High-level concurrency concepts

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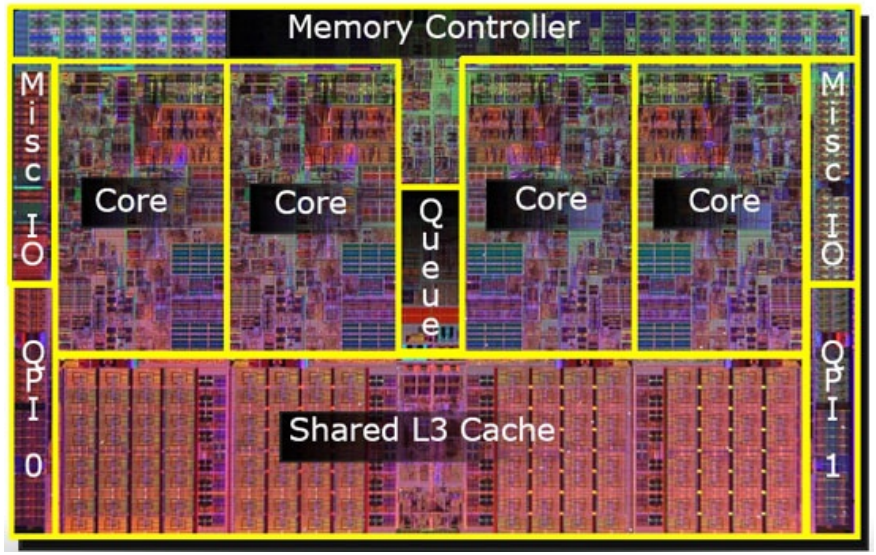
Why concurrency?

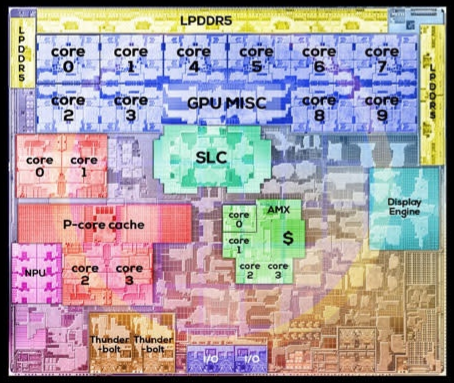


We’re all in the parallel computing business!

Apple M3 family
TSMC N3B (3nm)

High Yield

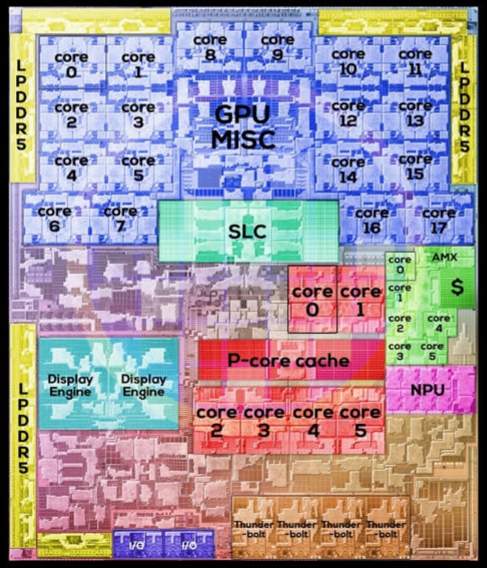
25bn transistors



M3 — High Yield

CPU 4 P-cores
CPU 4 E-cores
GPU 10 cores
128-bit LPDDR5
NPU
SLC

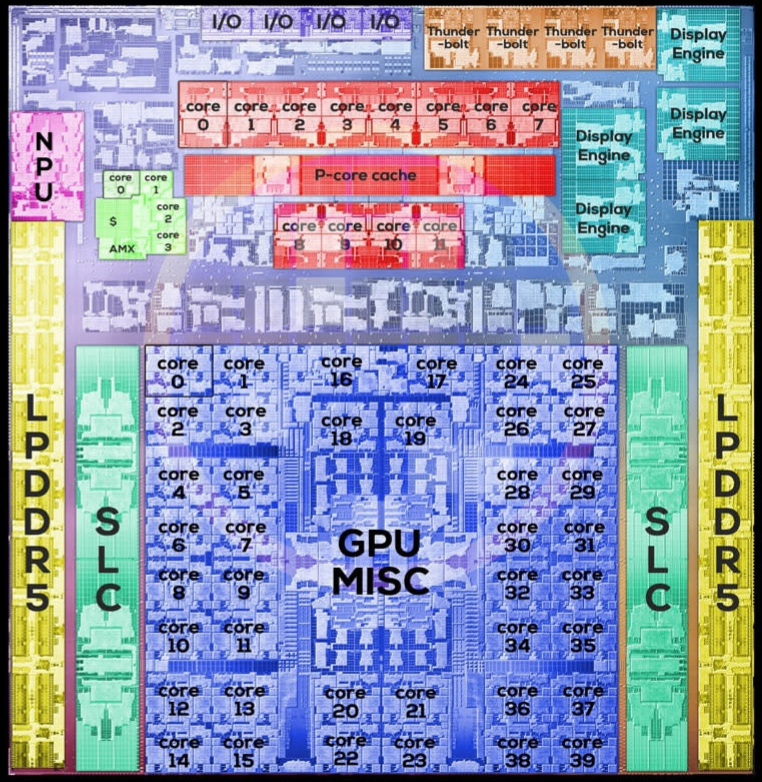
37bn transistors



M3 Pro — High Yield

CPU 6 P-cores
CPU 6 E-cores
GPU 18 cores
192-bit LPDDR5
NPU
SLC

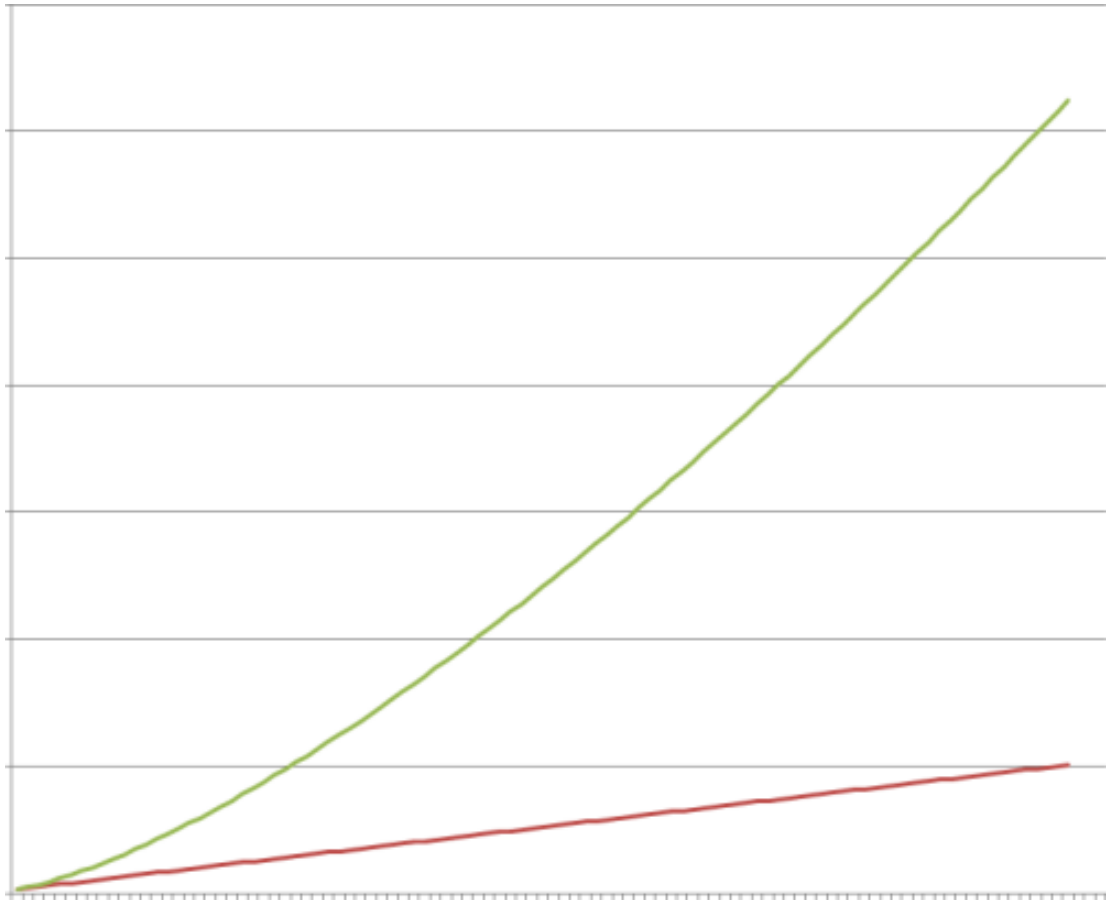
92bn transistors



M3 Max — High Yield

CPU 12 P-cores
CPU 4 E-cores
GPU 40 cores
512-bit LPDDR5
NPU
SLC

of cores



JVM low-level machinery

Thread, Runnable, Thread Pools, Virtual Threads

- *to run things in parallel*

JVM low-level machinery

Thread, Runnable, Thread Pools, Virtual Threads

- *to run things in parallel*

Synchronized blocks

Volatile

Locks

Atomic

- *to run things sequentially again*

Threads

```
def myRunnable = new Runnable {
    public void run() {
      ...
    }
}
new Thread(myRunnable).start()
```

Threads

```
def myRunnable = new Runnable {
    public void run() {
      ...
    }
}
new Thread(myRunnable).start()
```

Thread Pool

```
def pool = Executors.newFixedThreadPool(6)
def myCallable = new Callable<T> {
    public T call() {...}
}

Future<T> f = pool.submit(myCallable)
println f.get()
```

