High-level concurrency concepts

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NPRG014 2024/2025

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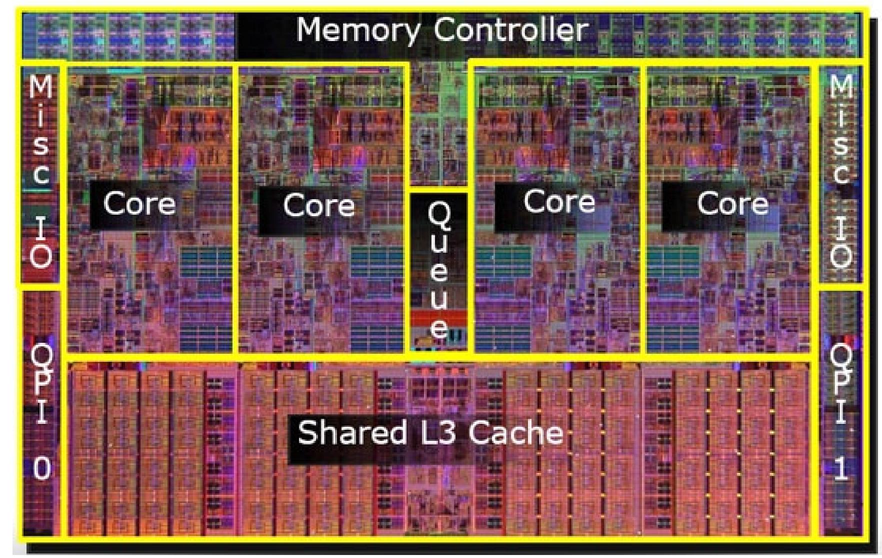
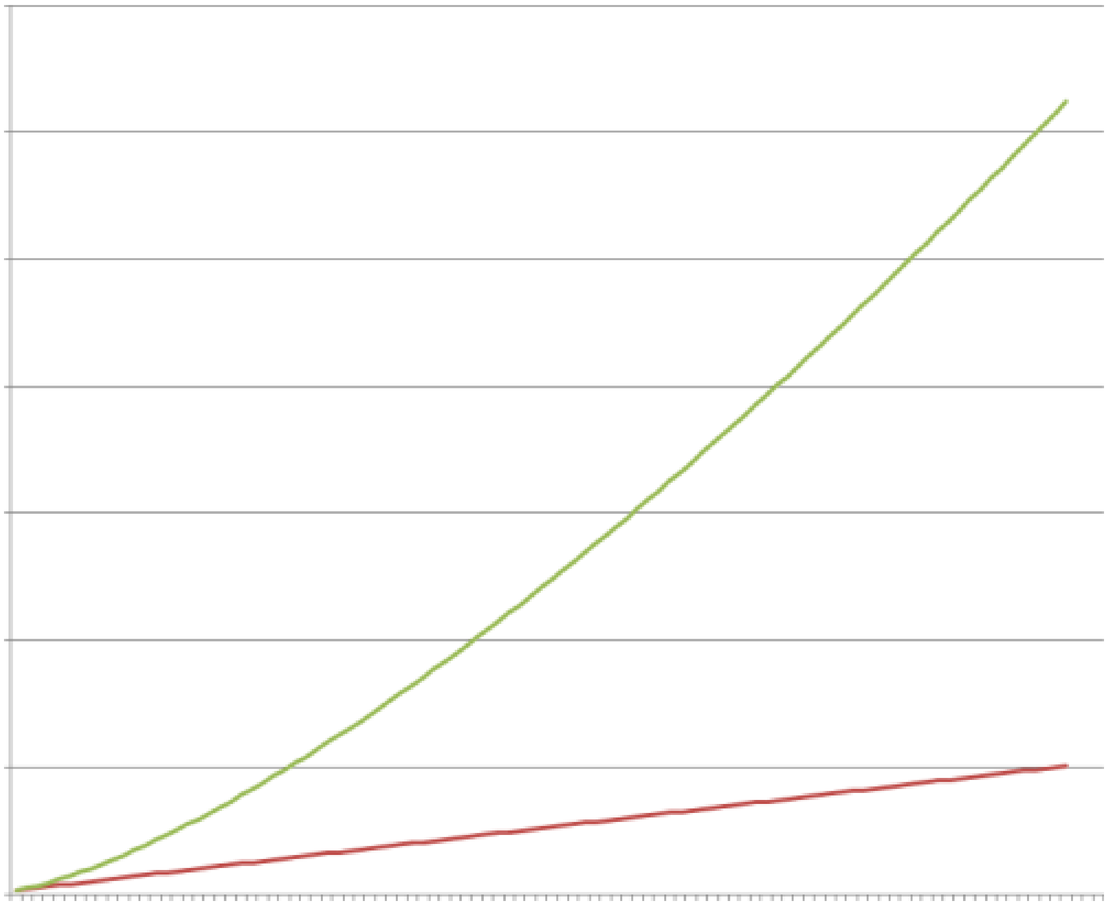
Why concurrency?



We're all in the parallel computing business!

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

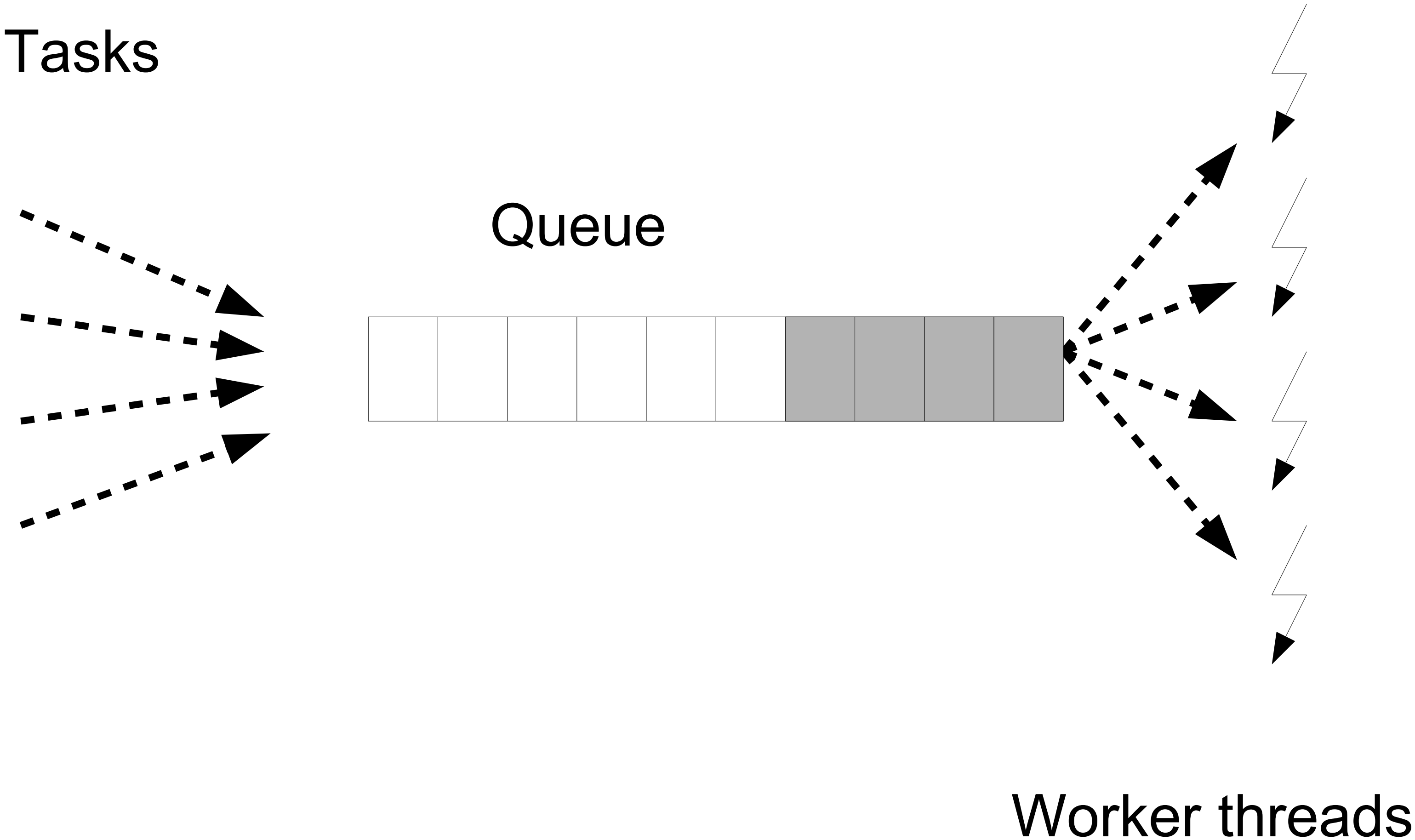
```
def myRunnable = new Runnable {
    public void run() {
      ...
    }
}
new Thread(myRunnable).start()
```

