# Concurrent Programming with Go

## Concepts of Programming Languages

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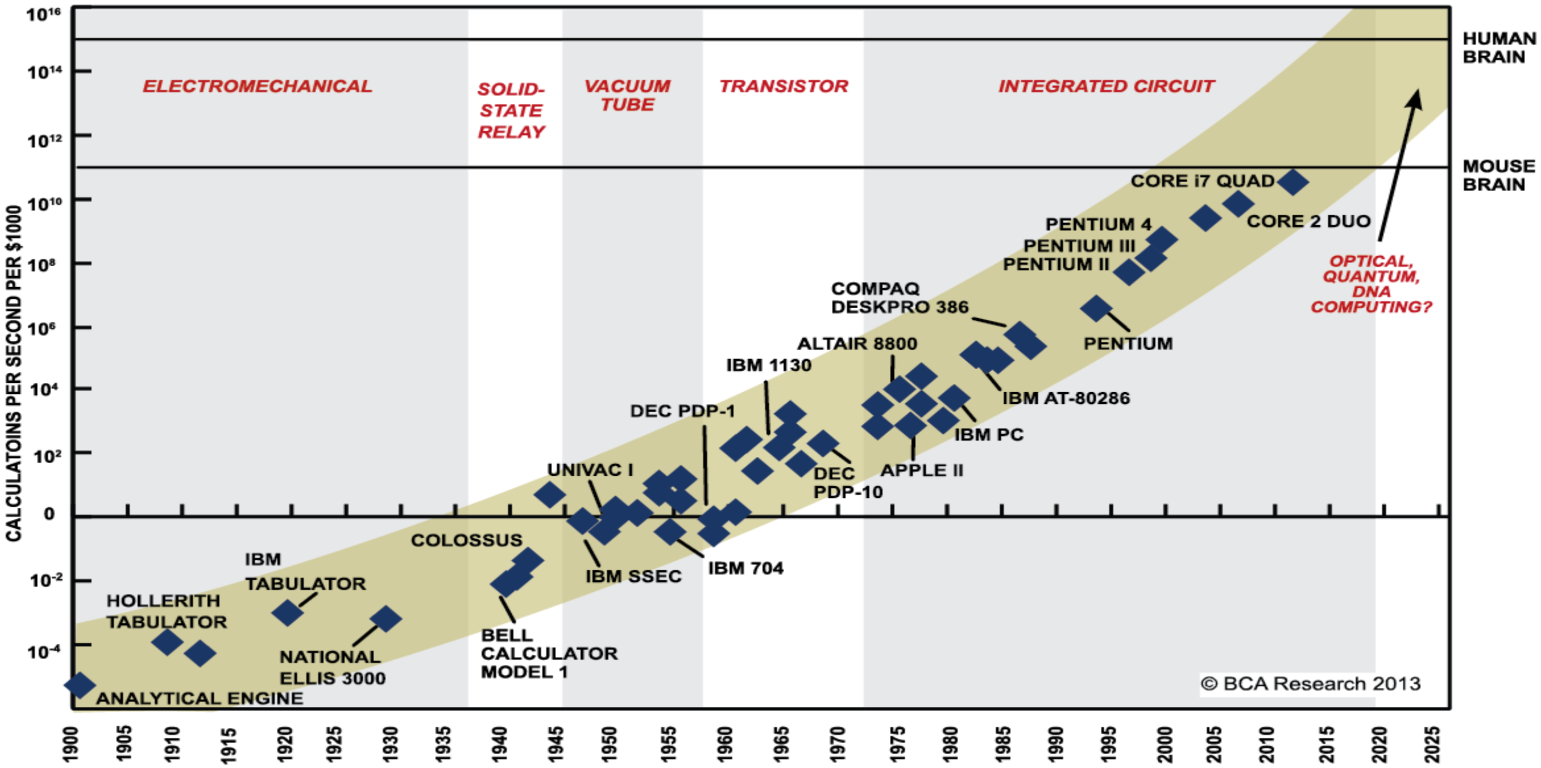
# Why Concurrent Programming?

