Concurrency in Go

Feb 12th 2021

Go Resources

https://tour.golang.org/list

https://play.golang.org

https://gobyexample.com

Outline

Two Synchronization Mechanisms

- Locks
- Channels

MapReduce

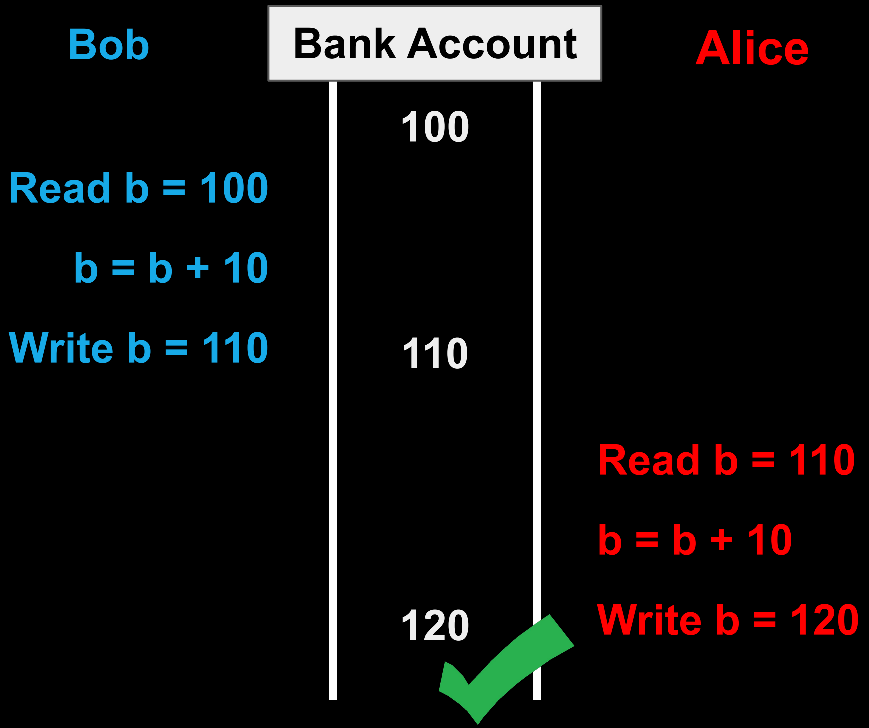
- A Case Study of WordCount

Two synchronization mechanisms

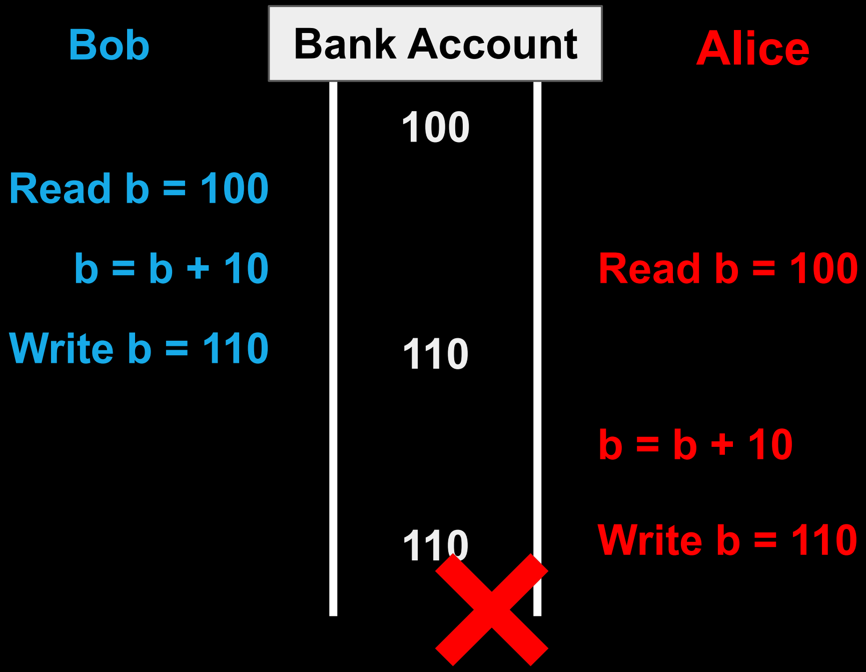
Locks - limit access to a critical section

Channels - pass information across processes using a queue

Example: Bank Account



Example: Bank Account



What went wrong?