Thread Pool

```
def pool = Executors.newFixedThreadPool(6)
def myCallable = new Callable<T> {
    public T call() {...}
}

Future<T> f = pool.submit(myCallable)
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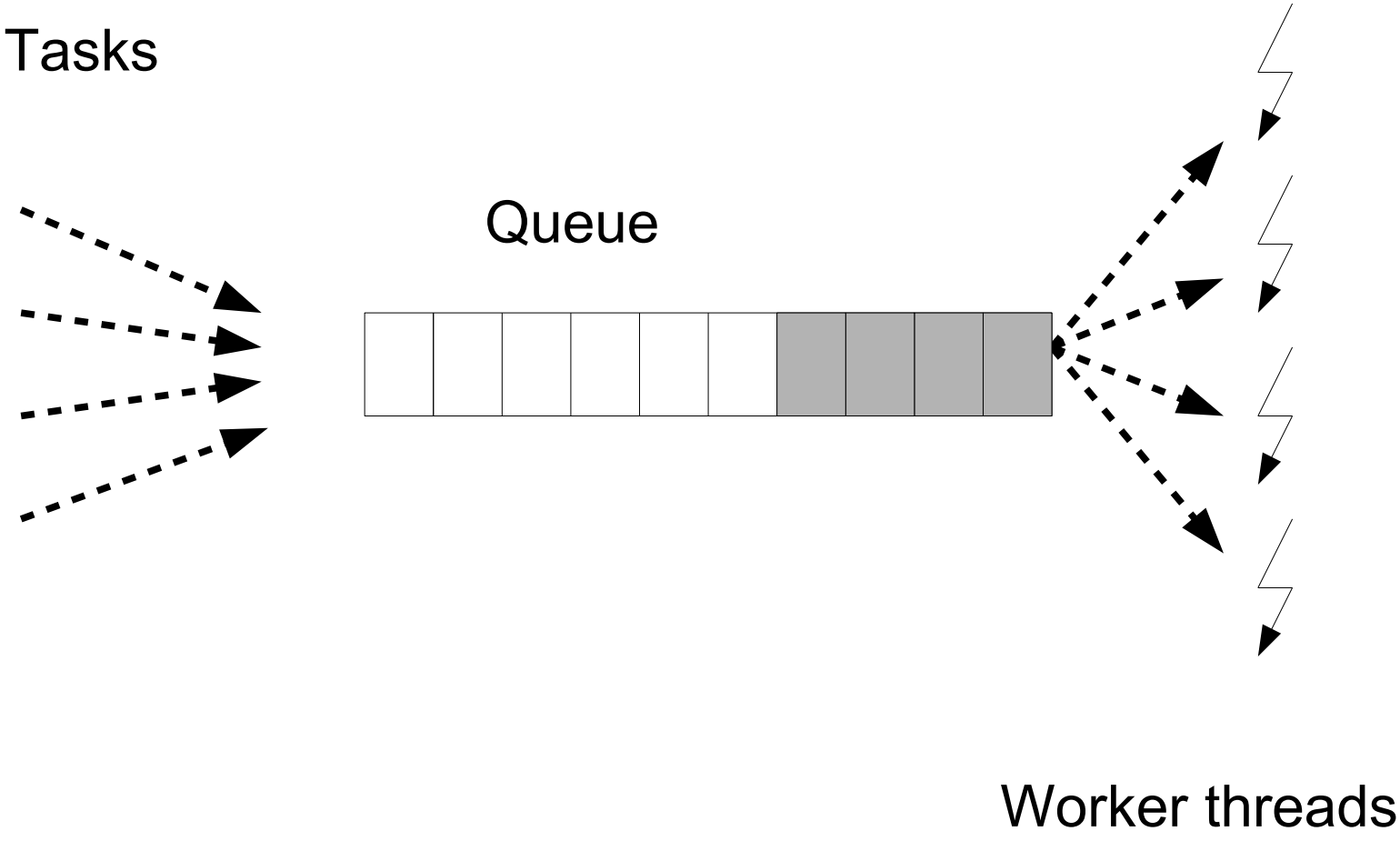
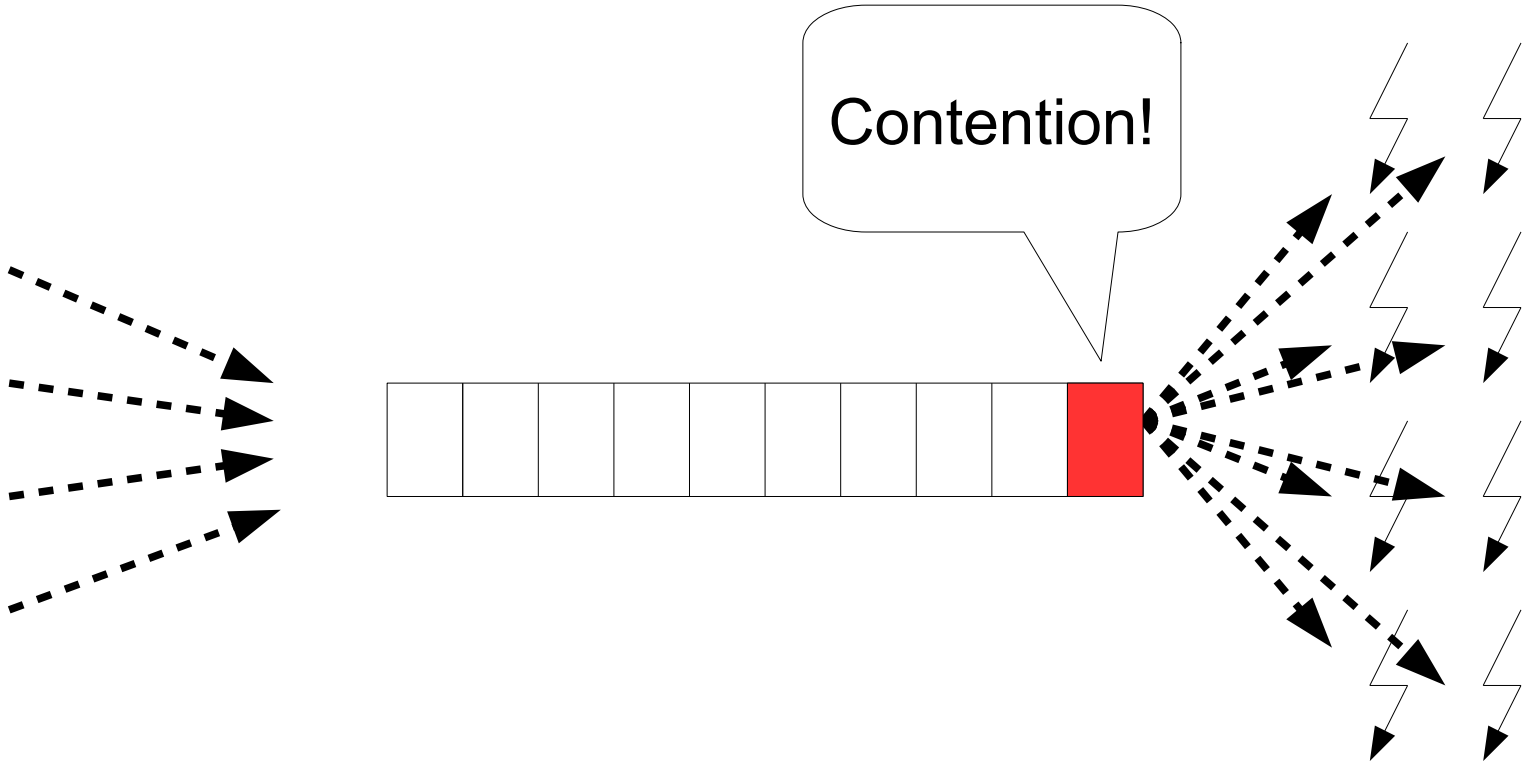
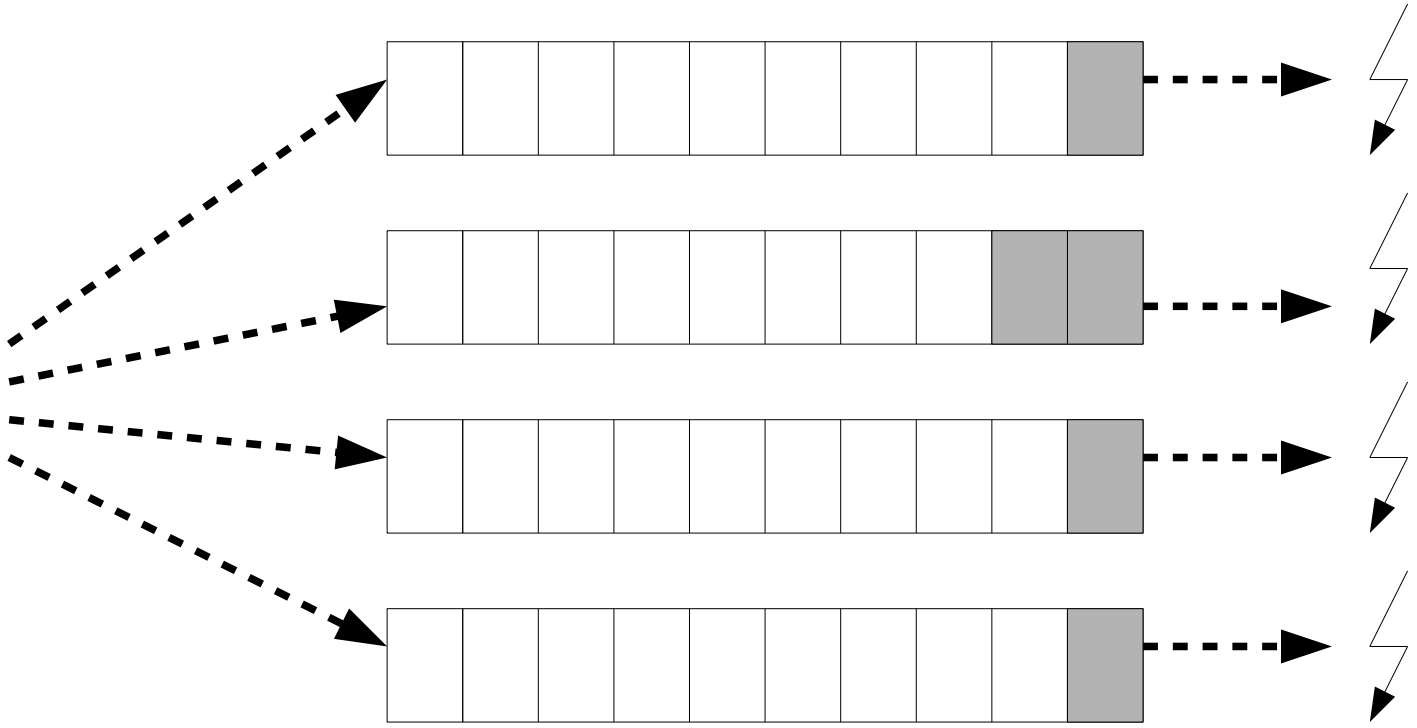
Thread Pool



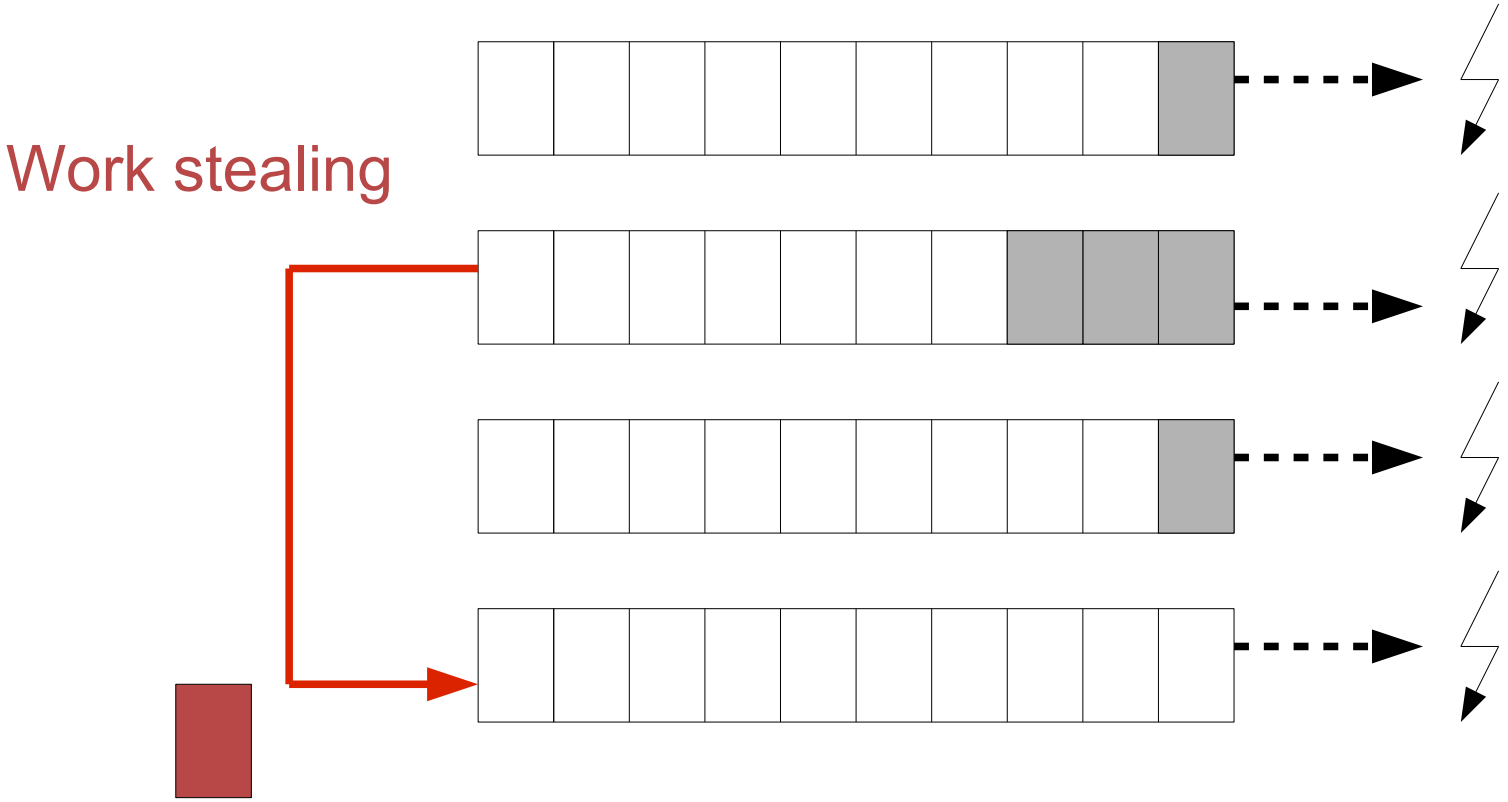
Thread Pool



Fork/Join Thread Pool



Fork/Join Thread Pool



Dealing with threads sucks!

```
public class Counter {
    private static long count = 0;

    public Counter() {

        count++;

    }
}
```

Dealing with threads sucks!

```
public class Counter {
    private volatile static long count = 0;

    public Counter() {

        count++;

    }
}
```

Dealing with threads sucks!

```
public class Counter {
    private volatile static long count = 0;

    public Counter() {

        count = count + 1;

    }
}
```

Dealing with threads sucks!

```
public class Counter {
    private static long count = 0;

    public Counter() {
        synchronized (this) {
            count++;
        }
    }
}
```

Dealing with threads sucks!

```
public class Counter {
    private static long count = 0;

    public Counter() {
        synchronized (this.getClass()) {
            count++;
        }
    }
}
```

Dealing with threads sucks!

```
public class Counter {
    private static Long count = 0;

    public Counter() {
        synchronized (count) {
            count++;
        }
    }
}
```

Dealing with threads sucks!

```
public class Counter {
    private static Long count = 0;

    public Counter() {
        synchronized (count) {
            count = new Long(count.longValue() + 1);
        }
    }
}
```

Dealing with threads sucks!

```
public class ClickCounter implements ActionListener {
    private int numberOfClicks;
    public ClickCounter(JButton button, int initValue) {
        button.addActionListener(this);
        numberOfClicks = initValue;
    }
    public void actionPerformed(final ActionEvent e) {
        numberOfClicks++;
    }
}
```

Dealing with threads sucks!

```
public class ClickCounter implements ActionListener {
    private int numberOfClicks;
    public ClickCounter(JButton button, int initValue) {
        button.addActionListener(this);
        numberOfClicks = initValue;
    }
    public void actionPerformed(final ActionEvent e) {
        numberOfClicks++;
    }
}
```

Low-level concurrency

- Monitors
- Volatile variables
- Atomic variables
- Locks – R/W, ReentrantLock
- Semaphors
- CountDownLatches
- Barriers

Stone age of parallel SW

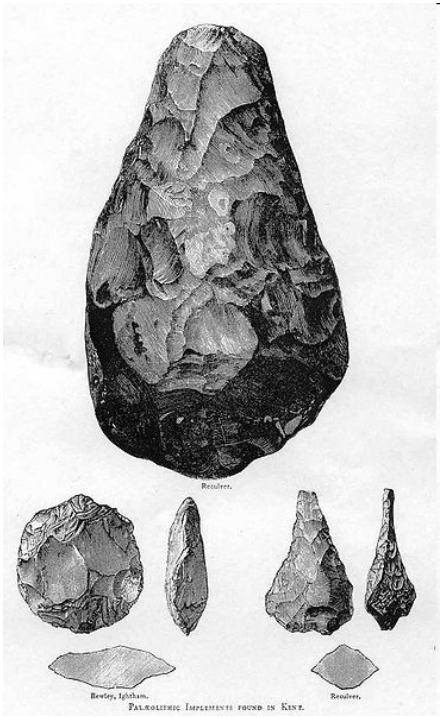
Dead-locks

Live-locks

Race conditions

Starvation

Shared Mutable State



The root problem

Shared mutable state

Approach 1

Shared **mutable** state

Use read-only data

Approach 2

Shared mutable state

Use only local thread-contained data

Structured concurrency

- Keep state **local** to a computation
  - Virtual threads
  - Coroutines
- CSP provides the cornerstone theory

CSP

Communicating Sequential Processes

Focus on composable processes more than on data

Two key components

Tasks (aka coroutines, goroutines)

- Implemented as (pooled) threads or virtual, lighweight threads

Data exchange between tasks

- Tasks' *promised* return value
- Dataflow variables
- Dataflow channels

Two key components

Tasks (aka coroutines, goroutines)

- Implemented as (pooled) threads or virtual, lighweight threads

Data exchange between tasks

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- Dataflow channels

Virtual Threads (Java 21)

```
def t = Thread.ofVirtual.start(myRunnable)
println f.join()
```

Virtual Threads (Java 21)

```
def t = Thread.ofVirtual.start(myRunnable)
println f.join()

def pool = Executors
.newVirtualThreadPerTaskExecutor()
Future<T> f = pool.submit(myCallable)
println f.get()
```

Scopes (Java 21)

```
Response handle() throws ExecutionException, InterruptedException {
    try (var scope = new StructuredTaskScope.ShutdownOnFailure()) {
        Supplier<String>  user  = scope.fork(() -> findUser());
        Supplier<Integer> order = scope.fork(() -> fetchOrder());

        scope.join()            // Join both subtasks
             .throwIfFailed();  // ... and propagate errors