- Computer clock rates do not get higher anymore (since 2004!)
- But Moores Law is still valid (Multicore!)



SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

# The modern world is parallel

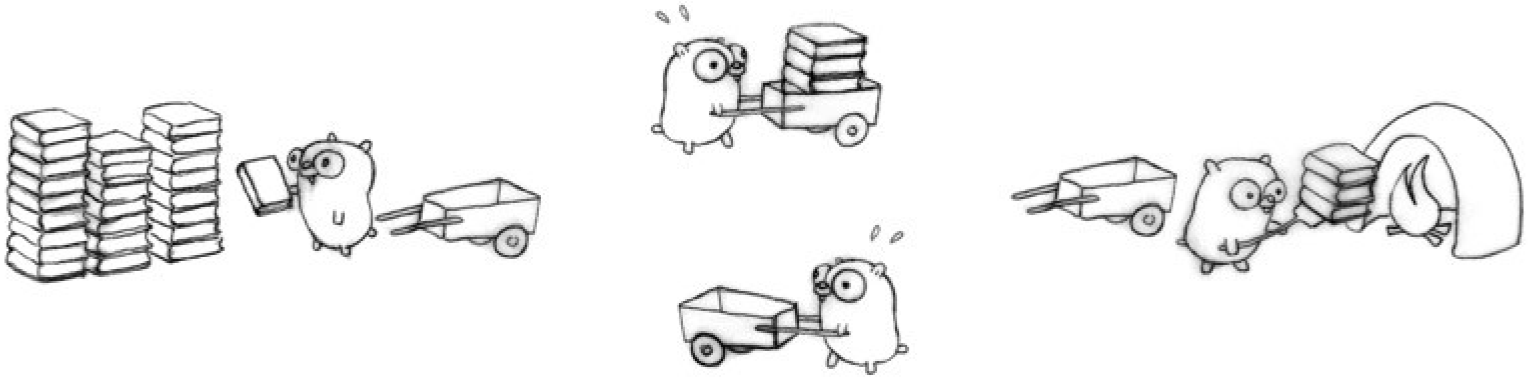
Multicore.

Networks.

Clouds of CPUs.

Loads of users.

# Concurrent Programming with Go



- Don't communicate by sharing memory; share memory by communicating (Rob Pike)

## Go provides:

- concurrent execution (goroutines)
- synchronization and messaging (channels)
- multi-way concurrent control (select)
- low level blocking primitives (locks) - Usually not needed!

# Goroutines

A goroutine is a function running independently in the same address space as other goroutines

```
f("hello", "world") // f runs; we wait
```

```
go f("hello", "world") // f starts running
g() // does not wait for f to return
```

Like launching a function with shell's & notation.

# Goroutines are not threads

- (They're a bit like threads, but they're much cheaper)
- Goroutines are multiplexed onto OS threads as required
- When a goroutine blocks the thread will execute other goroutines
- IO Calls and calls calls to the Go Standard Library trigger the scheduler
- There are no thread local variables in Go

# Lecturer 1: A simple example

No Goroutine used yet:

```
func lecturer() {
    for i := 0; i < 5; i++ {
        fmt.Printf("%d Bla bla goroutines bla channels bla bla\n", i)
        time.Sleep(time.Duration(rand.Intn(1e3)) * time.Millisecond)
    }
}

func main() {
    lecturer()
}
```

Run

What output do you expect?

# Lecturer 2: First Goroutine

Let's call `lecturer()` in a Goroutine:

```
func lecturer() {
    for i := 0; i < 5; i++ {
        fmt.Printf("%d Bla bla goroutines bla channels bla bla\n", i)
        time.Sleep(time.Duration(rand.Intn(1e3)) * time.Millisecond)
    }
}

func main() {
    go lecturer()
}
```

Run

What output do you expect?

