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Loom: Virtual Threads and StructuredConcurrency and ScopedValues in the JDK 20

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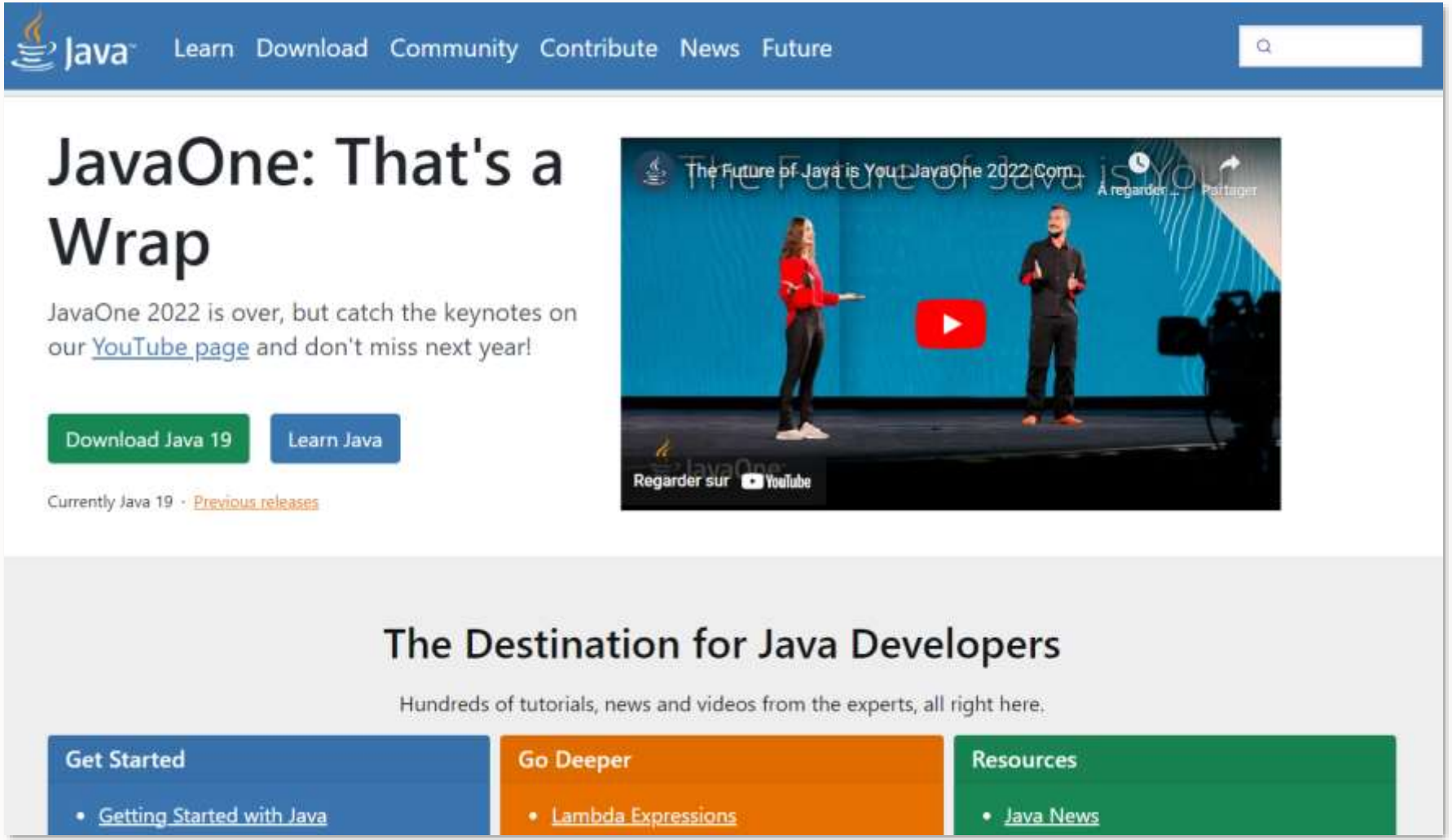

Tune in!

Inside Java Newscast

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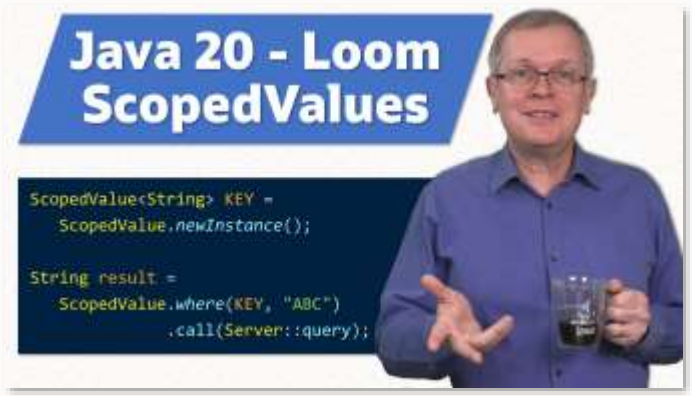

JEP Café

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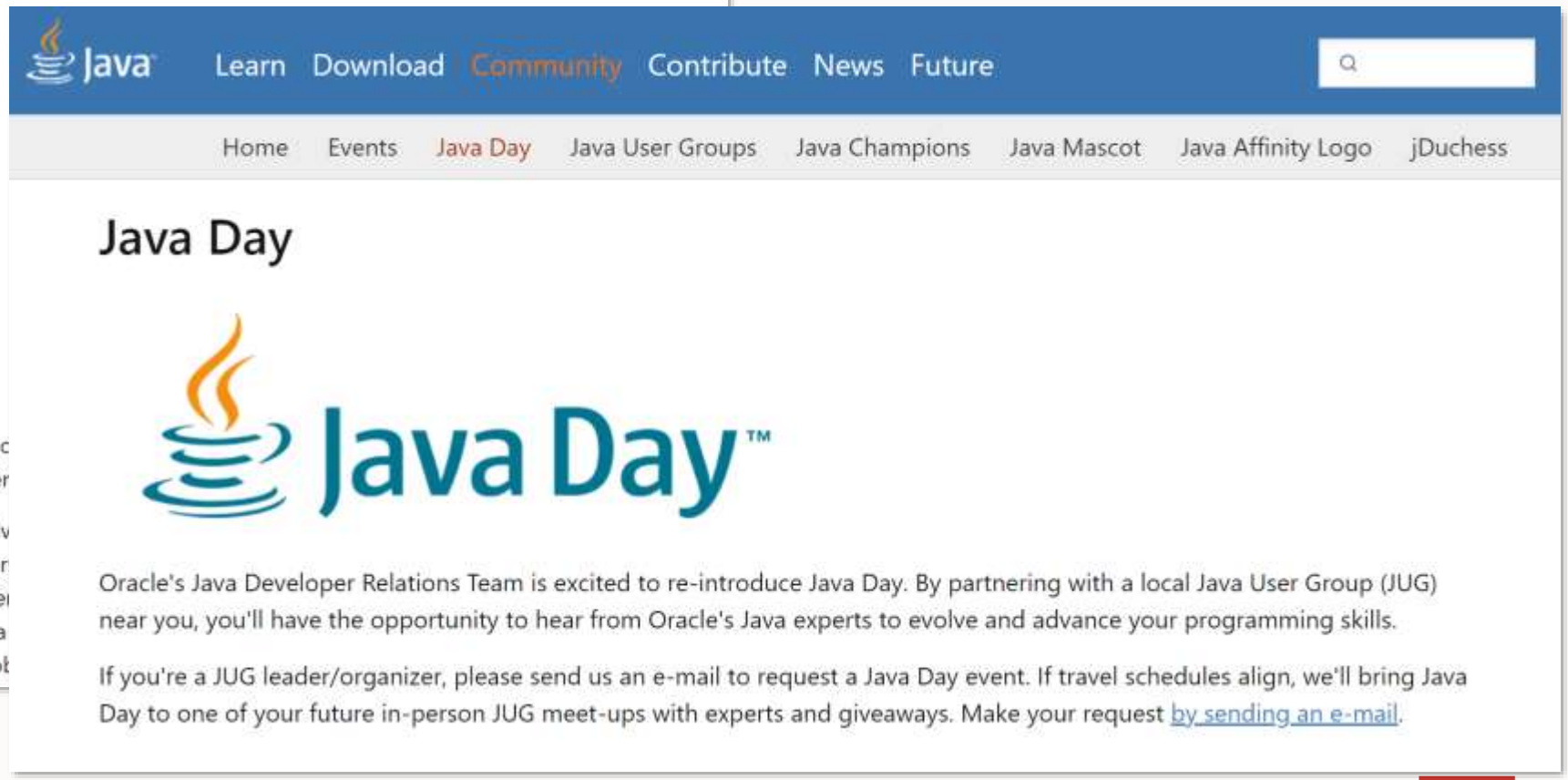