Thread Pool

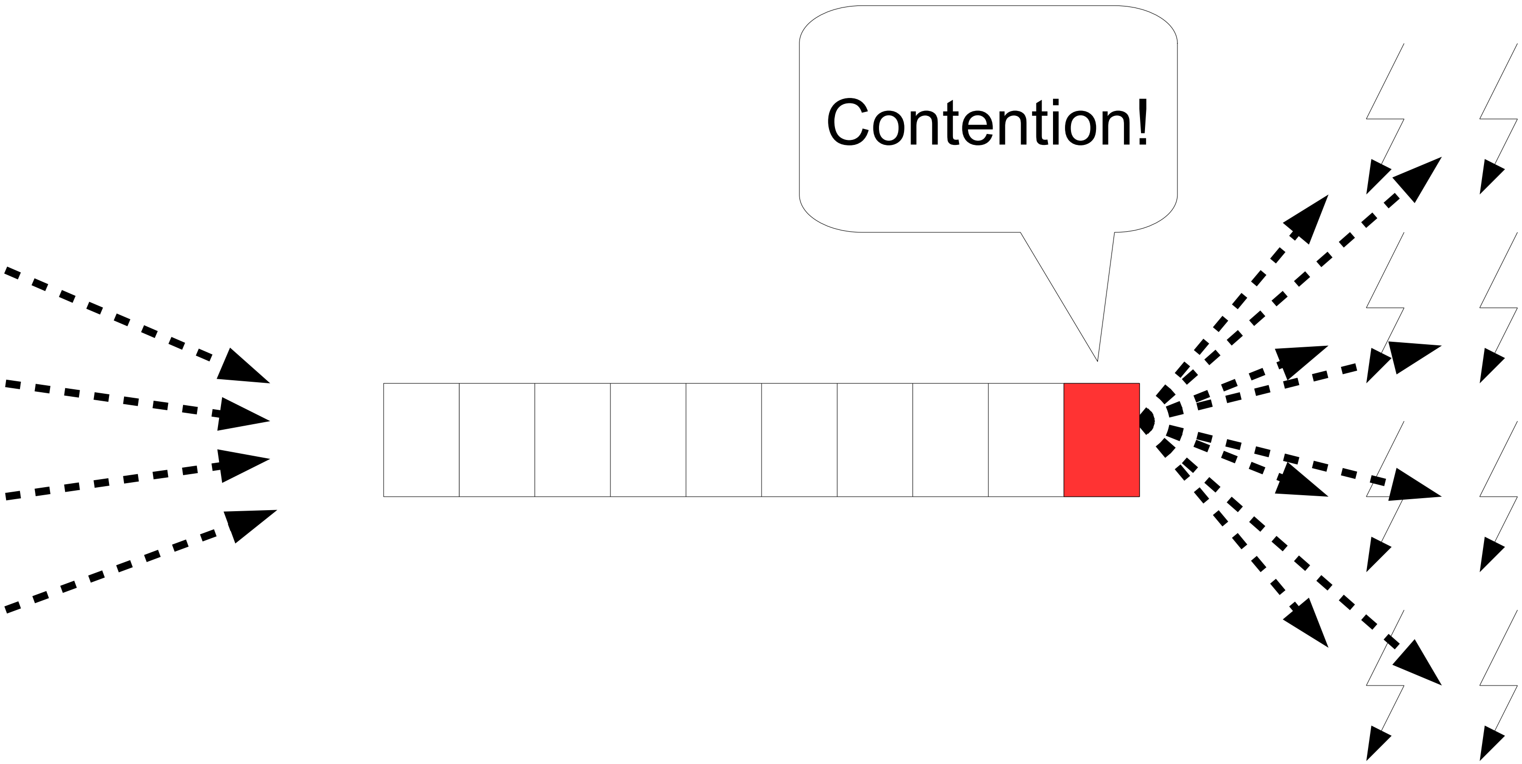
```
def pool = Executors.newFixedThreadPool(6)
def myCallable = new Callable<T> {
    public T call() {...}
}

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

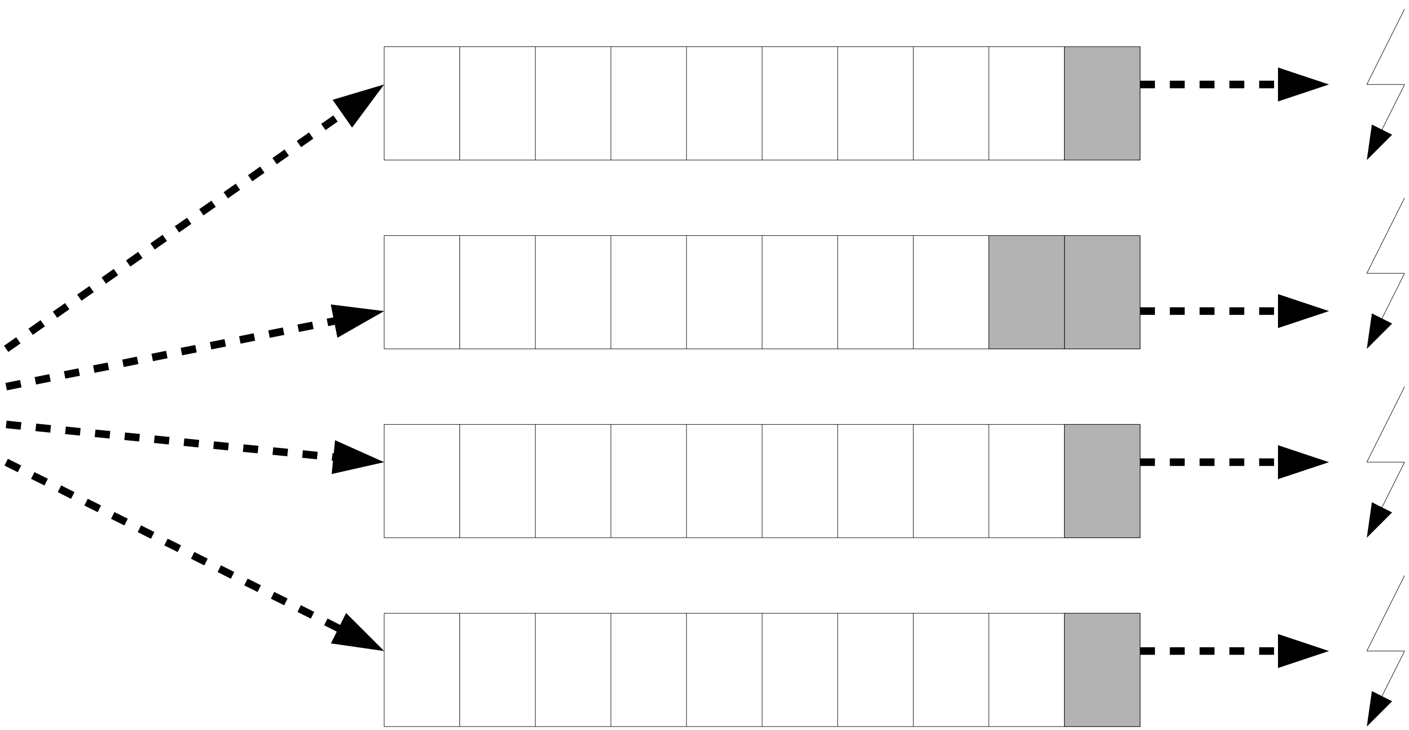
Thread Pool



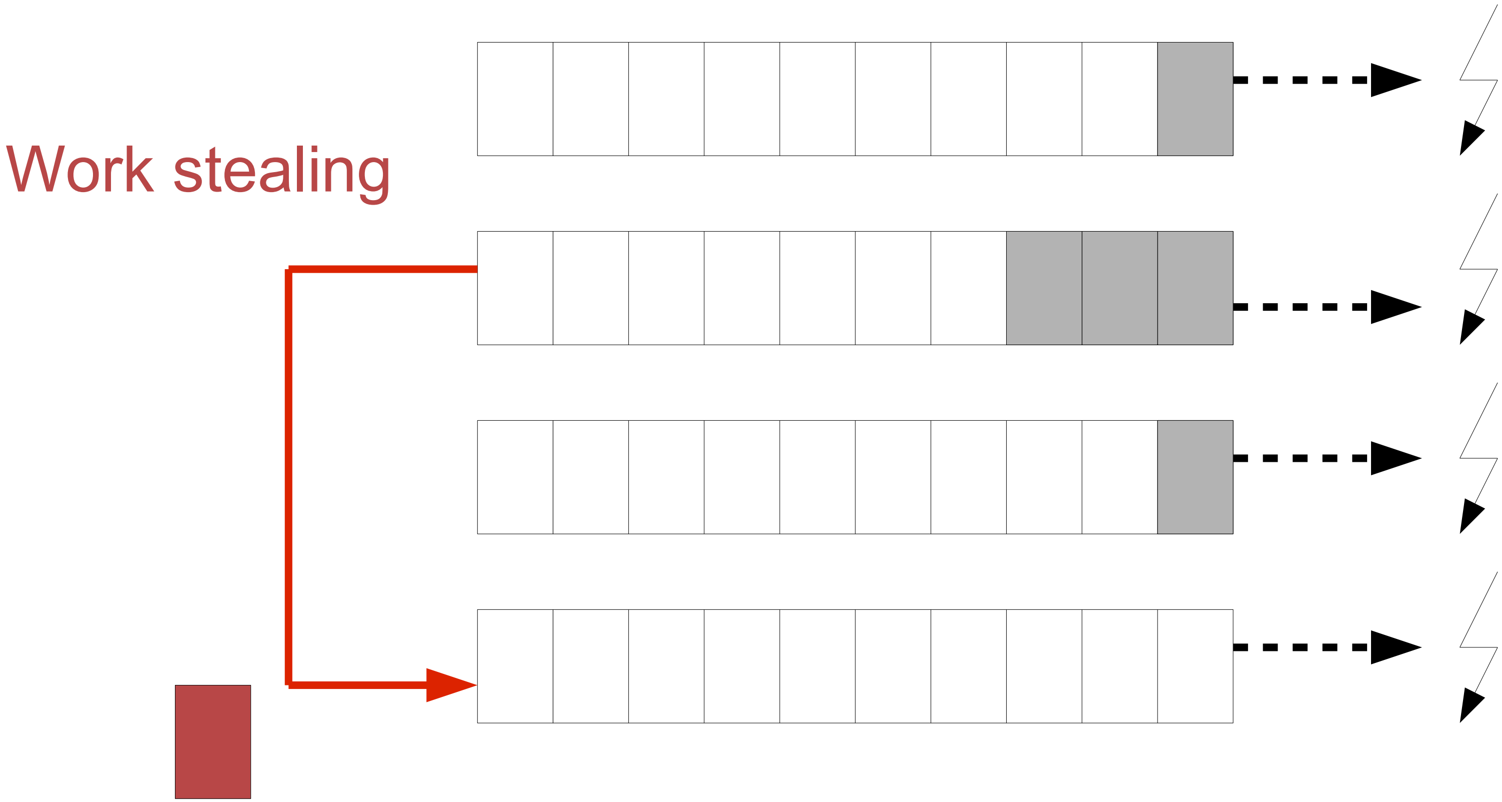
Thread Pool



Fork/Join Thread Pool



Fork/Join Thread Pool



Virtual Threads (Java 19)

```
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)

```java
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 alternatives

group.task {->…}

group.task new Runnable() {…}

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

Not implemented yet

```
group.cancelAll()

group.onFailureRestart()
group.onFailureCancelAll()

def subgroup = group.subgroup()
```

Dealing with threads sucks!

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

    public Counter() {

        count++;

    }
}
```

Dealing with threads sucks!

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

    public Counter() {

        count++;

    }
}
```

Dealing with threads sucks!

```java
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!

```java
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!

```java
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
- Locks – R/W, ReentrantLock
- Semaphors
- CountDownLatches
- Barriers

Stone age of parallel SW

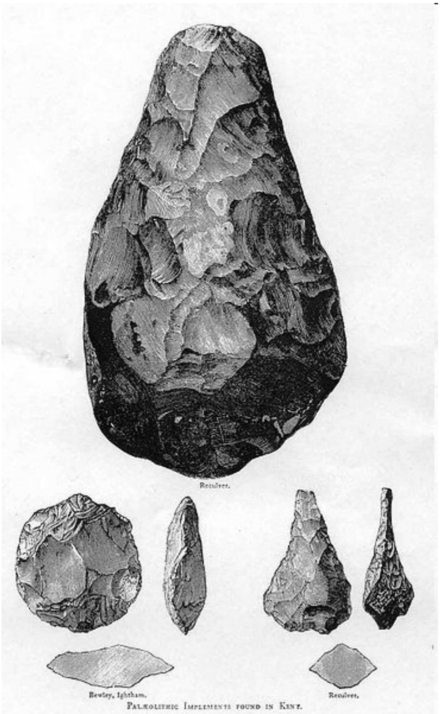
Dead-locks

Live-locks

Race conditions

Starvation

Shared Mutable State



Why high-level concurrency?

Multithreaded programs today work mostly by accident!

