Prepare for what *Loom*s ahead

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Javaspecialists.eu
java training

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- The Java Specialists' Newsletter
  - 303 editions, published since 2000
  - www.javaspecialists.eu
- Please say "hi" to heinz@javaspecialists.eu :-)
- A bit later ...
  - 3-way split for my Java Specialists Superpack '22
    - Stay tuned, don't miss it ...

When is Loom Coming?

- **Already part of Java 19-preview!**
  - **Structured concurrency in an incubator module**

Why do we need Virtual Threads?

- Asynchronous code can be hard to debug
- 1-to-1 Java thread to platform thread does not scale
  - ManyThreads demo
- Welcome to Project Loom
  - Millions of virtual threads in a single JVM
  - Supported by networking, java.util.concurrent, etc.
    - Anywhere you would block a thread

Best Deal Search

- **Our webpage server requires 4 steps**
  1. **Scan request for search terms**
  2. **Search partner websites**
  3. **Create advertising links**
  4. **Collate results from partner websites**
- **We can reorder some steps without affecting result**

Sequential Best Deal Search

- **Sequential processing is the simplest**

4.3 seconds

```
public void renderPage(HttpRequest request) {
  List<SearchTerm> terms = scanForSearchTerms(request); // 1
  List<SearchResult> results = terms.stream()
      .map(SearchTerm::searchOnPartnerSite) // 2
      .toList();
  createAdvertisingLinks(request); // 3
  results.forEach(this::collateResult); // 4
}
```

Page Renderer with Future

- **Search partner sites in the background with Callable**
  - **We might get better performance this way**
  - **If we are lucky, search results are ready when we need them**

Searching in Background Thread

4.1 seconds

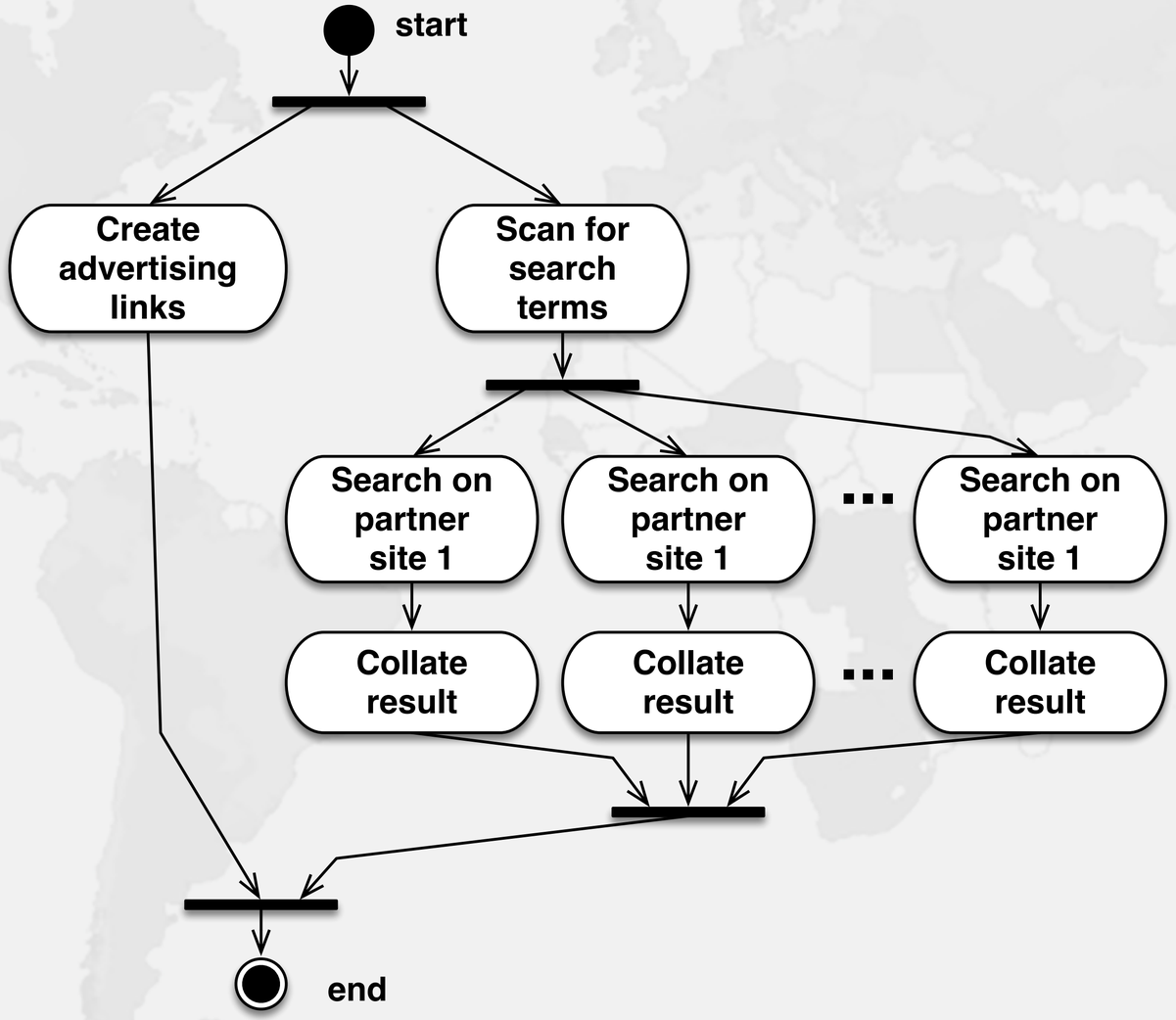
```
public class FutureRenderer extends BasicRenderer {
  private final ExecutorService executor;

  public FutureRenderer(ExecutorService executor) {
    this.executor = executor;
  }

  public void renderPage(HttpRequest request)
      throws ExecutionException, InterruptedException {
    List<SearchTerm> terms = scanForSearchTerms(request); // 1
    Callable<List<SearchResult>> task = () ->
        terms.stream()
            .map(SearchTerm::searchOnPartnerSite) // 2
            .toList();
    Future<List<SearchResult>> results = executor.submit(task);
    createAdvertisingLinks(request); // 3
    results.get().forEach(this::collateResult); // 4
  }
}
```