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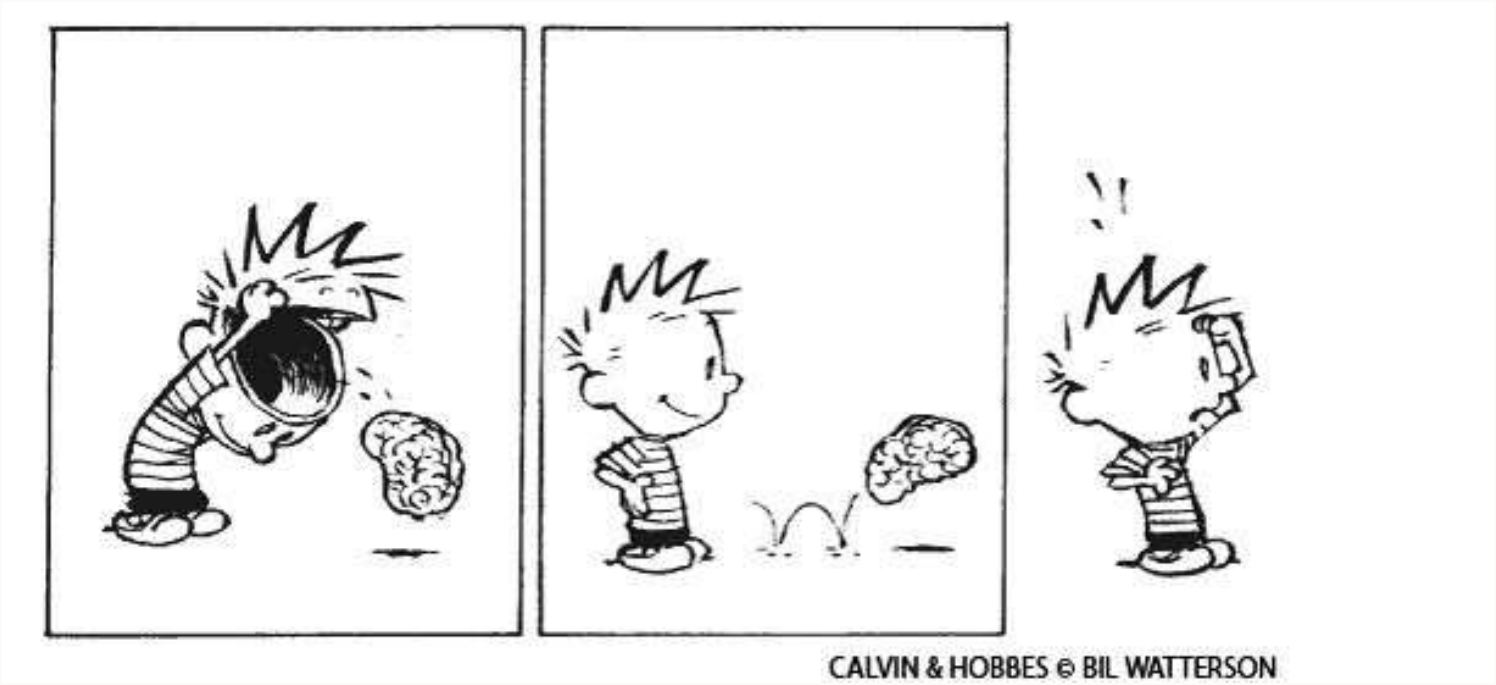
Loom is a Work in Progress

Don’t believe what we say!



Loom is a Work in Progress

Don’t believe what we sa

JEP 436: Virtual Threads (Second Preview)

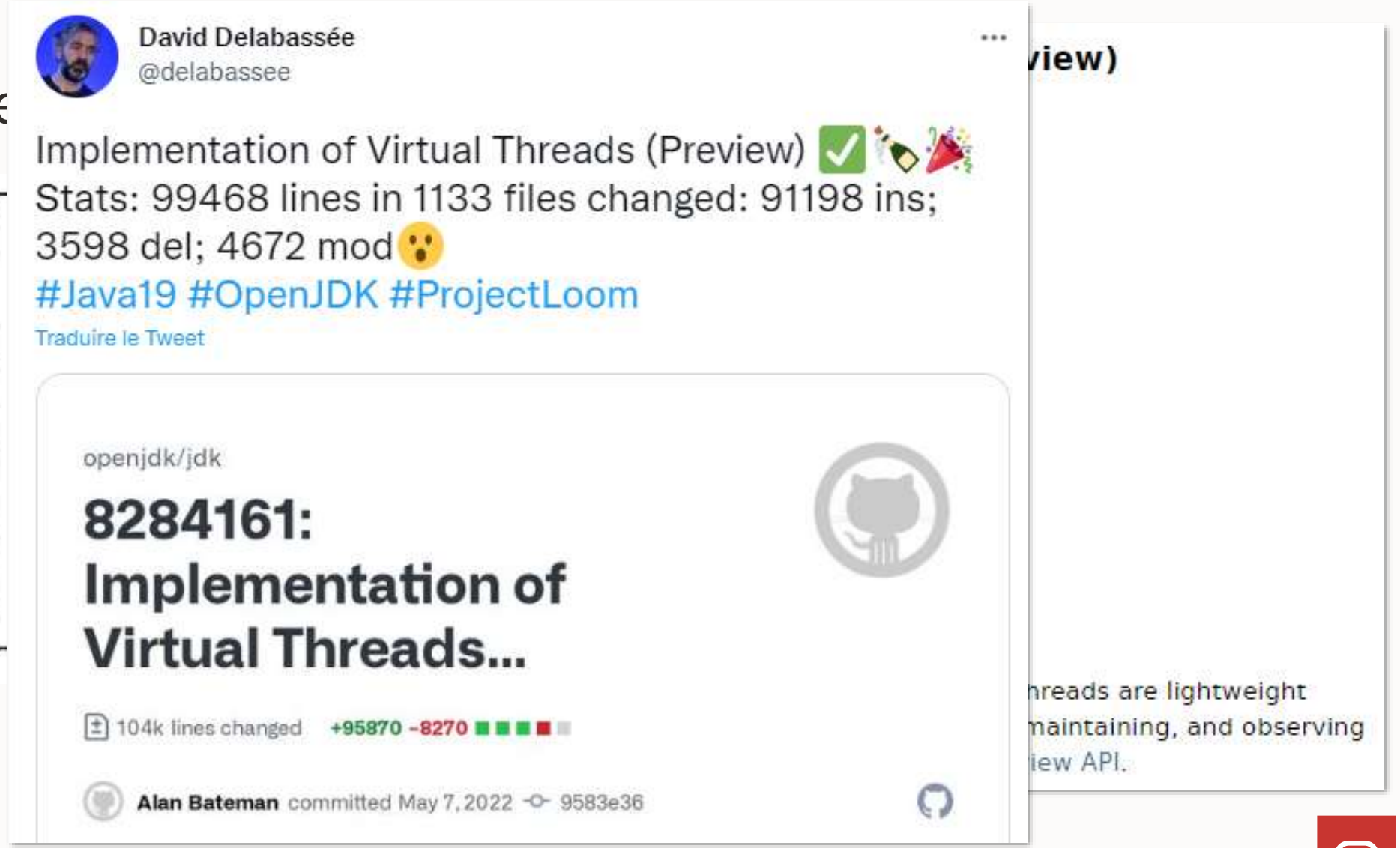
Authors	Ron Pressler, Alan Bateman
Owner	Alan Bateman
Type	Feature
Scope	SE
Status	Completed
Release	20
Component	core-libs
Discussion	loom dash dev at openjdk dot org
Relates to	JEP 425: Virtual Threads (Preview)
Reviewed by	Alex Buckley
Endorsed by	Brian Goetz
Created	2022/10/23 15:18
Updated	2023/01/18 21:51
Issue	8295817

Summary

Introduce *virtual threads* to the Java Platform. Virtual threads are lightweight threads that dramatically reduce the effort of writing, maintaining, and observing high-throughput concurrent applications. This is a preview API.