        // Here, both subtasks have succeeded, so compose their results
        return new Response(user.get(), order.get());
    }
    //...
}
```

Scope

Provides virtual threads with:

- a thread pool
- a context
- *life-cycle management*
- *control for sub-groups*
- *error handling for tasks and sub-groups*

Thread pools the Groovy way

```
task {
    calculation.process()
}
```

Scopes the Groovy way

```
def group = new NonDaemonPGroup(10)


group.task {
    calculation.process()
}
```

Task variants

```
group.task( {->…} )

group.task( new Runnable() {…} )

group.task( new Callable<V>() {…} )
```

Not implemented yet

group.cancelAll()

group.onFailureRestart()

group.onFailureCancelAll()

def subgroup = group.subgroup()

Control State Sharing

```
List registrations = []
submissions.each {form →
    group.task {
        if (form.process().valid) {
            registrations << form
        }
    }
}
```

Control State Sharing

Needs protection

```
List registrations = []
submissions.each {form →
    group.task {
        if (form.process().valid) {
            registrations << form
        }
    }
}
```

Control State Sharing

```
List registrations = []
submissions.each {form →
    group.task {
        synchronized(registrations) {
            if (form.process().valid) {
                registrations << form
            }
        } }}
```

Control State Sharing

```
List registrations = []
submissions.each {form →
    group.task {
        synchronized(registrations) {
            if (form.process().valid) {
                registrations << form
            }
        } }}
```

WRONG!
No possible parallelism for process()

Needs no lock, works on local data only

Control State Sharing

```
List registrations = []
submissions.each {form →
    group.task {
        if (form.process().valid) {
            synchronized(registrations) {
                registrations << form
            }
        } }}
```

Keep the scope of lock minimal

Two key components

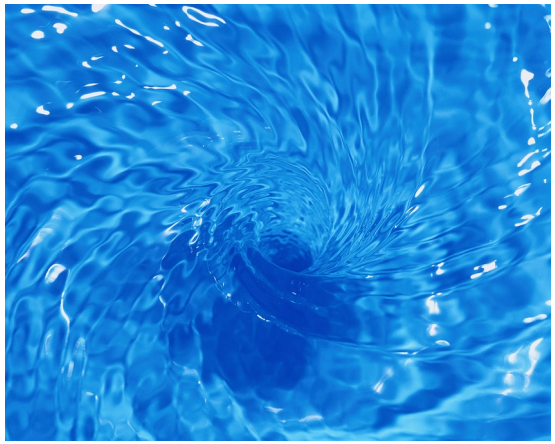
Tasks (aka coroutines, goroutines)

- Implemented as (pooled) threads or virtual, lighweight threads

Data exchange between tasks

- Tasks' *promised* return value
- Dataflow variables
- Dataflow channels

Dataflow Variables



No race-conditions

No live-locks

Deterministic deadlocks

Dataflow Variables

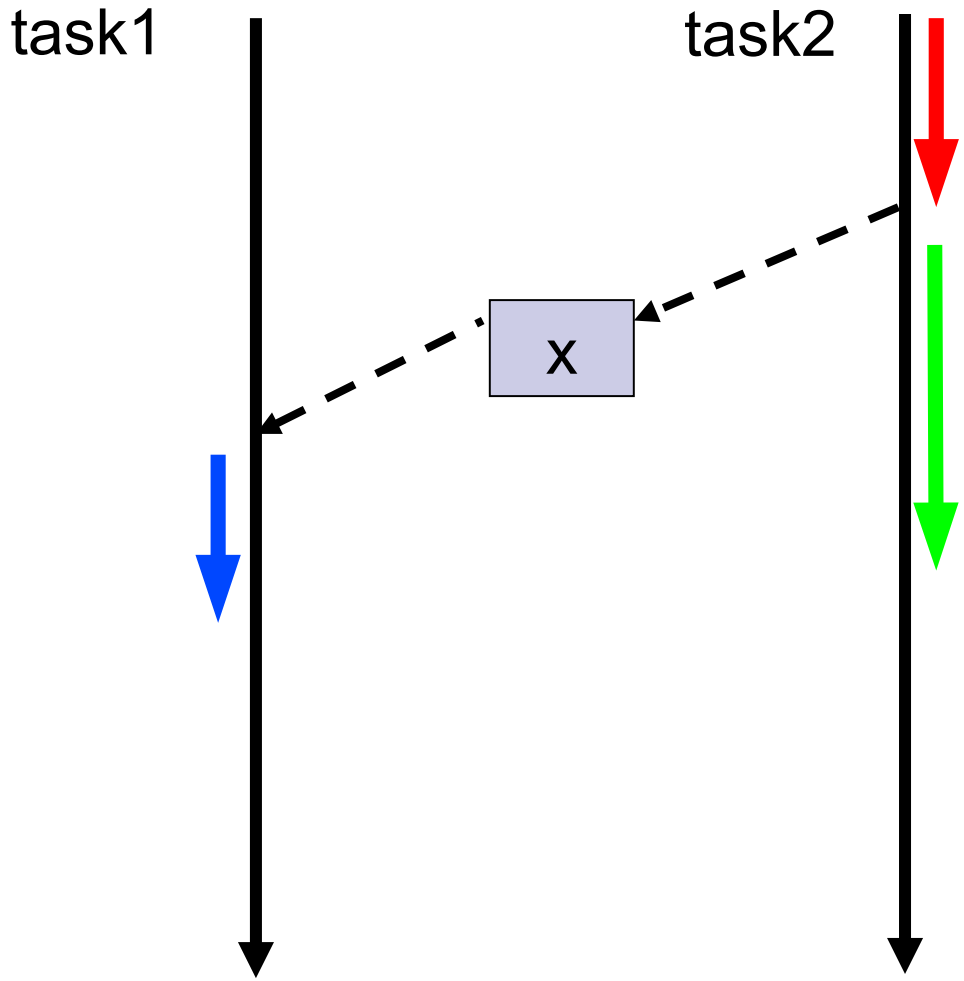
Start empty

set() / bind() / <<

- write a value, if still empty
- make **read-only** since then

get() / val – wait for a value, then read it

Dataflow Variables / Promises



DataflowVariables/Promises

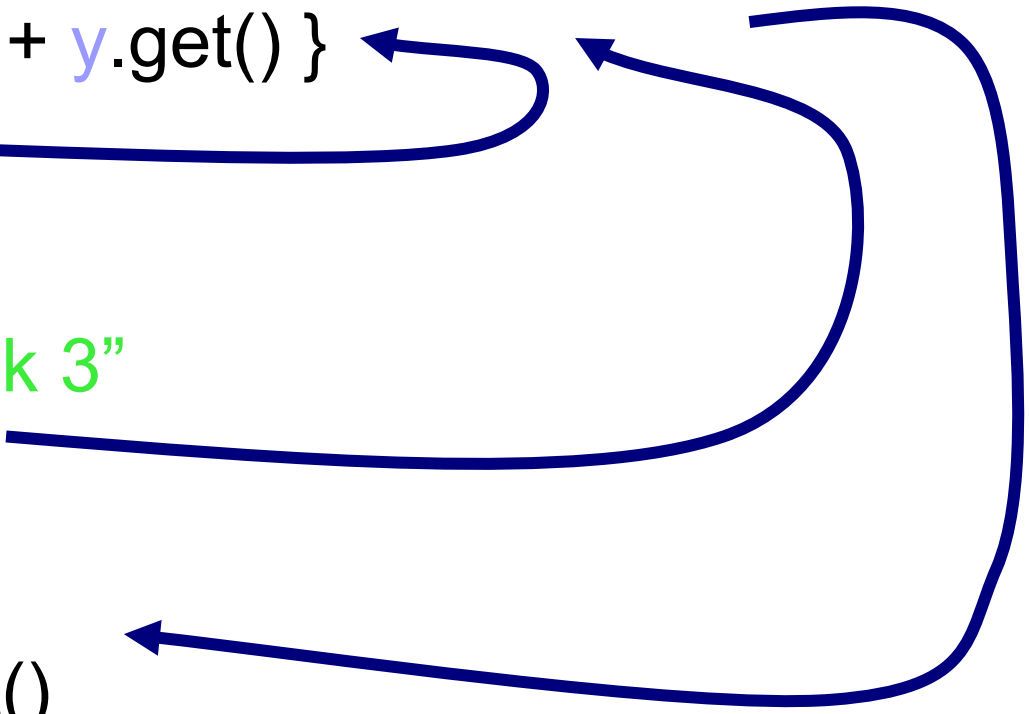
```
def x = new DataflowVariable()

task { println x.get() }
task {
    storeInDB(x.get())
}
task { x << 10 }
x.join()
```

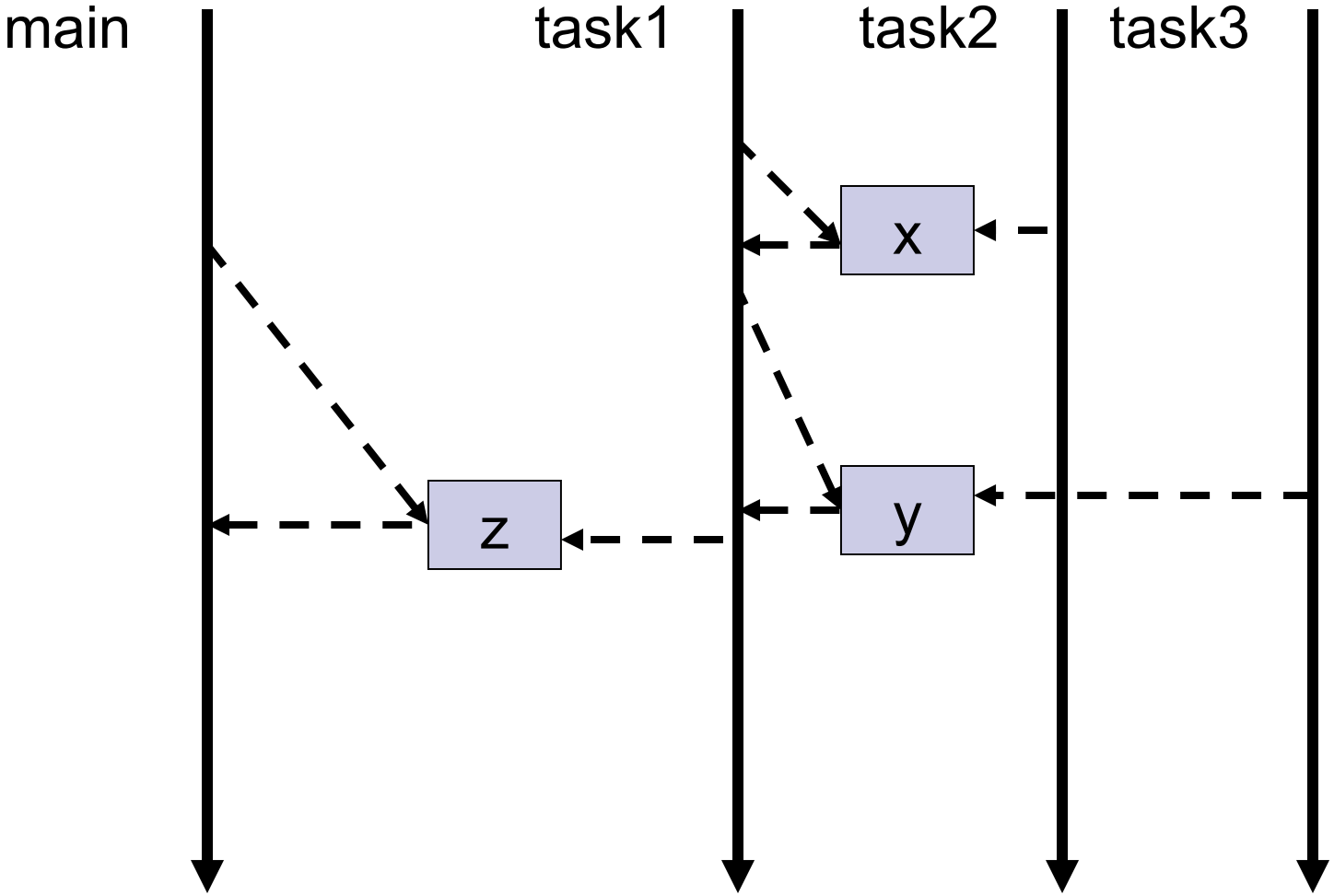
Promises to exchange data

```
def x,y,z = new DataflowVariable()

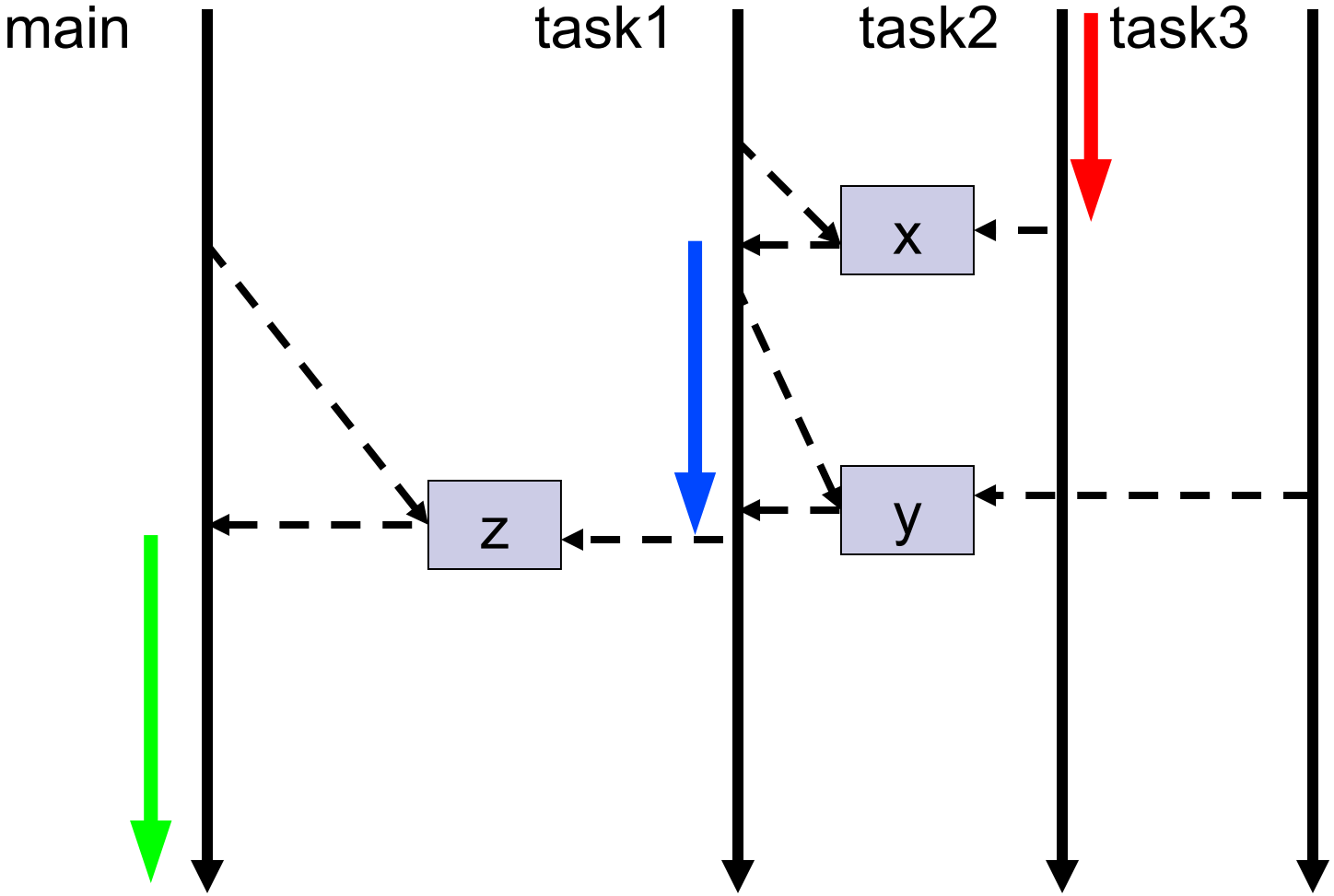
task { z << x.get() + y.get() }
task { x << 10 }
task {
    println ”I am task 3”
    y << 5
}
assert 15 == z.get()
```



Dataflow Variables / Promises



Dataflow Variables / Promises



Promises as return values

```
Promise x = new DataflowVariable()
task { x << 10 }
```

vs.