CompletableFuture

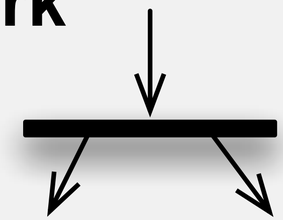
- **Convert each step into a CompletableFuture**
  - **Then combine these using *allOf()***
  - **Code is slightly faster, but a whole lot more complicated**
    - **Need separate pools for CPU and IO bound tasks**

Modeling Control Flow

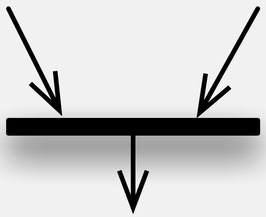
- **Our Renderer example as a UML Activity Diagram**



- **Fork**



- **Join**



renderPage() with CompletableFuture

```
public class RendererCF extends BasicRenderer {
  private final ExecutorService cpuPool, ioPool;

  public RendererCF(ExecutorService cpuPool, ExecutorService ioPool) {
    this.cpuPool = cpuPool;
    this.ioPool = ioPool;
  }

  public void renderPage(HttpRequest request) {
    renderPageCF(request).join();
  }

  public CompletableFuture<Void> renderPageCF(HttpRequest request) {
    return CompletableFuture.allOf(createAdvertisingLinksCF(request),
        scanSearchTermsCF(request)
            .thenCompose(this::searchAndCollateResults));
  }

  private CompletableFuture<Void> createAdvertisingLinksCF(
      HttpRequest request) {
    return CompletableFuture.runAsync(
        () -> createAdvertisingLinks(request), cpuPool);
  }
```

searchAndCollateResults()

```
private CompletableFuture<List<SearchTerm>> scanSearchTermsCF(
    HttpRequest request) {
  return CompletableFuture.supplyAsync(
      () -> scanForSearchTerms(request), cpuPool);
}

private CompletableFuture<Void> searchAndCollateResults(
    List<SearchTerm> list) {
  return CompletableFuture.allOf(
      list.stream()
          .map(this::searchAndCollate)
          .toArray(CompletableFuture<?>[]::new)
  );
}

private CompletableFuture<Void> searchAndCollate(SearchTerm term) {
  return searchOnPartnerSiteCF(term).thenCompose(this::collateResultCF);
}
```