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

High-level abstractions

- STM
- Hierarchical decomposition
- Geometrical decomposition
- Streams
- Agents, Actors, Active objects
- Communicating Sequential Processes

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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
        }
    }
}
```

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

Persistent Data Structures

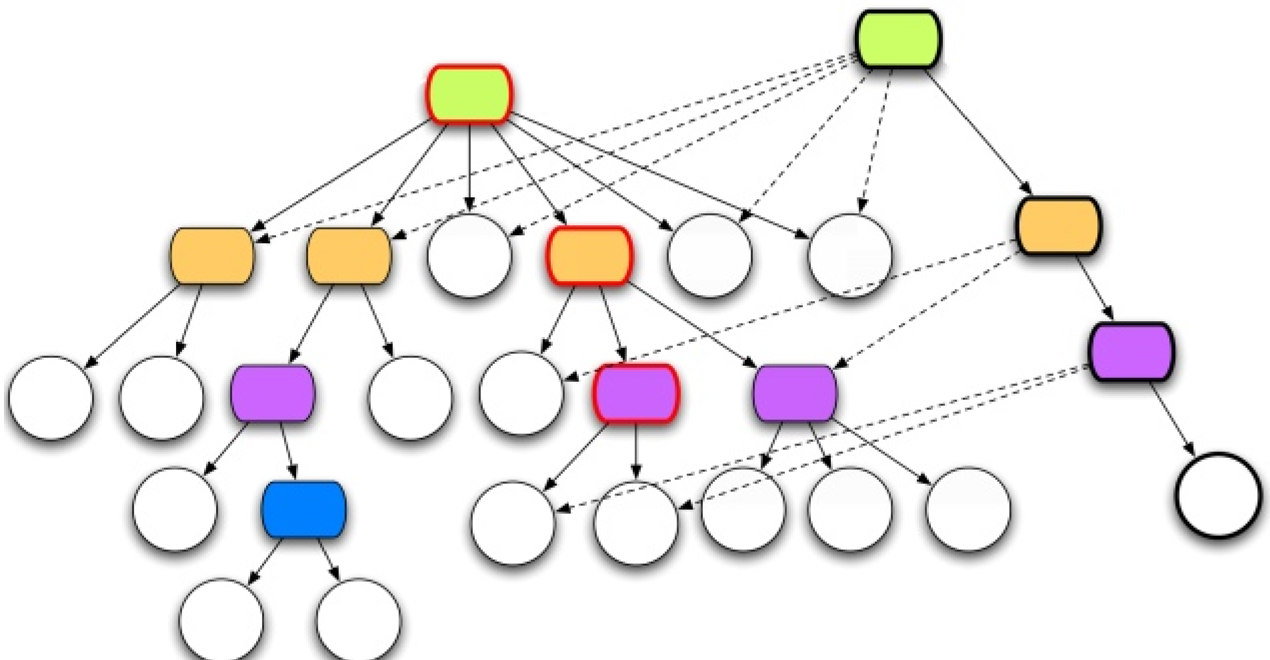

Illustration taken from Rich Hickey's presentation. Copyright Rich Hickey 2009

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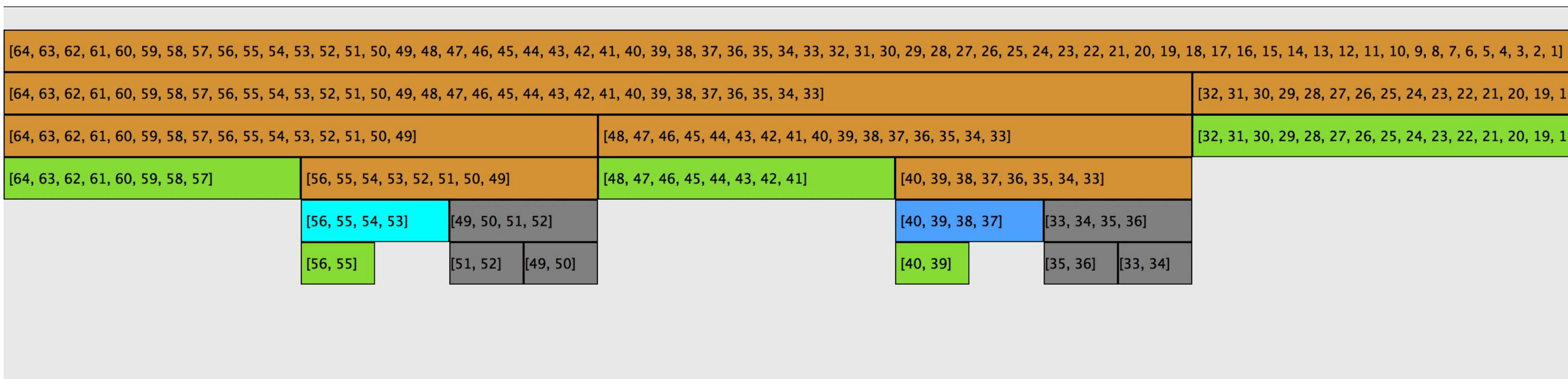
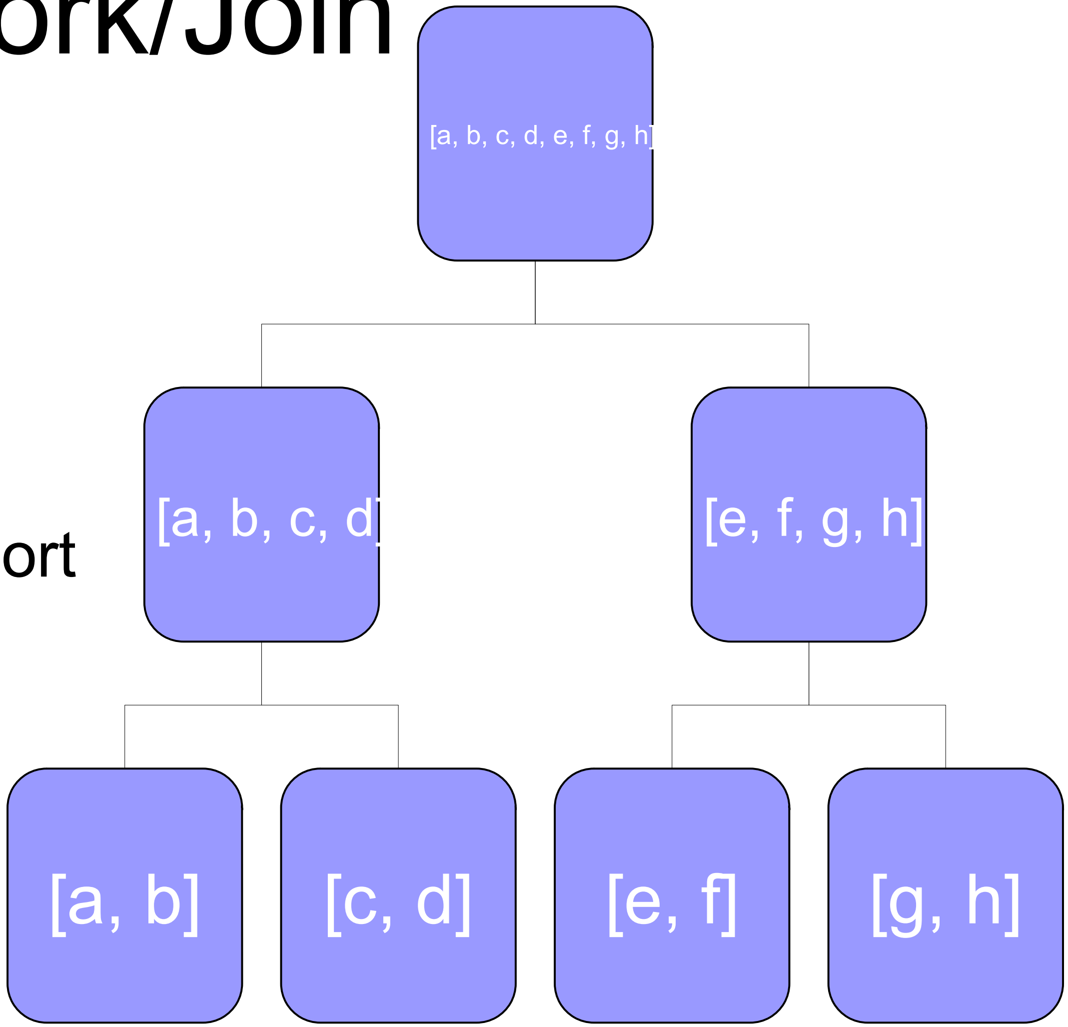
Hierarchical decomposition



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!

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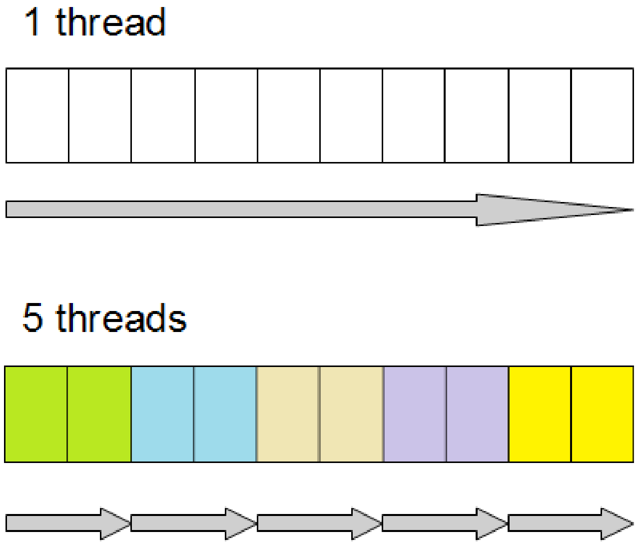
Geometric decomposition

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

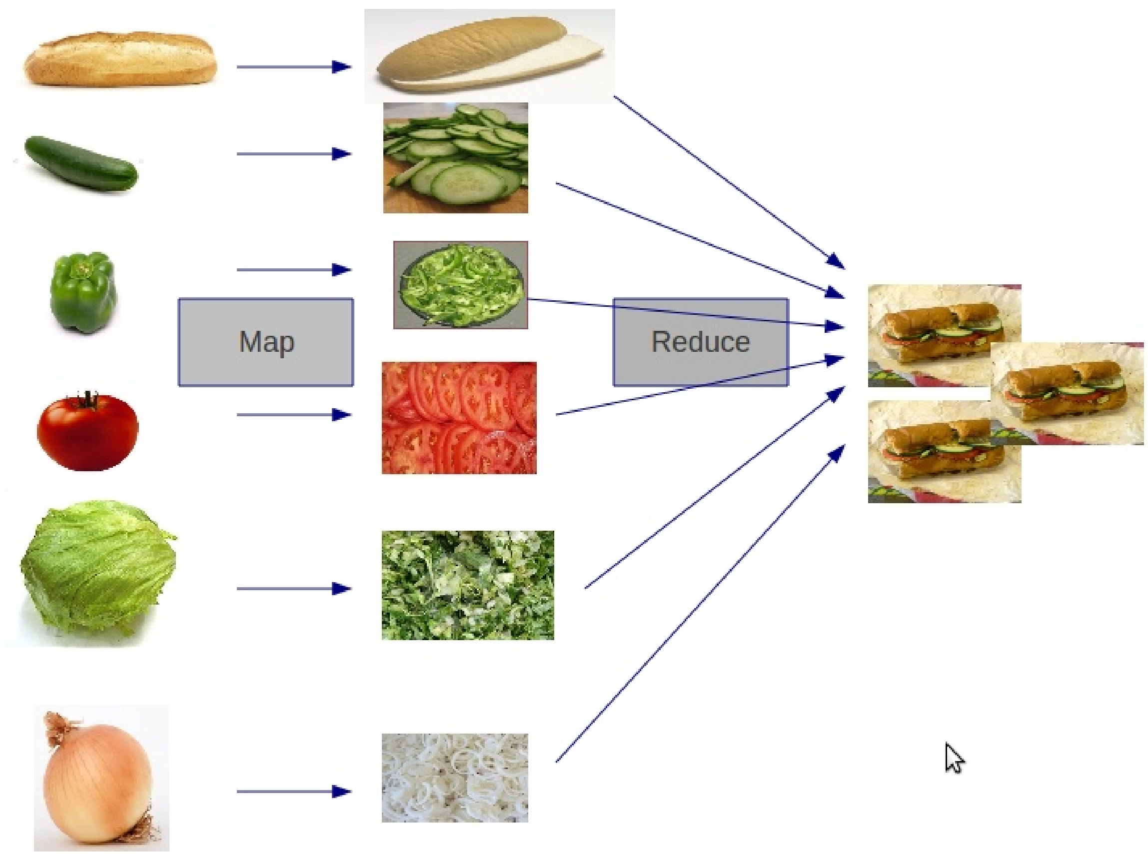


Geometric decomposition

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

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

Map - reduce



Frequent confusion

stackoverflow

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
    }
}
```