# Channels

- Go routines can use channels for safe communication
- Construct a channel

```
c := make(chan int)     // buffer size = 0
c := make(chan int, 10) // buffer size = 10
```

- Send to channel

```
c <- 1
```

- Read from channel

```
x = <- c
```

- size = 0 (=default): Sender blocks until a reader requests a value from the channel
- size = n: Sender is not blocked until the buffer size is reached

# Channels

Channels are typed values that allow goroutines to synchronize and exchange information.

```
timerChan := make(chan time.Time)
go func() {
    time.Sleep(deltaT)
    timerChan <- time.Now() // send time on timerChan
}()

// Do something else; when ready, receive.
// Receive will block until timerChan delivers.
// Value sent is other goroutine's completion time.
completedAt := <-timerChan
```

# Channel and Errors

- Channel can be closed. Readers will return immediately. Successive writes will cause panic.

```
close(c)
```

- If a channel was closed, the reader gets "false" as return code (second return value)

```
value, ok := <-c
```

- Reading from a channel until closed

```
for {
    x, ok := <-c
    if !ok {
        break
    }
    // do something with x
}
// channel closed
```

# Channels: Deadlocks

The following code might look good at first sight, but causes a deadlock:

```go
package main

import "fmt"

func main() {
	ch := make(chan int)
	ch <- 1
	ch <- 2 // dead by now
	fmt.Println(<-ch)
	fmt.Println(<-ch)
}
```

Run

Expected output?

# Lecturer 3: Channels

Let's use channels for communication:

```
func lecturer(c chan string) {
    for i := 0; i < 5; i++ {
        c <- fmt.Sprintf("%d Bla bla goroutines bla channels bla bla\n", i)
        time.Sleep(time.Duration(rand.Intn(1e3)) * time.Millisecond)
    }
}

func main() {
    c := make(chan string)
    go lecturer(c)
    for i := 0; i < 5; i++ {
        fmt.Printf(<-c)
    }
}
```

Run

# Lecturer 4: Channels

We can also return an (outgoing) channel instead of passing it as parameter:

```go
func lecturer() <-chan string {
    c := make(chan string)
    go func() {
        for i := 0; i < 5; i++ {
            c <- fmt.Sprintf("%d Bla bla goroutines bla channels bla bla\n", i)
            time.Sleep(time.Duration(rand.Intn(1e3)) * time.Millisecond)
        }
    }()
    return c
}

func main() {
    c := lecturer()
    for i := 0; i < 5; i++ {
        fmt.Printf(<-c)
    }
}
```

Run

# Exercise 1: Generator

Write a generator for Fibonacci numbers, i.e. a function that returns a channel where the next Fibonacci number can be read.

```
func main() {
    fibChan := fib() // <- write func fib
    for n := 1; n <= 10; n++ {
        fmt.Printf("The %dth Fibonacci number is %d\n", n, <-fibChan)
    }
}
```

Run

Also write a test for the `fib()` function.

# Lecturer 5: Anne & Bart

We're adding another (slower) lecturer to make it more interesting:

```go
func lecturer(name string, speed int) <-chan string {
    c := make(chan string)
    go func() {
        for i := 0; i < 5; i++ {
            c <- fmt.Sprintf("%s: %d Bla bla goroutines bla channels bla bla\n", name, i)
            time.Sleep(time.Duration(rand.Intn(1e3*speed)) * time.Millisecond)
        }
    }()
    return c
}

func main() {
    a := lecturer("Anne", 1)
    b := lecturer("Bart", 2)
    for i := 0; i < 5; i++ {
        fmt.Printf(<-a)
        fmt.Printf(<-b)
    }
}
```

Run

# Lecturer 6: Fan In

```go
// func lecturer(name string, speed int) <-chan string { ... }

func fanIn(c1, c2 <-chan string) <-chan string {
    c := make(chan string)
    go func() { for { c <- <-c1 } }()
    go func() { for { c <- <-c2 } }()
    return c
}

func main() {
    a := lecturer("Anne", 1)
    b := lecturer("Bart", 2)
    c := fanIn(a, b)
    for i := 0; i < 10; i++ {
        fmt.Printf(<-c)
    }
}
```