Tasks Wrapped in CompletableFutures

```
  private CompletableFuture<SearchResult> searchOnPartnerSiteCF(
      SearchTerm term) {
    return CompletableFuture.supplyAsync(
        term::searchOnPartnerSite, ioPool);
  }

  private CompletableFuture<Void> collateResultCF(SearchResult data) {
    return CompletableFuture.runAsync(
        () -> collateResult(data), cpuPool);
  }
}
```

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What about plain Thread?

- **Could we simply create one thread per task?**
  - **Code would be simpler than with the CompletableFuture**

renderPage() with platform threads

0.5 seconds

Started 11 threads

```
public void renderPage(HttpRequest request)
    throws InterruptedException {
  Thread createAdvertisingThread =
      new Thread(() -> createAdvertisingLinks(request)); // 3
  createAdvertisingThread.start();
  Collection<Thread> searchAndCollateThreads =
      scanForSearchTerms(request).stream() // 1
          .map(term -> {
            Thread thread = new Thread(// 2 & 4
              () -> collateResult(term.searchOnPartnerSite()));
            thread.start();
            return thread;
          })
          .toList();
  createAdvertisingThread.join();
  for (Thread searchAndCollateThread : searchAndCollateThreads)
    searchAndCollateThread.join();
}
```

Not scalable

- **Even one thread per client connection is too many**
  - **In our example we could be launching dozens of threads**

Virtual Threads

- Lightweight, less than 1 kilobyte
- Fast to create
- Over 23 million virtual threads in 16 GB of memory
- Executed by carrier threads
  - Scheduler is currently a ForkJoinPool
    - Carriers are by default daemon threads
    - # threads is Runtime.getRuntime().availableProcessors()
      - Can temporarily increase due to ManagedBlocker
  - Moved off carrier threads when blocking on IO
    - Also with waiting on synchronizers from java.util.concurrent

Before we continue ...

- 3-way split for Java Specialists Superpack '22
  - We all want to support Devoxx Ukraine!
  - 1/3 discount for you, 1/3 donation to Devoxx UA, 1/3 me
  - https://tinyurl.com/devua22
  - Offer expires Friday the 9th Sep 22, please don't miss it!

Let's go back to SingleThreadedRenderer

- **If threads are unlimited and free, why not create a new virtual thread for every task?**
- **This is how our single-threaded renderer looked**

```
public void renderPage(HttpRequest request) {
  List<SearchTerm> terms = scanForSearchTerms(request); // 1
  List<SearchResult> results = terms.stream()
      .map(SearchTerm::searchOnPartnerSite) // 2
      .toList();
  createAdvertisingLinks(request); // 3
  results.forEach(this::collateResult); // 4
}
```

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Virtual threads galore

```
public void renderPage(HttpRequest request)
    throws InterruptedException {
  Thread createAdvertisingThread =
      Thread.startVirtualThread(
          () -> createAdvertisingLinks(request)); // 3
  Collection<Thread> searchAndCollateThreads =
      scanForSearchTerms(request).stream() // 1
        .map(term -> Thread.startVirtualThread( // 2 & 4
            () -> collateResult(term.searchOnPartnerSite())))
        .toList();
  createAdvertisingThread.join();
  for (Thread searchThread : searchAndCollateThreads)
    searchThread.join();
}
```

0.5 seconds

How to create virtual threads

- **Individual threads**
  - **Thread.startVirtualThread(Runnable)**
  - **Thread.ofVirtual().start(Runnable)**
- **ExecutorService**
  - **Executors.newVirtualThreadPerTaskExecutor()**
  - **ExecutorService is now AutoCloseable**
    - **close() calls shutdown() and awaitTermination()**

