1 [chan send]:
main.main()
		D:/CourseGO/git/coursegopro/08-goroutines-channels/deadlock-simple/deadlock-simple.go:7 +0x37
```

Deadlock

- A goroutine can get stuck
  - either because it’s waiting for a channel or
  - because it is waiting for one of the locks in the sync package
- Common reasons are that
  - no other goroutine has access to the channel or the lock,
  - a group of goroutines are waiting for each other and none of them is able to proceed
- Currently Go only detects when the program as a whole freezes, NOT when a subset of goroutines get stuck.
- With channels it’s often easy to figure out what caused a deadlock. Programs that make heavy use of mutexes can, on the other hand, be notoriously difficult to debug.

Signaling to other goroutines and simple synchronization

- Use **struct{} {}** as sygnalling value – does not consume memory

```
func main() {
	orderReady := make(chan struct{})
	go func() {
		fmt.Println("Chef is preparing the pizza ...")
		time.Sleep(3 * time.Second)
		fmt.Println("Pizza is ready!")
		orderReady <- struct{} {}
	}()
	fmt.Println("Taking orders from clients")
	<- orderReady
	fmt.Println("Pizza is served ...")
	fmt.Println("Simulation complete.")
}
```

Select – multiplexing channel operations

- Similar to switch but for channels, not for types and values
- Selects non-deterministically the first channel that is ready to send or receive a value and executes the corresponding case operations
- Blocks if there is no channel that is ready to send or receive, and no default case is provided
- Example:

```go
select {
case out <- url:
        fmt.Printf("Generating URL: %s\n", url)
case <-ctx.Done():
        return
}
```

Select – multiplexing channel operations

```
func fibonacci(quit <-chan struct{}) <-chan int {
    fibChannel := make(chan int)
    go func() {
        defer close(fibChannel)
         fmt.Println("Generating fibonacci numbers ...")
         a, b := 0, 1
         for {
             select {
             case fibChannel <- a:  // out channel
                 fmt.Printf("a = %d\n", a)
                 a, b = b, a+b
             case <-quit:            // in channel
                 fmt.Println("Canceling generation.")
                 return
             }
         }
   }()
   return fibChannel
}
```

```
func main() {

    quitChannel := make(chan struct{})
    fibChannel := fibonacci(quitChannel)
    fmt.Println("Fibonacci consumer goroutine started ...")
    for i := 0; i < 10; i++ {
        value := <-fibChannel
        fmt.Printf("Fibonacci [%d] = %d\n", i, value)
    }
    quitChannel <- struct{}{}
    close(quitChannel)
    fmt.Println("Starting fibonacci generator ...")
    fmt.Printf("Final number of goroutines: %d\n",
             runtime.NumGoroutine())
}
```

Select with default case == non-blocking

```go
func fibonacci(quit <-chan struct{}) <-chan int {
    fibChannel := make(chan int)
    go func() {
        defer close(fibChannel)
        fmt.Println("Generating fibonacci numbers ...")
        a, b := 0, 1
        for {
            select {
            case fibChannel <- a:  // out channel
                fmt.Printf("a = %d\n", a)
                a, b = b, a+b
            case <-quit:              // in channel
                fmt.Println("Canceling generation.")
                return
            default:
                fmt.Println("No activity – sleeping ...")
                time.Sleep(100 * time.Millisecond)
            }
        }
    }()
    return fibChannel
}
```

```go
func main() {

    quitChannel := make(chan struct{})
    fibChannel := fibonacci(quitChannel)
    fmt.Println("Fibonacci consumer goroutine started ...")
    for i := 0; i < 10; i++ {
        value := <-fibChannel
        fmt.Printf("Fibonacci [%d] = %d\n", i, value)
    }
    quitChannel <- struct{}{}
    close(quitChannel)
    fmt.Println("Starting fibonacci generator ...")
    fmt.Printf("Final number of goroutines: %d\n",
            runtime.NumGoroutine())
}
```

Nil channels

- Generally NOT vary useful!
- Nil channels have a few interesting behaviors:
  - Sends to them block forever
  - Receives from them block forever
  - Closing them leads to panic

```
func main() {
	var c chan string
	c <- "message" // Deadlock
}
func main() {
	var c chan string
	fmt.Println(<-c) // Deadlock
}
```

But sometimes NIL channels can be useful:

```go
func sendTo(c chan<- int, iter int) {
   for i := 0; i <= iter; i++ {
      c <- i
   }

   close(c)
}
```

```go
func main() {
   ch1 := make(chan int)
   ch2 := make(chan int)
   go sendTo(ch1, 5)
   go sendTo(ch2, 10)
   for {
      select {
      case x, ok := <-ch1:
         if ok {
            fmt.Println("Channel 1 sent", x)
         } else { ch1 = nil  }
      case y, ok:= <-ch2:
         if ok {
            fmt.Println("Channel 2 sent", y)
         } else {  ch2 = nil  }
      }
      if ch1 == nil && ch2 == nil { break }
   }
   fmt.Println("Program finished normally.")
}
```

Semaphors: limiting the number of concurrent goroutines

```
func DoWork(n int, jobs <-chan struct{}) {
        fmt.Println("doing", n)
        time.Sleep(500 * time.Millisecond)
        fmt.Println("finished", n)
        <-jobs // release the token
}
func main() {
        // concurrentJobs is a buffered channel implemeting semaphore that blocks
        // if more than 20 goroutines are started at once
        var concurrentJobs = make(chan struct{}, 5)
        for i := 0; i < 30; i++ {
                concurrentJobs <- struct{}{} // acquire a  token
                go DoWork(i, concurrentJobs)
                fmt.Printf("Current number of goroutines: %d\n", runtime.NumGoroutine())
        }
}
```

Quiz 1

- Can you tell, what will be printed by the following main function?

```
func main() {
        select {}
        fmt.Println("Demo finished")
}
```

Quiz 2

- Can you tell, what will be printed by the following main function?

```
func main() {
        ch := make(chan string)
        go func() { ch <- "hi" }()
        select {
        case case1 := <-ch:
                fmt.Printf("case1: %s\n", case1)
        case case2 := <-ch:
                fmt.Printf("case2: %s\n", case2)
        case <-time.After(time.Nanosecond):      // Timeout !!!
                fmt.Printf("Timeout after 1 ns\n")
        default:
                fmt.Printf("No activity ...\n")
        }
}
```

Recommended Literature

- The Go Documentation - https://golang.org/doc/
- The Go Bible: Effective Go - https://golang.org/doc/effective_go.html
- David Chisnall, *The Go Programming Language Phrasebook*, Addison Wesley, 2012
- Alan A. A. Donovan, Brian W. Kernighan, *The Go Programming Language*, Addison Wesley, 2016
- Nathan Youngman, Roger Peppé, *Get Programming with Go*, Manning, 2018
- Naren Yellavula, *Building RESTful Web Services with Go*, Packt, 2017

Thank's for Your Attention!

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