LEARN THE GO PROGRAMMING LANGUAGE

For experienced developers or
those of an adventurous nature

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LESSON 05

Concurrency
Goroutines & Channels

v0.3 draft

Concurrency in Go

- The concurrency story is based on two primitives:
  - goroutines
  - channels
- And one control flow statement:
  - select

GOROUTINES

GOROUTINES ARE…

- Conceptually, lightweight threads (green threads)
- To be very specific, they are not processes or OS threads or coroutines
- goroutines **share memory**
- A running program consists of one or more goroutines
- Spec definition: "a function call as an independent concurrent thread of control"

More Info

- http://golang.org/ref/spec#Go_statements
- http://golang.org/doc/effective_go.html#goroutines

JUST USE GO

```
go fmt.Println(“immediately”)
go Later()


func Later() {
    time.Sleep(20 * time.Second)
    fmt.Print(“Some Time Later”)
}
```

MAIN()

- A running program consists of one or more goroutines
    - Except that main() is very special
- **When main() exits, all goroutines are immediately terminated**
- In this particular case, main exits long before fmt has a chance to print anything to the console:

```
package main

import "fmt"

func main() {
    go fmt.Println("If a goroutine is in a forest")
}

// outputs nothing at all
```

WaitGroups

```
func main() {
    var wg sync.WaitGroup
    for i := 0; i < 5; i++ {
        wg.Add(1)
        x := i
        go func() {
            time.Sleep(/*random*/)
            fmt.Println(x)
            wg.Done()
        }()
    }
    wg.Wait()
}
// will output 0-4 in unknown order
```

1) increment our wait group

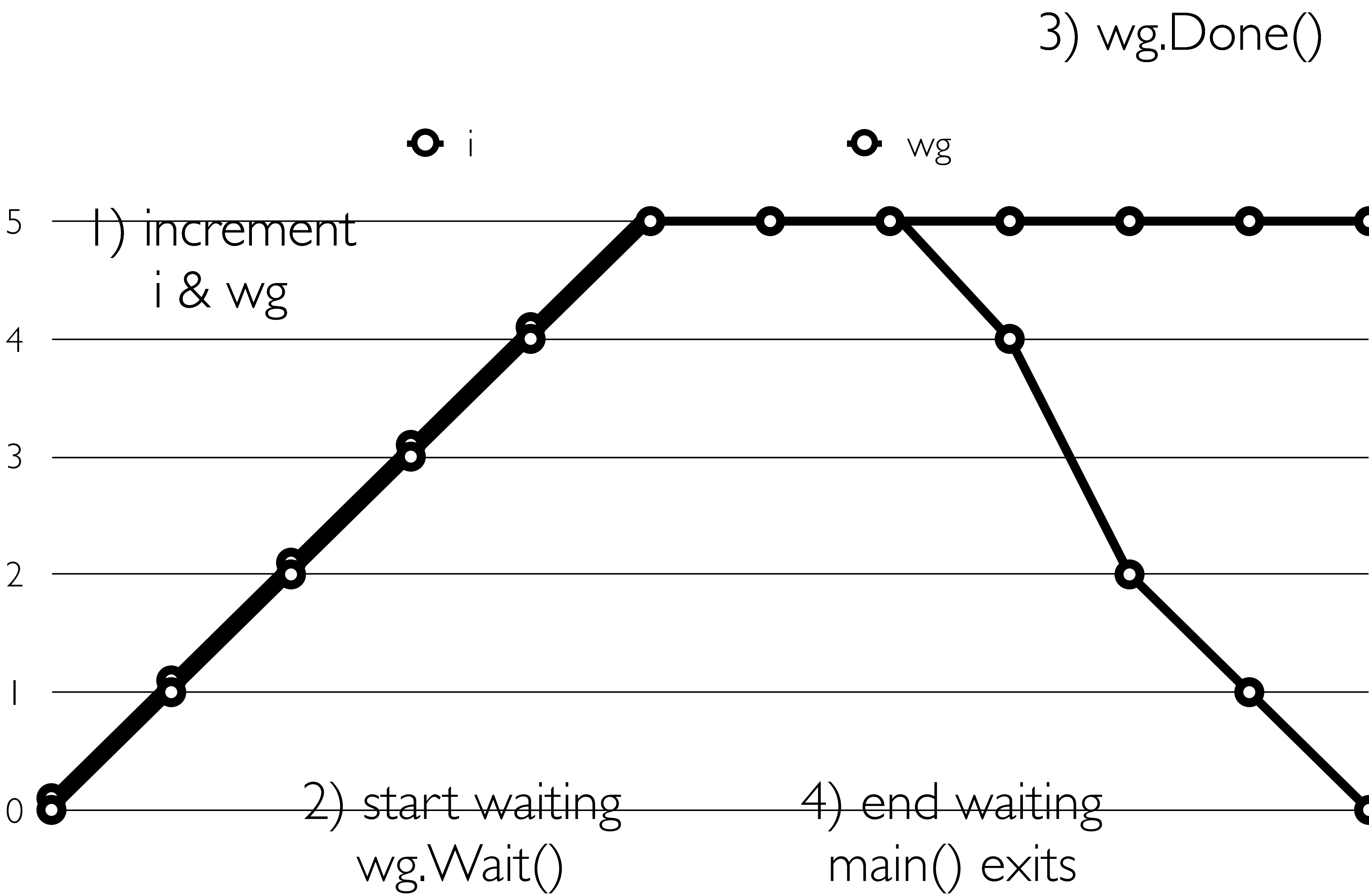
3) after a little nap, our goroutines will decrement the wait group