Run

# Lecturer 7: Select

```go
func lecturer(name string, speed int) <-chan string {
    c := make(chan string)
    go func() {
        for i := 0; i < 5; i++ {
            c <- fmt.Sprintf("%s: %d Bla bla goroutines bla channels bla bla\n", name, i)
            time.Sleep(time.Duration(rand.Intn(1e3*speed)) * time.Millisecond)
        }
    }()
    return c
}

func main() {
    a := lecturer("Anne", 1)
    b := lecturer("Bart", 2)
    for i := 0; i < 10; i++ {
        select {
        case msgFromAnne := <-a: fmt.Printf(msgFromAnne)
        case msgFromBart := <-b: fmt.Printf(msgFromBart)
        }
    }
}
```

Run

# Select

The `select` statement is like a `switch`, but the decision is based on ability to communicate rather than equal values.

```
select {
    case v := <-ch1:
        fmt.Println("channel 1 sends", v)
    case v := <-ch2:
        fmt.Println("channel 2 sends", v)
    default: // optional
        fmt.Println("neither channel was ready")
}
```

Without default case, the select blocks until a message is received on one of the channels.

## Exercise 2: Timeout

Write a function `setTimeout()` that times out an operation after a given amount of time. Hint: Have a look at the built-in `time.After()` function and make use of the `select` statement.

```
func main() {
	res, err := setTimeout(func() int {
		time.Sleep(2000 * time.Millisecond)
		return 1
	}, 1*time.Second)

	if err != nil {
		fmt.Println(err.Error())
	} else {
		fmt.Printf("operation returned %d", res)
	}
}
```

Run

Also write a test for the `setTimeout()` function.

# Fan In

- Merge n channels into one

```go
// FanIn reads from N-Channels and forwards the result to the output channel.
func FanIn(channels []chan int, output chan int) {
    for i := 0; i < len(channels); i++ {
        // fan in
        go func(i int) {
            for {
                n, ok := <-channels[i]
                if !ok {
                    break
                }
                output <- n
            }
            log.Println("input channel closed: done.")
        }(i)
    }
}
```

# Fan Out

- Read tasks from a channel and start parallel processing. Results will be written in a result channel.

```go
// FanOut reads from a channel and starts an async processing task.
// The result values of the tasks will be returned in the result channel
func FanOut(input chan int, task func(int, chan int)) chan int {
	result := make(chan int)
	go func() {
		for {
			x, ok := <-input
			if !ok {
				break
			}
			go task(x, result)
		}
	}()
	return result
}
```

# Go really supports concurrency

Really.

It's routine to create thousands of goroutines in one program.
(not unusual to debug a program after it had created even millions goroutines)

Stacks start small, but grow and shrink as required.

Goroutines aren't free, but they're very cheap.

More information about Go and concurrency:

- youtu.be/f6kdp27TYZs?t=1 (https://youtu.be/f6kdp27TYZs?t=1)

# Java like BlockingQueue with Channels

```go
// BlockingQueue is a FIFO container with a fixed capacity.
// It  blocks a reader when it is empty and a writer when it is full.
type BlockingQueue struct {
    channel chan interface{}
}

// NewBlockingQueue constructs a BlockingQueue with a given capacity.
func NewBlockingQueue(capacity int) *BlockingQueue {
    q := BlockingQueue{make(chan interface{}, capacity)}
    return &q
}

// Put puts an item in the queue and blocks it the queue is full.
func (q *BlockingQueue) Put(item interface{}) {
    q.channel <- item
}

// Take takes an item from the queue and blocks if the queue is empty.
func (q *BlockingQueue) Take() interface{} {
    return <-q.channel
}

// EOF
```

# Java like BlockingQueue - Test

```
func TestBlockingQueue(t *testing.T) {
    bq1 := NewBlockingQueue(1)
    done := make(chan bool)
    // slow writer
    go func(bq *BlockingQueue) {
        bq.Put("A")
        time.Sleep(100 * time.Millisecond)
        bq.Put("B")
        time.Sleep(100 * time.Millisecond)
        bq.Put("C")
    }(bq1)
    // reader will be blocked
    go func(bq *BlockingQueue) {
        item := bq.Take()
        fmt.Printf("Got %v\n", item)
        item = bq.Take()
        fmt.Printf("Got %v\n", item)
        item = bq.Take()
        fmt.Printf("Got %v\n", item)
        done <- true
    }(bq1)

    <-done
}
```

