Loom is looming

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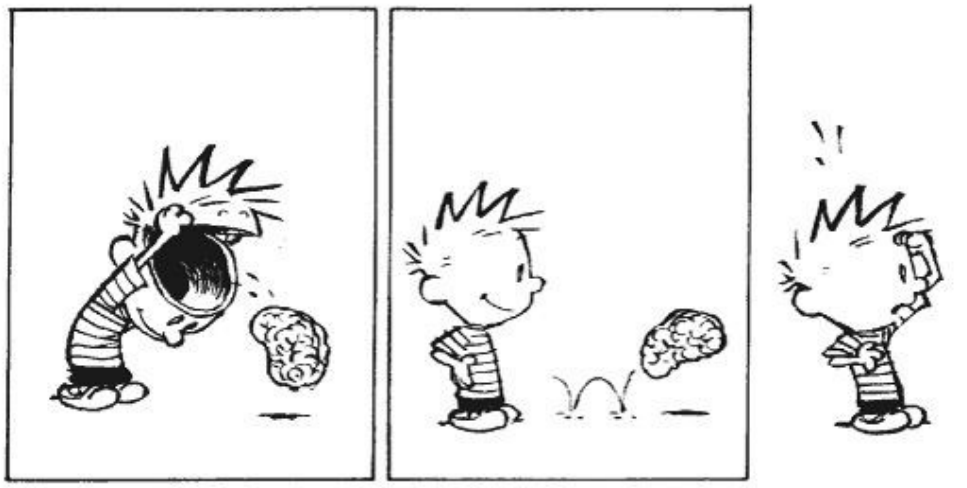


Don’t believe what we are saying !

What is Loom ?

OpenJDK project started late 2017
by Ron Pressler (Oracle)

Goal: Lowering the cost of concurrency

Should be integrated soon as preview feature

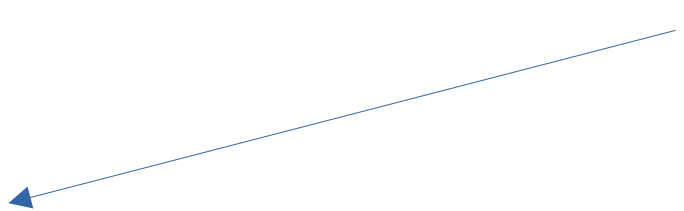
How many threads can I run ?

DEMO

How many threads can I run ?

```
var threads = IntStream.range(0, 100_000)
    .mapToObj(i -> new Thread(() -> {
      try {
        Thread.sleep(5_000);
      } catch (InterruptedException e) {
        throw new AssertionError(e);
      }
    }))
    .toList();

var i = 0;
for (var thread: threads) {
  System.out.println(i++);
  thread.start();
}

for (var thread : threads) {
  thread.join();
}
```

How many threads can I run ?




```
...
4065
4066
4067
4068
[0.373s][warning][os,thread] Failed to start thread "Unknown thread" -
pthread_create failed (EAGAIN) for attributes: stacksize: 2048k,
guardsize: 16k, detached.
[0.373s][warning][os,thread] Failed to start the native thread for
java.lang.Thread "Thread-4066"
Exception in thread "main" java.lang.OutOfMemoryError: unable to create
native thread: possibly out of memory or process/resource limits reached
        at java.base/java.lang.Thread.start0(Native Method)
        at java.base/java.lang.Thread.start(Thread.java:1451)
        at _3_how_many_platform_thread.printHowManyThreads(...java:19)
        at _3_how_many_platform_thread.main(...java:46)
```

OS/Platform threads are not cheap !

What if I’ve more than 4068 clients
for my web server ?