```
Promise x = task { return 10 }
```

Promises as return values

```
Promise x = task { return 10 }
Promise y = task {
    println ”I am task 3”
    return 5
}
Promise z = task {x.get() + y.get() }
assert 15 == z.get()
```

Promises as return values

```
Promise t1 = task {
    def data = loadDataFromDB("Joe")
    data.optimize()
    return data
}
Promise t2 = task { printData(t1.get()) }
t2.join()
```

Kotlin coroutines

```
val time = measureTimeMillis {
    val one = async { doSomethingUsefulOne() }
    val two = async { doSomethingUsefulTwo() }
    println("The answer is ${one.await() + two.await()}")
}
println("Completed in $time ms")
```

Reactive/callback approach

- Needed when tasks are implemented on top of system threads *(unlike virtual/lightweight threads)*
- Blocking in *Promise.get()* is too expensive

Allows for callbacks to be registered on *Promises*

Callbacks

```
Promise x = new DataflowVariable()

x.then { println it }
task {
    x.then { storeInDB(it) }
      .then {dbStatus → println dbStatus}
}
task { x << 10 }
x.join()
```

Chaining promises

```
def h1 = download('url') then {text → text.trim()} then hash
```

Chaining promises

```
def h1 = download('url') then {text → text.trim()} then hash
```

```
def h1 = download('url') | {text → text.trim()} | hash
```

Error handling

```
url.then(download)
    .then(calculateHash)
    .then(formatResult)
    .then(printResult, printError)
    .then(sendNotificationEmail);
```

CompletableFuture (Java)

```java
final CompletableFuture<Integer> f = CompletableFuture.supplyAsync(() -> 10);

final CompletableFuture<Integer> f2 = f.thenApplyAsync(x -> 2 * x)
                                       .handleAsync((x, e) -> 3 * x);

final CompletableFuture<Integer> f3 = f.thenComposeAsync(x -> CompletableFuture.supplyAsync(() -> 2 * x))
                                       .handleAsync((x, e) -> 3 * x);

final CompletableFuture<Integer> f4 = f2.thenCombineAsync(f3, (x, y) -> x + y);
```

Glue tasks together

```
Promise c1 = task { compile(module1) }
Promise c2 = task { compile(module2) }
```

Glue tasks together

```
Promise c1 = task { compile(module1) }
Promise c2 = task { compile(module2) }

Promise j1 = c1.then {jar it}
Promise j2 = c2.then {jar it}
```

Glue tasks together

```
Promise c1 = task { compile(module1) }
Promise c2 = task { compile(module2) }

Promise j1 = c1.then {jar it}
Promise j2 = c2.then {jar it}
whenAllBound(j1, j2) {m1, m2 → deploy(m1, m2)}
j1.then {pushToRepo it}
```

Glue tasks together

```
Promise c1 = task { compile(module1) }
Promise c2 = task { compile(module2) }

Promise j1 = c1.then {jar it}
Promise j2 = c2.then {jar it}
whenAllBound(j1, j2) {m1, m2 → deploy(m1, m2)}
j1.then {pushToRepo it}
iWillSendEmailWhenJarred(j1)
```

Glue tasks without callbacks

```
Promise c1 = task { compile(module1) }
Promise c2 = task { compile(module2) }

Promise j1 = task { jar c1.get() }
Promise j2 = task { jar c2.get() }
task { deploy(j1.get(), j2.get()) }
task {pushToRepo j1.get()}
iWillSendEmailWhenJarred(j1.get())
```

Dataflow variables wrap-up

- *Promise* is the reading side
- Blocking read – *val*, *get()*, *await()*
- Callbacks – *then,* |, *whenAllBound*
- Callback handlers can be chained
- Promises are typically returned from async calls – *task*, *async*

Abstractions

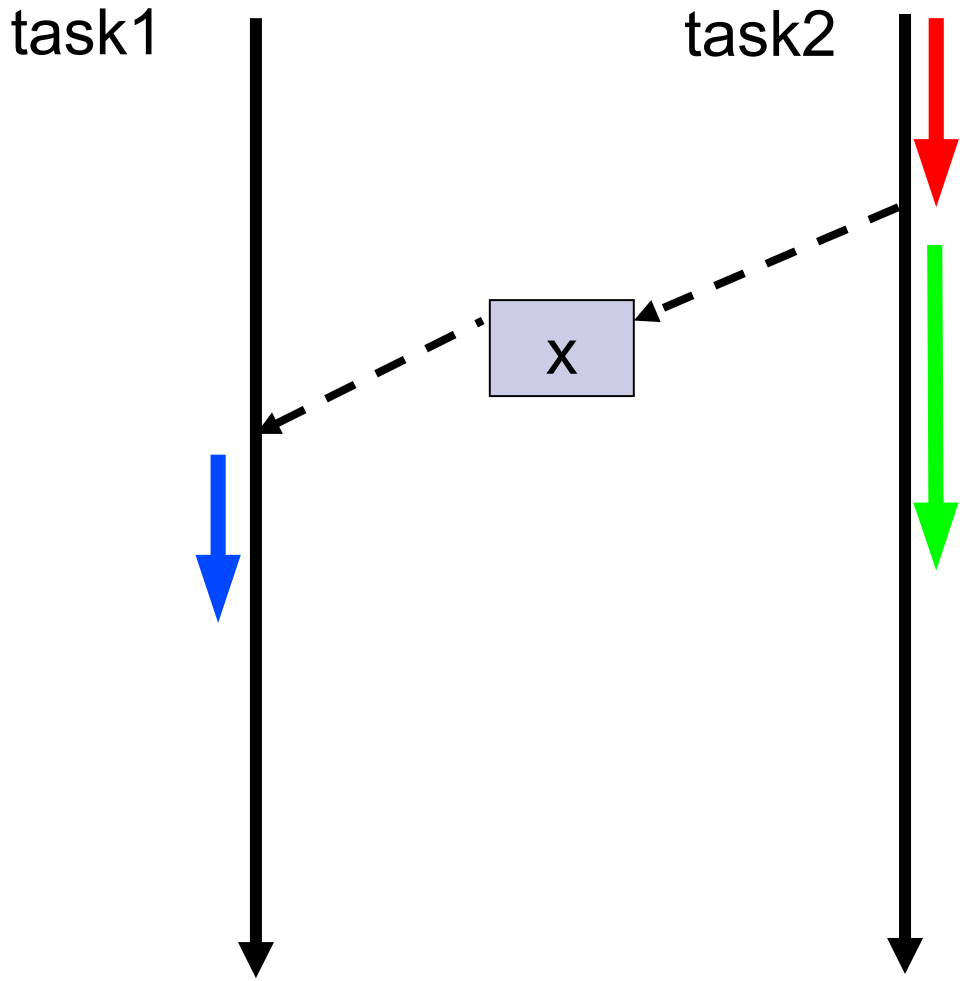
Tasks (aka coroutines, goroutines)

- Implemented as (pooled) threads or virtual, lighweight threads

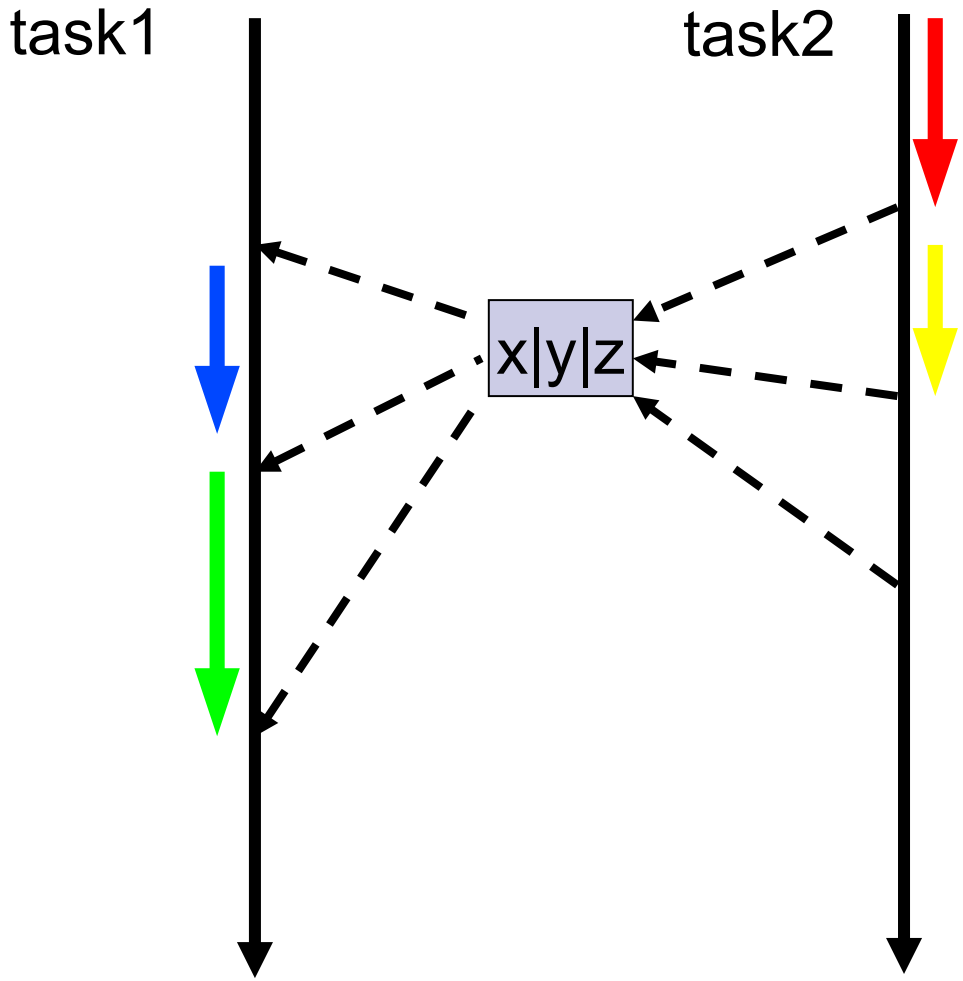
Data exchange between tasks

- Tasks' return value
- Dataflow variables
- **Dataflow channels**

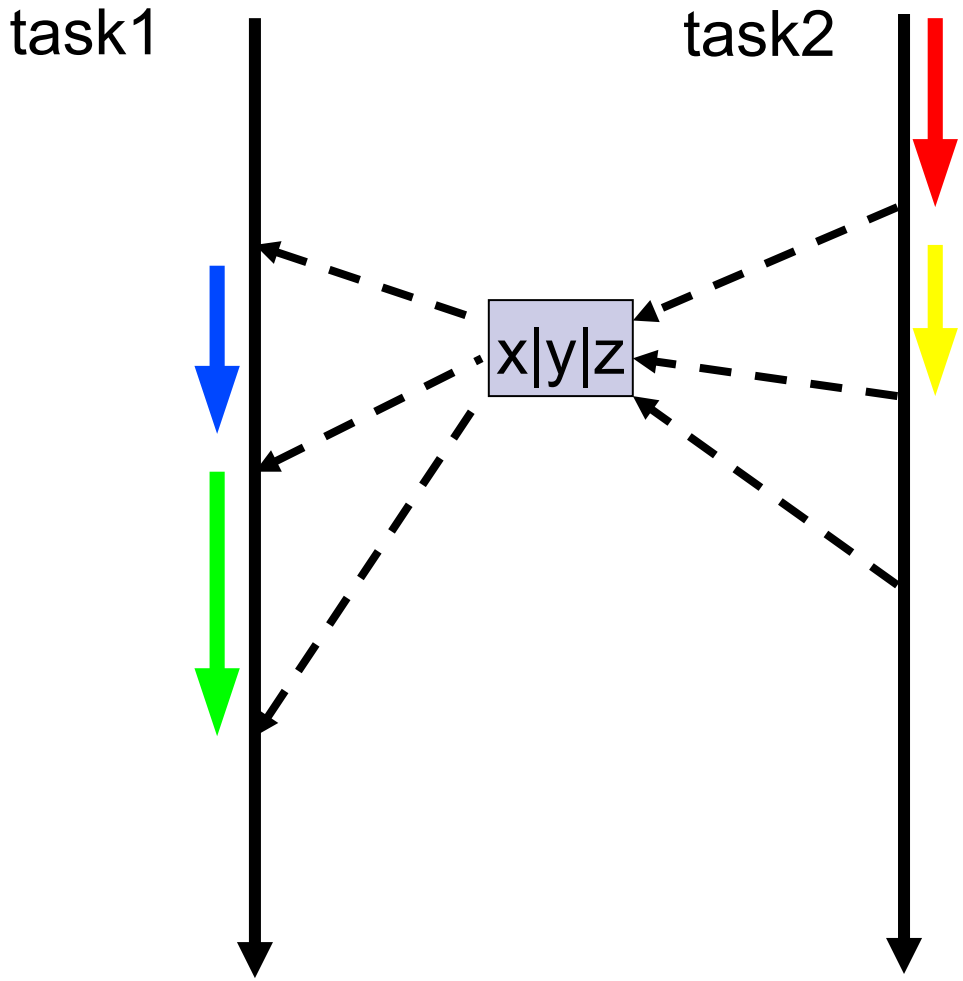
Dataflow Variables / Promises



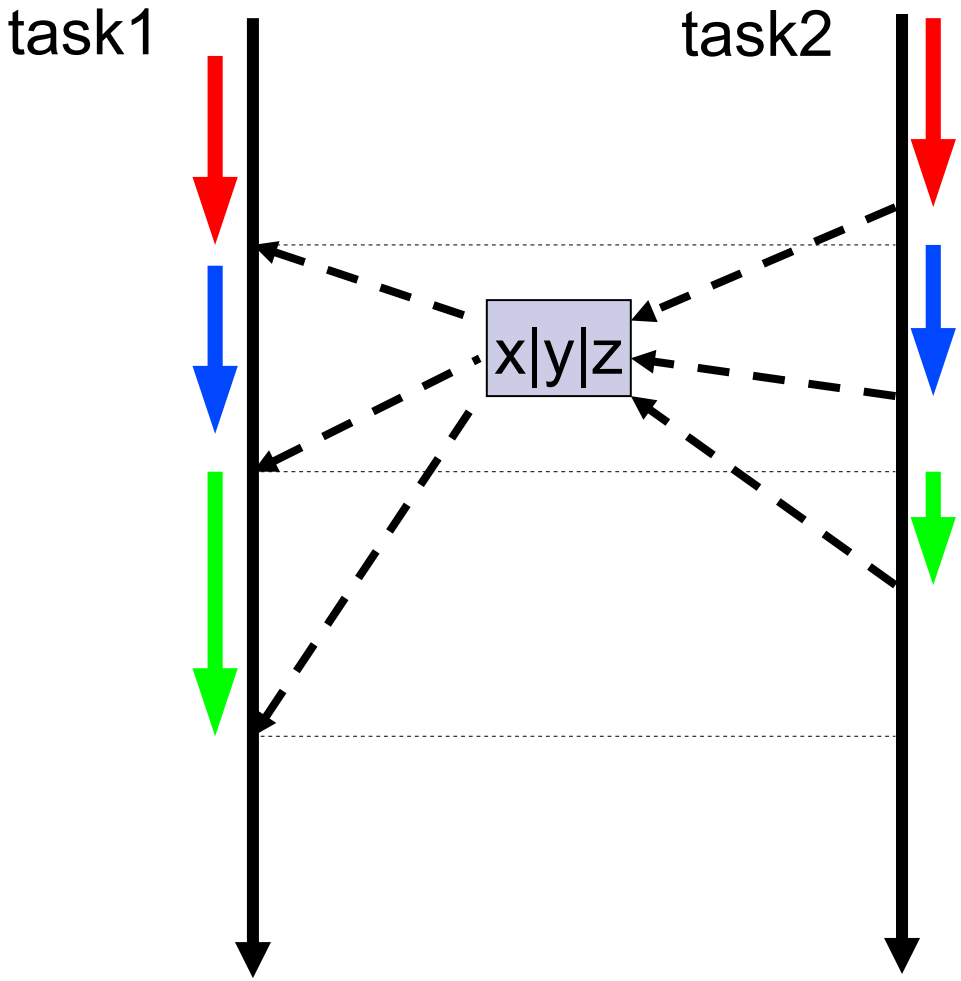
Dataflow Channels



Buffered Channels



Synchronous Channels



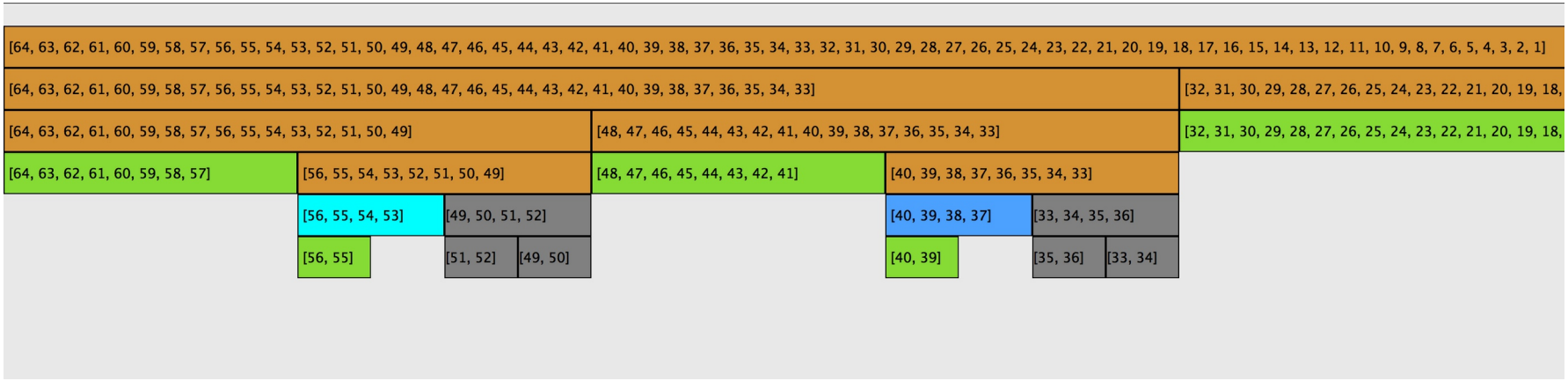
Tasks as processes (CSP)