Loom is a Work in Progress

Don’t believe



Loom is a Work in Progress

Don’t believe what we say

JEP 437: Structured Concurrency (Second Incubator)

Authors	Alan Bateman, Ron Pressler
Owner	Alan Bateman
Type	Feature
Scope	JDK
Status	Completed
Release	20
Component	core-libs
Discussion	loom dash dev at openjdk dot org
Reviewed by	Alex Buckley
Endorsed by	Brian Goetz
Created	2022/10/28 12:41
Updated	2023/01/13 17:18
Issue	8296037

Summary

Simplify multithreaded programming by introducing an API for *structured concurrency*. Structured concurrency treats multiple tasks running in different threads as a single unit of work, thereby streamlining error handling and cancellation, improving reliability, and enhancing observability. This is an incubating API.

Loom is a Work in Progress

Don’t believe what we s

JEP 429: Scoped Values (Incubator)

Authors	Andrew Haley, Andrew Dinn
Owner	Andrew Haley
Type	Feature
Scope	JDK
Status	Integrated
Release	20
Component	core-libs
Discussion	loom dash dev at openjdk dot java dot net
Relates to	8286666: JEP 429: Implementation of Scoped Values (Incubator)
Reviewed by	Alan Bateman, Alex Buckley
Endorsed by	John Rose
Created	2021/03/04 11:03
Updated	2022/12/07 11:19
Issue	8263012

Summary

Introduce *scoped values*, which enable the sharing of immutable data within and across threads. They are preferred to thread-local variables, especially when using large numbers of virtual threads. This is an incubating API.

Loom is a Work in Progress

Don’t believe what we s

JEP 429: Scoped Values (Incubator)

Authors	Andrew Haley, Andrew Dinn
Owner	Andrew Haley
Type	Feature
Scope	JDK
Status	Integrated
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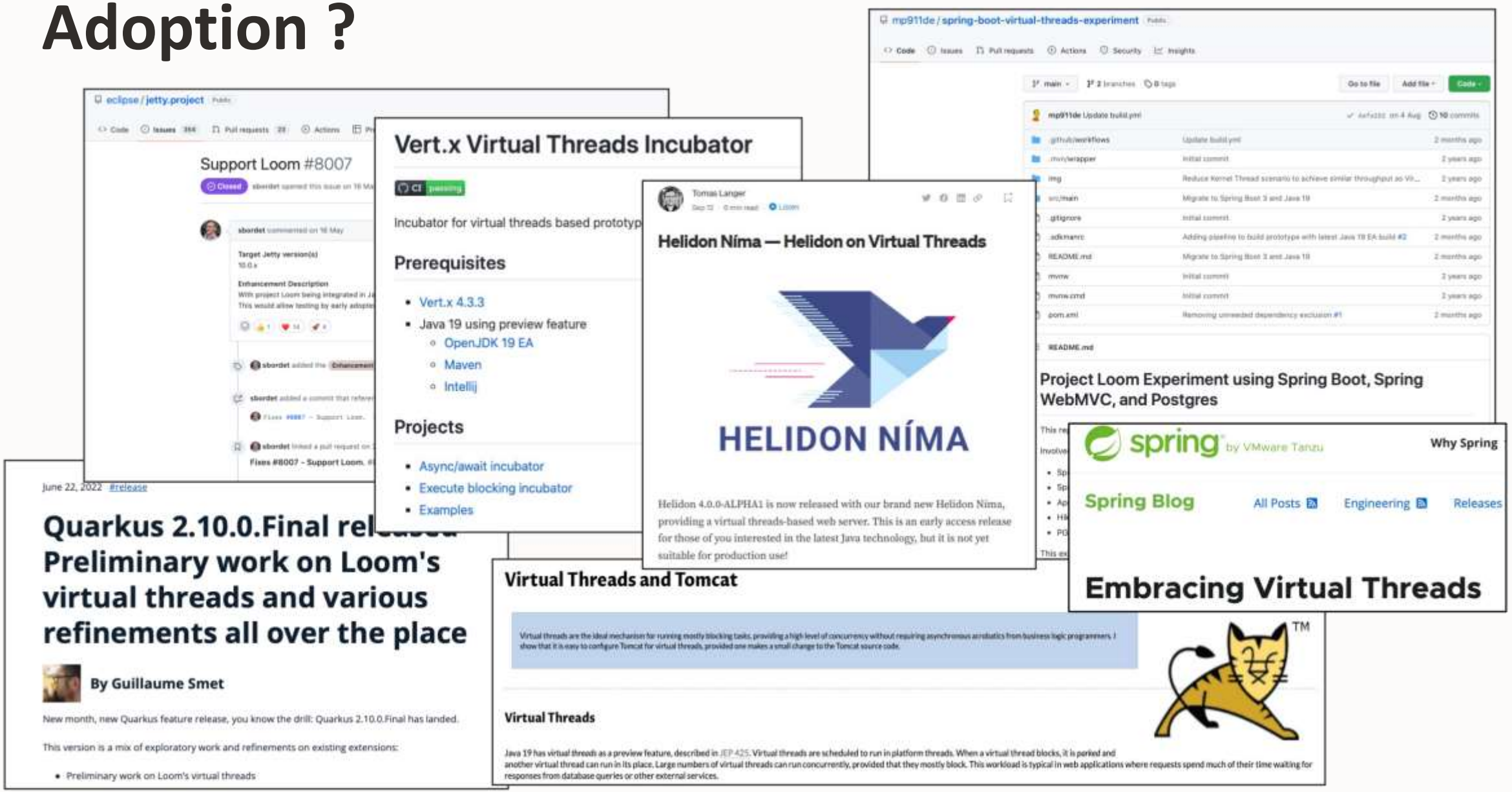
Created	2021/03/04 11:03
Updated	2022/12/07 11:19
Issue	8263012

Summary

Introduce *scoped values*, which enable the sharing of immutable data within and

http://jdk.java.net/loom/

Adoption ?

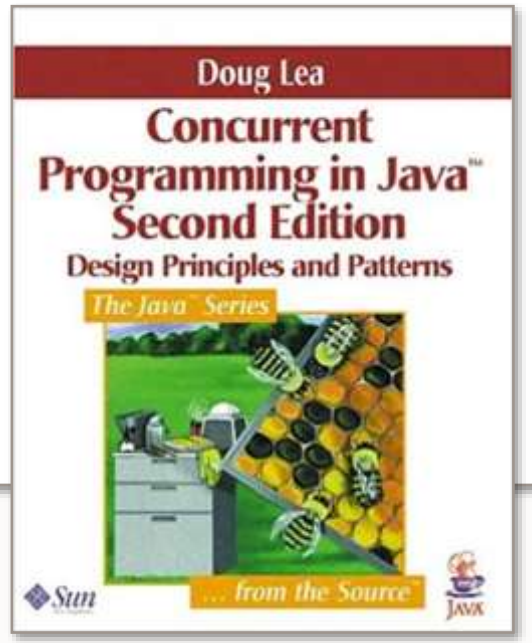


It all Started with a Runnable…

1995: Threads and Runnables

1995: Thread, Runnable

```
Runnable task = new Runnable() {
    void run() {
        System.out.println("I am running in thread " +
            Thread.currentThread().getName());
    }
};
Thread thread = new Thread(task);
thread.start();
thread.join(); // blocks
```



1995: Threads and Runnables

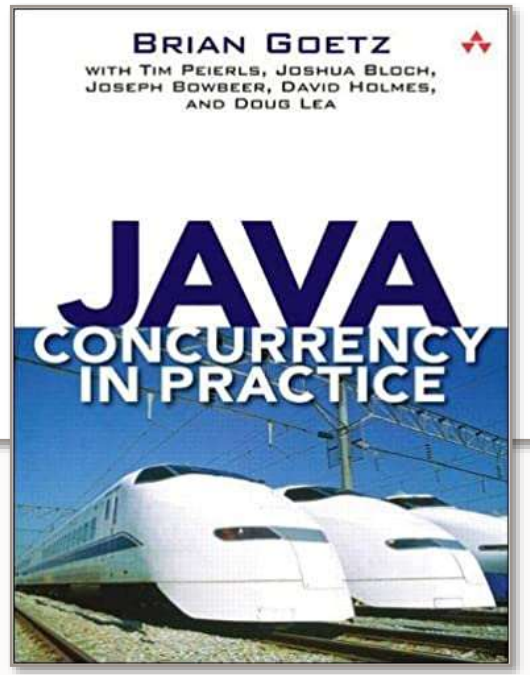
1995: Thread, Runnable

```
Object key = new Object();

synchronized(key) {
    System.out.println("Only one thread can execute me!");
}
```


2004: Java Util Concurrent

2004: Java 5, `java.util.concurrent`

```
Callable<String> task = new Callable<String>() {

    @Override
    public String call() throws Exception {
        return "I am running in thread " +
            Thread.currentThread().getName();
    }
};
```



2004: Java Util Concurrent

2004: Java 5, `java.util.concurrent`

```
ExecutorService service =
    Executors.newFixedThreadPool(4);

Future<String> future = service.submit(task);
```

Wait lists inside!