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Using ExecutorService

```
public void renderPage(HttpRequest request) {
  try (ExecutorService mainPool =
          Executors.newVirtualThreadPerTaskExecutor()) {
    mainPool.submit(() -> createAdvertisingLinks(request)); // 3
    mainPool.submit(() -> {
      List<SearchTerm> terms = scanForSearchTerms(request); // 1
      try (ExecutorService searchAndCollatePool =
              Executors.newVirtualThreadPerTaskExecutor()) {
          terms.forEach(term -> searchAndCollatePool.submit( // 2 & 4
              () -> collateResult(term.searchOnPartnerSite())));
      }
    });
  }
}
```

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Structured Concurrency (Incubator)

- **Better approach for describing concurrent flows**
  - **https://openjdk.org/jeps/428**
- **Idioms are still being developed, e.g.**

0.5 seconds

```
public void renderPage(HttpRequest request)
    throws InterruptedException, ExecutionException {
  try (var scope = new StructuredTaskScope.ShutdownOnFailure()) {
    scope.fork(() -> createAdvertisingLinks(request)); // 3
    List<SearchTerm> terms = scanForSearchTerms(request); // 1
    terms.forEach(term -> scope.fork(
        () -> collateResult(term.searchOnPartnerSite()))); // 2 & 4
    scope.join();            // Join all forks
    scope.throwIfFailed();  // ... and propagate errors
  }
}
```

ManagedBlocker

- ForkJoinPool makes more threads when blocked
  - ForkJoinPool is configured with desired parallelism
- Uses in the JDK
  - Java 7: Phaser
  - Java 8: CompletableFuture
  - Java 9: Process, SubmissionPublisher
  - Java 14: AbstractQueuedSynchronizer
    - ReentrantLock, ReentrantReadWriteLock, CountDownLatch, Semaphore
  - Java 17: LinkedTransferQueue, SynchronousQueue
  - Loom: SelectorImpl, Object.wait(), old I/O

ManagedBlocker

- **Might need to update our code base**
  - **Ideally we should never block a thread with native methods**
  - **If we cannot avoid it, wrap the code in a ManagedBlocker**

Java IO Implementation Rewritten

- **JEP353 Reimplement Legacy Socket API**
  - **PlainSocketImpl replaced by NioSocketImpl**
  - **https://openjdk.java.net/jeps/353**
- **JEP373 Reimplement Legacy DatagramSocket API**
  - **https://openjdk.java.net/jeps/373**

Synchronized ⇒ ReentrantLock

- **synchronized/wait is not fully compatible with Loom**
  - **Virtual thread will stall the underlying carrier thread**
    - **It will create additional threads through ManagedBlocker**

no output

```
Object monitor = new Object();
for (int i = 0; i < 10_000; i++) {
  Thread.startVirtualThread(() -> {
    synchronized (monitor) {
      try {
        monitor.wait();
      } catch (InterruptedException ignore) {}
    }
  });
}
Thread.startVirtualThread(() -> System.out.println("done")).join();
```

Object.wait()

```
public final void wait(long timeoutMillis)
    throws InterruptedException {
  Thread thread = Thread.currentThread();
  if (thread.isVirtual()) {
    try {
      Blocker.managedBlock(() -> wait0(timeoutMillis));
    } catch (Exception e) {
      if (e instanceof InterruptedException)
        thread.getAndClearInterrupt();
      throw e;
    }
  } else {
    wait0(timeoutMillis);
  }
}
```

Synchronized ⇒ ReentrantLock

- We might need to migrate our synchronized code to
  - ReentrantLock
  - StampedLock
- In both cases, idioms are more complicated
  - But fully compatible with virtual threads

Biased Locking Turned Off

- ConcurrentHashMap uses synchronized
  - Earlier versions used ReentrantLock
- Uncontended ConcurrentHashMap in Java 15 is measurably slower on some hardware
  - -XX:+UseBiasedLocking to enable it again
  - Please report if turning it on makes a big difference