```
group.task {
        doStuff()
        logChannel << 'initialized'
        def result = doWork(workQueue.get())
        if (result.isError) errors << result
        else results << result
        logChannel << 'finished'
}
```

Channel Selection

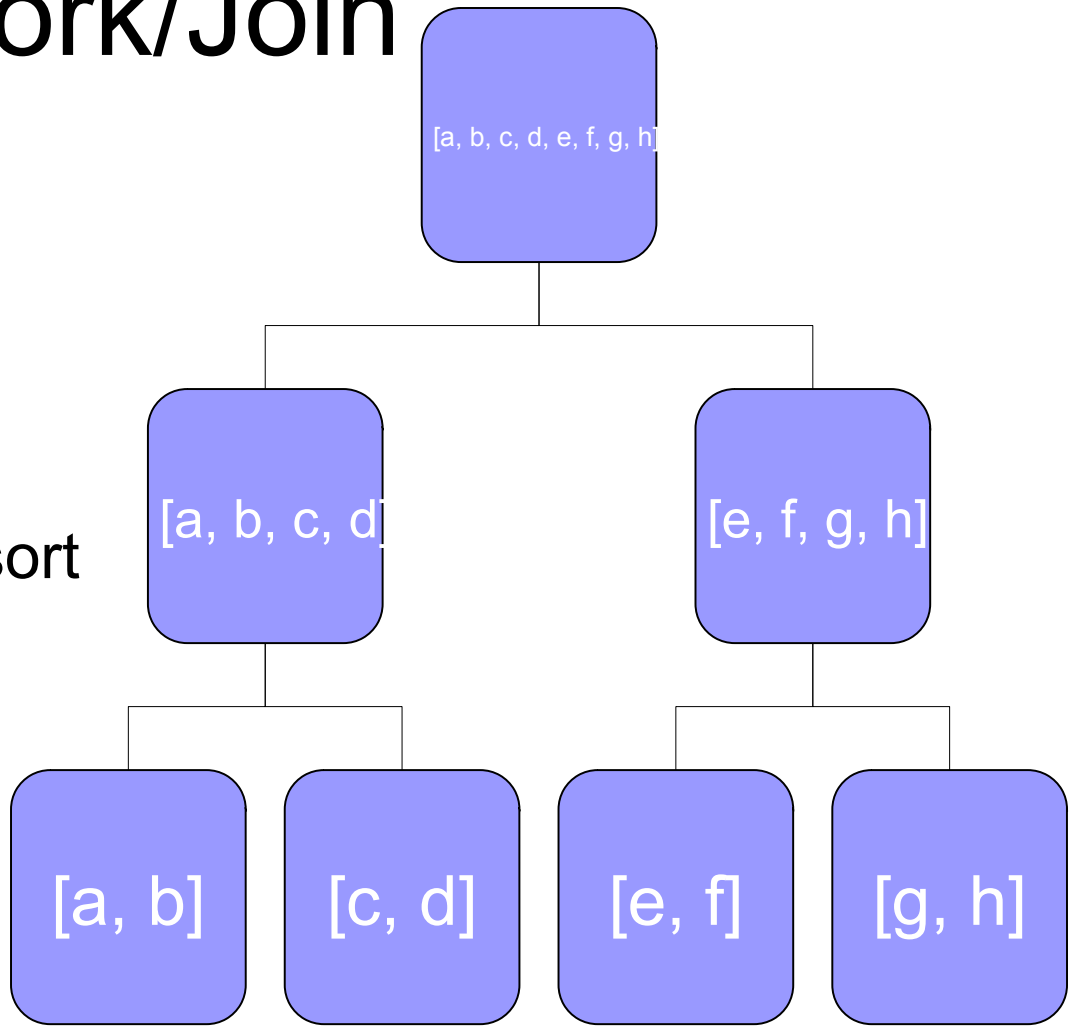
```
Select alt = group.select(validForms, invalidForms)

SelectResult selectResult = alt.select()  //alt.prioritySelect()

switch (selectResult.index) {
        case 0: registrations << selectResult.value; break
        case 1: ...
}
```

Hierarchical decomposition



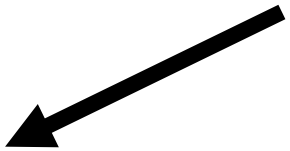
Fork/Join

- Solve hierarchical problems
  - Divide and conquer
- Merge sort, Quick sort
- Tree traversal
- File scan / search
- …



Fork/Join (GPars)

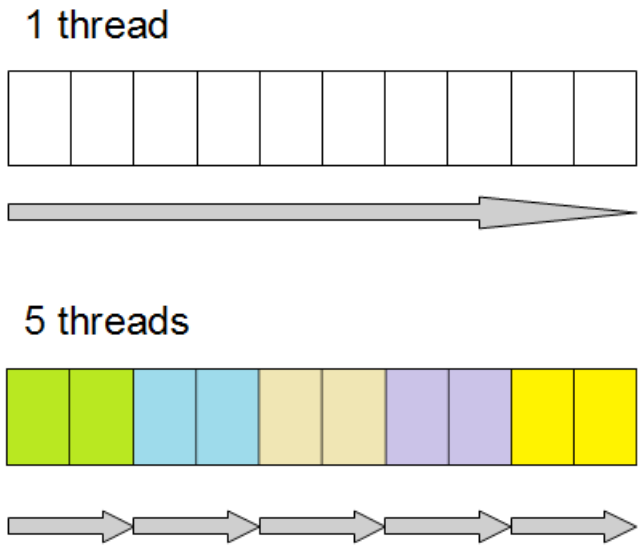
```
{currentDir ->
    long count = 0;
    currentDir.eachFile {
        if (it.isDirectory()) {
            forkOffChild it
        } else {
            count++
        }
    }
    return count + childrenResults.sum(0)
}
```



Waits for children without blocking the thread!

Geometrical decomposition

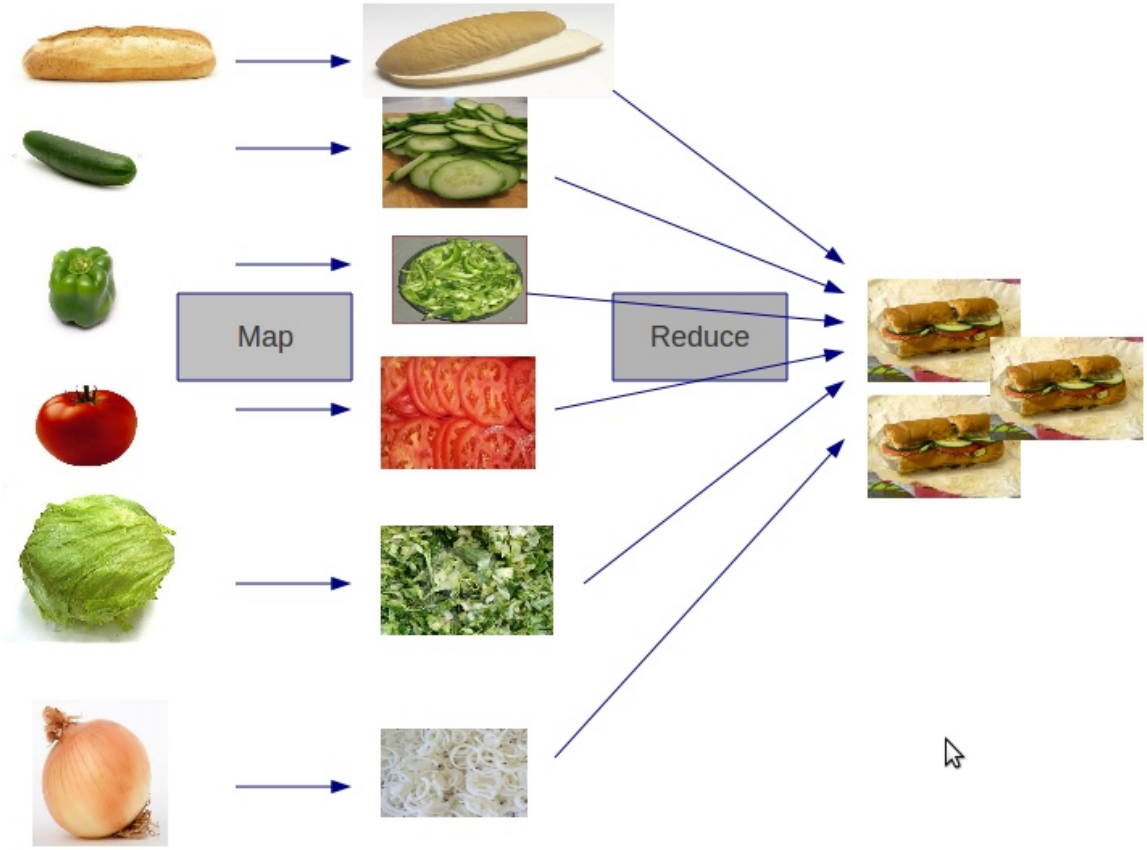
```
images.eachParallel {it.process()}
documents.sumParallel()
candidates.maxParallel {it.salary}.marry()
```



Geometric decomposition

```
registrations = submissions
        .collectParallel { form -> form.process()}
        .findAllParallel { it.valid }

registrations = submissions.parallel
        .map { form -> form.process()}
        .filter { it.valid }.collection
```

Map - reduce



Frequent confusion

Questions | Tags | Users | Badges | Unanswered

parallel quick sort outdone by single threaded quicksort

0

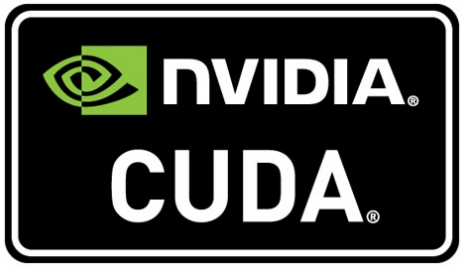
I've been reading , here is the example in the book using futures to implement parallel quick sort.

But I found this function is more than twice slower than the single threaded quick sort function without using any asynchronous facilities in c++ standard library. Tested with g++ 4.8 and visual c++ 2012.

I used 10M random integers to test, and in visual c++ 2012,this function spawned 6 threads in total to perform the operation in my quad core PC.

I am really confused about the performance. Any body can tell me why?

GPU



Improper use 1

```
def accumulator = 0


myCollection.eachParallel {
    accumulator += calculate(it)
}
```

Do not accumulate, map-reduce!