2004: Java Util Concurrent

2004: Java 5, `java.util.concurrent`

```
String result = future.get(); // blocks

String result = future.get(10, TimeUnit.MICROSECONDS);

boolean cancelled = future.cancel(true);
```


2004: Java Util Concurrent

2004: Java 5, `java.util.concurrent`

```
Lock lock = new ReentrantLock();
lock.lock();
try {

   System.out.println("Only one thread can execute me!");

} finally {
   lock.unlock();
}
```


2004: Java Util Concurrent

2004: Java 5, `java.util.concurrent`

Plus many more concurrent classes:

- Lock, Semaphore, Barrier, CountDownLatch
- BlockingQueue, ConcurrentMap
- CopyOnWriteArrayList

2011: Fork / Join

2011 – 2014 (Java 7, Java 8):

- Fork / Join, parallel Stream

Allows to compute elements in parallel

Two phases:

- fork = splits a task in two sub-tasks
- join = merge the result of two sub-tasks

Uses work stealing to spread the tasks among threads

2014: CompletionStage

2011 – 2014 (Java 7, Java 8):

- `CompletionStage`, `CompletableFuture`

Subtype of Future

Asynchronous programming model

Allows to trigger tasks on the outcome of other tasks

User can control which thread executes what task

Exceptions handling

One thing stays the same

Once a thread begins to process a task it cannot release it

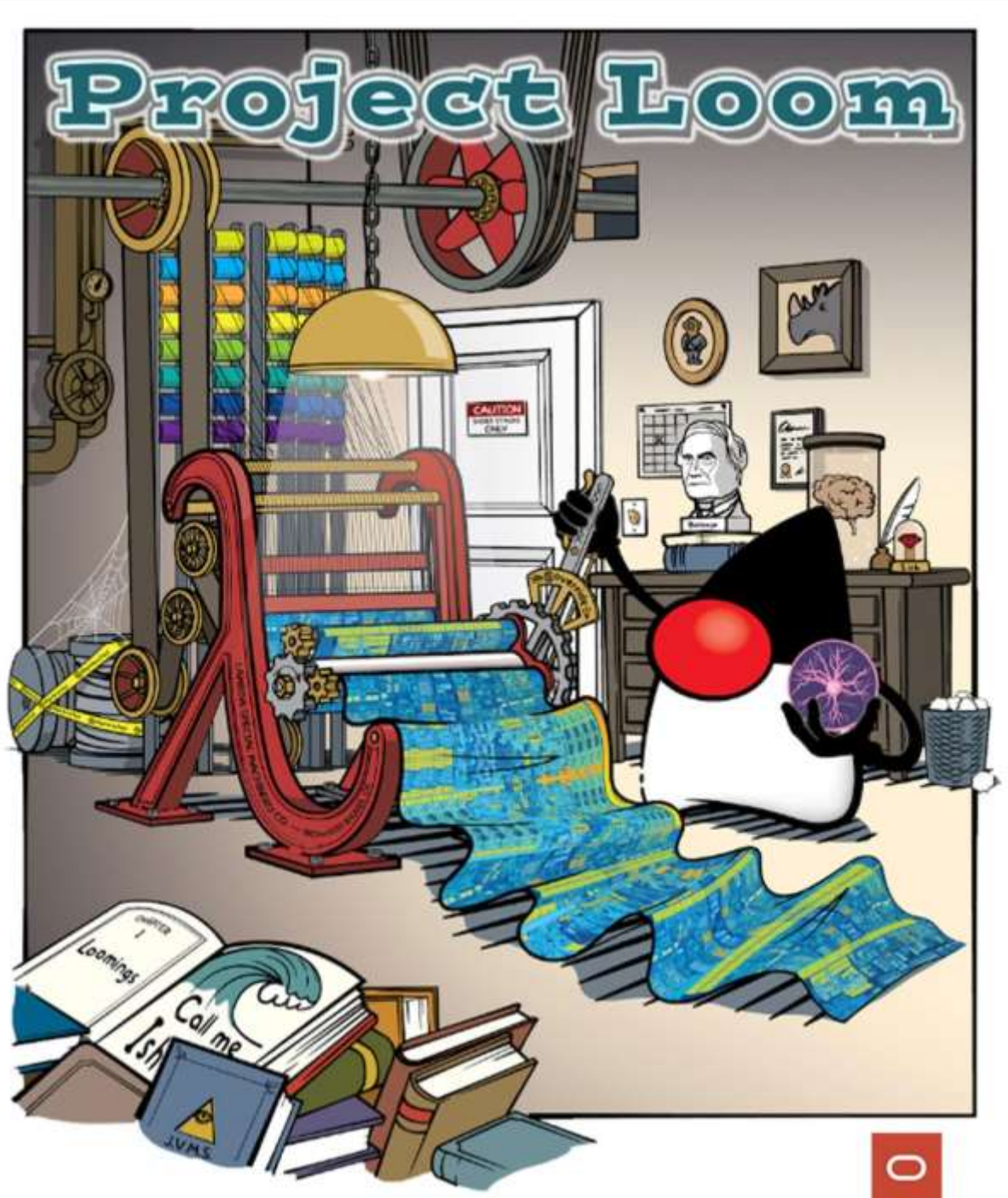
Either the task completes with a result

Or is completes with an exception

It may be an `InterruptedException`

2023?: Loom!

2022+ (prev. in Java 19)



Why Do We Need Concurrency?

Concurrency: Computations vs. I/O

Concurrency may be used in two different contexts:

1) Processing in-memory data in parallel, using all the CPU cores
   - Each thread uses 100% of your CPU cores
   - Threads are mostly not blocking

Concurrency: Computations vs. I/O

Concurrency may be used in two different contexts:

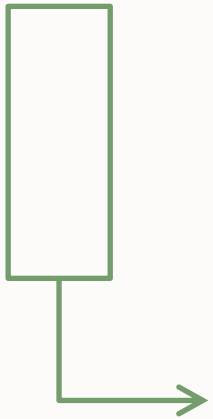
2) Handling numerous blocking requests / responses

HTTP Server → 1 request <=|=> 1 thread
DB Server → 1 transaction <=|=> 1 thread

Concurrency for I/O

Processing I/O data:

- Each task waits for the data it needs to process

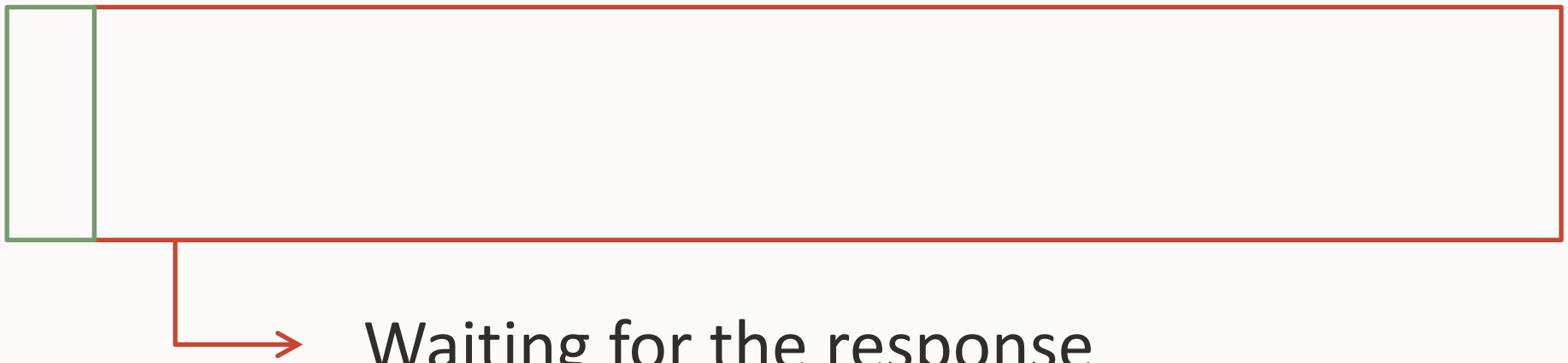


Preparing the request
Time scale: 10ns

Concurrency for I/O

Processing I/O data:

- Each task waits for the data it needs to process



Concurrency for I/O

Processing I/O data:

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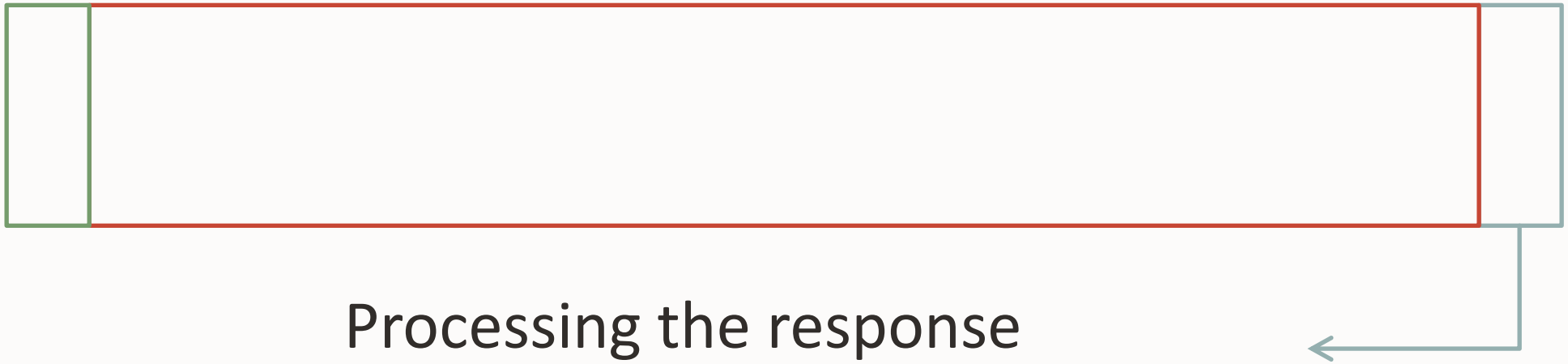
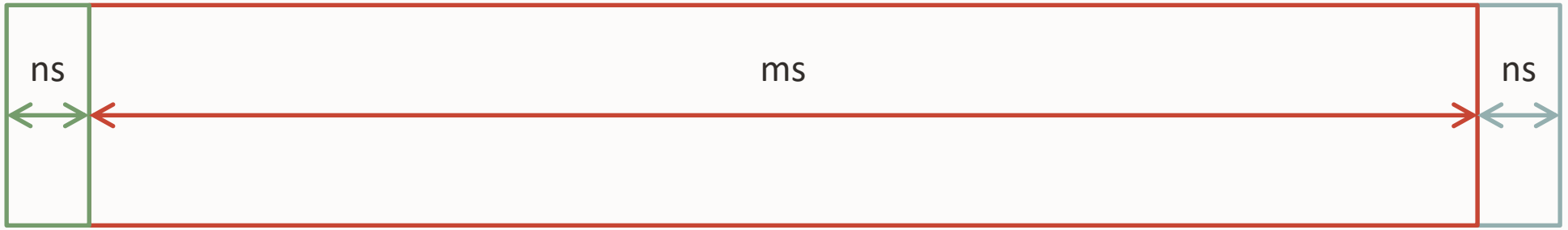


Concurrency for I/O

Processing I/O data:

A Thread is idle 99.9999% of the time!



How many threads do you need to keep your CPU busy?

Concurrency for I/O

A thread is not cheap!

- Thread startup time: ~1ms
- Thread memory consumption: 2MB of stack
- Context switching: ~100µs (depends on the OS)

Having 1 million platform threads is not possible!

Solutions?

CompletionState / CompletableFuture

Asynchronous / Reactive programming

Async / Await (C# or Kotlin)

Mono / Multi (Spring)

Uni / Multi (Quarkus)

Solutions?

Breaking down a request handling into small stages

Then compose them into a pipeline

The code becomes:

- hard to read and write (callback hell)
- hard to debug (call stack?)
- hard to test
- hard to profile

Loom to the Rescue

Virtual Thread!

```
// platform threads
var pthread = new Thread(() -> {
  System.out.println("platform " + Thread.currentThread());
});
pthread.start();
pthread.join();
```


Virtual Thread!

```
// virtual threads
var vthread = Thread.startVirtualThread(() -> {
  System.out.println("virtual " + Thread.currentThread());
});
vthread.join();
```

```
// platform threads
var pthread = Thread.ofPlatform(() -> {
  System.out.println("platform " + Thread.currentThread());
});
pthread.join();
```


Virtual Thread!

```
// platform threads
platform Thread[#14,Thread-0,5,main]

// virtual threads
virtual VirtualThread[#15]/runnable@ForkJoinPool-1-worker-1
```

A virtual thread runs on a carrier thread from a Fork-Join pool (not the common fork join pool)

This pool implements a FIFO queue (instead of a LIFO one)

Thread Polymorphic Builder

```
// platform threads
var pthread = Thread.ofPlatform()
      .name("platform-", 0)
      .start(() -> {
          System.out.println("platform " + Thread.currentThread());
      });
pthread.join();

// virtual threads
var vthread = Thread.ofVirtual()
      .name("virtual-", 0)
      .start(() -> {
          System.out.println("virtual " + Thread.currentThread());
      });
vthread.join();
```


How many **virtual** threads can I run?

Running a Thread

Platform/OS thread (starts in ms)

- Creates a 2MB stack upfront
- System call to ask the OS to schedule the thread

Virtual thread (starts in µs)

- Grow and shrink the stack dynamically
- Use a specific fork-join pool of platform threads (carrier threads)
- One platform thread per core

How does it work under the hood?

Continuation

Where Does the Magic Come From?

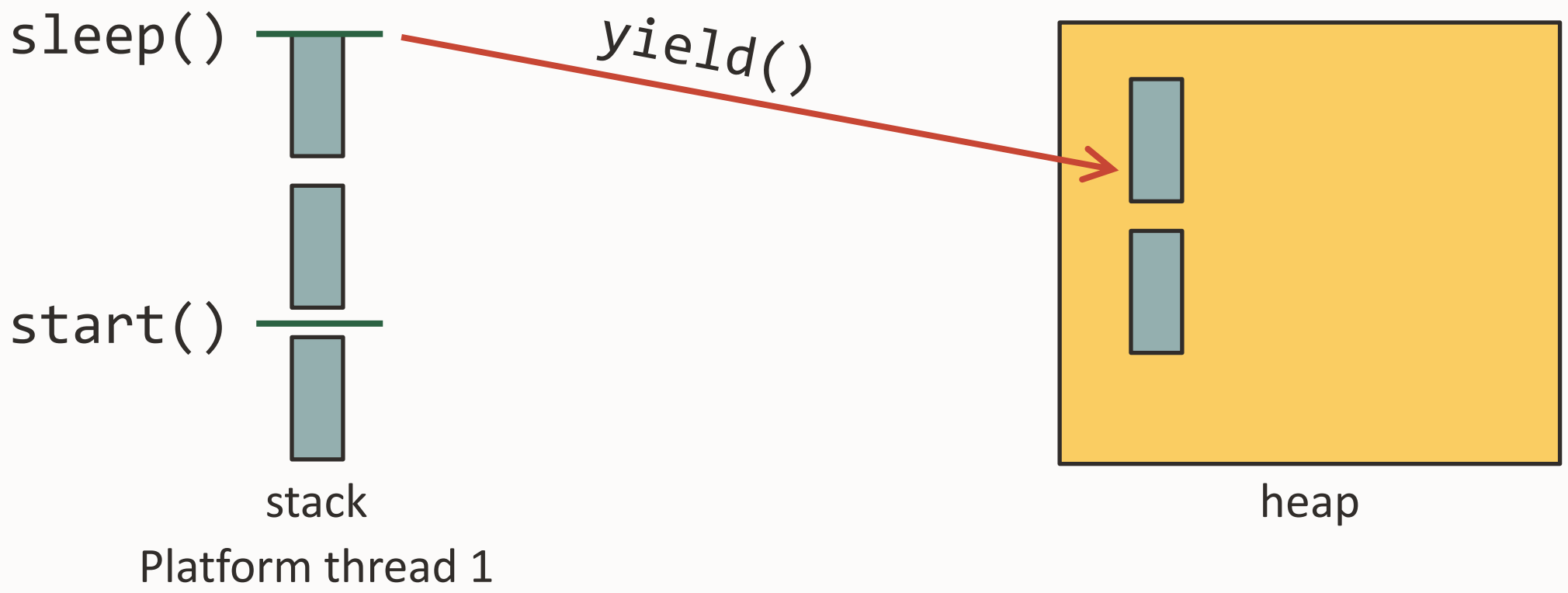
Internal API

```
@ChangesCurrentThread
private boolean yieldContinuation() {
    boolean notifyJvmti = notifyJvmtiEvents;
    // unmount
    if (notifyJvmti) notifyJvmtiUnmountBegin(false);
    unmount();
    try {
        return Continuation.yield(VTHREAD_SCOPE);
    } finally {
        // re-mount
        mount();
        if (notifyJvmti) notifyJvmtiMountEnd(false);
    }
}
```