Need to change the model

1 request <=|=> 1 thread

Paradigmatic change
Asynchronous/Reactive programming

CompletableFuture (JDK)

Async/await (C# or Kotlin)

Mono/Flux (Spring) or Uni/Multi (Quarkus)

Paradigmatic change
Asynchronous/Reactive programming

But I loose the stack trace
=> debugging is harder
=> profiling is harder
=> testing is harder
+
colored function problem

Other solution => continuation

… like Erlang / Golang

In Java,

virtual threads

DEMO

Virtual thread

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

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

Virtual thread

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

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

Use a dedicated fork-join thread pool internally

Warning! This pool is not **the** common fork join pool

Using a *polymorphic* builder

Thread builder

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

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

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

DEMO

How many virtual threads can I run ?

```
var counter = new AtomicInteger();
var threads = IntStream.range(0, 100_000)
    .mapToObj(i -> Thread.ofVirtual().unstarted(() -> {
      try {
        Thread.sleep(5_000);
      } catch (InterruptedException e) {
        throw new AssertionError(e);
      }
      counter.incrementAndGet();
    }))
    .toList();

for (var thread : threads) { thread.start(); }

for (var thread : threads) { thread.join(); }

System.out.println(counter);
```

Running a thread

Platform/OS thread (starts in ms)

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

Virtual thread (starts in µs)

- Growing stack using stack banging
- Use a specific fork-join pool of platform threads (carrier threads)
  - One platform thread per core

Concurrency of Loom

Two strategies for concurrency

- Competitive: all threads compete for the CPUs/cores
- Cooperative: each thread hand of the CPUs to the next

Loom does both, carrier threads compete and virtual threads cooperate

How it works under the hood ?