```
def accumulator = myCollection.parallel
                              .map {calculate(it)}
                              .reduce {a, b → a + b}
```

Improper use 2

```
new File("/file.txt").withReader{reader ->
    reader.eachParallel {
        def r1 = step1(r)
        def r2 = step2(r1)
        def r3 = step3(r2)
    }
}
```

Unroll iterations into streams

```
def pipeline = data | step1 | step2 | step3


new File("/file.txt").withReader{reader ->
    reader.each {
        data << it
    }
}
```

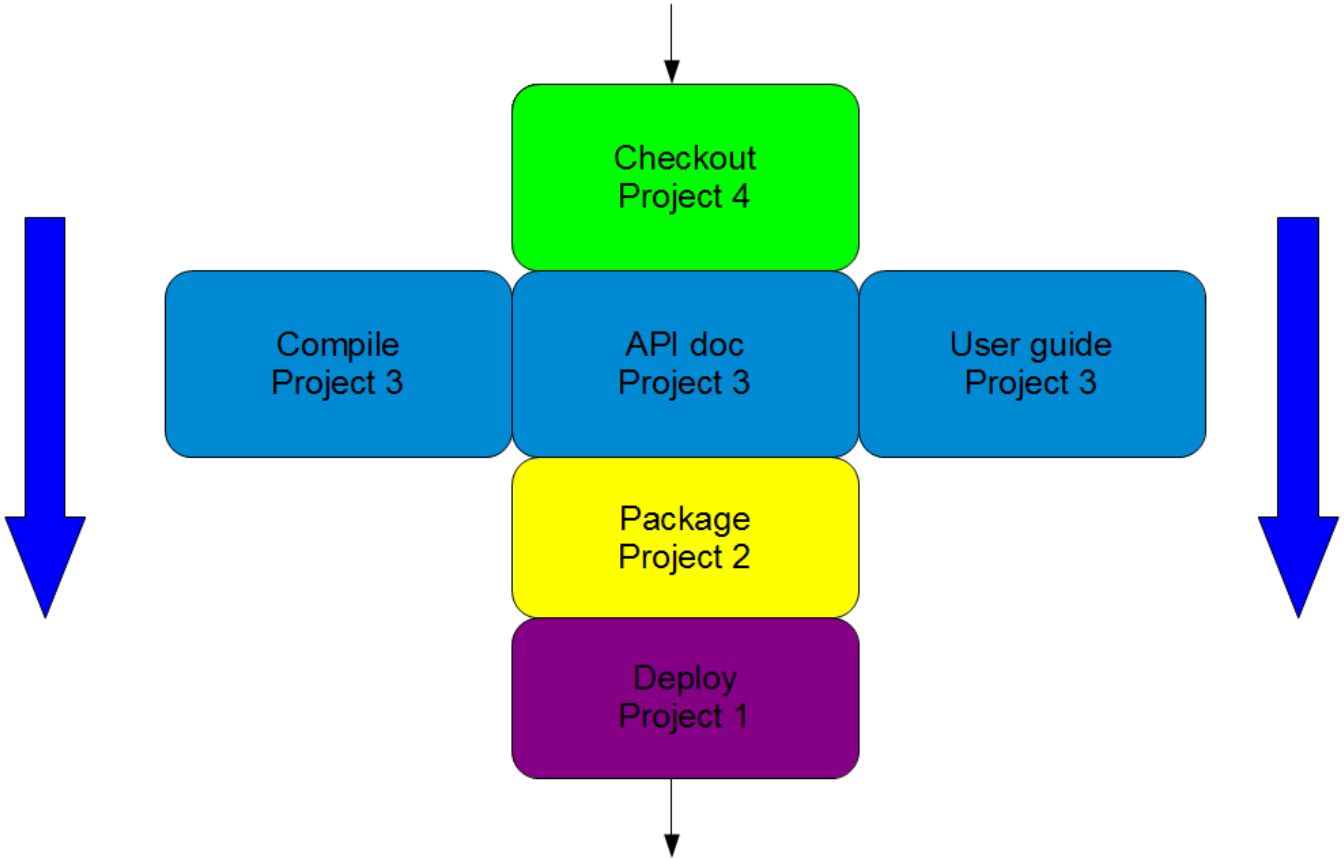
Unroll iterations

```
[project1, project2, project3, project4].eachParallel {
    checkout it
    compile it
    package it
    deploy it
}
```

vs.

```
def results = projects | checkout | compile | package | deploy
```

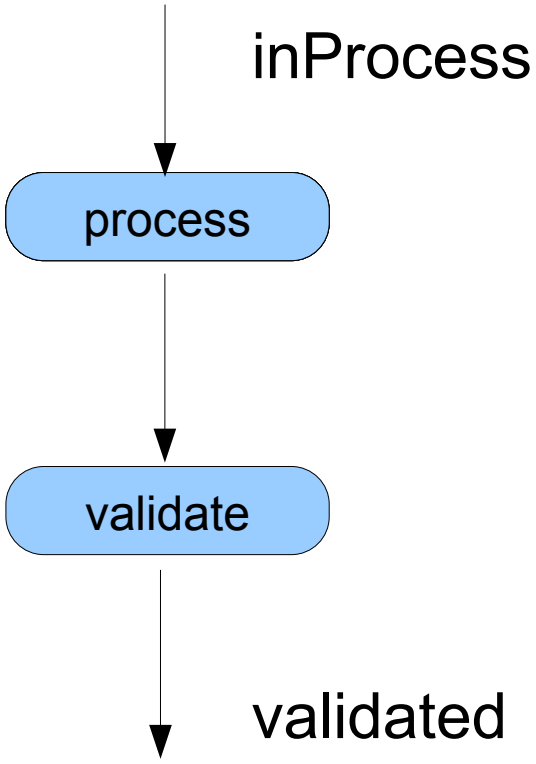
Unroll iteration



Reactive streams

Pipeline DSL

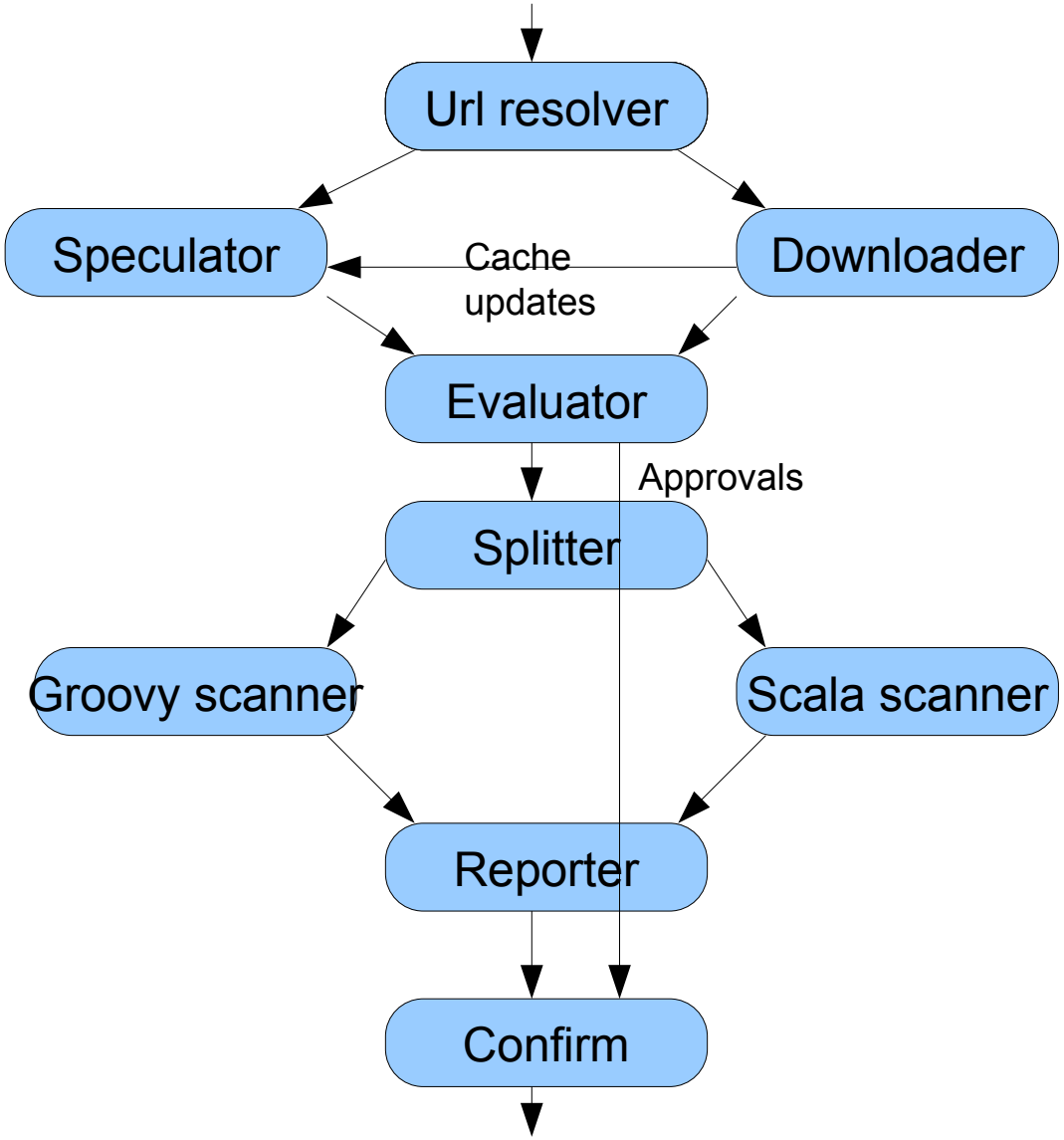
```
def toProcess = new DataflowQueue()
def validated = new DataflowQueue()

toProcess |  {form -> process(form)} |
    {processedForm -> validate(processedForm)} | validated