Changes to balance are not ***atomic***

```
func Deposit(amount) {
    lock balanceLock
    read balance
    balance = balance + amount
    write balance
    unlock balanceLock
}
```

Critical section

Locks in Go

```go
package account

import "sync"

type Account struct {
	balance int
	lock sync.Mutex
}

func NewAccount(init int) Account {
	return Account{balance: init}
}
```

```go
func (a *Account) CheckBalance() int {
	a.lock.Lock()
	defer a.lock.Unlock()
	return a.balance
}

func (a *Account) Withdraw(v int) {
	a.lock.Lock()
	defer a.lock.Unlock()
	a.balance -= v
}

func (a *Account) Deposit(v int) {
	a.lock.Lock()
	defer a.lock.Unlock()
	a.balance += v
}
```

Read Write Locks in Go

```go
package account

import "sync"

type Account struct {
	balance int
	lock sync.RWMutex
}

func NewAccount(init int) Account {
	return Account{balance: init}
}
```

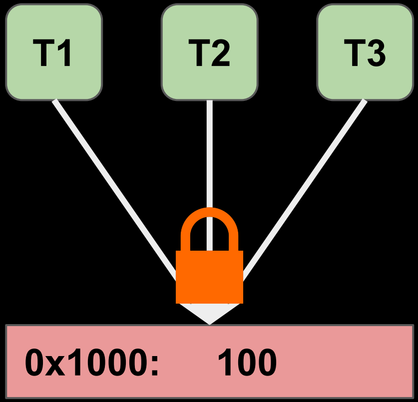
```go
func (a *Account) CheckBalance() int {
	a.lock.RLock()
	defer a.lock.RUnlock()
	return a.balance
}

func (a *Account) Withdraw(v int) {
	a.lock.Lock()
	defer a.lock.Unlock()
	a.balance -= v
}

func (a *Account) Deposit(v int) {
	a.lock.Lock()
	defer a.lock.Unlock()
	a.balance += v
}
```

Two Solutions to the Same Problem

Locks:

Multiple threads can reference same memory location

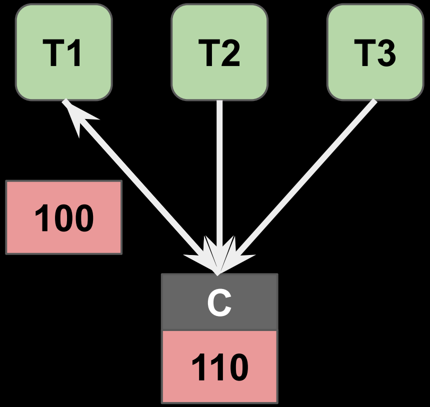
Use lock to ensure only one thread is updating it at any given time



Channels:

Data item initially stored in channel

Threads must request item from channel, make updates, and return item to channel



Go channels

Channels also allow us to safely communicate between ***goroutines***

```go
result := make(chan int, numWorkers)

// Launch workers
for i := 0; i < numWorkers; i++ {
    go func() {
        // ... do some work
        result <- i
    }()
}

// Wait until all worker threads have finished
for i := 0; i < numWorkers; i++ {
    handleResult(<-result)
}
fmt.Println("Done!")
```

Go channels

Easy to express asynchronous RPC

Awkward to express this using locks

```
result := make(chan int, numServers)

// Send query to all servers
for i := 0; i < numServers; i++ {
    go func() {
        resp := // ... send RPC to server
        result <- resp
    }()
}

// Return as soon as the first server responds
handleResponse(<-result)
```

Bank Account Code (using channels)

```go
package account

type Account struct {
	// Fill in Here
}

func NewAccount(init int) Account {
	// Fill in Here
}
```

```go
func (a *Account) CheckBalance() int {
	// What goes Here?
}

func (a *Account) Withdraw(v int) {
	// ???
}

func (a *Account) Deposit(v int) {
	// ???
}
```

Bank Account Code (using channels)

```go
package account

type Account struct {
	balance chan int
}

func NewAccount(init int) Account {
	a := Account{make(chan int, 1)}
	a.balance <- init
	return a
}
```

```go
func (a *Account) CheckBalance() int {
	// What goes Here?
}

func (a *Account) Withdraw(v int) {
	// ???
}

func (a *Account) Deposit(v int) {
	// ???
}
```

Bank Account Code (using channels)

```go
package account

type Account struct {
	balance chan int
}

func NewAccount(init int) Account {
	a := Account{make(chan int, 1)}
	a.balance <- init
	return a
}
```

```go
func (a *Account) CheckBalance() int {
	bal := <-a.balance
	a.balance <- bal
	return bal
}

func (a *Account) Withdraw(v int) {
	// ???
}

func (a *Account) Deposit(v int) {
	//???
}
```

Bank Account Code (using channels)

```go
package account

type Account struct {
	balance chan int
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func NewAccount(init int) Account {
	a := Account{make(chan int, 1)}
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	return a
}
```

```go
func (a *Account) CheckBalance() int {
	bal := <-a.balance
	a.balance <- bal
	return bal
}

func (a *Account) Withdraw(v int) {
	bal := <-a.balance
	a.balance <- (bal - v)
}

func (a *Account) Deposit(v int) {
	//???
}
```