2) wait for our wait group's internal counter to hit zero

WaitGroups

```
func main() {
    var wg sync.WaitGroup
    for i := 0; i < 5; i++ {
        wg.Add(1)
        x := i
        go func() {
            time.Sleep(/*random*/)
            fmt.Println(x)
            wg.Done()
        }()
    }
    wg.Wait()
}
// will output 0-4 in random order
```

nuance!



3) wg.Done()
i
wg
5
4
3
2
1
0
1) increment
i & wg
2) start waiting
wg.Wait()
4) end waiting
main() exits

WAITGROUPS

```
func main() {
    var wg sync.WaitGroup
    for i := 0; i < 5; i++ {
        wg.Add(1)
        go func() {
            time.Sleep(/*random*/)
            fmt.Println(i)
            wg.Done()
        }()
    }
    wg.Wait()
}
// will output 5's
```

i increments to 5

while i is 5, the our goroutines are sleeping…

and when they wake up, they will all print "5"

WaitGroups

- The wg.Add() should happen before the goroutine is launched
- Make sure you evenly match wg.Add(…) and wg.Done() calls
- Use defer on the wg.Done() call if you need to

More Things

- goroutines are cheap
  - modern hardware can launch millions of them
  - stack size starts small and grow as necessary
- The scheduler can run goroutines on different processors/cores
- goroutines are the very best part of go

More Things

```
# GOMAXPROCS env variable
# go1.4 and earlier: defaults to 1
# go1.5 and later: defaults to NumCPU()
# rule of thumb:
# set this to the number of logical cores you have
export GOMAXPROCS=4

// or use the runtime package
import runtime

func main() {
    runtime.GOMAXPROCS(runtime.NumCPU())
}
```

Channels

Channels Are…

- A type that provides communication
  - Channels are a reference type
- Conceptually they are bidirectional "typed pipes"
- Typically used to safely send/receive values across goroutines
- Also used for synchronization
  - send/receive are atomic operations

CREATION SYNTAX

- Use `make` to create channels

```
chInt       := make(chan int)
chShapes    := make(chan Shape)
chQs        := make(chan Quacker)
```

chQs is a variable that holds a channel than can tx/rx anything that implements the Quacker interface

The Arrow

- There is only a “leftward” arrow!

- To send data through a channel, use the arrow

```
chInt <- 3
```

- To receive data via a channel, use the arrow

```
var i int
i <-chInt   // “pull” an int, store in i
<-chInt     // “pull” an int, discard it
```

Buff/Unbuff, Async/Sync

- By default, channels are unbuffered, or synchronous

- You can make asynchronous channels (buffered), but more on those later.

```
// buffer capacity of 42 ints:
chInt := make(chan int, 42)
```

SYNCHRONOUS CHANNELS

- **Channel communication is atomic**
  - A send operation on a channel blocks until a receiver is available for the same channel
  - A receive operation for a channel blocks until a sender is available for the same channel
  - When a channel is shared by two different goroutines, they will block until one is ready to send *and* the other is ready to receive.
  - This is *synchronization* and it happens at the moment the data passes through the channel.