submissions.each {toProcess << it}  //feed data to the pipe
```


inProcess
process
validate
validated

Generalization

An operation can take multiple inputs and outputs

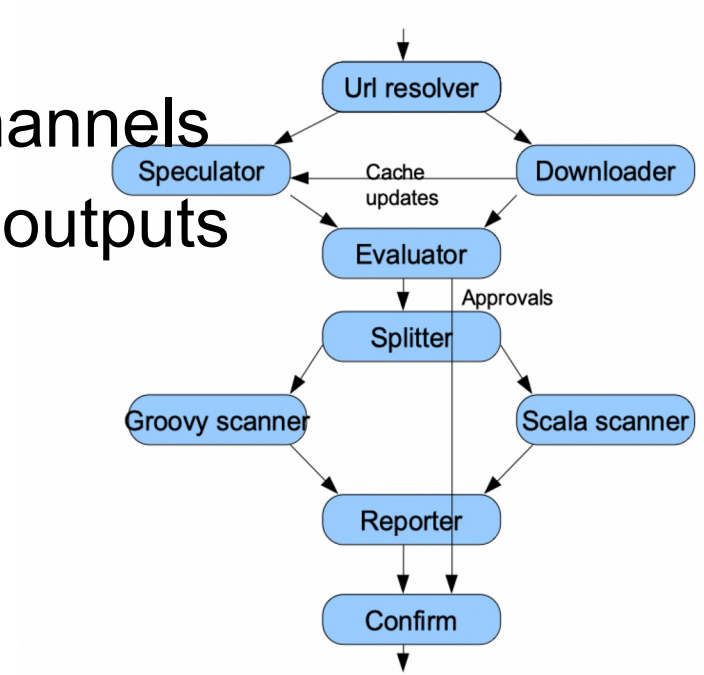
Operations adressed indirecly using channels


Url resolver
Speculator
Cache
updates
Downloader
Evaluator
Approvals
Splitter
Groovy scanner
Scala scanner
Reporter
Confirm

Dataflow Operators

Like functions

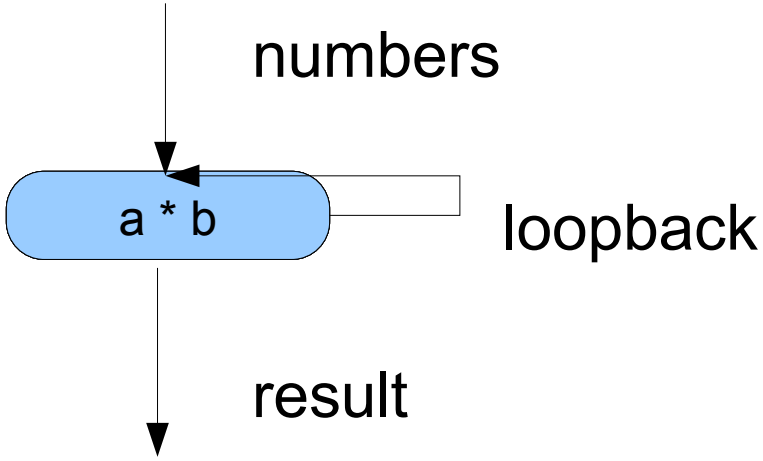
- wired together with channels
- possibly with multiple outputs
- may be recursive

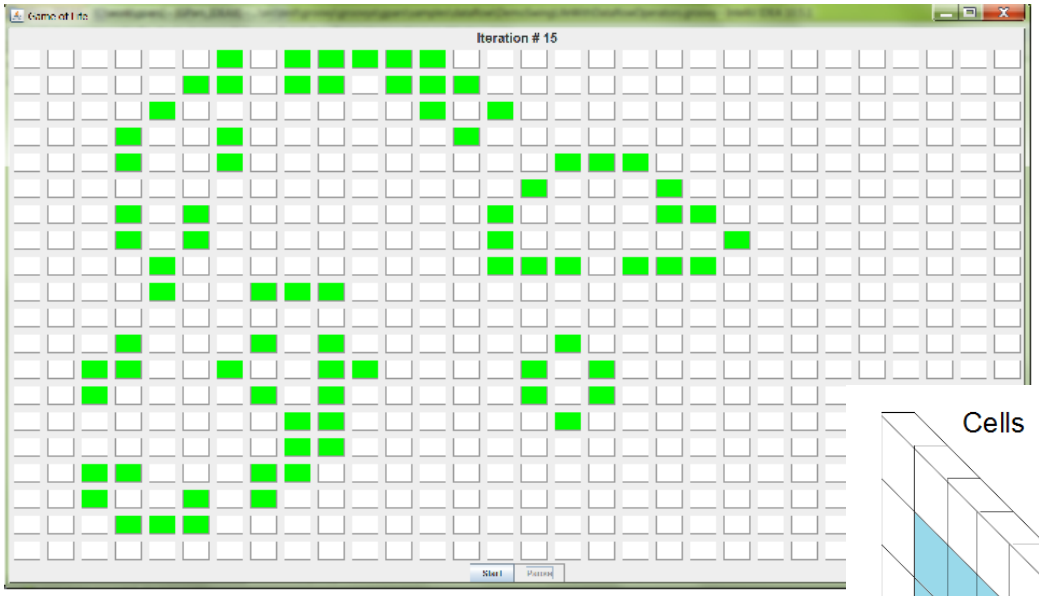


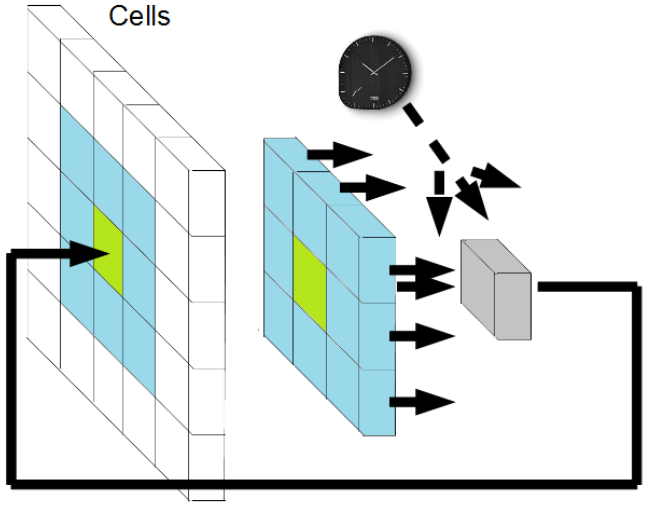
Dataflow Operators

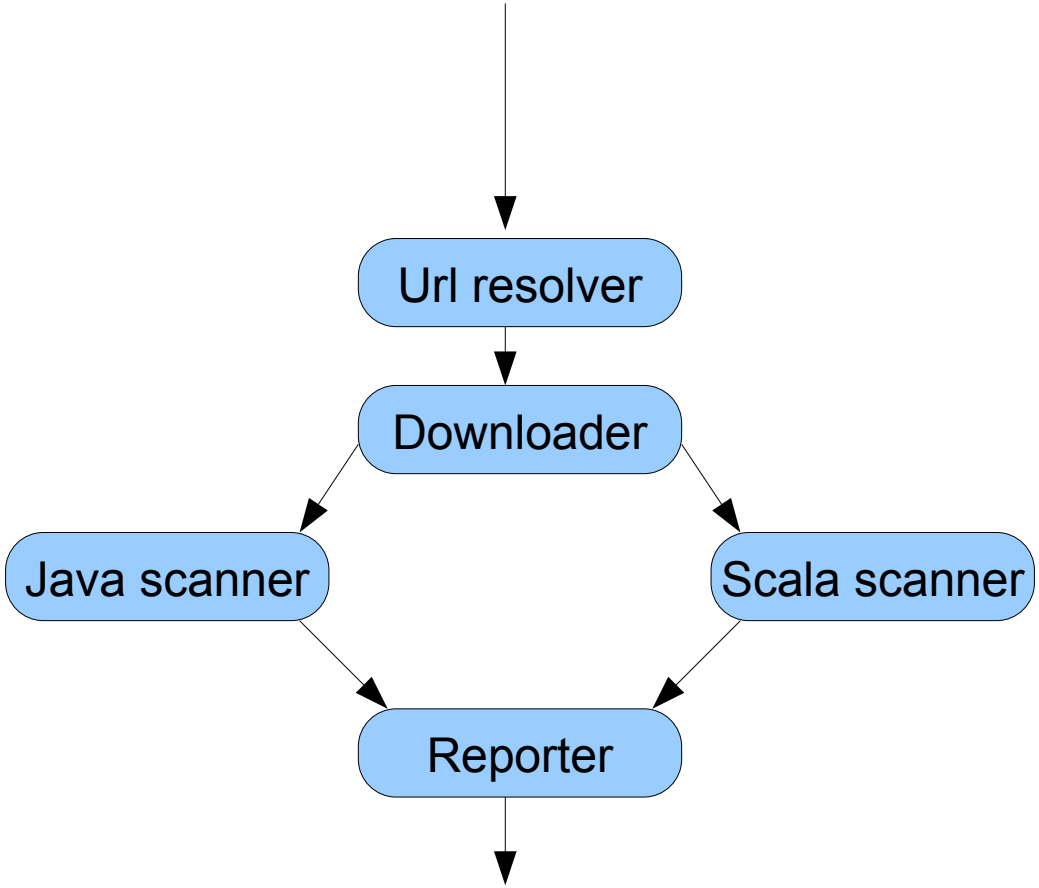
```
operator(inputs: [headers, bodies, footers],
         outputs: [articles, summaries])
    {header, body, footer ->
        def article = buildArticle(header, body, footer)
        bindOutput(0, article)
        bindOutput(1, buildSummary(article))
    }
```

Factorial




Iteration # 15
Start
Pause


Cells


Url resolver
Downloader
Java scanner
Scala scanner
Reporter

Vision/trend

- Structured concurrency and reactive streams go well together

Shared mutable state

High-level abstractions

- STM
- Agents
- Actors

STM (Akka - Scala)

```
atomic {
    .. // do something within a transaction
}

atomic(maxNrOfRetries) { .. }
atomicReadOnly { .. }

atomically {
    .. // try to do something
} orElse {
    .. // if tx clash; try do do something else
}
```

Sample taken from Akka documentation - http://doc.akkasource.org/stm

Control State with STM

Needs protection

```
List registrations = []
submissions.each {form →
    group.task {
        if (form.process().valid) {
            registrations << form
        }
    }
}
```

Control State with STM

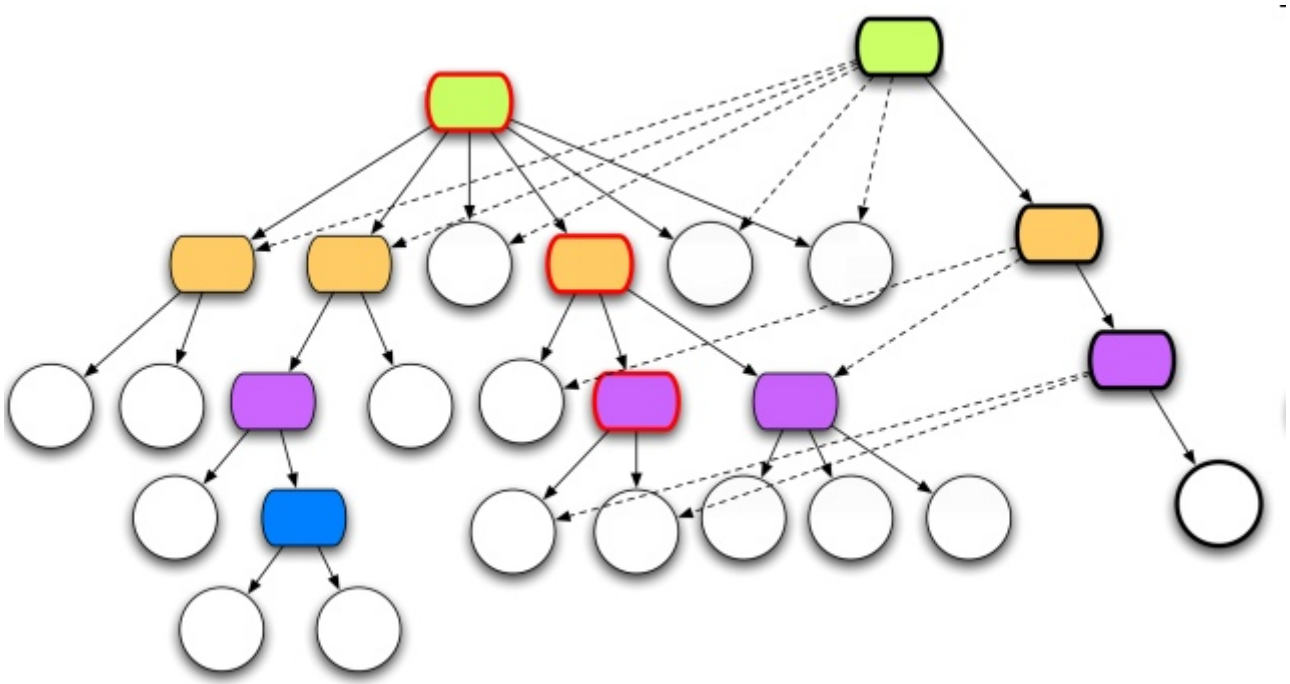
```
List registrations = []
submissions.each {form →
    group.task {
        atomic {
            if (form.process().valid) {
                registrations << form
            }
        }  }}
```

Control State with STM

Which List class?

```
List registrations = []
submissions.each {form →
    group.task {
        atomic {
            if (form.process().valid) {
                registrations << form
            }
        }  }}
```

Persistent Data Structures

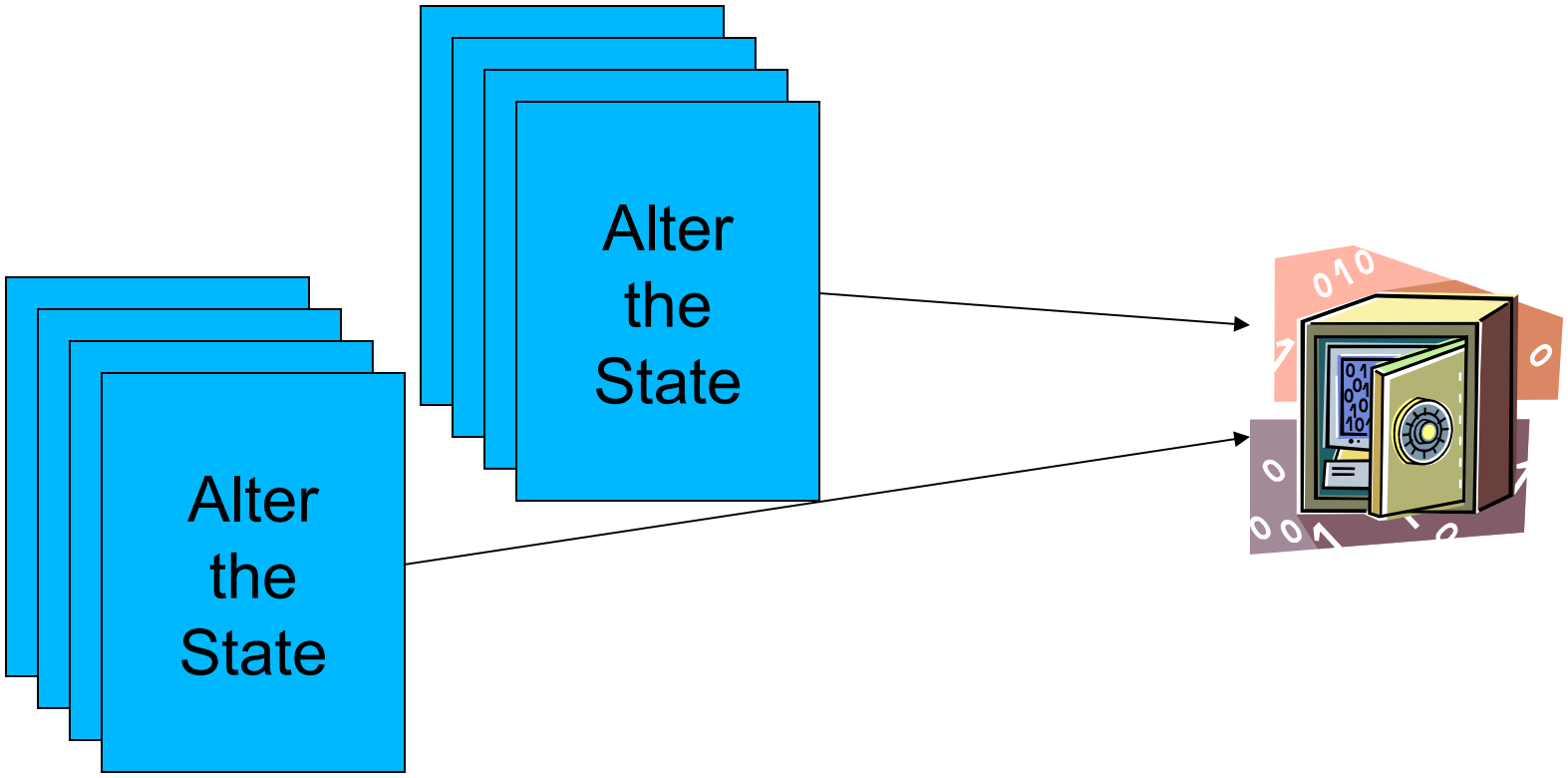


High-level abstractions

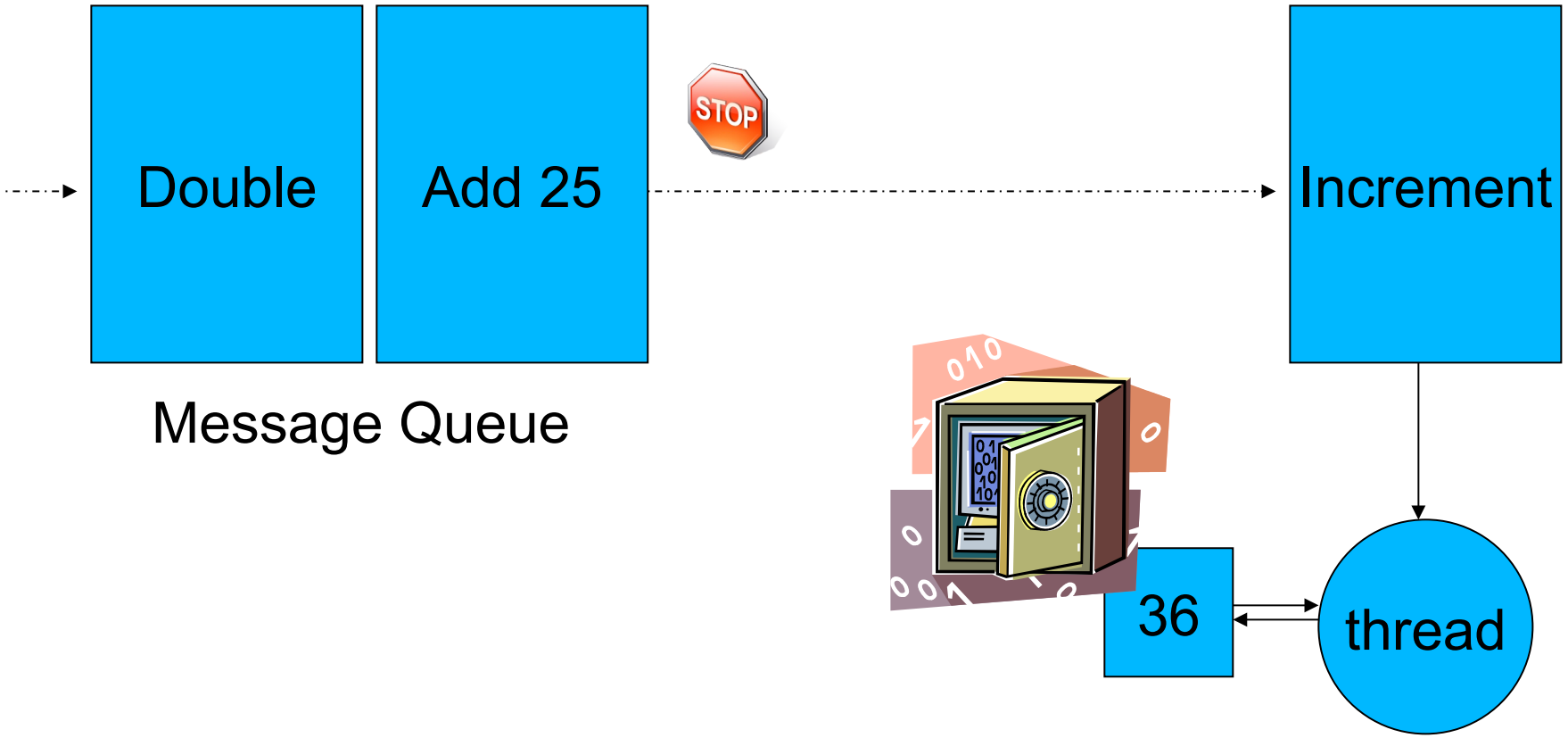
- STM
- Agents

Agent

Lock Shared Mutable State in a Safe



Agent inside



Control State with Agents

Needs protection

