

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();
```

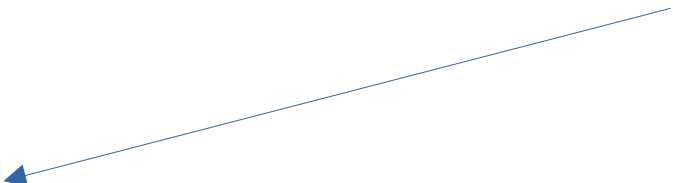
```
var i = 0;
for (var thread: threads) {
    System.out.println(i++);
    thread.start();
}

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

How many threads can I run ?

On a MacBook Air M1 (16G of RAM)

```
...  
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 $\leq | = >$ 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 => user-level thread
... like Erlang process / Golang goroutine

Official name 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**)

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

How it works under the hood ?

Loom internals

Two strategies for concurrency

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

Loom implementation does both

- OS schedule carrier threads to CPU/cores and
- JDK codes schedule virtual threads to carrier threads

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");
});

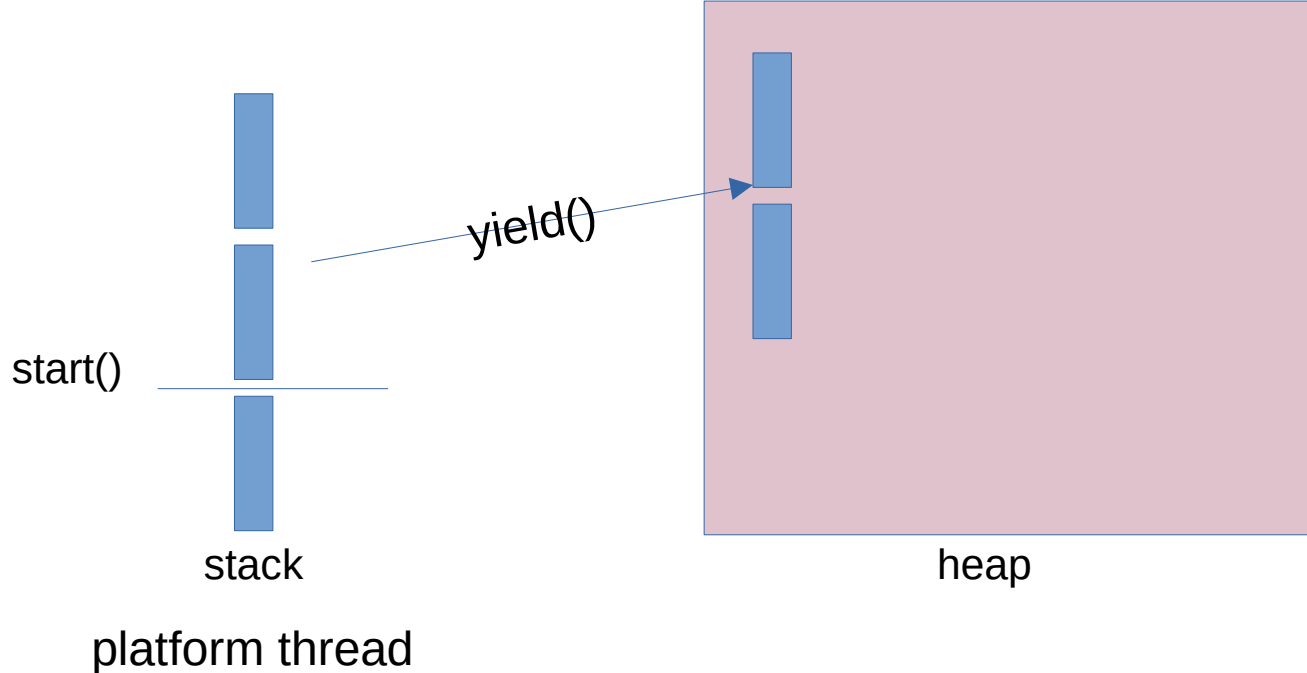
System.out.println("start");
continuation.run();
System.out.println("came back");
continuation.run();
System.out.println("back again");
continuation.run();
System.out.println("back again again");
```