Synchronous Channels

```
func main() {
  ch := make(chan int)
  // we try to send 42, but we have no receivers
  // the next line blocks and the whole thing hangs
  ch <- 42
}

func main() {
  ch := make(chan int)
  // we try to receive an int, but we wait forever
  // the next line blocks and the whole thing hangs
  receivedInt := <-ch
}
```

Synchronous Channels

```
func main() {
  ch := make(chan int)
  go func() {
    // we try to send 42, but no receivers yet…
    ch <- 42
  }()

  // after two seconds, pull a value from ch
  time.Sleep(2 * time.Second)
  receivedInt := <-ch
  fmt.Println(receivedInt)
}
```

RANDOM NUMBER PUMP

```
rnp := make(chan int64)
go func() {
  for ;; {
    rnp <- rand.Int63()
  }
}
```

Hypothetical HW-Assisted Random Number Pump

```
// Assume we have a hardware entropy device.
// Also assume that the hardware device can only be
// read by one thread/process/goroutine at a time.

rnp := make(chan int64)
go func() {
  for ;; {
    /* seed from HW device */
    rand.Seed(GetHWEntropy())
    rnp <- rand.Int63()
  }
}
```

Instead of mutexes we can use a channel to isolate access to GetHWEntropy()

Idiomatic, Hypothetical HW-Assisted Random Number Pump

```
var rnp chan int64

// hide the global variable behind an accessor
func randomNumberPump() chan int64 {
	if rnp == nil {
		rnp = make(chan int64)
	}
	go func() {
		for ;; {
			/* seed from HW device */
			rand.Seed(GetHWEntropy())
			rnp <- rand.Int63()
		}
	}()
	return rnp
}
```

Get used to "functions that return channels." You will use them often

Buffered (Asynch) Channels

- Buffered channels have an internal buffer with a fixed capacity:

```
// buffer capacity of 2 ints:
chInt := make(chan int, 2)
```

- Buffered channels don’t block, unless the buffer is full:

```
func main() {
  ch := make(chan int, 2)
  ch <- 42    // doesn’t block
  ch <- 43    // doesn’t block
  ch <- 44    // does block
}
```

Buffered (Asynch) Channels

- Buffer capacity cannot change
- Buffer capacity is not part of type

```
var someChannel chan int
var someOtherChannel chan int

someChannel = make(chan int, 2)
someChannel = make(chan int)
someOtherChannel = someChannel
someOtherChannel = make(chan int, 2)
```

CHANNEL EXAMPLES

- An implementation of the Sieve of Eratosthenes with channels:
  - http://golang.org/ref/spec#An_example_package
- http://blog.golang.org/go-concurrency-patterns-timing-out-and

FOR RANGE CHANNEL

- When receiving values indefinitely, we can use for and range
- This will loop and print out a random int64 every second:

```
func main() {
  rnp := randomNumberPump()

  for randomInt := range rnp {
    fmt.Println(randomInt)
    time.Sleep(1 * time.Second)
  }
}
```

Closing a Channel

- Use the close() built-in:
  `close(chInt)`
- Closing will terminate a for range statement
- Closed channels return the zero value when you try to pull from them
- You don't *have* to close a channel. It's not a file.
- Channels are garbage-collected regardless of being open or close
- You can use the two element variation to check if a channel is closed:

```
i, isOpen := <-chInt
```

Closing a Channel

```
  func main() {
    rnp := randomNumberPump()

    randomInt, isOpen := <-rnp
    fmt.Println(randomInt, isOpen) // 55770067 true

    close(rnp)

    randomInt, isOpen = <-rnp
    fmt.Println(randomInt, isOpen) // 0 false
}
```

Closing a Channel

```
func main() {
  rnp := randomNumberPump()

  go func() {
    time.Sleep(5 * time.Second)
    close(rnp)
  }()

  for randomInt := range rnp {
    fmt.Println(randomInt)
    time.Sleep(1 * time.Second)
  }

  fmt.Println("All Done")
}

// writing to a closed channel panics.
```

CHANNEL DIRECTIONALITY

- By default channels are bi-directional
- You can annotate a channel variable to make it unidirectional:

```
var recvOnly <-chan int
var sendOnly chan<- int
```