Rather do not use ThreadLocal

- Virtual threads support ThreadLocal by default
  - However, it is costly
  - Virtual threads not reused
    - ThreadLocals often do not make sense
- Disallow with Builder.allowSetThreadLocals(false)
- Replaced by Extent-Local Variables (Incubator)
  - https://openjdk.org/jeps/429

```
public class ThreadLocalTest {
  private static final ThreadLocal<DateFormat> df =
      ThreadLocal.withInitial(() ->
          new SimpleDateFormat("yyyy-MM-dd") {
            {
              System.out.println("Making SimpleDateFormat");
            }
          });

  public static void main(String... args) throws Exception {
    Runnable task = () -> {
      try {
        for (int i = 0; i < 3; i++) {
          System.out.println(df.get().parse("2022-05-04"));
        }
      } catch (ParseException e) { e.printStackTrace(); }
    };
    System.out.println("Standard Virtual Thread");
    Thread.startVirtualThread(task).join();

    System.out.println();

    System.out.println("Disallowing Thread Locals");
    Thread.ofVirtual().allowSetThreadLocals(false)
        .start(task).join();
  }
}
```

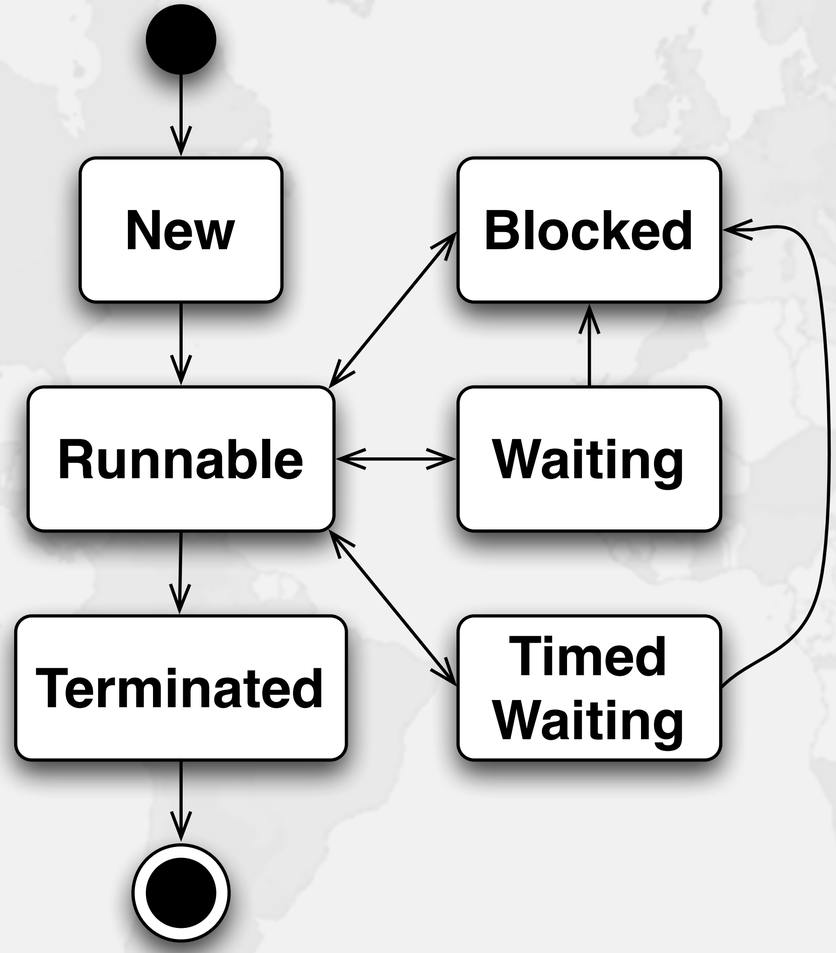
```
Standard Virtual Thread
Making SimpleDateFormat
Mon May 04 00:00:00 EEST 2022
Mon May 04 00:00:00 EEST 2022
Mon May 04 00:00:00 EEST 2022

Disallowing Thread Locals
Making SimpleDateFormat
Mon May 04 00:00:00 EEST 2022
Making SimpleDateFormat
Mon May 04 00:00:00 EEST 2022
Making SimpleDateFormat
Mon May 04 00:00:00 EEST 2022
```