DEMO

jdk.internal.vm.Continuation

Internal API

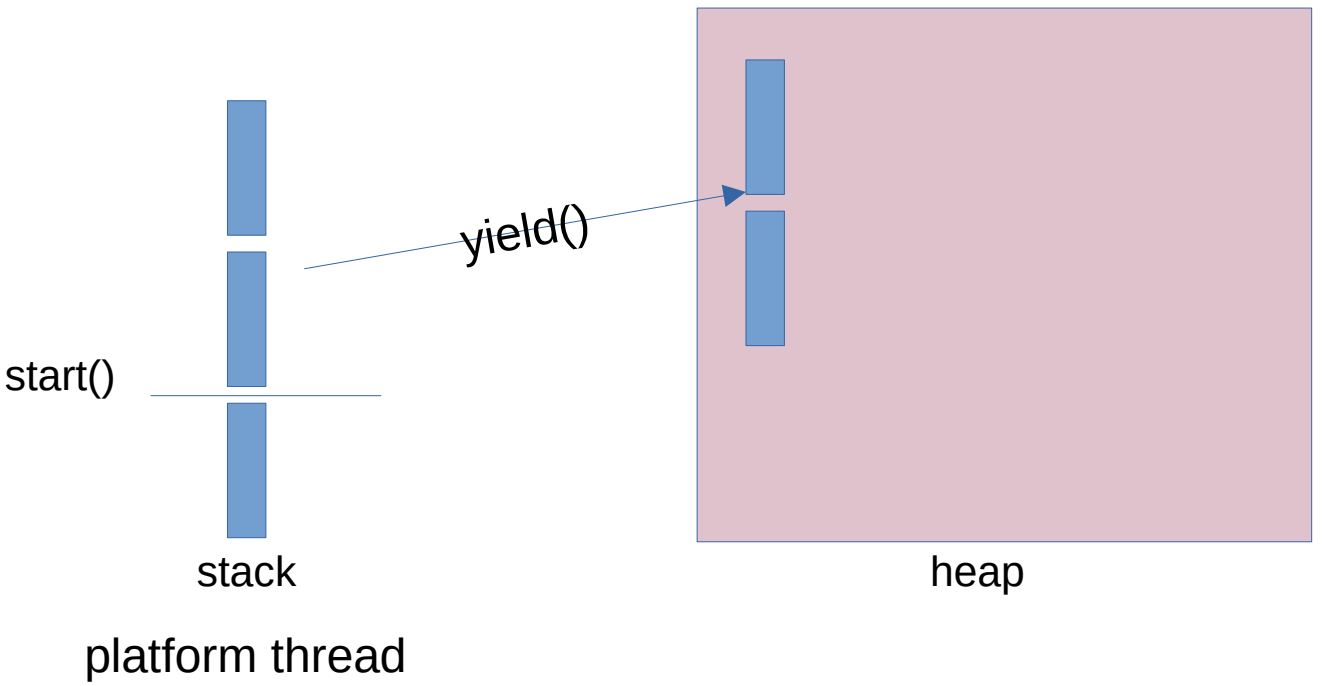
```
var scope = new ContinuationScope("hello");
var continuation = new Continuation(scope, () -> {
  System.out.println("C1");
  Continuation.yield(scope);
  System.out.println("C2");
  Continuation.yield(scope);
  System.out.println("C3");
});

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

Continuation.yield()

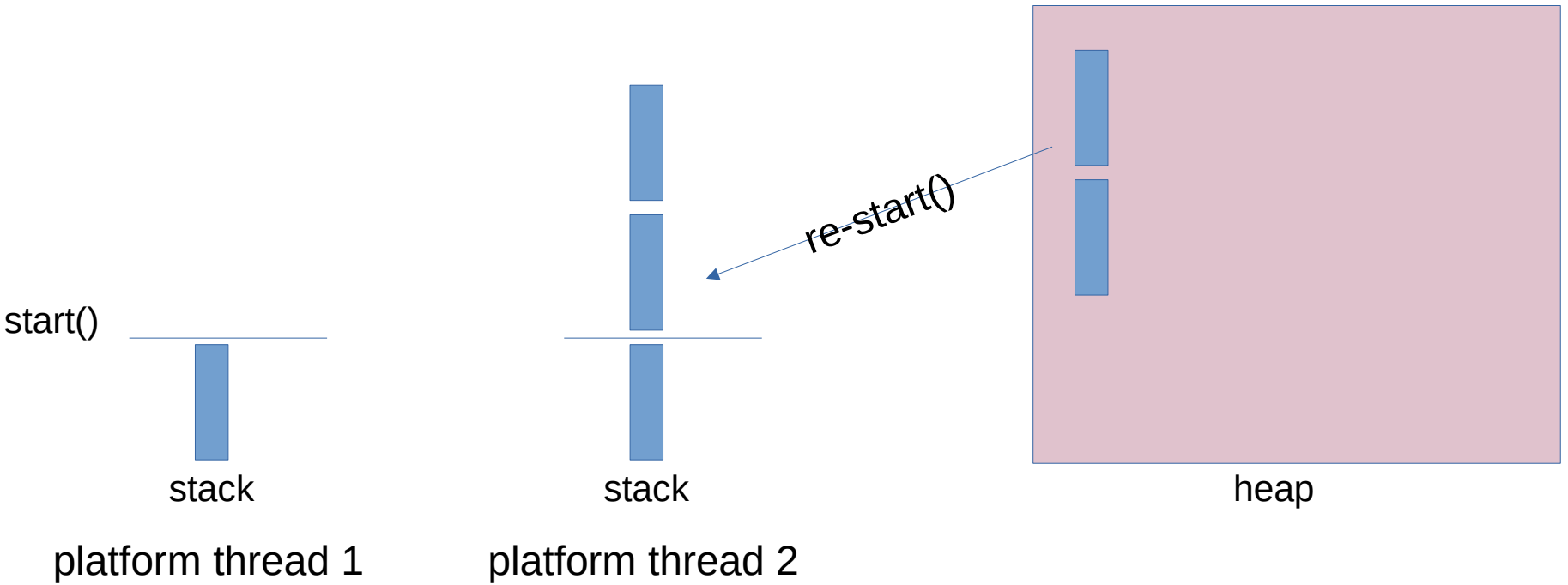
yield() copy the stack to the heap



platform thread

Continuation.start()

start() copy from the heap to another stack



Loom is **not** implemented ”by the JVM”

Most of the code of the virtual thread 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
- GC 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)
    - When the handler is called, find a carrier thread and called Continuation.start()
  - Call Continuation.yield()

Example with Thread.sleep()

```
private static void sleepMillis(long millis) throws InterruptedException {
  Thread thread = currentThread();
  if (thread instanceof VirtualThread vthread) {
    long nanos = NANOSECONDS.convert(millis, MILLISECONDS);
    vthread.sleepNanos(nanos);
  } else {
    sleep0(millis);
  }
}
```

```
void sleepNanos(long nanos) throws ...
  long remainingNanos = ...;
  while (remainingNanos > 0) {
    parkNanos(remainingNanos);
    ...
  }
}
```