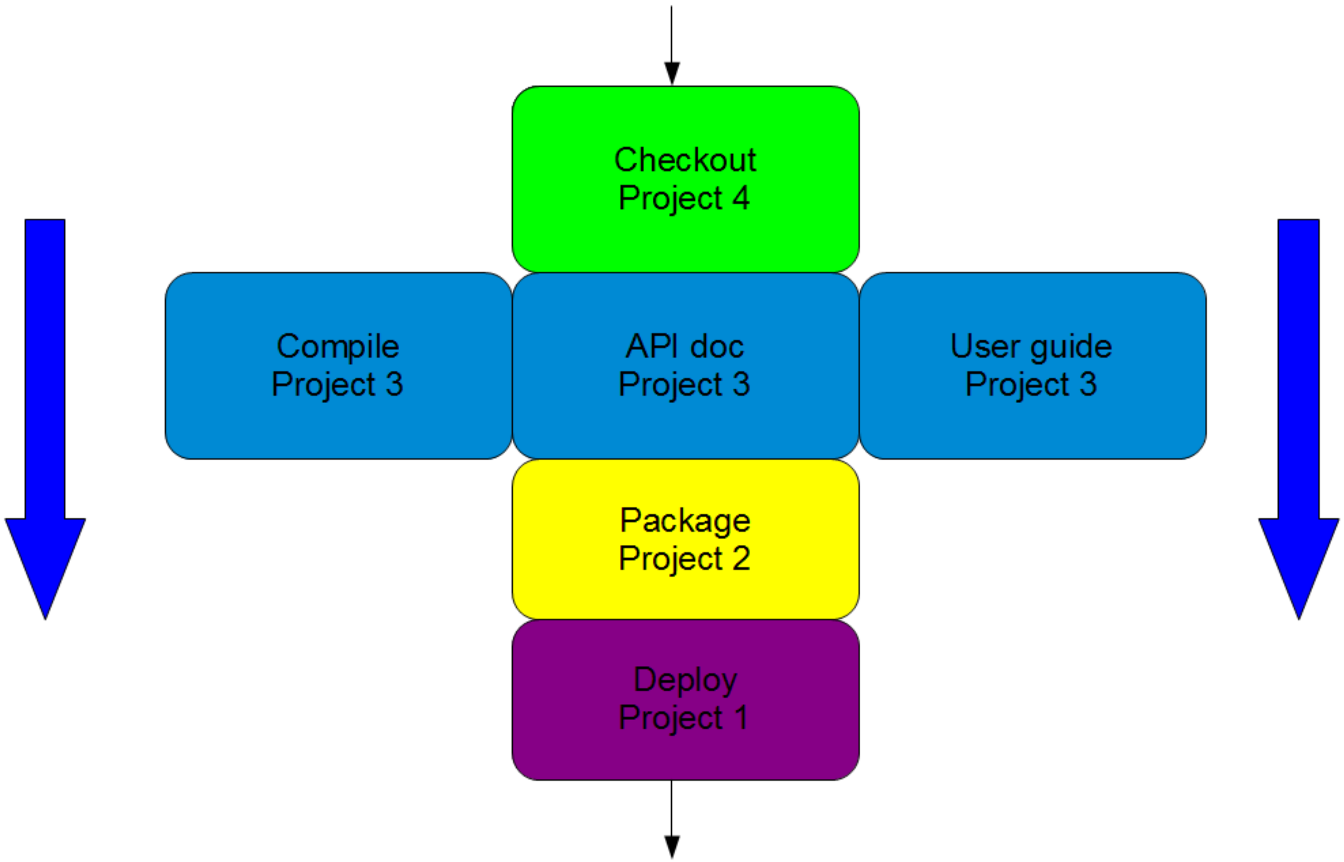
Unroll iterations

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

vs.

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

Unroll iteration



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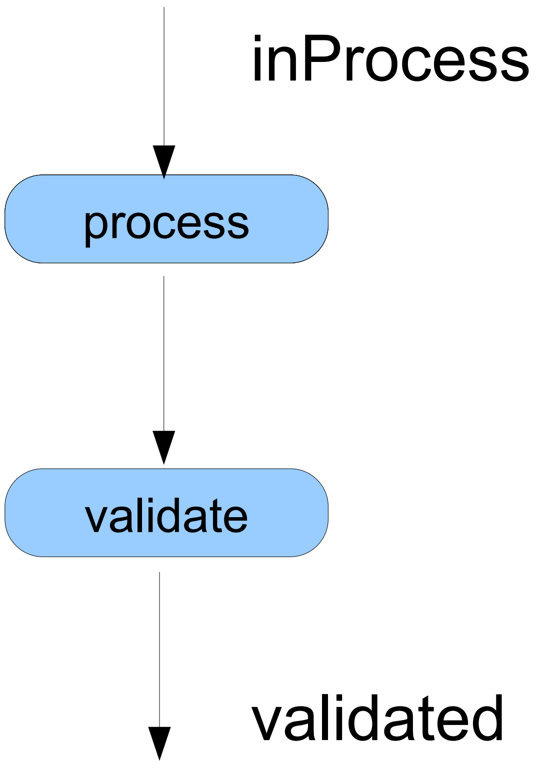
Pipeline DSL

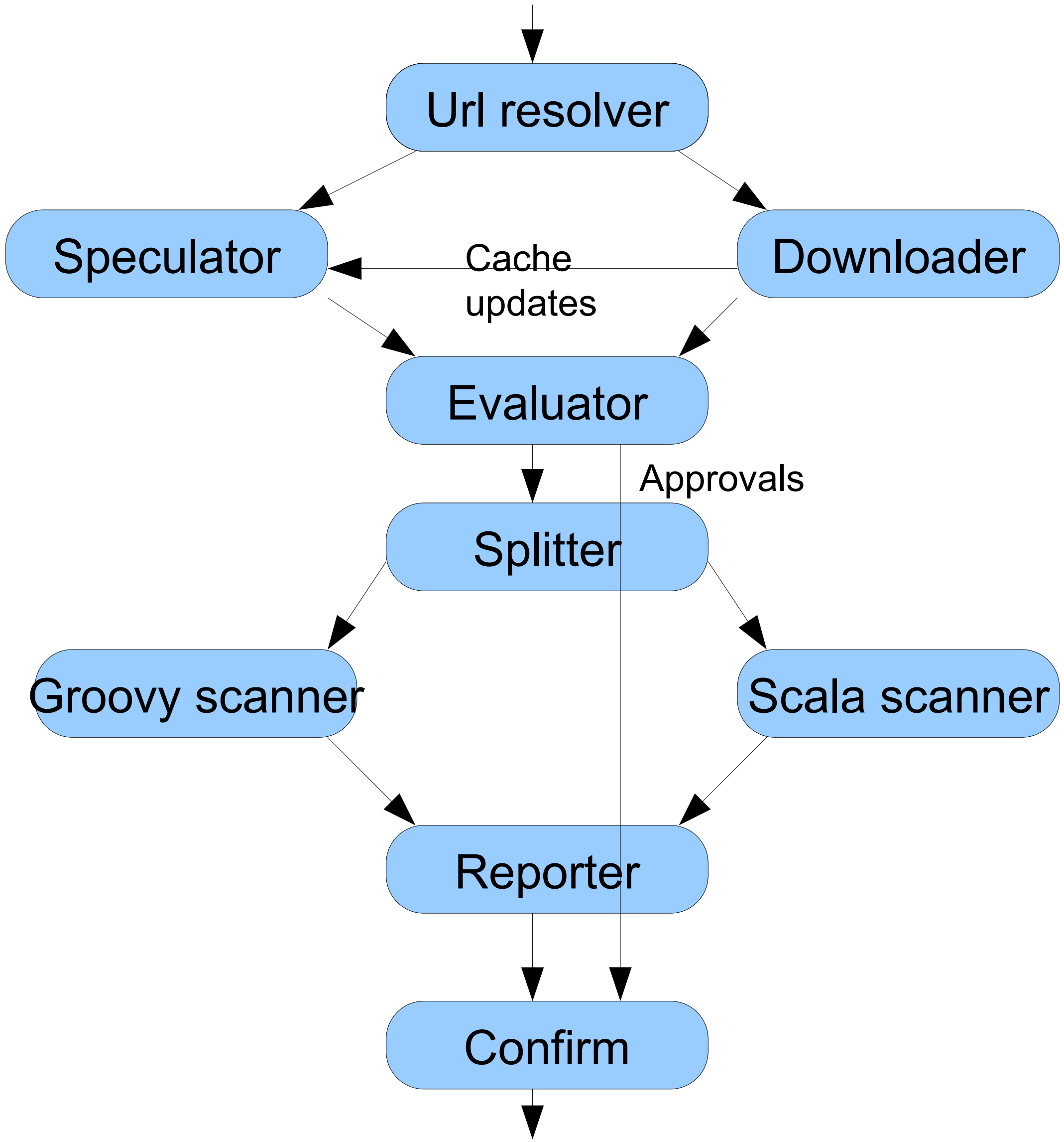
```
def toProcess = new DataflowQueue()
def validated = new DataflowQueue()

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

submissions.each {toProcess << it}
```


inProcess
process
validate
validated

Generalization

An operation can take multiple inputs and outputs

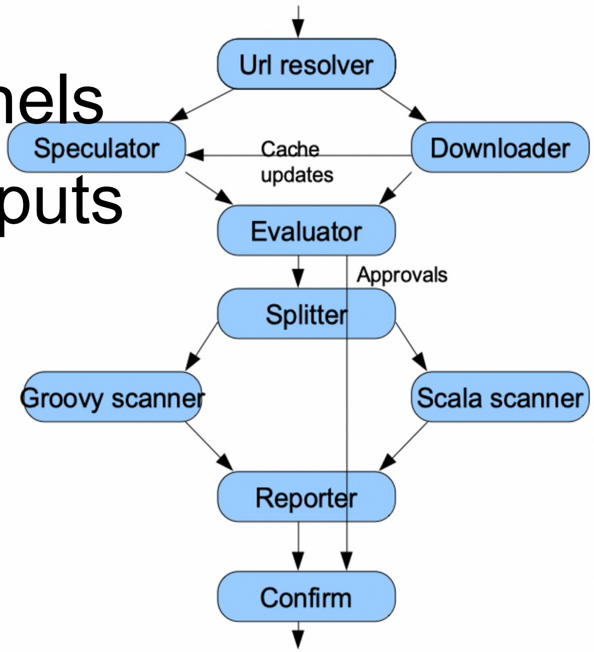
Operations adressed indirecly using channels


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

Dataflow Operators

Like functions

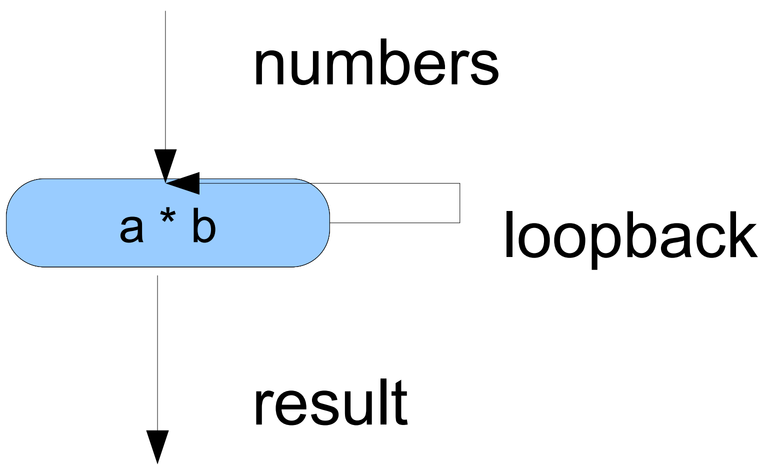
- wired together with channels
- possibly with multiple outputs
- may be recursive