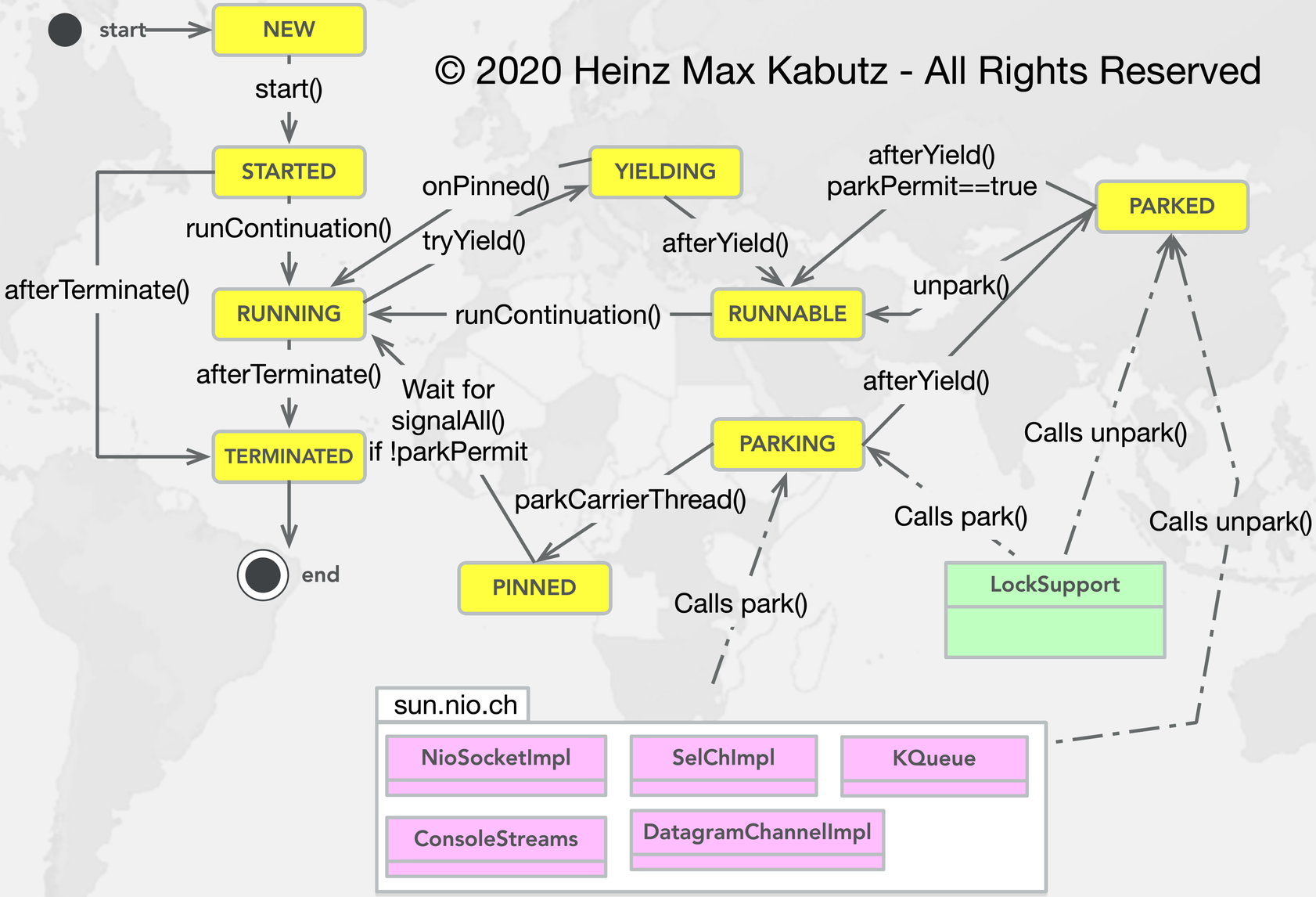
Naming

- **Virtual threads do not have a name**
  - **Most of the time, sufficient to generate own with threadId()**
    - **Unlike getId(), this threadId() guarantees a unique final value**

java.lang.Thread States



java.lang.VirtualThread States



VirtualThread.getState()