Continuation.yield()

Internal API

`yield()` copies the stack to the heap



Continuation.yield()

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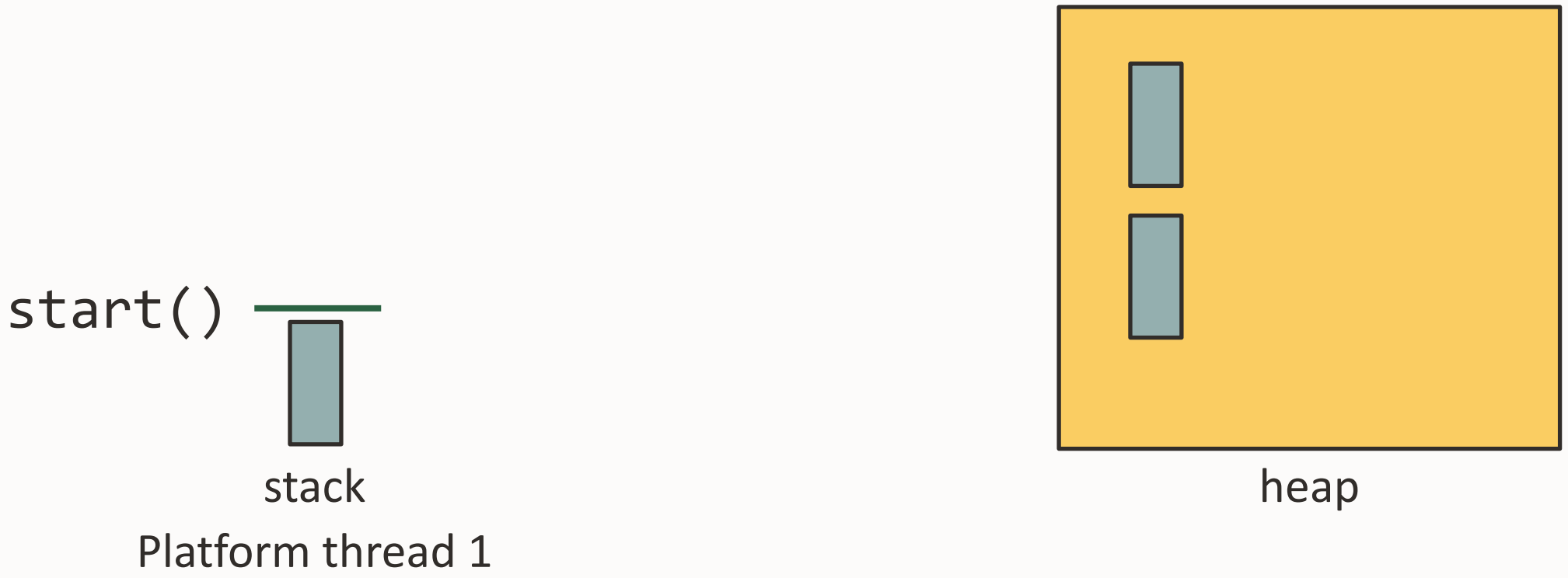
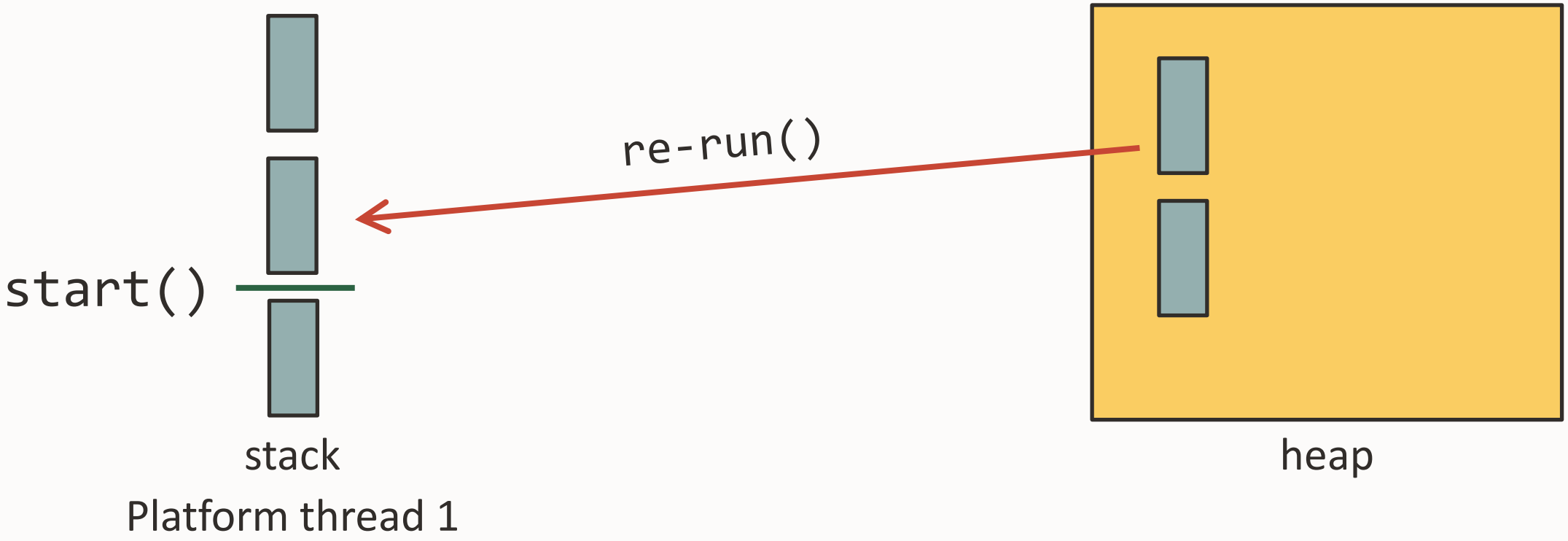


Continuation.run()

Internal API

`run()` copies from the heap to another stack

(optimization: only copies the topmost stack frames)



Continuation.run()