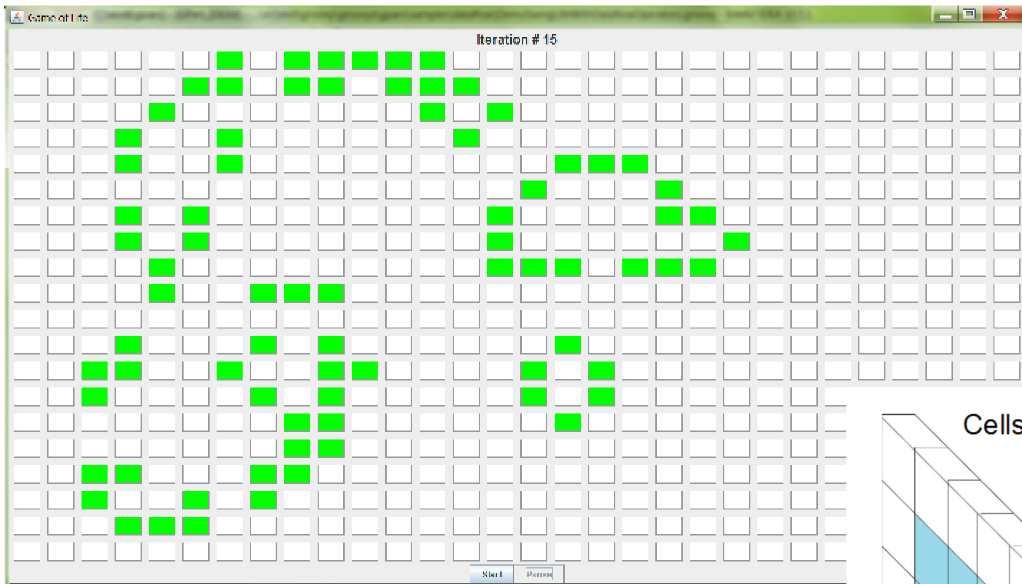


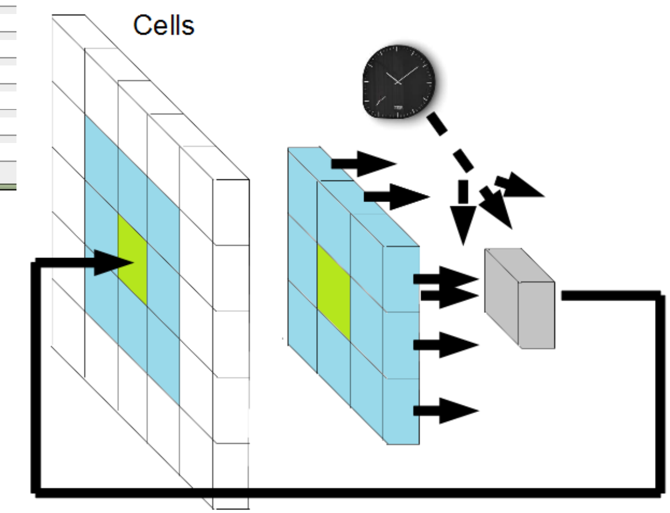
Dataflow Operators

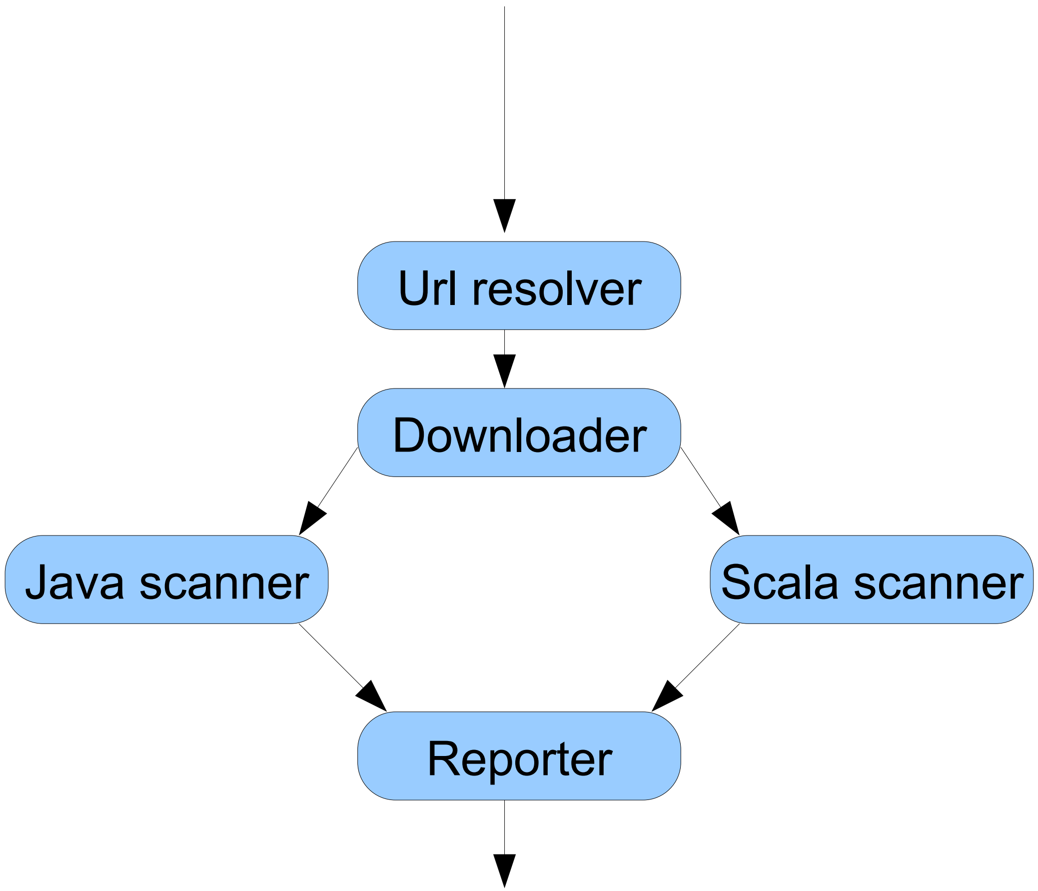
```
operator(inputs: [headers, bodies, footers],
         outputs: [articles, summaries])
  {header, body, footer ->
    def article = buildArticle(header, body, footer)
    bindOutput(0, article)
    bindOutput(1, buildSummary(article))
  }
```

Factorial




Game of Life
Iteration # 15
Start
Pause


Cells


Url resolver
Downloader
Java scanner
Scala scanner
Reporter

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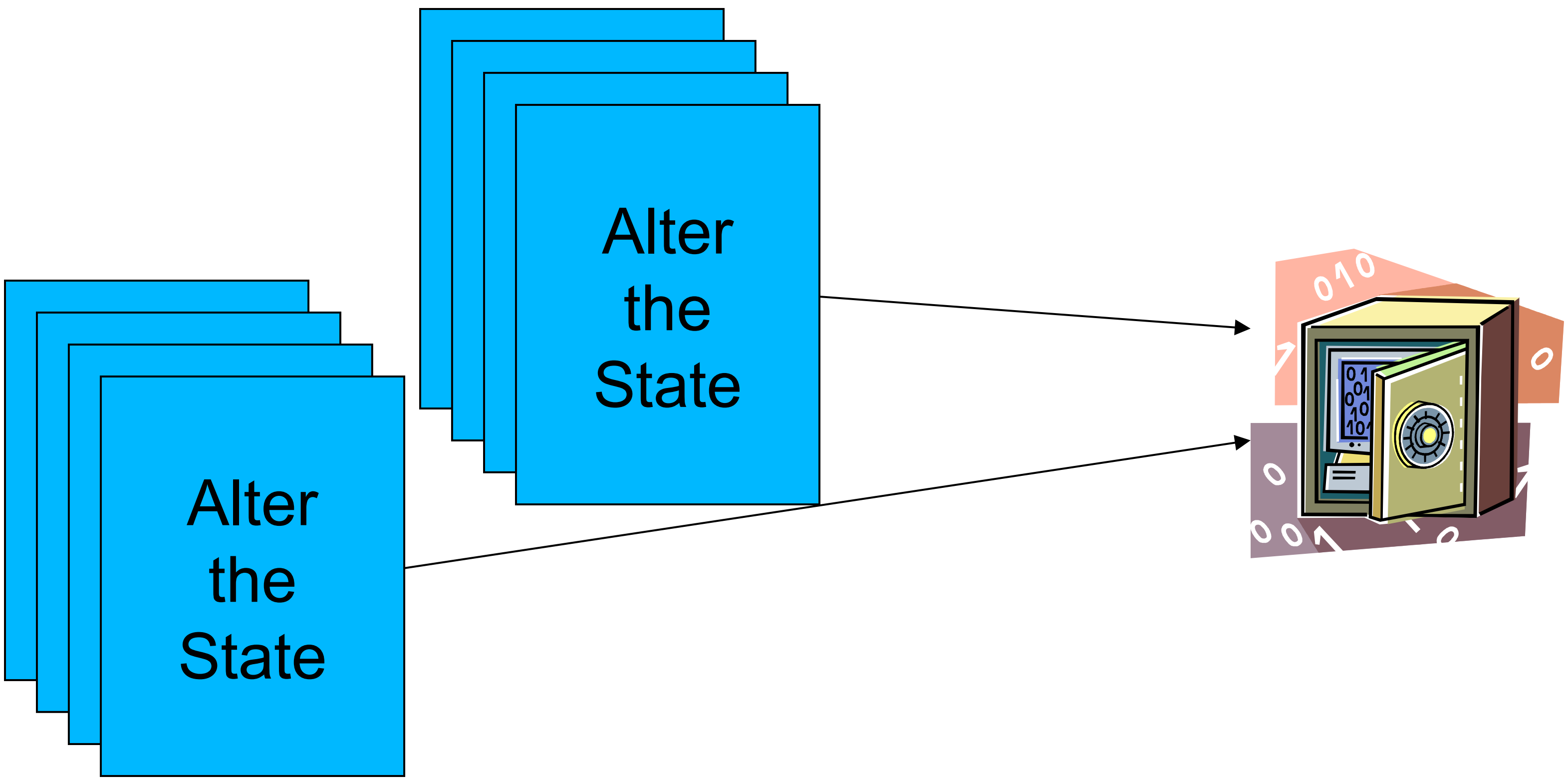
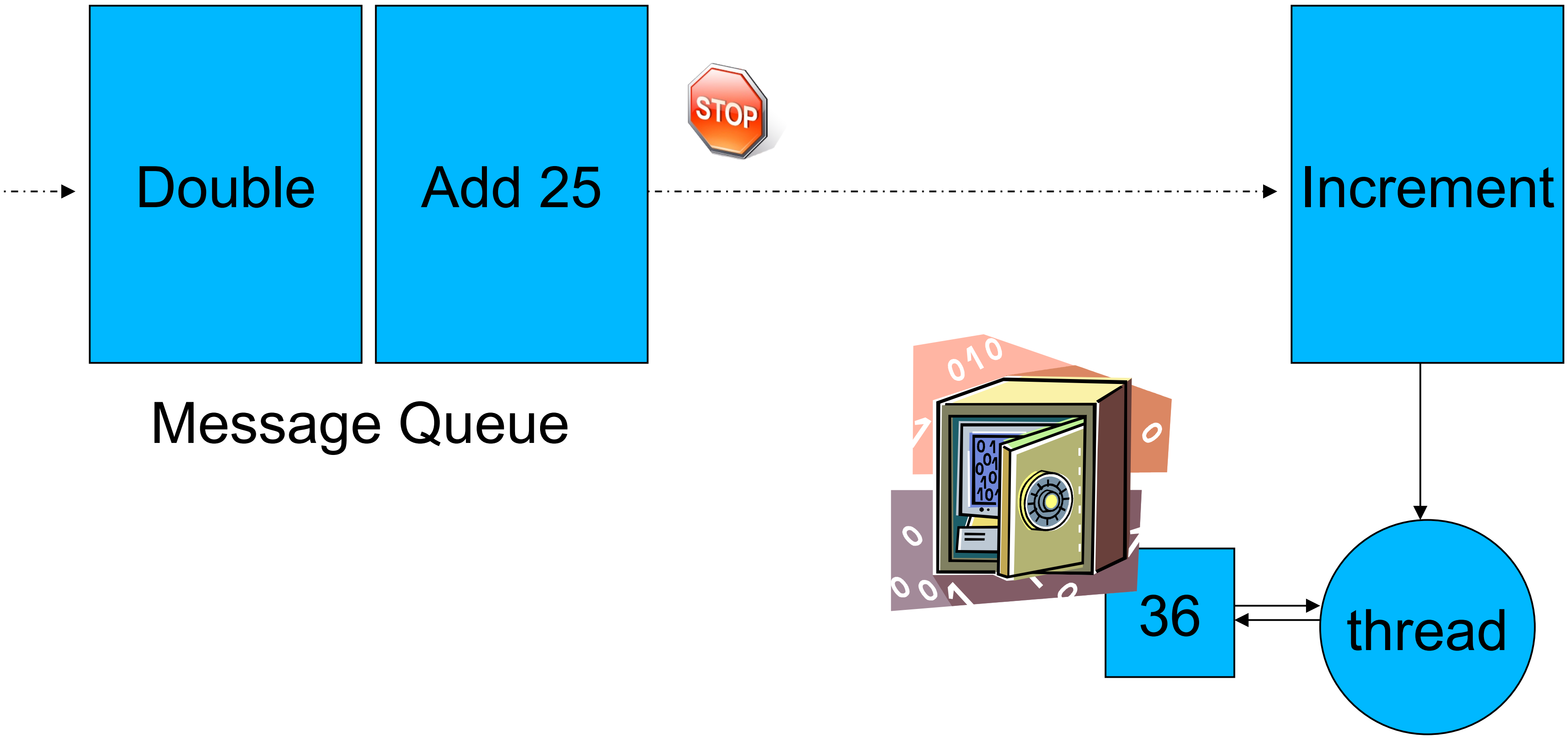
Agent