- Under the hood, all channels are bidirectional, assigning a bidirectional channel to a unidirectional channels is a good practice for safety & understandability.

```
chInt := make(chan int)
sendOnly = chInt
recvOnly = chInt
```

SELECT

```
// Superficially, the select statement looks like a switch:

chInt := make(chan int)
chInt2 := make(chan int)
chString := make(chan string)

select {
case i := <-chInt:
  fmt.Printf(“got an int %d”, i)
case i2 := <-chInt2:
  fmt.Printf(“got an int %d”, i)
case s := <-chString:
  fmt.Printf(“got a string %s”, s)
default:
  fmt.Printf(“default”)
}
```

SELECT

Every case must be a send or receive expression

All send/receive statements are evaluated.

```
select {
case i := <-chInt:
  fmt.Printf(“got an int %d”, i)
case i2 := <-chInt2:
  fmt.Printf(“got an int %d”, i)
case s := <-chString:
  fmt.Printf(“got a string %s”, s)
default:
  fmt.Printf(“default”)
}
```

If only one is ready, it is run.

If more than one is ready, one is selected at random “fairly”.

If none are ready, default is run.

if none are ready and there is no default clause, it blocks

SELECT: TIMEOUT

```
chInt := make(chan int)

select {
  case i := <-chInt:
    fmt.Println("got an int", i)
  case <-time.After(5 * time.Second):
}
```

You don't have to use the value you receive.

REQ/RESP: BASIC SERVER

```
type Req struct {
  question string
  respChan chan *Resp
}

type Resp struct {
  responseCode int
  answer       string
}

func start(handler func(*Req), reqCh <-chan *Req) {
  for {
    go handler(<-reqCh)
  }
}
```

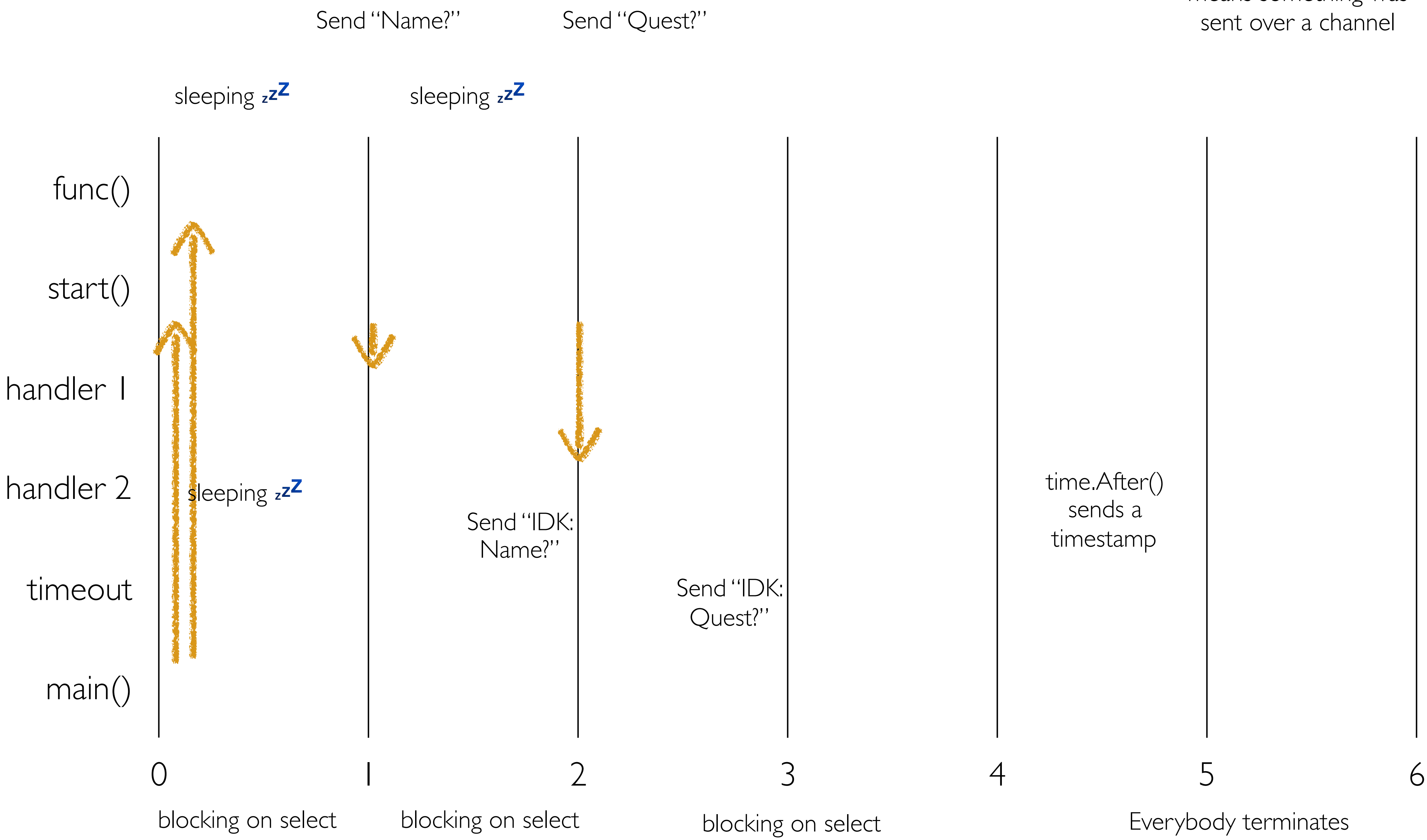
REQ/RESP: MAIN

```
func main() {
    handler := func(req *Req) {
        req.respChan <- &Resp{404, "I don't know the answer to '"+req.question+"'"}
    }
    reqCh := make(chan *Req)
    respCh := make(chan *Resp)

    go start(handler, reqCh)

    go func() {
        time.Sleep(1 * time.Second)
        reqCh <- &Req{"What is your name?", respCh}
        time.Sleep(1 * time.Second)
        reqCh <- &Req{"What is your quest?", respCh}
     }()

    for {
        select {
        case resp := <-respCh:
            fmt.Println(resp)
        case <-time.After(3 * time.Second):
            fmt.Println("timed out")
            return // exit main
        }
    }
}
```