Bank Account Code (using channels)

```go
package account

type Account struct {
	balance chan int
}

func NewAccount(init int) Account {
	a := Account{make(chan int, 1)}
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	return a
}
```

```go
func (a *Account) CheckBalance() int {
	bal := <-a.balance
	a.balance <- bal
	return bal
}

func (a *Account) Withdraw(v int) {
	bal := <-a.balance
	a.balance <- (bal - v)
}

func (a *Account) Deposit(v int) {
	bal := <-a.balance
	a.balance <- (bal + v)
}
```

Select statement

`select` allows a goroutine to wait on multiple channels at once

```
for {
    select {
        case money := <-dad:
            buySnacks(money)
        case money := <-mom:
            buySnacks(money)
    }
}
```

Select statement

`select` allows a goroutine to wait on multiple channels at once

```
for {
    select {
        case money := <-dad:
            buySnacks(money)
        case money := <-mom:
            buySnacks(money)
        case default:
            starve()
            time.Sleep(5 * time.Second)
    }
}
```

Handle timeouts using select

```go
result := make(chan int)
timeout := make(chan bool)

// Asynchronously request an
// answer from server, timing
// out after X seconds
askServer(result, timeout)

// Wait on both channels
select {
    case res := <-result:
        handleResult(res)
    case <-timeout:
        fmt.Println("Timeout!")
}
```

```go
func askServer(
    result chan int,
    timeout chan bool) {

    // Start timer
    go func() {
        time.Sleep(5 * time.Second)
        timeout <- true
    }()

    // Ask server
    go func() {
        response := // ... send RPC
        result <- response
    }()
}
```

Handle timeouts using `select`

```go
result := make(chan int)
timeout := make(chan bool)

// Asynchronously request an
// answer from server, timing
// out after X seconds
askServer(result, timeout)

// Wait on both channels
select {
	case res := <-result:
		handleResult(res)
	case <-timeout:
		fmt.Println("Timeout!")
}
```

```go
func askServer(
	result chan int,
	timeout chan bool) {

	// Start timer
	go func() {
		time.Sleep(5 * time.Second)
		timeout <- true
	}()

	// Ask server
	go func() {
		response := // ... send RPC
		result <- response
	}()
}
```

Exercise: Implementing a mutex using channels

```
type Lock struct {
    // ???
}

func NewLock() Lock {
    // ???
}

func (l *Lock) Lock() {
    // ???
}

func (l *Lock) Unlock() {
    // ???
}
```

Exercise: Implementing a mutex using channels

```go
type Lock struct {
	ch chan bool
}

func NewLock() Lock {
	// ???
}

func (l *Lock) Lock() {
	// ???
}

func (l *Lock) Unlock() {
	// ???
}
```

Exercise: Implementing a mutex using channels

```go
type Lock struct {
	ch chan bool
}

func NewLock() Lock {
	l := Lock{make(chan bool, 1)}
	l.ch <- true
	return l
}

func (l *Lock) Lock() {
	// ???
}

func (l *Lock) Unlock() {
	// ???
}
```

Exercise: Implementing a mutex using channels

```go
type Lock struct {
	ch chan bool
}

func NewLock() Lock {
	l := Lock{make(chan bool, 1)}
	l.ch <- true
	return l
}

func (l *Lock) Lock() {
	<-l.ch
}

func (l *Lock) Unlock() {
	// ???
}
```

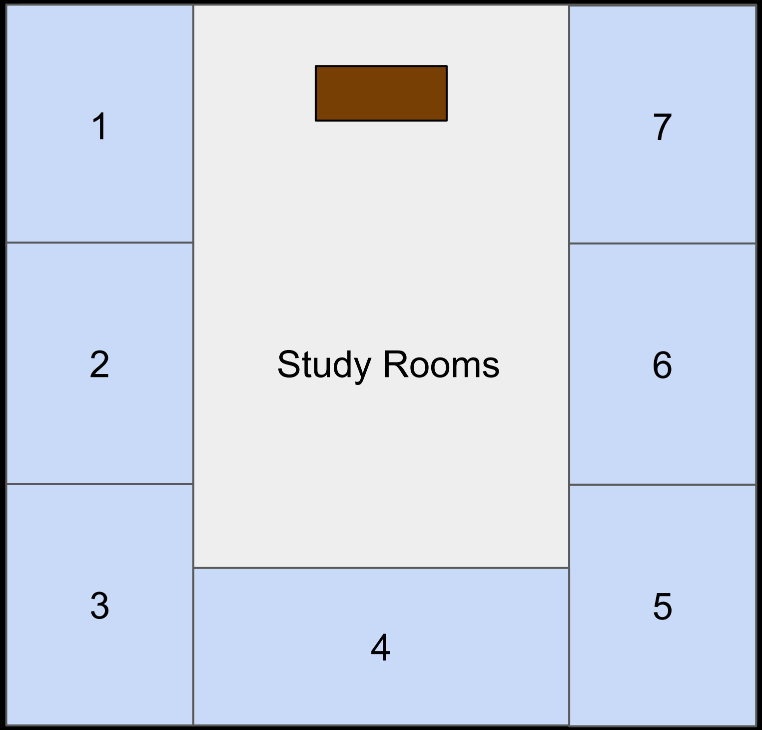
Exercise: Implementing a mutex using channels

```go
type Lock struct {
	ch chan bool
}

func NewLock() Lock {
	l := Lock{make(chan bool, 1)}
	l.ch <- true
	return l
}

func (l *Lock) Lock() {
	<-l.ch
}

func (l *Lock) Unlock() {
	l.ch <- true
}
```