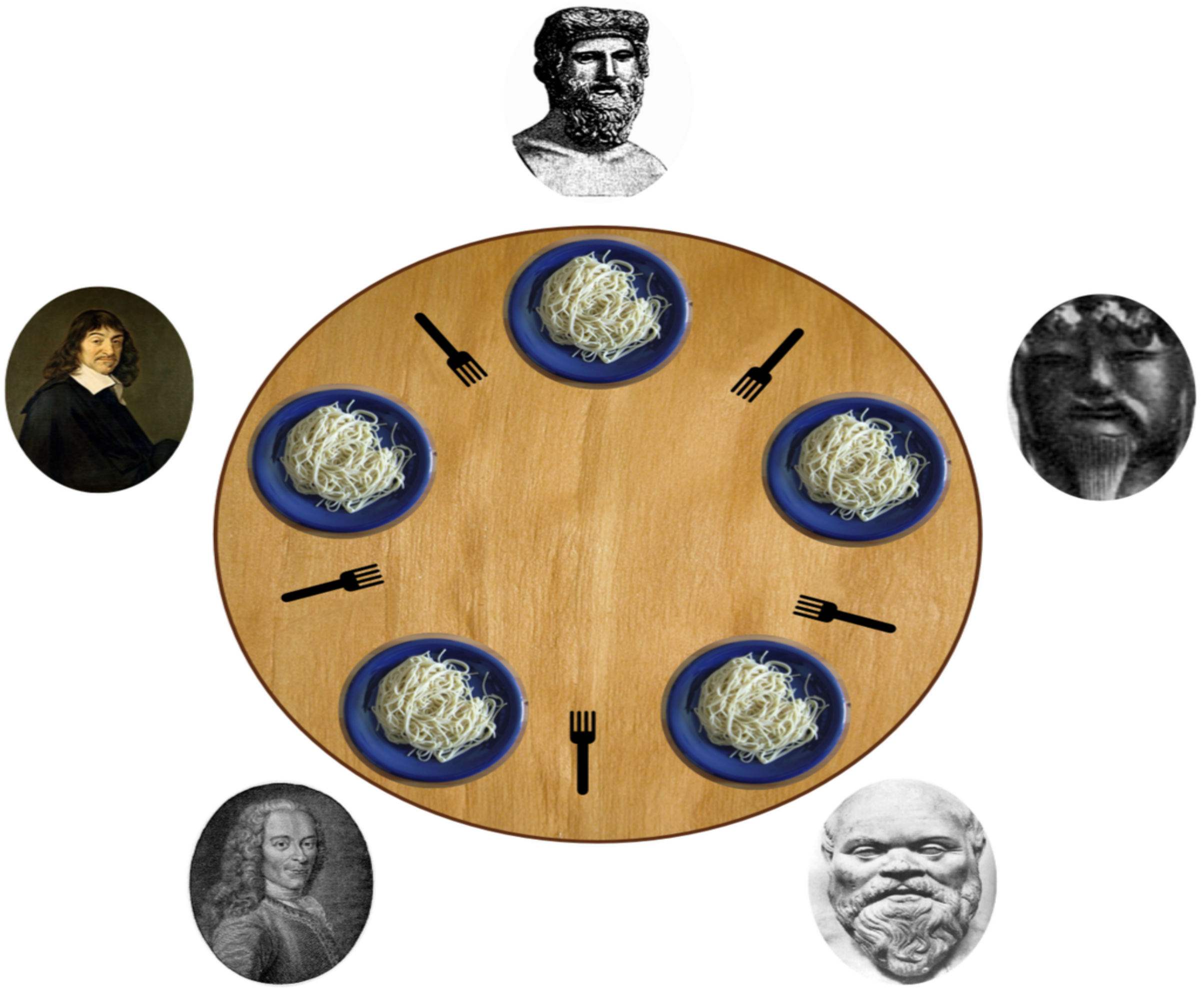
# Java like BlockingQueue with Locks (Low Level)

```
// BlockingQueue is a FIFO container with a fixed capacity.
// It  blocks a reader when it is empty and a writer when it is full.
type BlockingQueue struct {
    m        sync.Mutex
    c        sync.Cond
    data     []interface{}
    capacity int
}

// NewBlockingQueue constructs a BlockingQuee with a given capacity.
func NewBlockingQueue(capacity int) *BlockingQueue {
    q := new(BlockingQueue)
    q.c = sync.Cond{L: &q.m}
    q.capacity = capacity
    return q
}

// A1
```