Req/Resp: Timeline

Yellow arrow means go routines was launched

Solid grey arrow means something was sent over a channel



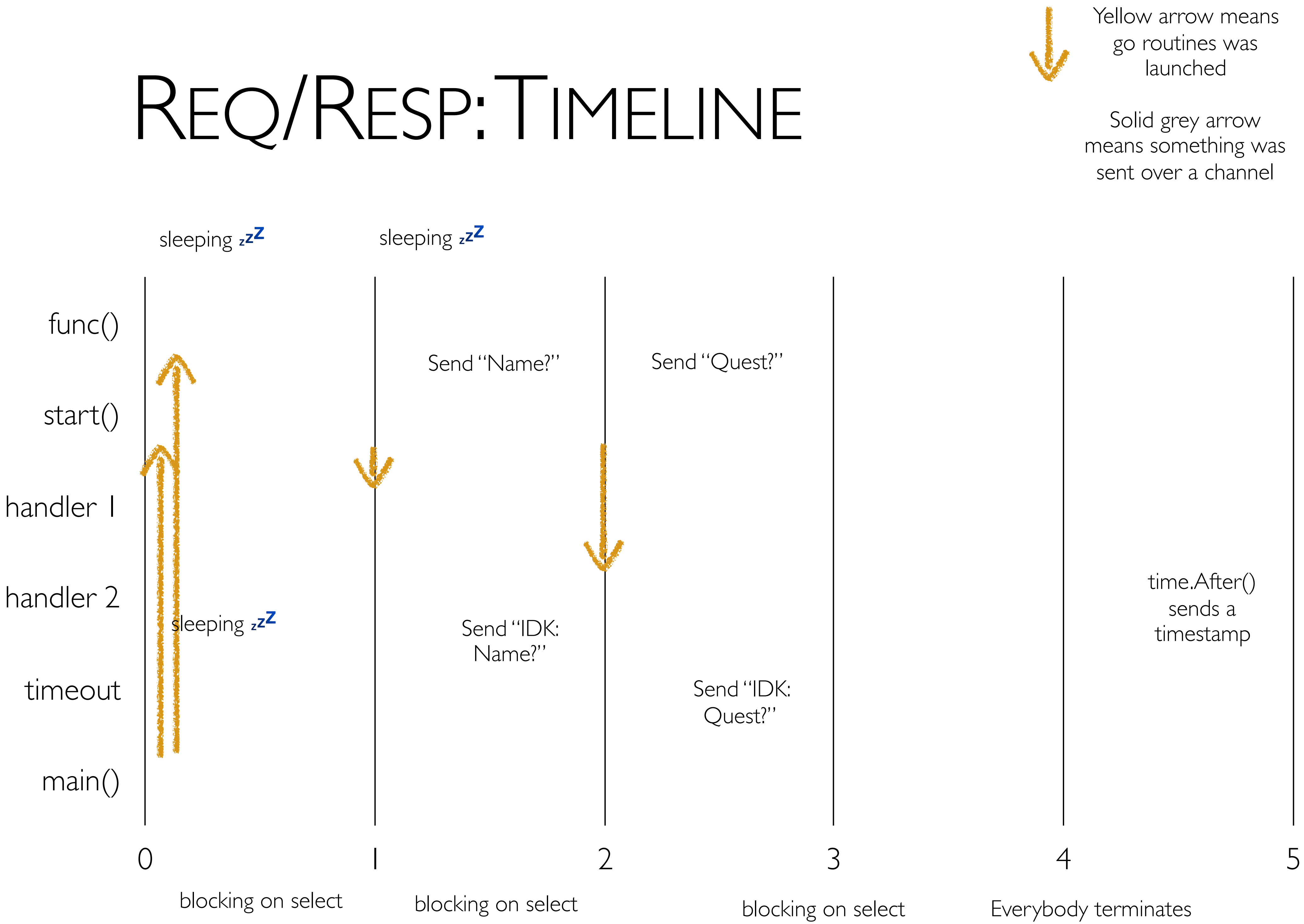
QUIT CHANNELS

```
func start(handler func(string) *Resp,
           reqCh <-chan *Req,
           quit <-chan bool) {
  for {
    select {
      case req := <-requests:
        req.respChan <- handler(req.question)
      case <-quit:
        return
    }
  }
}
```