Mutexes vs. Semaphores

Mutexes allow 1 process to enter critical section at a time. Allows at most *n* concurrent accesses

Semaphores allow up to **N** processes to enter critical section simultaneously



Outline

Two synchronization mechanisms

- Locks
- Channels

MapReduce

- A Case Study of WordCount

Application: WordCount

How much wood would a woodchuck chuck if a woodchuck could chuck wood?

WordCount

how: 1, much: 1, wood: 2, would: 1, a: 2, woodchuck: 2, chuck: 2, if: 1, could: 1

Application: WordCount

Locally: Tokenize and store words in a hash map

How do you parallelize this?

Split document by half

Build two hash maps, one for each half

Merge the two hash maps (by key)

How do you do this in a distributed environment?

When in the Course of human events, it becomes necessary for one people to dissolve the political bands which have connected them with another, and to assume, among the Powers of the earth, the separate and equal station to which the Laws of Nature and of Nature's God entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation.

Input document

When in the Course of human events, it becomes necessary for one people to

dissolve the political bands which have connected them with another, and to assume,

among the Powers of the earth, the separate and equal station to which the Laws of

Nature and of Nature's God entitle them, a decent respect to the opinions of mankind

requires that they should declare the causes which impel them to the separation.

Partition

When in the Course
of human events, it
becomes necessary
for one people to

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equal station to which
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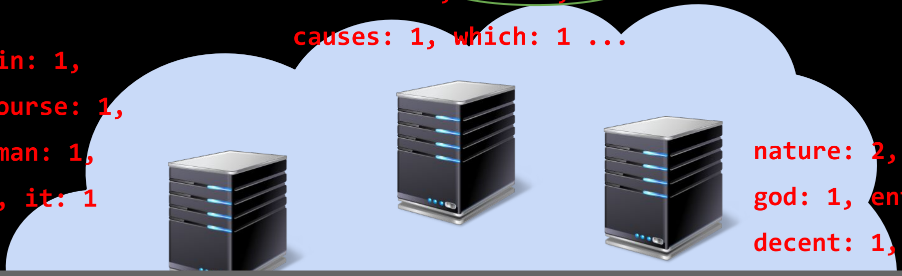
Nature and of Nature's
God entitle them, a
decent respect to the
opinions of mankind

requires that they
should declare the
causes which impel them
to the separation.

Compute word counts locally



Now ...

How to merge results?