VirtualThread State	Thread State
NEW	NEW
STARTED, RUNNABLE	RUNNABLE
RUNNING	if mounted, carrier thread state else RUNNABLE
PARKING, YIELDING	RUNNABLE
PINNED, PARKED, PARKED_SUSPENDED	WAITING
TERMINATED	TERMINATED

Cost of old IO Streams

- **Benefit of Virtual Threads, is we can use the old java.io.InputStream and java.io.Reader**
  - **As opposed to java.nio Channel and Buffer**
- **But, they actually use a lot of memory**

Memory overhead of IO Streams

	OutputStream	InputStream	Writer	Reader
Print	**17400**		80	
Buffered	8312	8296	16488	**16496**
Data	80	328		
File	176	176	936	8552
GZIP	768	1456		
Object	2264	2256		
Adapter			808	**8424**

Used to be slightly worse

	OutputStream	InputStream	Writer	Reader
Print	**25064**		80	
Buffered	8312	8296	16480	**16496**
Data	80	328		
File	176	176	8608	8552
GZIP	768	1456		
Object	2264	2256		
Adapter			8480	**8424**

Deadlocks in Virtual Threads

- **Deadlocks with a virtual thread not in thread dump**
  - **https://www.javaspecialists.eu/archive/Issue302.html**

```
"platform" #30 cpu=1.75ms elapsed=4.42s waiting for monitor entry
  java.lang.Thread.State: BLOCKED (on object monitor)
    at SimpleLockOrderingDeadlockMixedThreads.lambda$main$0
    - waiting to lock <0x000000043fce3d90> (a java.lang.Object)
    - locked <0x000000043fce3d80> (a java.lang.Object)
    at SimpleLockOrderingDeadlockMixedThreads$$Lambda$14
    at java.lang.Thread.run

"ForkJoinPool-1-worker-1" #32 daemon cpu=0.70ms elapsed=4.41s
  Carrying virtual thread #31
    at jdk.internal.vm.Continuation.run
    at java.lang.VirtualThread.runContinuation
    at java.lang.VirtualThread$$Lambda$22
    at java.util.concurrent.ForkJoinTask$RunnableExecuteAction.exec
    at java.util.concurrent.ForkJoinTask.doExec
    at java.util.concurrent.ForkJoinPool$WorkQueue.topLevelExec
    at java.util.concurrent.ForkJoinPool.scan
    at java.util.concurrent.ForkJoinPool.runWorker
    at java.util.concurrent.ForkJoinWorkerThread.run
```

How to find out what thread #31 is doing?

- **Run the JVM with -Djdk.trackAllThreads=true**
- **Once deadlock occurs**
  - **jcmd pid Thread.dump_to_file some_file**

```
#31 "virtual" virtual
  SimpleLockOrderingDeadlockMixedThreads.lambda$main$1\
    (SimpleLockOrderingDeadlockMixedThreads.java:22)
  java.base/java.lang.VirtualThread.run
  java.base/java.lang.VirtualThread$VThreadContinuation.lambda$new$0
  java.base/jdk.internal.vm.Continuation.enter0
  java.base/jdk.internal.vm.Continuation.enter
```

Deadlocks with ReentrantLock

- **Does not pin the carrier thread**
  - **Much harder to find these**
  - **Good luck!**

Retrofitting to Asynchronous Code

- If your system works fine asynchronously, leave it
  - Virtual threads help to alleviate some of the pain
  - But are not necessarily faster
  - And retrofitting them is probably more trouble than worth
- Backpressure
  - With virtual thread model, use Semaphore or BlockingQueue
    - Be careful though, Semaphore is a rather primitive construct
      - Has no record of who owns the Semaphore
      - If a permit is lost due to an exception, parallelism is reduced

When will Loom be ready?

- Currently in Java 19-preview
- Some parts already in mainstream Java
- However, Java has different levels of readiness
  - Part of the JDK
  - Preview feature
    - Mostly done, can still change
    - Has to be supported by all Java runtimes of that version !
  - Experimental feature
    - Epsilon GC
    - Does not have to be supported by Java runtimes
  - Incubator

Don't forget ...

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