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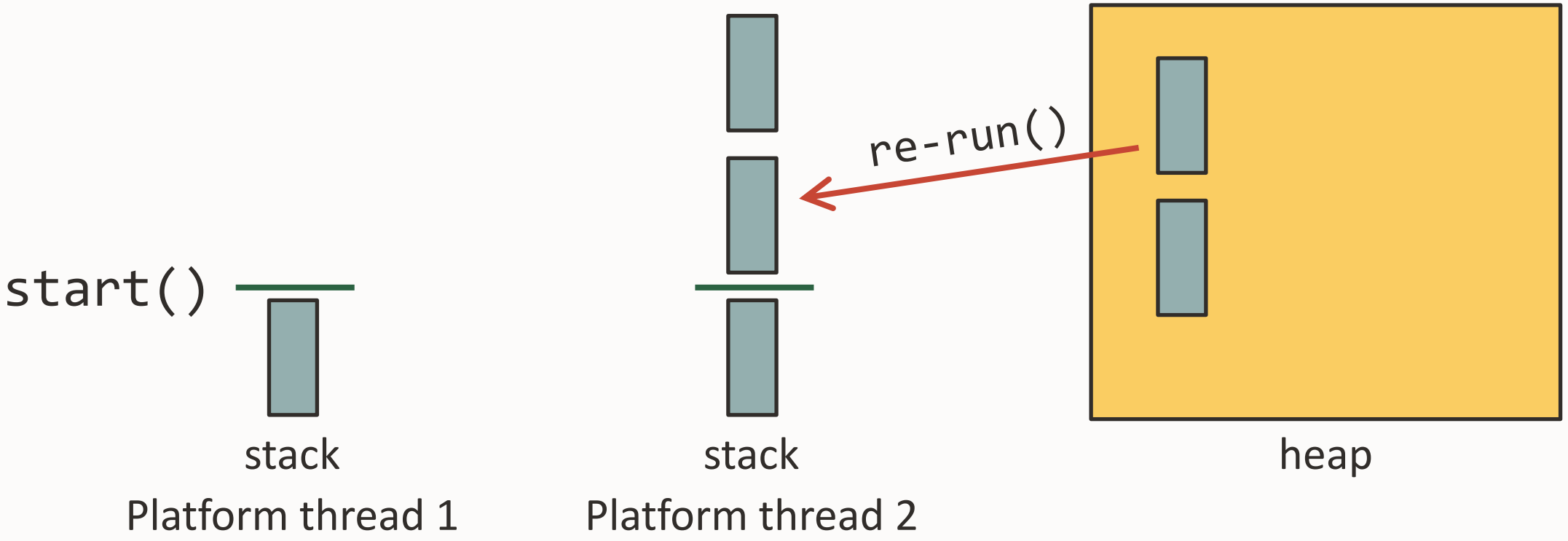


jdk.internal.vm.Continuation

Internal API

```
var scope = new ContinuationScope("hello");
var continuation = new Continuation(scope, () -> {
  System.out.println("C1");
  Continuation.yield(scope);
  System.out.println("C2");
  Continuation.yield(scope);
  System.out.println("C3");
});
System.out.println("start");
continuation.run();
System.out.println("came back");
continuation.run();
System.out.println("back again");
continuation.run();
System.out.println("back again again");
```

Execution:

```
start
C1
came back
C2
back again
C3
back again again
```

There Are Cases Where It Does Not Work

Sometimes virtual threads are pinned to their carrier thread

Native code that does an upcall to Java may use an address on stack

$\Rightarrow$ the stack frames can not be copied

Running a Virtual Thread

A Platform Thread is a thin wrapper on an OS Thread
A Virtual Thread is not tied to a particular OS Thread

A Virtual Thread only consumes an OS Thread
when it performs calculations on the CPU

Creating a virtual thread is cheap

Blocking a virtual thread is cheap

Pooling virtual threads is useless

Loom is not Implemented « By the JVM »

Most of the code of the virtual threads scheduling is written in Java in the JDK (`jdk.internal.vm.Continuation`)

Written in C in the JVM:

- Copy of the stack frames back and forth
- GCs modified to find references in stack on heap

In the JDK

All blocking codes are changed to

- Check if current thread is a virtual thread
  - If it is, instead of blocking:
    - Register a handler that will be called when the OS is ready (using NIO)
    - Call `Continuation.yield()`
    - When the handler is called, find a carrier thread and call `Continuation.start()`

There Are Cases Where It Does Not Work

Sometimes virtual threads are pinned to their carrier thread

Synchronized block are written in assembly and uses an address on the stack

$\Rightarrow$ the stack frames can not be copied

Prefer `ReentrantLock` over `synchronized()`

Stealth Rewrite of the JDK for Loom

Java 13

- JEP 353 Reimplement the Legacy Socket API

Java 14

- JEP 373 Reimplement the Legacy Datagram Socket API
- JEP 374 Deprecate and Disable Biased Locking

Stealth Rewrite of the JDK for Loom

Java 18

- JEP 416 Reimplement Core Reflection with Method Handles
- JEP 418 (Internet-Address Resolution SPI) in JDK 18 defined a service-provider interface for host name and address lookup. This will allow third-party libraries to implement alternative java.net.InetAddress resolvers that do not pin threads during host lookup

Loom Idea: Under the Hood

The JDK creates as many virtual threads as the user want

- Mount a virtual thread to an available carrier thread when starting
- If blocking, unmount the current virtual thread and mount another virtual thread


Coffee (or whatever)
break!

Structured Concurrency

Why Do You Need Structured Concurrency?

Because thread dumps work well with several thousands of threads, not millions of threads

Not to talk about what can happen in your IDE…

You need to structure these threads

Structured Task Scope

Welcome to Loom Scopes

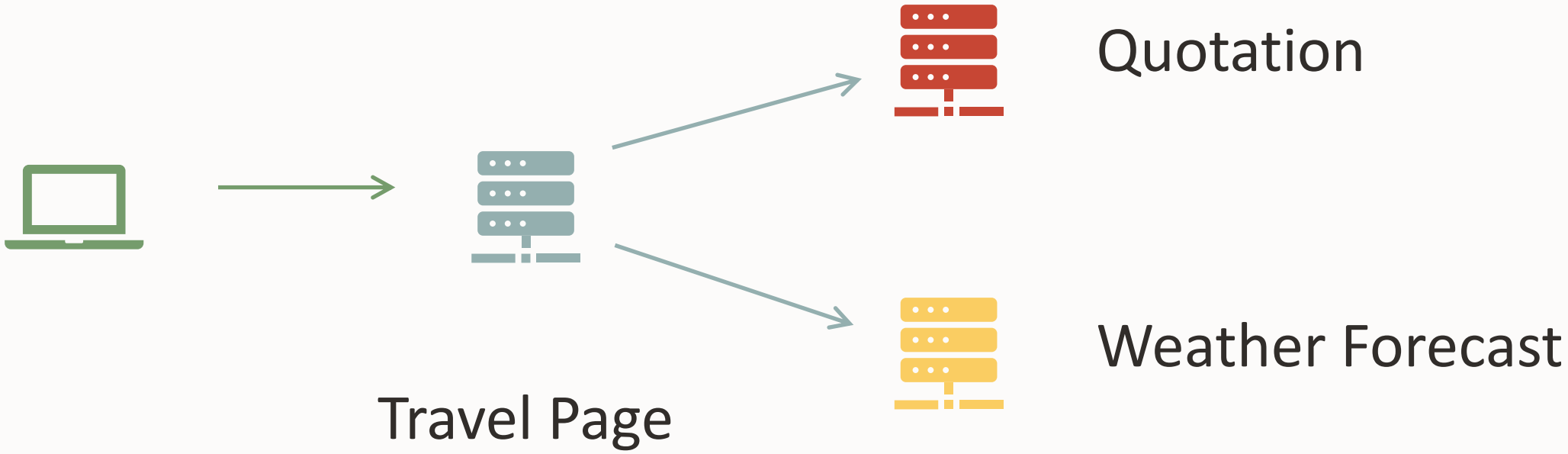
- It’s a pool of threads, that creates virtual threads on demand
- Once a task is done, the thread dies

The Travel Agency Example

A travel agency sells travels. On the response page, it wants to display:

- the quotation
- the weather forecast for the destination

The Travel Agency Example

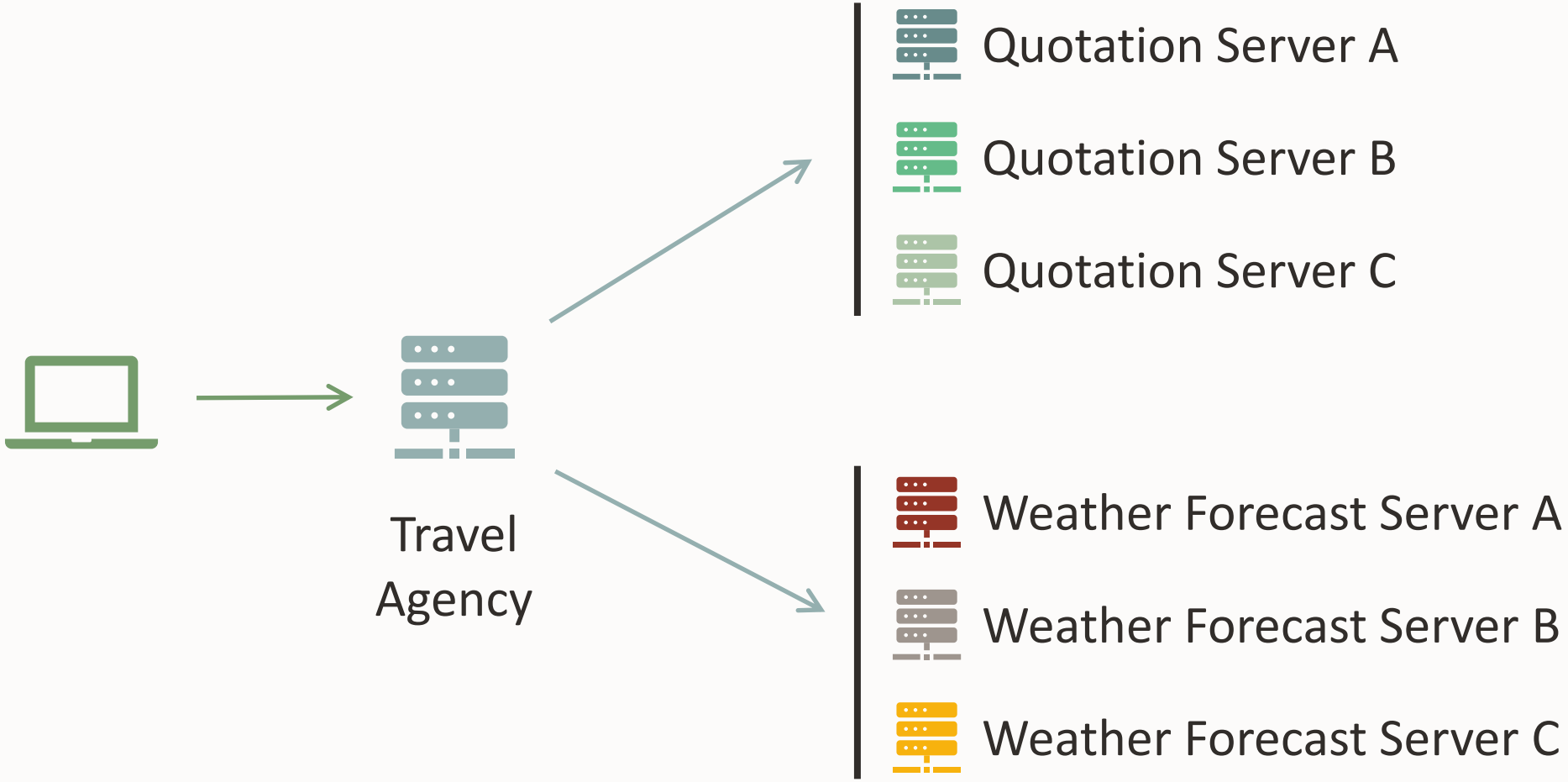


CompletableFuture Based Travel Agency

```
var quotationCF =
   CompletableFuture.supplyAsync(() -> getQuotation());
var weatherCF =
   CompletableFuture.supplyAsync(() -> getWeather());

CompletableFuture<Page> travelPageCF =
   quotationCF
      .exceptionally(t -> {
            weatherCF.cancel(true);
            throw new RuntimeException(t);
      })
      .thenCompose(
            quotation -> weatherCF
                        // .completeOnTimeout(Weather.UNKNOWN, 100, MILLISECONDS)
                        .exceptionally(e -> Weather.UNKNOWN)
                        .thenApply(
                            weather ->
                                buildPage(quotation, weather)));
```

The Travel Agency Example



Structured Scope

It needs to be closed (try with resources FTW!)

It creates virtual threads on demand

Pattern:

- Launch tasks
- Call `join()`
- Get the results

StructuredTaskScope

A `StructuredTaskScope` object looks like an `ExecutorService`

- It takes tasks and run then
- And returns `Future`

But:

- An executor lives with your application
- A task scope lives with your tasks

StructuredTaskScope

- ShutdownOnSuccess
- ShutdownOnFailure

Can be extended to implement specific needs

Extending StructuredTaskScope

Allows you to implement your own logic and error handling

`handleComplete(Future<>)` is the method you need to override

CompletableFuture Based Travel Agency

```
var quotationCF =
   CompletableFuture.supplyAsync(() -> getQuotation());
var weatherCF =
   CompletableFuture.supplyAsync(() -> getWeather());

CompletableFuture<Page> travelPageCF =
   quotationCF
      .exceptionally(t -> {
            weatherCF.cancel(true);
            throw new RuntimeException(t);
      })
      .thenCompose(
            quotation -> weatherCF
                        // .completeOnTimeout(Weather.UNKNOWN, 100, MILLISECONDS)
                        .exceptionally(e -> Weather.UNKNOWN)
                        .thenApply(
                            weather ->
                                buildPage(quotation, weather)));
```

Stuctured Concurrency Based Travel Agency

```
try (var scope = new WeatherScope()) {

    scope.fork(() -> readWeatherFromA());
    scope.fork(() -> readWeatherFromB());
    scope.fork(() -> readWeatherFromC();

    scope.join();

    Weather firstWeather = scope.getFirstWeather();
    return firstWeather;
}
```


Stuctured Concurrency Based Travel Agency

```
try (var scope = new QuotationScope()) {

    scope.fork(() -> readQuotationFromA());
    scope.fork(() -> readQuotationFromB());
    scope.fork(() -> readQuotationFromC();

    scope.join();

    Quotation bestQuotation = scope.getBestQuotation();
    return bestQuotation;
}
```


Stuctured Concurrency Based Travel Agency

```
try (var scope = new TravelPageScope()) {

    scope.fork(() -> getFirstWeather());
    scope.fork(() -> getBestQuotation());

    scope.join();

    TravelPage page = scope.buildTravelPage();
    return page;
}
```


Stuctured Concurrency Based Travel Agency

```
protected void handleComplete(Future<Quotation> future) {

    switch (future.state()) {
        case RUNNING -> throw new IllegalStateException("Ooops");
        case SUCCESS -> this.quotations.add(future.resultNow());
        case FAILED -> this.exceptions.add(future.exceptionNow());
        case CANCELLED -> { }
}
```


Stuctured Concurrency Based Travel Agency

```
public Quotation bestQuotation() {
    return this.quotations.stream()
                .min(Comparator.comparing(Quotation::quotation))
                .orElseThrow(this::exceptions);
}

public QuotationException exceptions() {
    QuotationException exception = new QuotationException();
    this.exceptions.forEach(exception::addSuppressed);
    return exception;
}
```


```
try (var scope = new TravelPageScope()) {

    scope.fork(() -> getFirstWeather());
    scope.fork(() -> getBestQuotation());

    scope.join();

    TravelPage page = scope.buildTravelPage();
    return page;
}
```


Stack Trace, ThreadDumps?

```
> jcmd <pid> Thread.dump_to_file –format-json <filename.json>
```


ThreadLocal?

ThreadLocal are made to pass some information

Without relying to method parameters!

ThreadLocal?

ThreadLocal is a variable bound to a thread

That can be read through this thread

```
ThreadLocal<String> threadLocal = new ThreadLocal<>();

threadLocal.set("KEY_1");

System.out.println(threadLocal.get()); // KEY_1

new Thread(
    () -> System.out.println(threadLocal.get())
).start(); // null
```


ThreadLocal under the hood

1) Thread local variables are stored in a map
   And are mutable!
2) Creating a new thread copies the map from the current thread
3) You know that there is a `remove()` method on `ThreadLocal`?

Virtual Threads support ThreadLocal variables

but you can do better!

Virtual Threads support ThreadLocal variables

but you can do better!

Welcome to ScopedValue

ScopedValues are non-modifiable

They are not bound to a particular thread

```
ScopedValue<String> key = new ScopedValue.newInstance();

ScopedValue.where(key, "KEY_1")
           .run(() -> doSomethingSmart()));

ScopedValue.where(key, "KEY_2")
           .run(() -> doSomethingSmart())
           .run(() -> soSomethingSmarter());
```



Loom is Great!