Compute word counts locally

Merging results computed locally

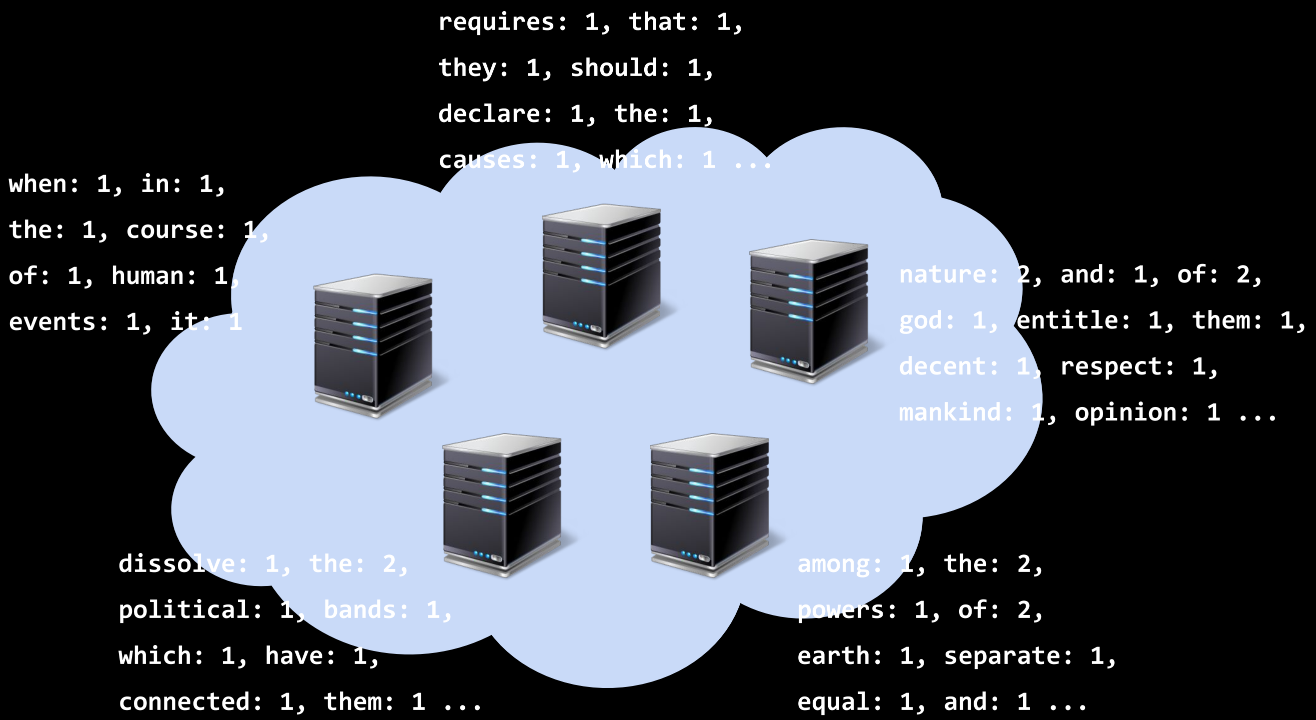
Several options

Don't merge — requires additional computation for correct results

Send everything to one node — what if data is too big? Too slow…

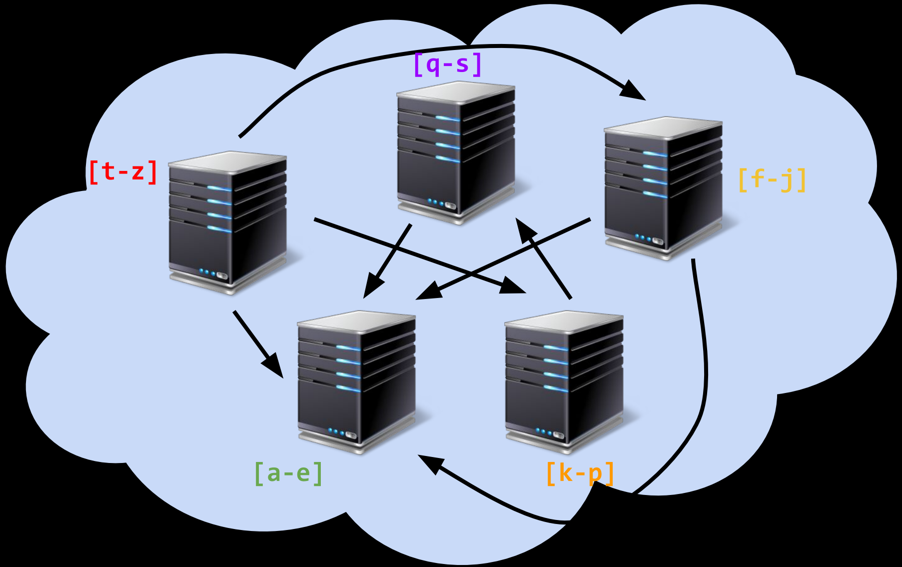
Partition key space among nodes in cluster (e.g. `[a-e]`, `[f-j]`, `[k-p]` ...)

1. Assign a key space to each node
2. Split local results by the key spaces
3. Fetch and merge results that correspond to the node's key space


requires: 1, that: 1,
they: 1, should: 1,
declare: 1, the: 1,
causes: 1, which: 1 ...
when: 1, in: 1,
the: 1, course: 1,
of: 1, human: 1,
events: 1, it: 1
nature: 2, and: 1, of: 2,
god: 1, entitle: 1, them: 1,
decent: 1, respect: 1,
mankind: 1, opinion: 1 ...
dissolve: 1, the: 2,
political: 1, bands: 1,
which: 1, have: 1,
connected: 1, them: 1 ...
among: 1, the: 2,
powers: 1, of: 2,
earth: 1, separate: 1,
equal: 1, and: 1 ...