Lock Shared Mutable State in a Safe



Agent inside



Sharing through agents

```
Agent registrations = new Agent( [] )
submissions.each {form →
    task {
        if (form.process().valid) {
            registrations.send {it << form}
        }
    }
}
```

Actors

Agents send commands

Actors send data

Both use direct addressing (no channels)

Actors

Isolated state

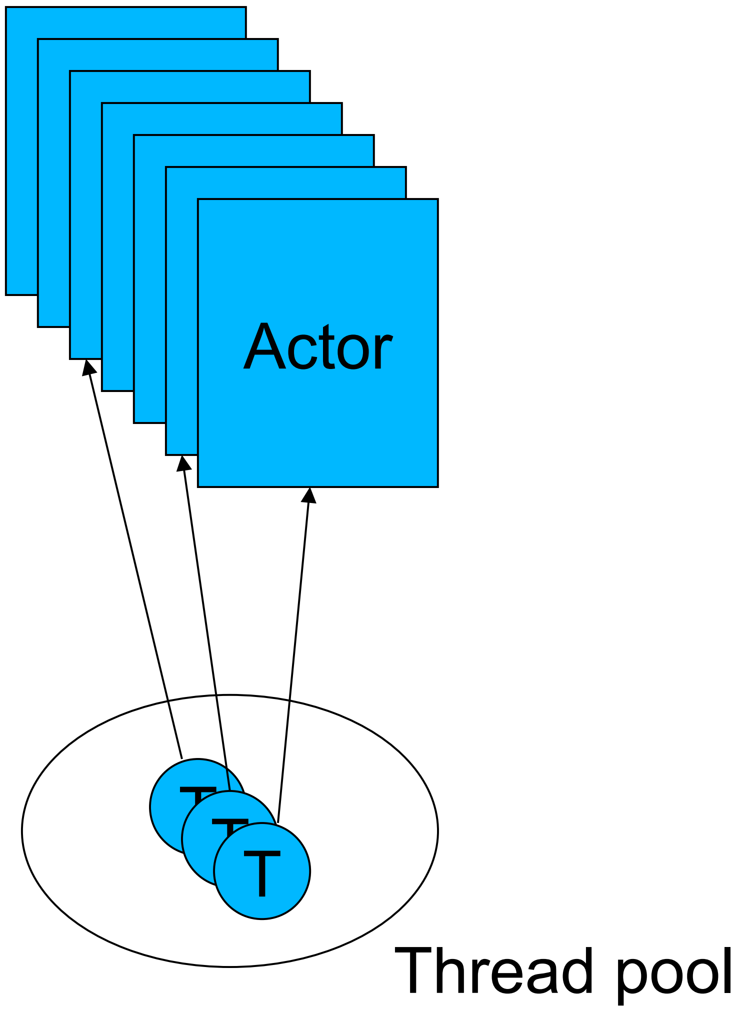
Active - shared threads

Async Communication

- Direct addressing
- Immutable messages

Activities:

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



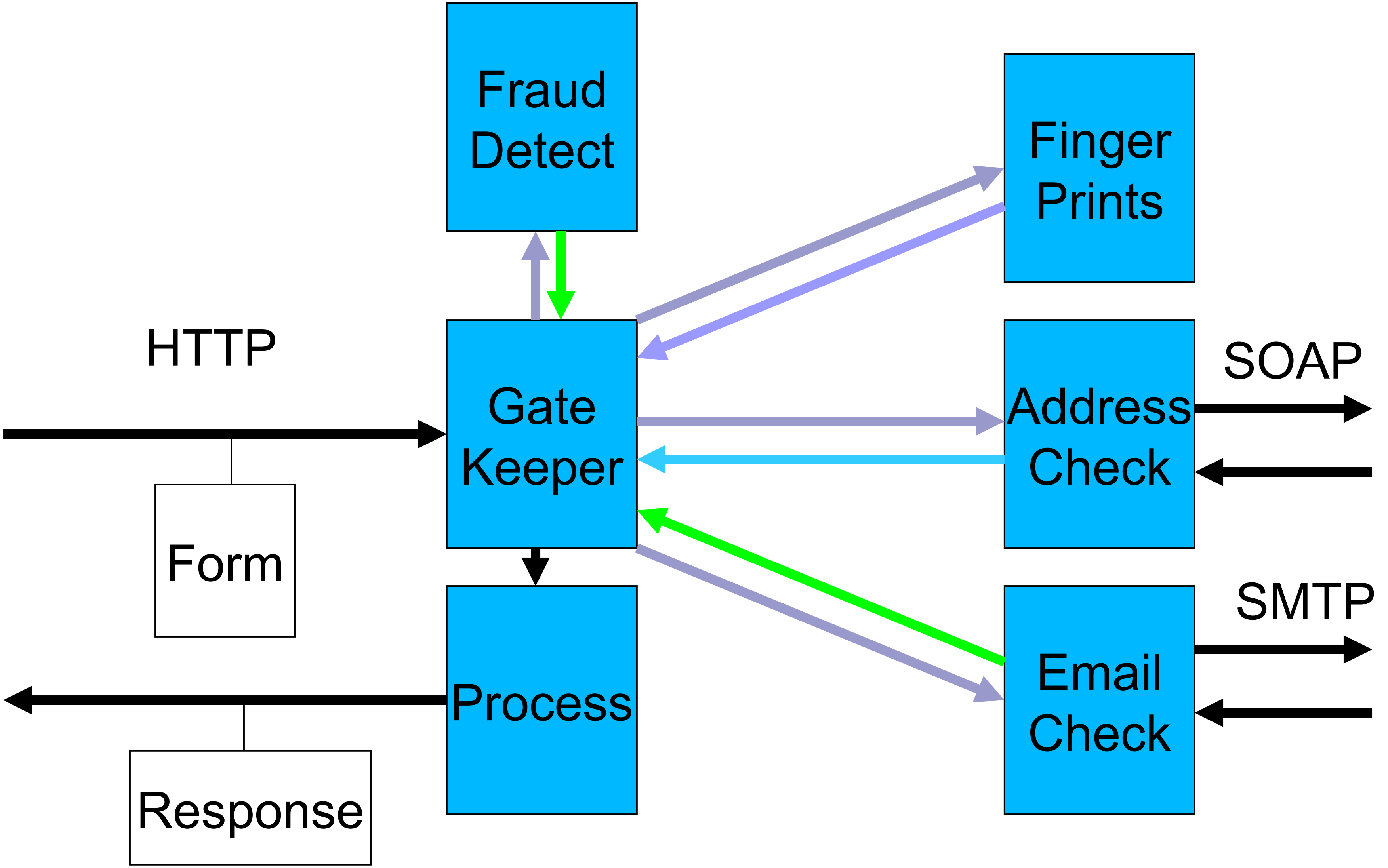
Actor definition

```
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

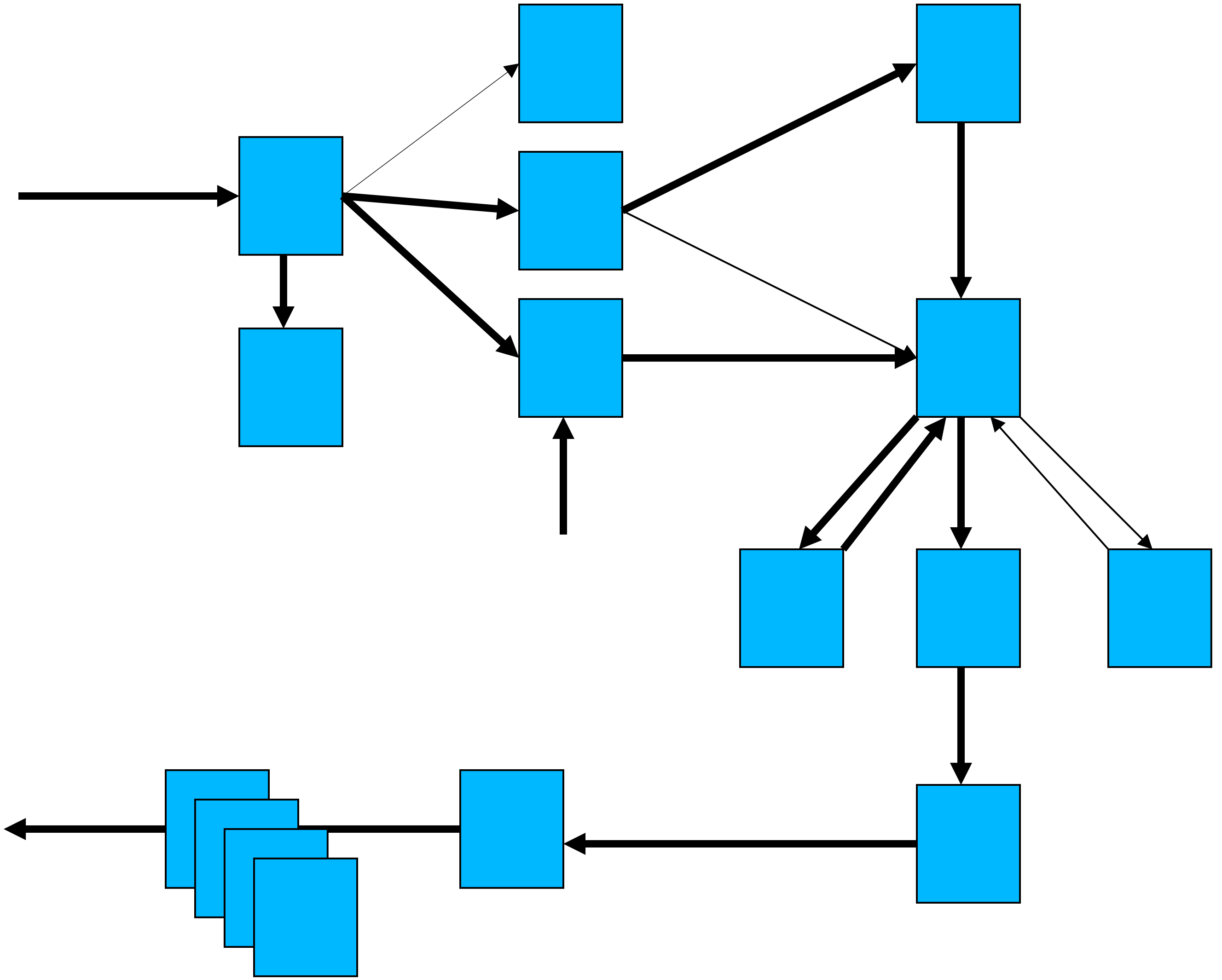
```
buddy.send 10.eur