```
void parkNanos(long nanos) {
  long startTime = System.nanoTime();
  boolean yielded;
  Future<?> unparker = scheduleUnpark(nanos);
  setState(PARKING);
  try {
    yielded = yieldContinuation();
  } finally {
    cancel(unparker);
  }

  // park on the carrier thread for remaining time when pinned
  if (!yielded) {
    parkOnCarrierThread(true, deadline - System.nanoTime());
  }
}
```

yield() can fail !

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

=> the stack frames can not be copied

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

=> the stack frames can not be copied

Stealth rewrite of the JDK for Loom

Java 13

- JEP 353 Reimplement the Legacy Socket API

Java 15

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

Java 18

- JEP 416 Reimplement Core Reflection with Method Handles

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

There are still some issues

Synchronized blocks

=> use ReentrantLock instead

Native code that does an upcall

=> no such call in the JDK anymore

Problems with some external libraries using native codes
Hadoop, Spark, ...

Thread Local issue

1_000_000 threads => 1_000_000 thread locals ??

ThreadLocal impl issue

ThreadLocal implementation

- store the values in a Map inside java.lang.Thread
  - Does not scale well !
- is mutable (can call ThreadLocal.set() anywhere)

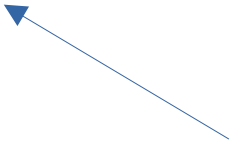
=> provide a more lightweight implementation

jdk.incubator.concurrent.ScopeLocal

DEMO

Thread Local

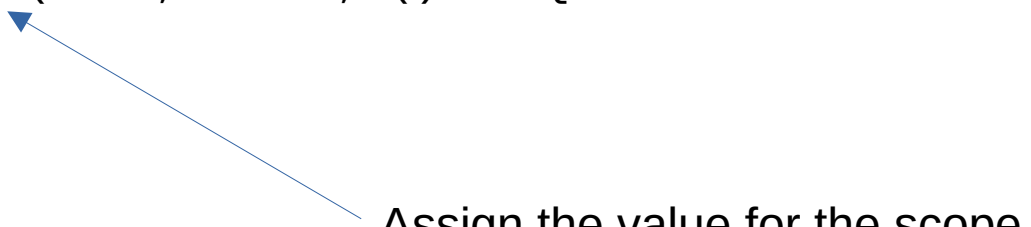
```
private static final ThreadLocal<String> USER = new ThreadLocal<>();

private static void sayHello() {
  System.out.println("Hello " + USER.get());
}

public static void main(String[] args) throws InterruptedException {
  var vthread = Thread.ofVirtual()
      .allowSetThreadLocals(true)
      .start(() -> {
    USER.set("Bob");
    try {
      sayHello();
    } finally {
      USER.remove();
    }
  });

  vthread.join();
}
```



Can be used to disallow thread locals
throw an ISE when calling ThreadLocal.set()

Scope Local

```
private static final ScopeLocal<String> USER = ScopeLocal.newInstance();

private static void sayHello() {
  System.out.println("Hello " + USER.get());
}

public static void main(String[] args) throws InterruptedException {
  var vthread = Thread.ofVirtual()
      .allowSetThreadLocals(false)
      .start(() -> {
    ScopeLocal.where(USER, "Bob", () -> {
      sayHello();
    });
  });

  vthread.join();
}
```



ScopeLocal

WARNING API in progress

- Replacement for ThreadLocal
- Stores the value inside the stack, not inside java.lang.Thread

  => faster (if not too many locals)

  => use far less memory
- API amenable to JITs
  - Hoists Scopelocal.get() out of loops ?

Executor and structured concurrency

Executors

An executor recycle the threads

- Do we need an executor if creating a virtual thread does not cost much ?

An executor as another role

- Manage all the submitted tasks
  - But cancellation/exception management is wrong !

Structured Concurrency

WARNING API in progress

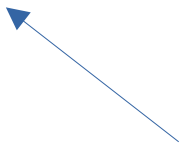
Use syntactic constructions to represent the dependency tree of the tasks

Try to fix executor problems

DEMO

VirtualThreadPerTaskExecutor

```
var executor = Executors.newCachedThreadPool();
//var executor = Executors.newVirtualThreadPerTaskExecutor();

var future1 = executor.submit(() -> {
  Thread.sleep(10);
  return 42;
});
var future2 = executor.submit(() -> {
  Thread.sleep(1_000);
  return 100;
});

executor.shutdown();

var result = future1.get() + future2.get();
System.out.println(result);