[a-e]
[f-j]
[k-p]
[q-s]
[t-z]

Split local results by key space



All-to-all shuffle

[a-e]

[f-j]

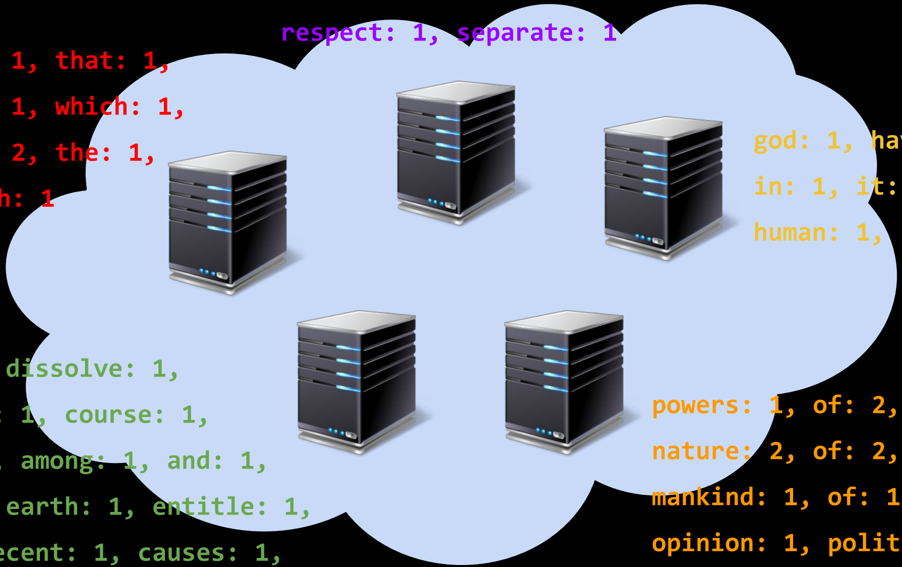
[k-p]

[q-s]

[t-z]

requires: 1, should: 1,
respect: 1, separate: 1

when: 1, the: 1, that: 1,
they: 1, the: 1, which: 1,
them: 1, the: 2, the: 1,
them: 1, which: 1

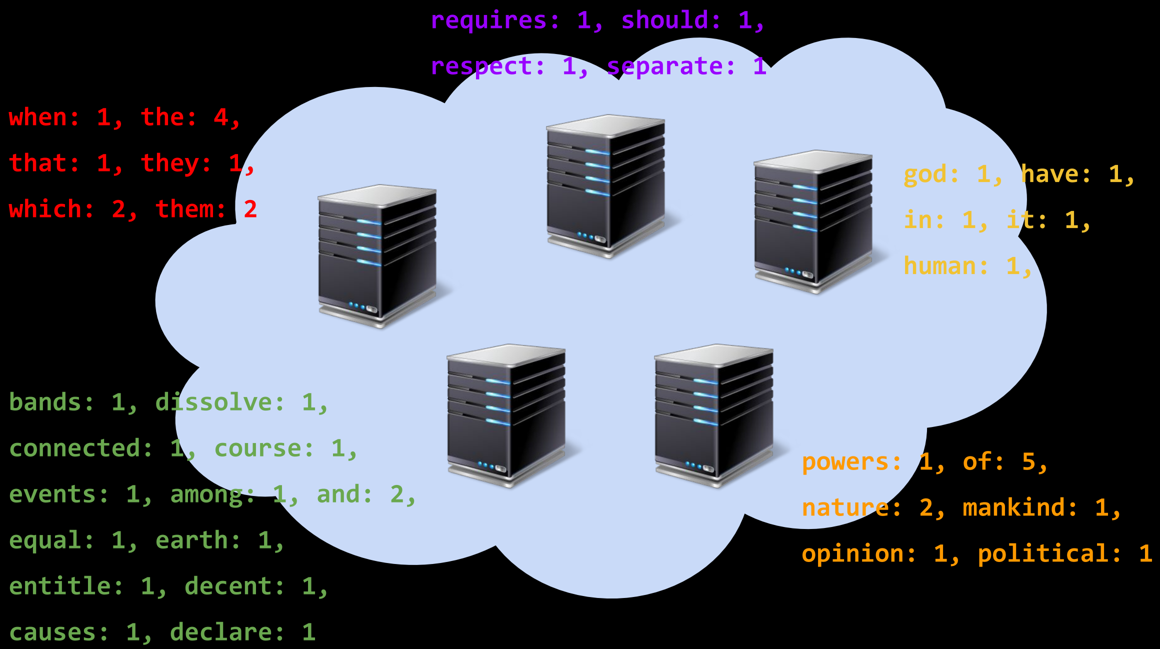


god: 1, have: 1,
in: 1, it: 1,
human: 1,

bands: 1, dissolve: 1,
connected: 1, course: 1,
events: 1, among: 1, and: 1,
equal: 1, earth: 1, entitle: 1,
and: 1, decent: 1, causes: 1,
declare: 1

powers: 1, of: 2,
nature: 2, of: 2,
mankind: 1, of: 1,
opinion: 1, political: 1

Note the duplicates...