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
Address Check
SOAP
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
    }
}
```

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CSP

Communicating Sequential Processes

Focus on composable processes more than on data

Abstractions

Tasks (aka coroutines, goroutines)

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

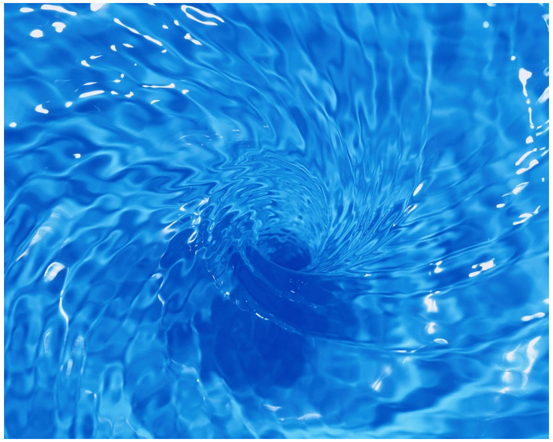
Data exchange between tasks

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

Tasks

```
requests.each {r ->
    task {
        r.handle()
        println "Done processing " + r.id
    }
}
```

Dataflow Variables

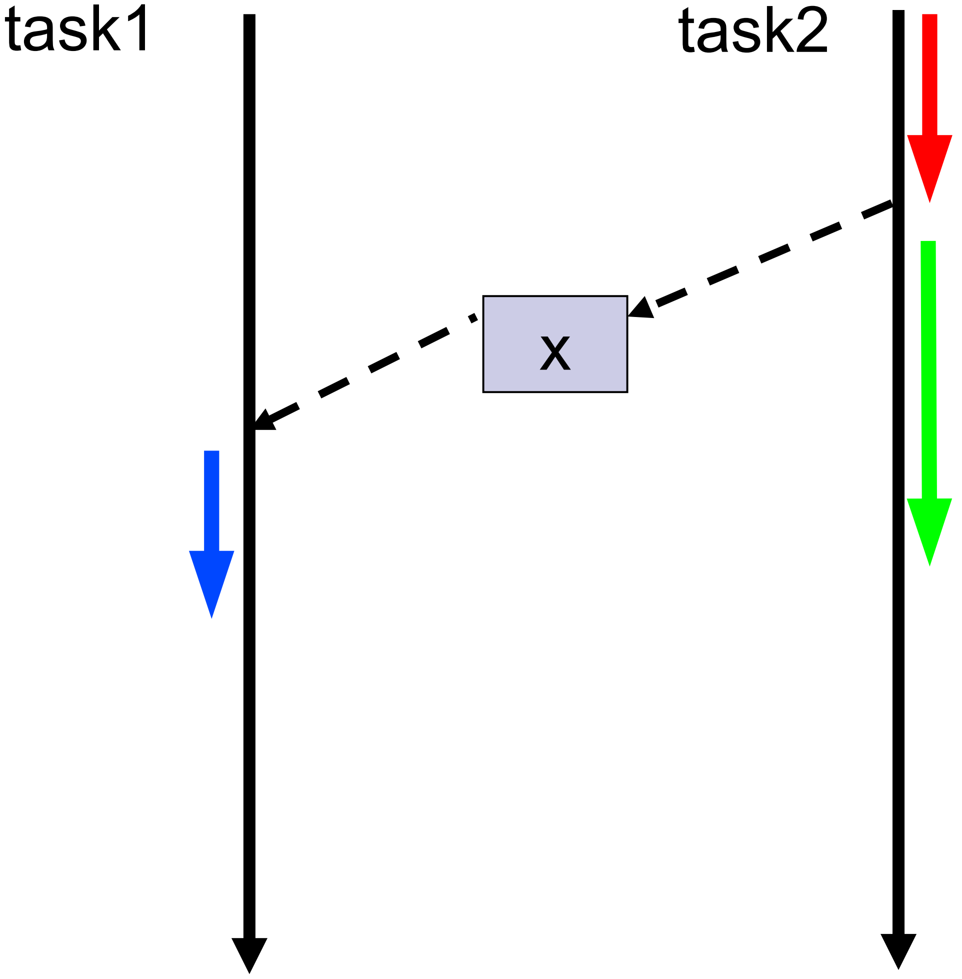


No race-conditions

No live-locks

Deterministic deadlocks

Dataflow Variables / Promises



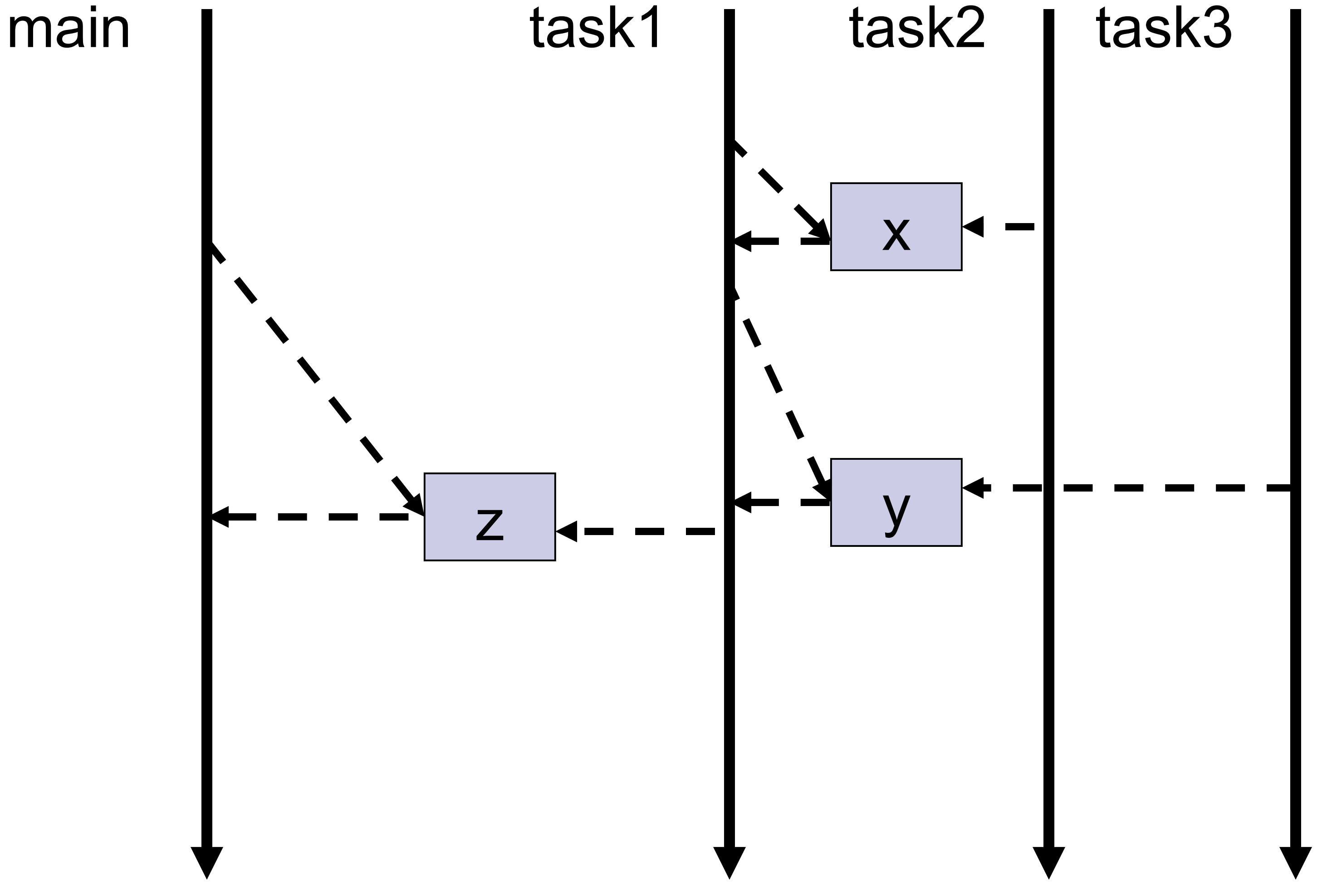
DataflowVariables/Promises

```
def x = new DataflowVariable()

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

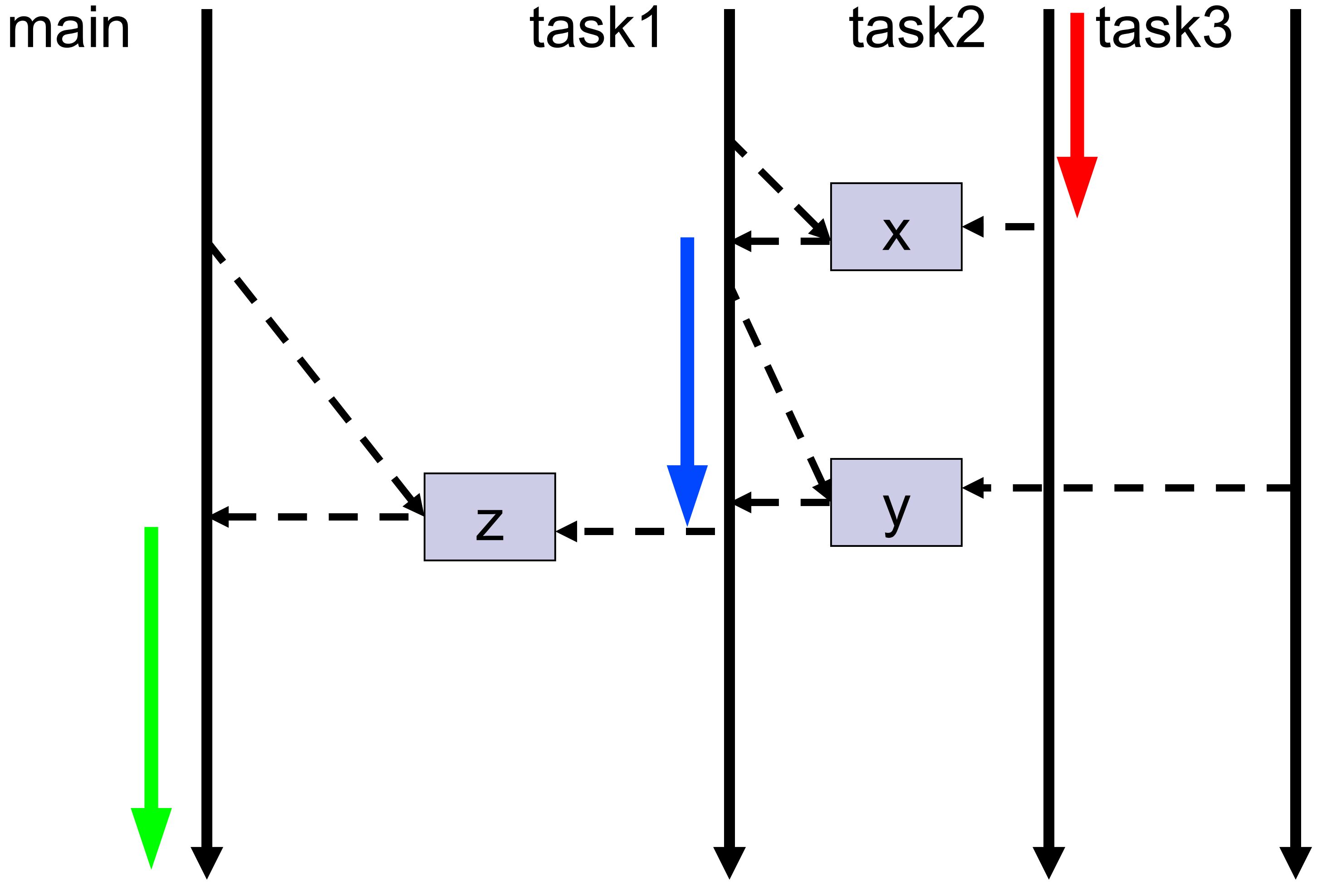
Promises to exchange data

```
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 = 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

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

Kotlin coroutines