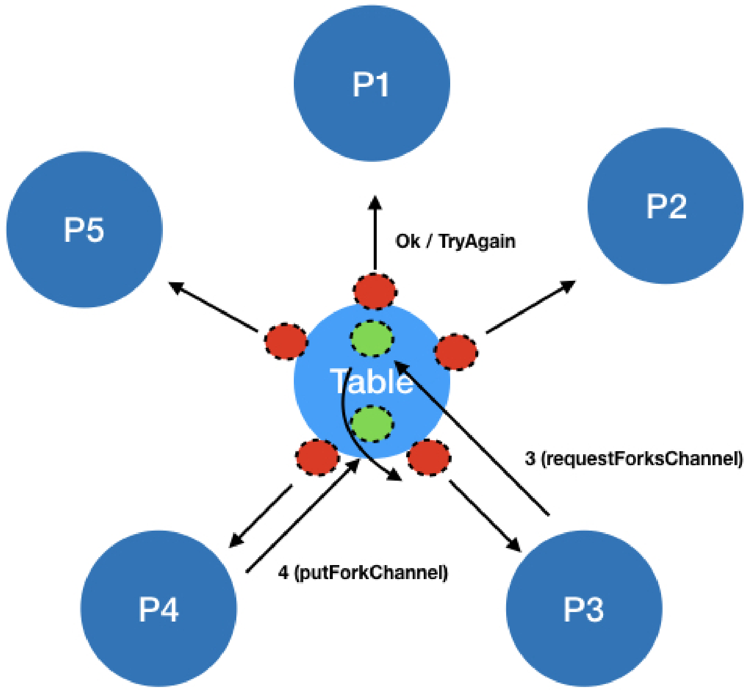
# Java like BlockingQueue with Locks (Low Level)

```go
// Put puts an item in the queue and blocks it the queue is full.
func (q *BlockingQueue) Put(item interface{}) {
    q.c.L.Lock()
    defer q.c.L.Unlock()

    for q.isFull() {
        q.c.Wait()
    }
    q.data = append(q.data, item)
    q.c.Signal()
}

// Take takes an item from the queue and blocks if the queue is empty.
func (q *BlockingQueue) Take() interface{} {
    q.c.L.Lock()
    defer q.c.L.Unlock()

    for q.isEmpty() {
        q.c.Wait()
    }
    result := q.data[0]
    q.data = q.data[1:len(q.data)]
    q.c.Signal()
    return result
}

// A2
```

# Exercise 3: Dining Philosophers



# Dining Philosophers with Channels



## Dining Philosophers - Hints

- Never grab one fork and wait for the other. This is a deadlock situation.
- If you cant get the second fork, you should immediately release the first one.
- The table itself should be a Go Routine and return the forks to a requesting philosopher, this makes synchronization easy (the table is single threaded)
- The philosopher loop looks like this:

```go
// Main loop
func (p *Philosopher) run() {
    for {
        p.takeForks()
        p.eat()
        p.putForks()
        p.think()
    }
}
```

## Wrong Solutions

- There are many wrong solution on the web.
- Most of them share the problem that the Philosopher picks up the left fork (implemented with channels or locks) and immediately the right fork.
- The problem arises, when the second fork is in use. There is a potential deadlock, when all Philosophers wait on the second fork.
- In theory a deadlock occurs if there is a cycle in the Resource Allocation Graph.

play.golang.org/p/rXCotNNY24 (https://play.golang.org/p/rXCotNNY24)

## Summary

- With Go you can solve sync problems with channels
- Channels use Message Passing instead of locks
- Go has a low level lock API, but this is seldom needed
- It is possible to port all classes from java.util.locking easily

# Thank you

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