// everything is fine here, right !
```



Special executor using virtual threads
Warning! the carrier threads are *deamon*

Running task (1) with an Executor

```
var executor = Executors.newCachedThreadPool();

var future1 = executor.submit(() -> {
  Thread.sleep(10);
  return 1;
});

var future2 = executor.submit(() -> {
  Thread.sleep(1_000);
  System.out.println("end");
  return 2;
});

executor.shutdown();

//var result = future1.get() + future2.get();
var result = future1.get();
System.out.println(result);

// future2 still running here !
```

Oops !

Running task (2) with an Executor

```
var executor = Executors.newCachedThreadPool();

var future1 = executor.<Integer>submit(() -> {
  throw new AssertionError("oops");
});

var future2 = executor.submit(() -> {
  Thread.sleep(1_000);
  System.out.println("end");
  return 2;
});

executor.shutdown();

Try {
  var result = future1.get() + future2.get();
  System.out.println(result);
} catch(ExecutionException e) {
  throw new AssertionError(e.getCause());
}

// future2 still running here !
```

Oops !

jdk.incubator.concurrent.StructuredTaskScope

```
try (var scope = new StructuredTaskScope<>()) {
  var start = System.currentTimeMillis();

  var future1 = scope.fork(() -> {
    Thread.sleep(1_000);
    return 1;
  });

  var future2 = scope.fork(() -> {
    Thread.sleep(1_000);
    return 2;
  });

  scope.join();

  var end = System.currentTimeMillis();
  System.out.println("elapsed " + (end – start));
  var result = future1.resultNow() + future2.resultNow();
  System.out.println(result);
} // call close() !
```

Wait for all computations

Throw an exception in case of dangling tasks

Future state()

```
try (var scope = new StructuredTaskScope<>()) {
  var future = scope.fork(() -> {
    Thread.sleep(1_000);
    return 42;
  });

  System.out.println(future.state());  // RUNNING

  //scope.shutdown();

  scope.join();

  System.out.println(future.state());  // SUCCESS
}
```

Future state() with a shutdown()

```
try (var scope = new StructuredTaskScope<>()) {
  var future = scope.fork(() -> {
    Thread.sleep(1_000);
    return 42;
  });

  System.out.println(future.state());  // RUNNING

  scope.shutdown();

  scope.join();

  System.out.println(future.state());  // CANCEL
}
```

StructuredTaskScope.shutdown()

If called by the main thread

- Shutdown all the tasks

If called by one task

- Shutdown all the tasks but the caller task

Shutdown() on failure

```
try (var scope = new StructuredTaskScope.ShutdownOnFailure()) {
  var start = System.currentTimeMillis();

  var future1 = scope.<Integer>fork(() -> {
    throw new AssertionError("oops");
  });

  var future2 = scope.fork(() -> {
    Thread.sleep(1_000);
    System.out.println("end");
    return 2;
  });

  scope.join();

  var end = System.currentTimeMillis();
  System.out.println("elapsed " + (end – start));
  var result = future1.resultNow() + future2.resultNow();
  System.out.println(result);

}  // future and future2 are not running here !
```

Shutdown() on success

```
try (var scope = new StructuredTaskScope.ShutdownOnSuccess<Integer>()) {
  var start = System.currentTimeMillis();

  var future1 = scope.fork(() -> {
    Thread.sleep(1_000);
    return 1;
  });

  var future2 = scope.fork(() -> {
    Thread.sleep(42);
    return 2;
  });

  scope.join();

  var end = System.currentTimeMillis();
  System.out.println("elapsed " + (end – start));

  System.out.println(scope.result());
}
```

This task completes first

The result is stored in the scope

Summary

Loom

Will be integrated soon, in Java 19 (or 20)

Introduce virtual threads (better for IO latency)

caveat: synchronized() block or native code with an upcall pins the virtual thread to its carrier thread

More APIs to come (jdk.incubator.concurrent)

- ScopeLocal (~ ThreadLocal replacement)
- StructuredTaskScope (~~ Executor replacement)

Questions ?

https://github.com/forax/loom-fiber