```kotlin
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 approach

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

Reactive allows for callbacks to be registered on Promises

Callbacks

```
def 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

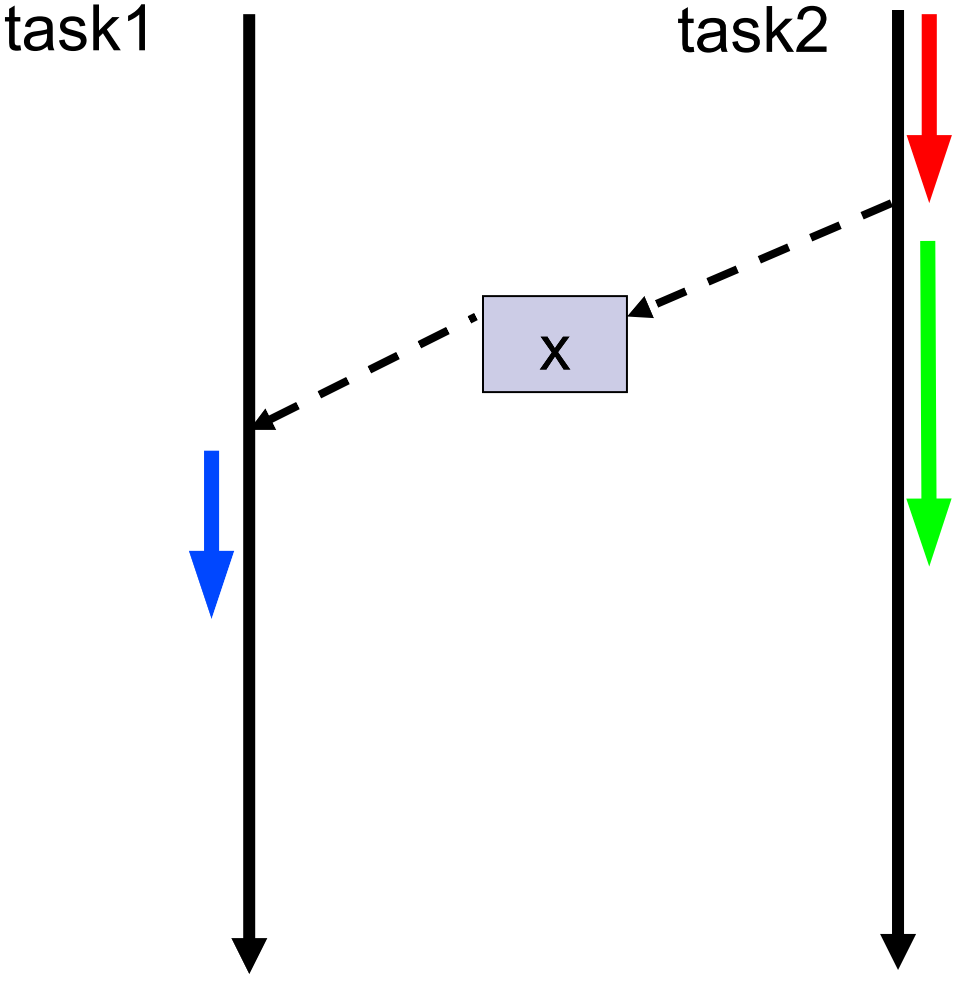
Tasks (aka coroutines, goroutines)

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

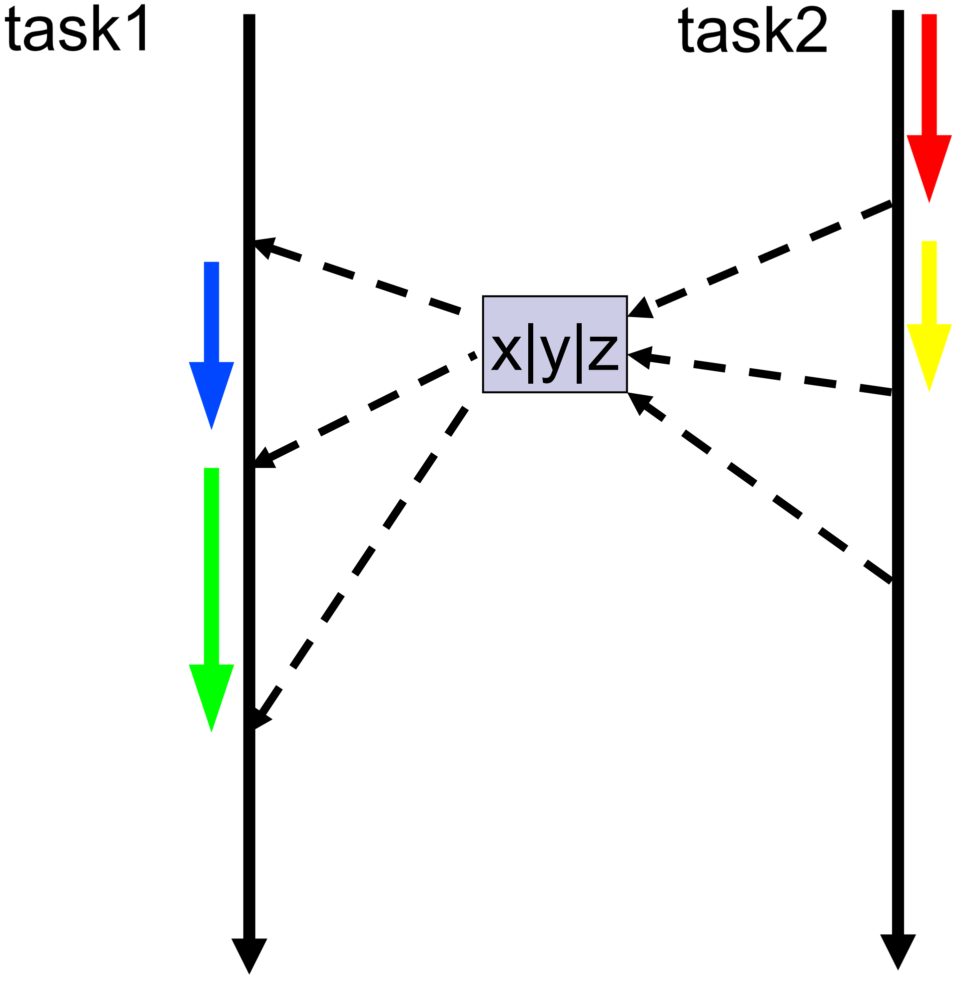
Data exchange between tasks

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

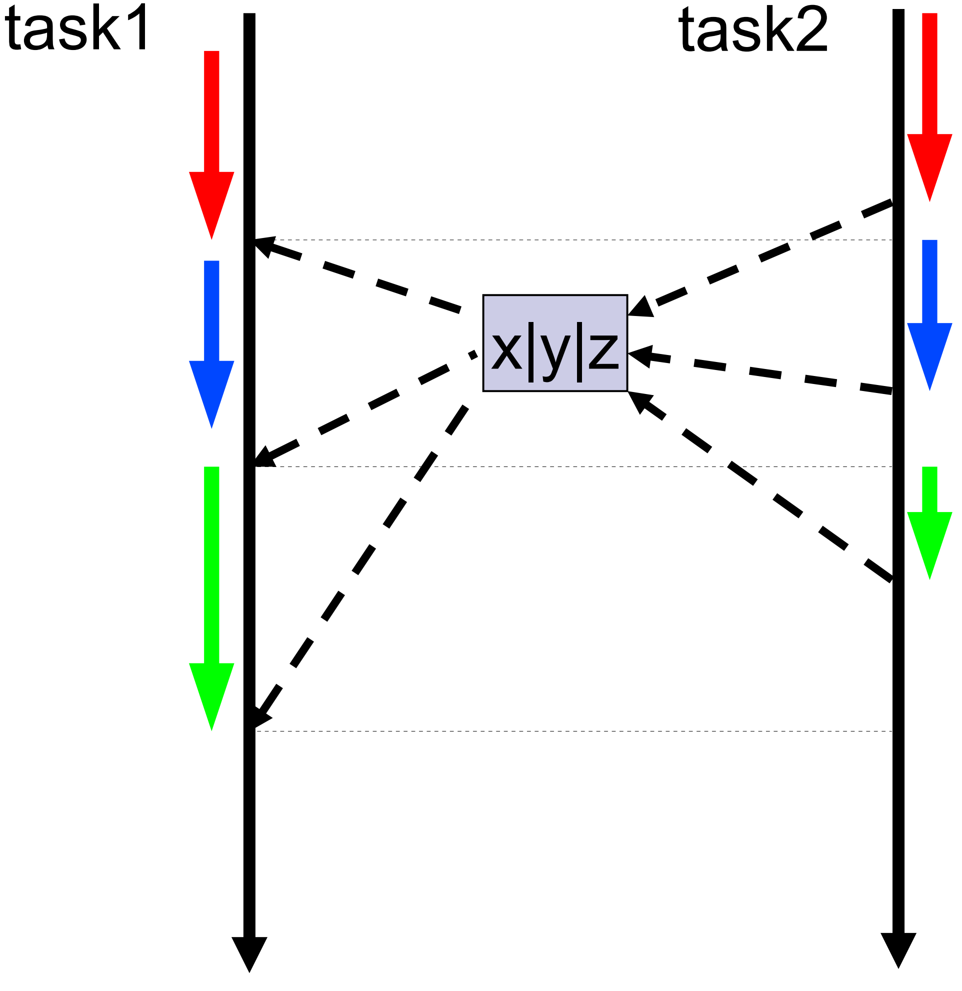
Dataflow Variables / Promises



Dataflow Channels



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: ...
}
```

High-level abstractions

- STM
- Hierarchical decomposition
- Geometrical decomposition
- Streams
- Agents, Actors, Active objects
- Communicating Sequential Processes

Summary

Parallelism is not hard, multi-threading is

Jon Kerridge, Napier University

References

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