REQ/RESP: QUITTER

```
func main() {
    handler := func(req *Req) {
        req.respChan <- &Resp{404, "I don’t know the answer to '"+req.question+"'"}
    }
    reqCh := make(chan *Req)
    respCh := make(chan *Resp)

    go start(handler, reqCh)

    go func() {
        time.Sleep(1 * time.Second)
        reqCh <- &Req{"What is your name?", respCh}
        time.Sleep(1 * time.Second)
        reqCh <- &Req{"What is your quest?", respCh}
     }()

    quitCh := time.After(4 * time.Second)
    for {
        select {
        case resp := <-respCh:
            log.Println(resp)
        case <-quitCh:
            log.Println("quitting")
            return // exit main
        }
    }
}
```

Req/Resp: Timeline



Putting It All Together

- Putting it all together:
  - channel send & receive gives you atomic communication
  - select gives you multiplexed receiving
  - channels as first class objects means that you can pass them around cheaply

The Golden Rule of Concurrency in Go

Do not communicate by sharing memory.

Instead, share memory by communicating.

MORE INFO

- http://blog.golang.org/share-memory-by-communicating
- http://golang.org/doc/codewalk/sharemem/
- http://blog.golang.org/concurrency-is-not-parallelism
- Go Concurrency patterns: http://www.youtube.com/watch?v=f6kdp27TYZs
- http://blog.golang.org/advanced-go-concurrency-patterns
- http://blog.golang.org/go-concurrency-patterns-timing-out-and
- http://blog.golang.org/pipelines
- http://golang.org/doc/effective_go.html#concurrency

LAST TIPS

- The learning curve is relatively steep
  - But worthwhile and powerful as you become familiar
- Performance is hard to predict: Use the profiler
- sync package has some useful primitives:
  - Once, Mutex, RWMutex, Cond

THANK YOU, CREDITS & LICENSE

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- Much of the content is inspired by (and in some cases, outright taken from) a CCA3.0 Licensed (http://creativecommons.org/licenses/by/3.0/us/), 3 day Go Course by Rob Pike that predates Go 1.0 and is considered **out of date:**
  - http://go.googlecode.com/hg-history/release-branch.r60/doc/GoCourseDay1.pdf
  - http://go.googlecode.com/hg-history/release-branch.r60/doc/GoCourseDay2.pdf
  - http://go.googlecode.com/hg-history/release-branch.r60/doc/GoCourseDay3.pdf

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