Merge results received from other nodes

MapReduce

Partition dataset into many chunks

Map stage: Each node processes one or more chunks locally

Reduce stage: Each node fetches and merges partial results from all other nodes

MapReduce Interface

`map(key, value) -> list(<k′, v′>)`

Apply function to (key, value) pair

Outputs list of intermediate pairs

`reduce(key, list<value>) -> <k′, v′>`

Applies aggregation function to values

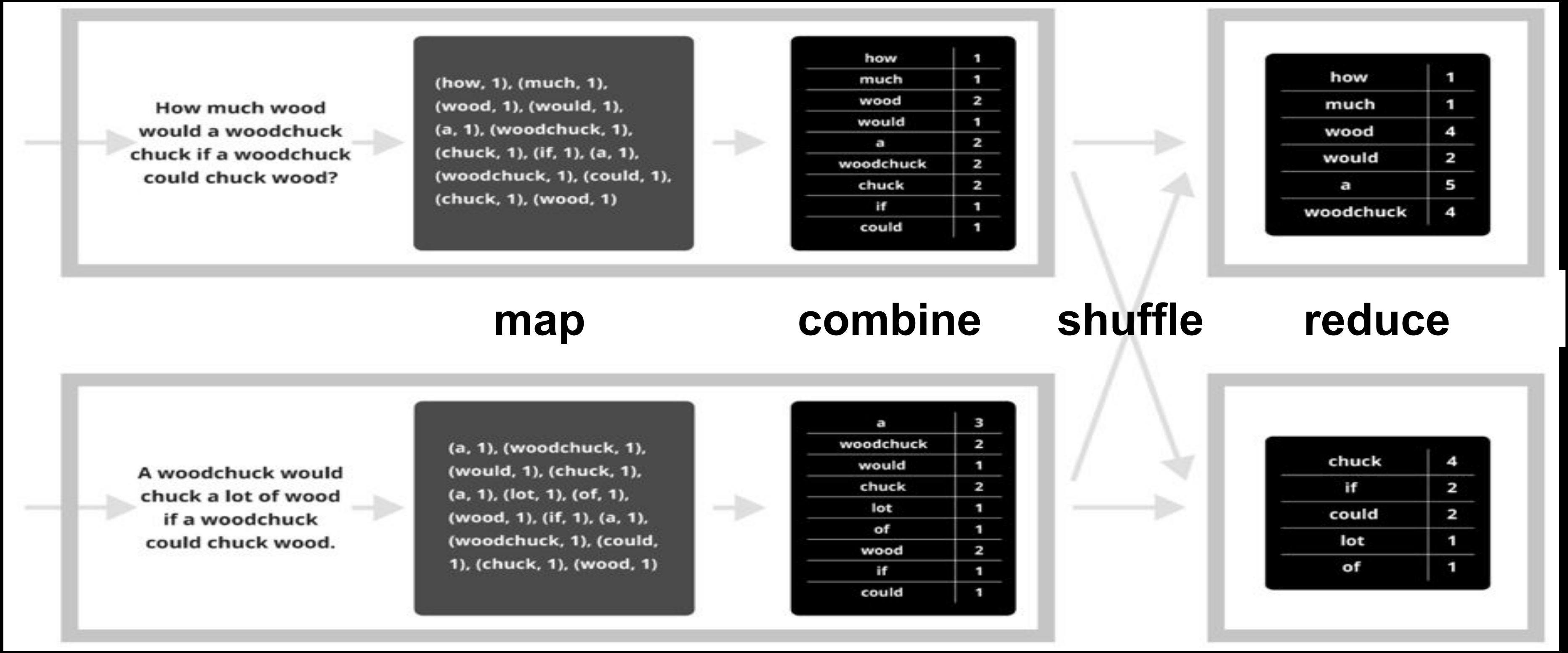
Outputs result

MapReduce: WordCount

```
map(key, value):
    // key = document name
    // value = document contents
    for each word w in value:
        emit (w, 1)

reduce(key, values):
    // key = the word
    // values = number of occurrences of that word
    count = sum(values)
    emit (key, count)
```

MapReduce: WordCount



Why is this hard?