```
List registrations = []
submissions.each {form →
    group.task {
        if (form.process().valid) {
            registrations << form
        }
    }
}
```

Control State with Agents

```
Agent regAgent = new Agent( [] )
submissions.each {form →
    task {
        if (form.process().valid) {
            regAgent.send {List regs → regs.add form}
        }
    }
}
```

Actors

Isolated state

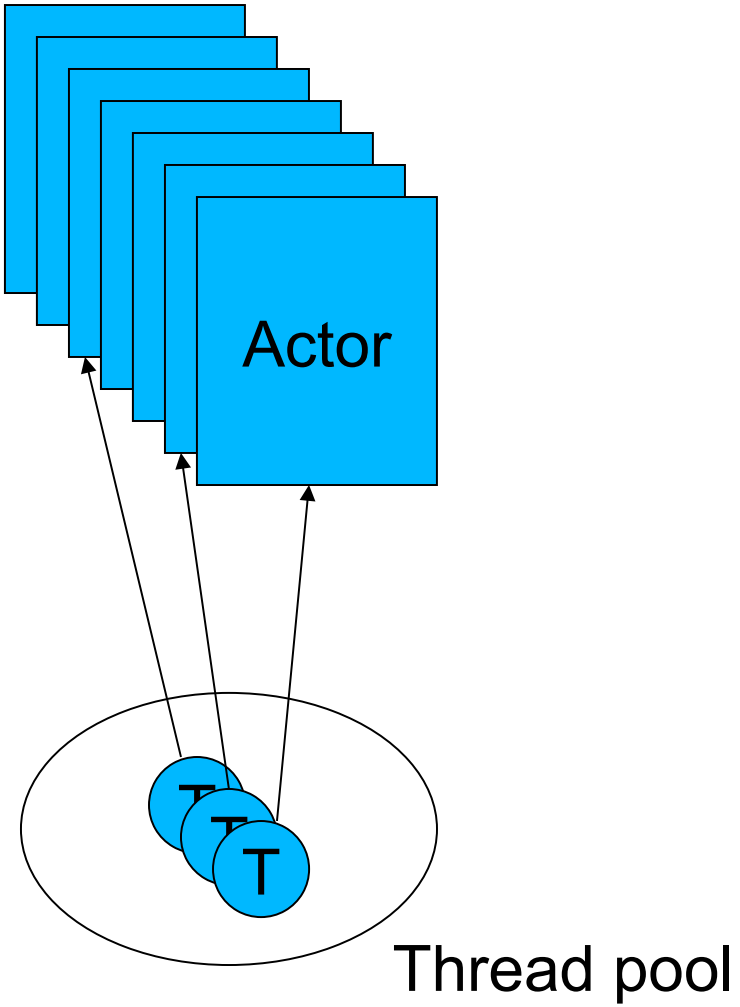
Active - shared threads

Async Communication

- Direct addressing
- Immutable messages

Activities:

- Create a new actor
- Send a message
- Receive a message



Actors vs. Agents

Agents send commands

Actors send data

Both use direct addressing (no channels)

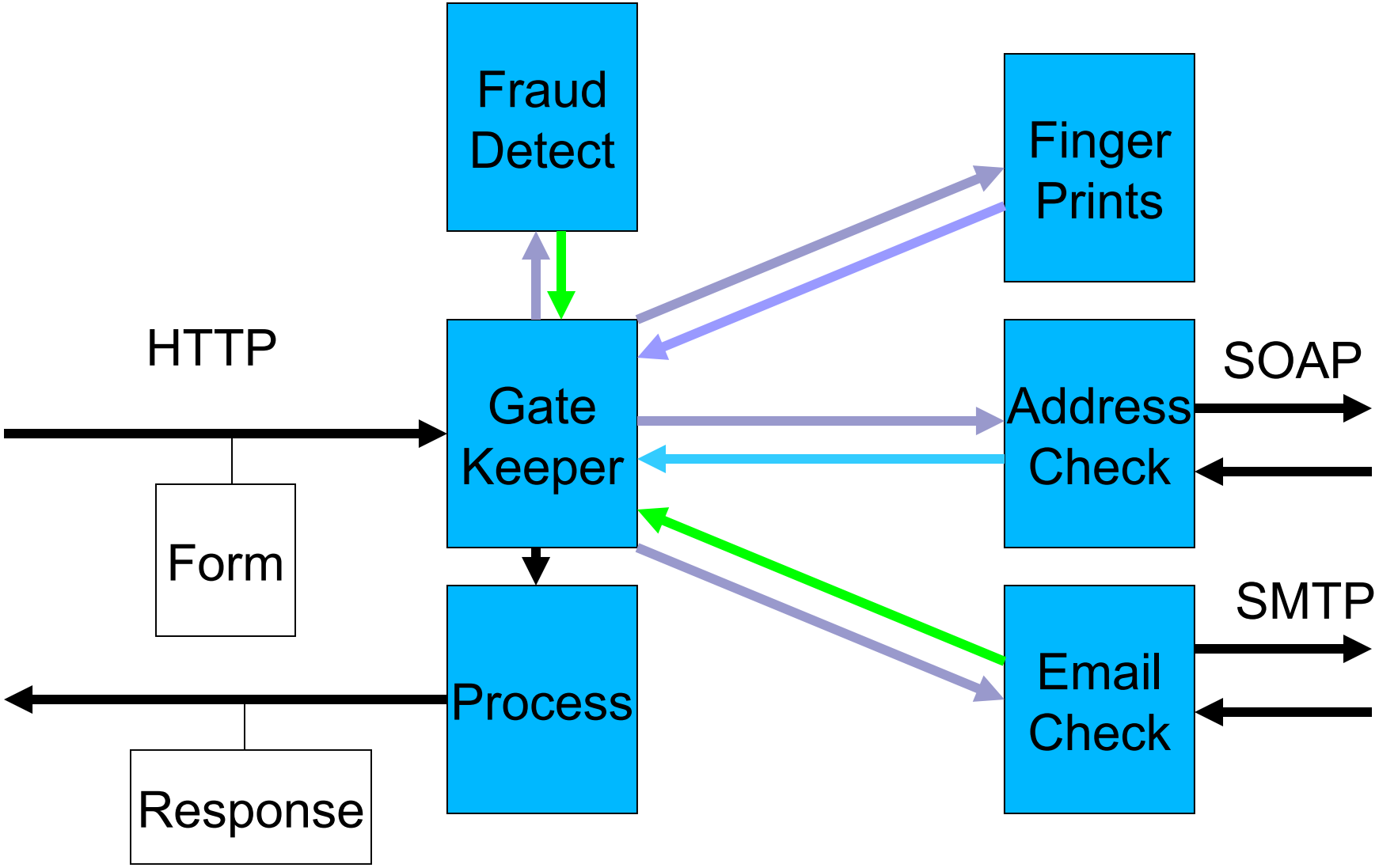
Actor definition

```
class MyActor extends DynamicDispatchActor {
    private int counter = 0

    public void onMessage(String msg) {
        this.counter += msg.size()
    }
    public void onMessage(Integer number) {
        this.counter += number
    }
    public void onMessage(Money cash) {
        this.counter += cash.amount
        reply 'Thank you'
    }
}
```

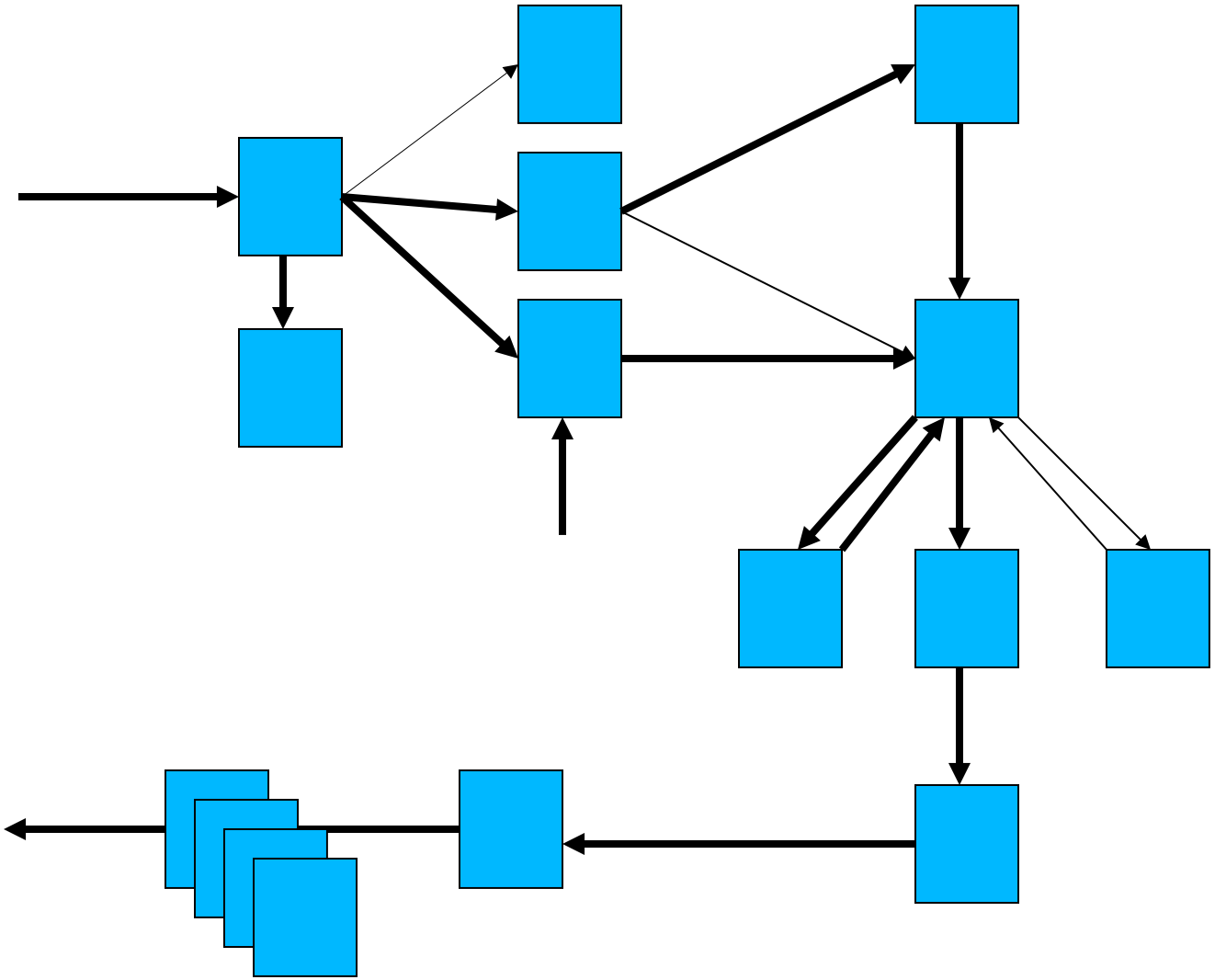
Sending messages

```
buddy.send 10.eur

buddy << new Book(title:'Groovy Recipes',
                  author:'Scott Davis')

def canChat = buddy.sendAndWait 'Got time?'

buddy.sendAndContinue 'Need money!', {cash->
    pocket.add cash
}
```

Actors use


Fraud Detect
Finger Prints
HTTP
Gate Keeper
SOAP
Address Check
Form
Process
SMTP
Email Check
Response

Actors patterns



Enricher

Router

Translator

Endpoint

Splitter

Aggregator

Filter

Re-sequencer

Checker

Active objects

```
@ActiveObject
class MyCounter {
    private int counter = 0


 @ActiveMethod
    def incrementBy(int value) {
        println "Received an integer: $value"
        this.counter += value
    }
}
```

Summary

Parallelism is not hard, multi-threading is

Jon Kerridge, Napier University

References

http://groovy-lang.org

http://grails.org

https://docs.oracle.com/en/java/javase/20/core/virtual-threads.html

https://akka.io/