Execution:

start
C1
came back
C2
back again
C3
back again again

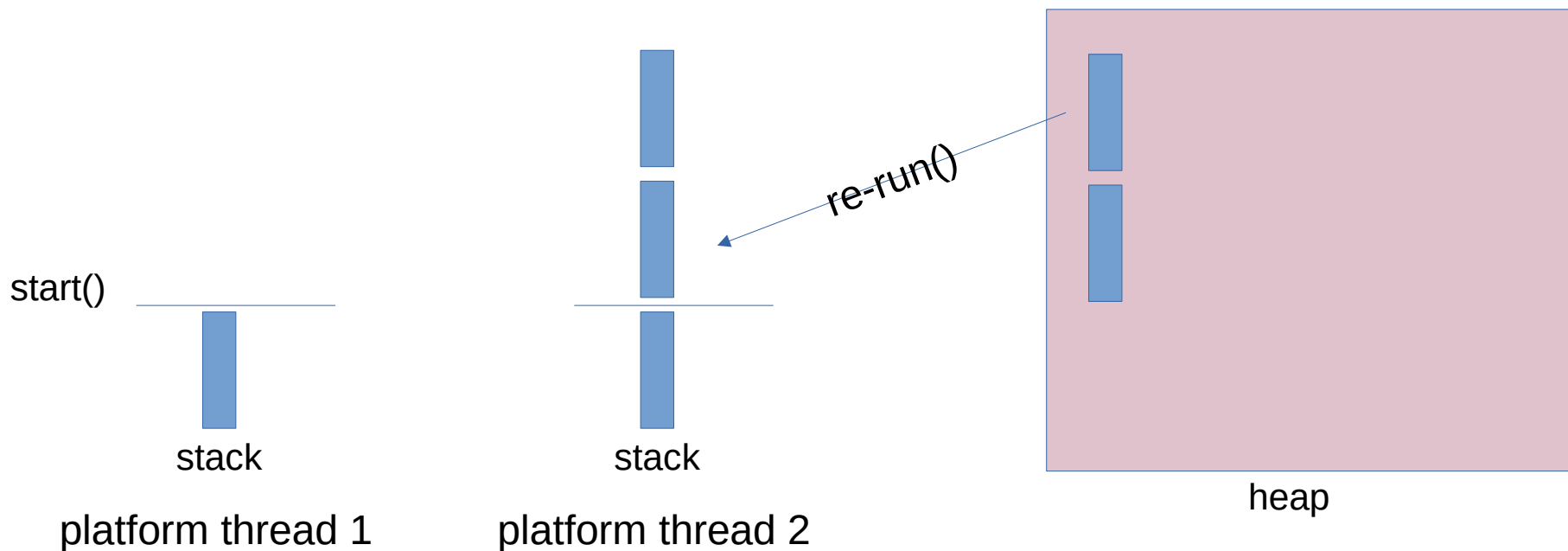
Continuation.yield()

yield() copy the stack to the heap



Continuation.run()

run() copy from the heap to another stack
(optimization: only copy the top most stack frames)



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 stacks 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 (around slow/frequent IOs)

=> 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

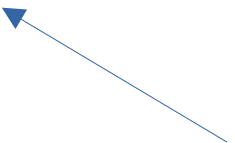
Thread Local

```
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 UOE when calling ThreadLocal.set()

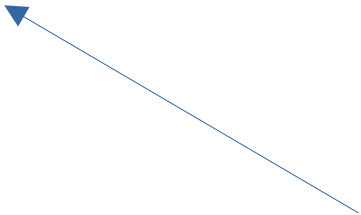


Scope Local

```
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();
}
```



Assign the value for the scope

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 ?

ExecutorService and structured concurrency

ExecutorService

Implementations recycle the threads

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

An ExecutorService also

- 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 tasks

Provide a better API than `ExecutorService`

DEMO

VirtualThreadPerTaskExecutor

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

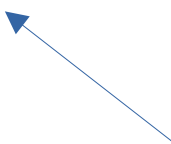
```
var future1 = executor.submit(() -> {  
    Thread.sleep(10);  
    return 42;  
});
```

```
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 *daemon*

Tasks using an ExecutorService (1)


```
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 !
```

Tasks using an ExecutorService (2)

```
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 !
```



This task fails

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` (~ `ExecutorService` replacement)

Questions ?

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