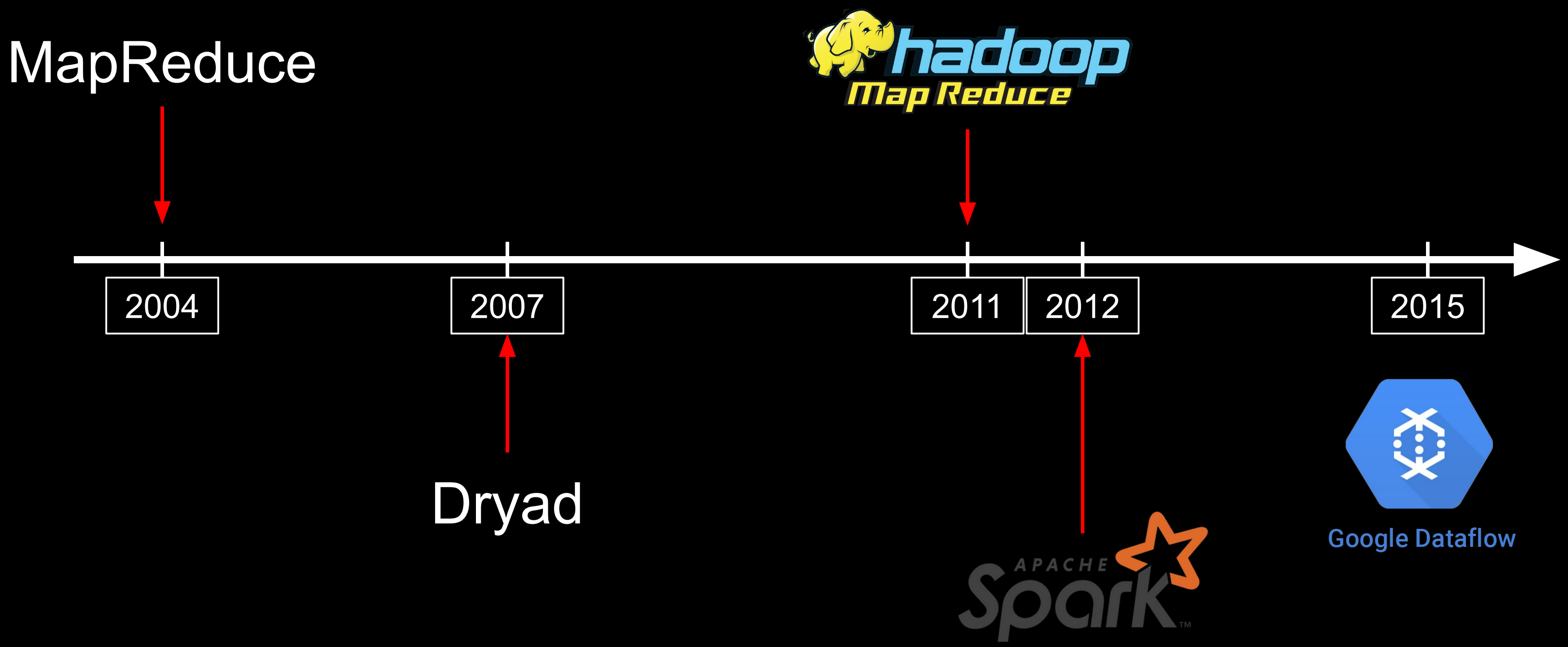
Failure is common

Even if each machine is available p = 99.999% of the time, a datacenter with n = 100,000 machines still encounters failures $(1-p^n) = 63\%$ of the time

Data skew causes unbalanced performance across cluster

Problems occur at scale

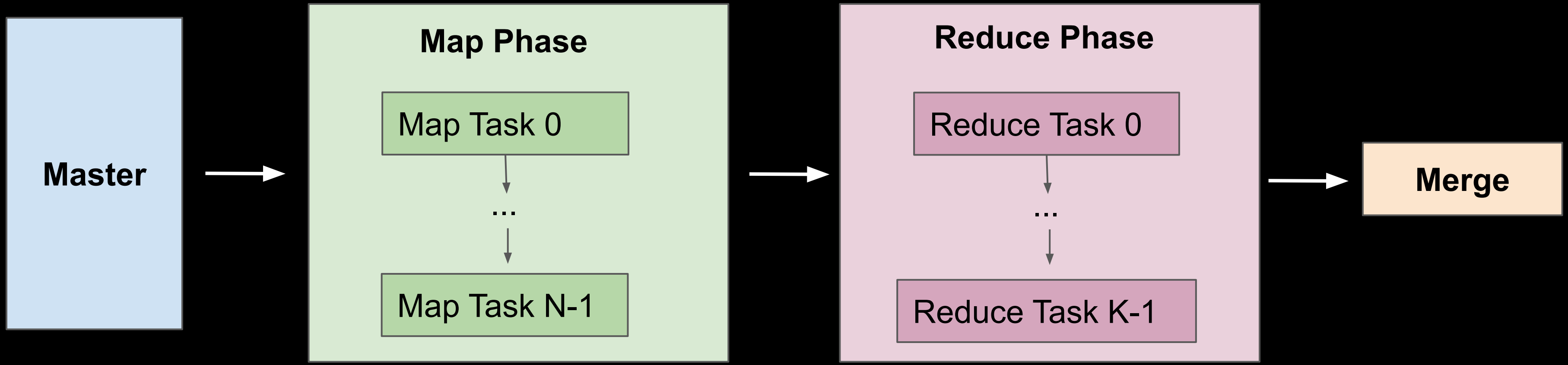
Hard to debug!


MapReduce
hadoop
Map Reduce
2004
2007
2011
2012
2015
Dryad
APACHE
Spark
Google Dataflow

Assignment 1.2 is due 2/16

Assignment 1.3 is due 2/18

Sequential MapReduce



Distributed MapReduce