Prepare for what *Loom*s ahead

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Last updated 2021-05-04

Javaspecialists.eu
java training

Why do we need Virtual Threads?

- Asynchronous code is hard to debug
- 1-to-1 Java thread to native thread does not scale
- 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
      .collect(Collectors.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

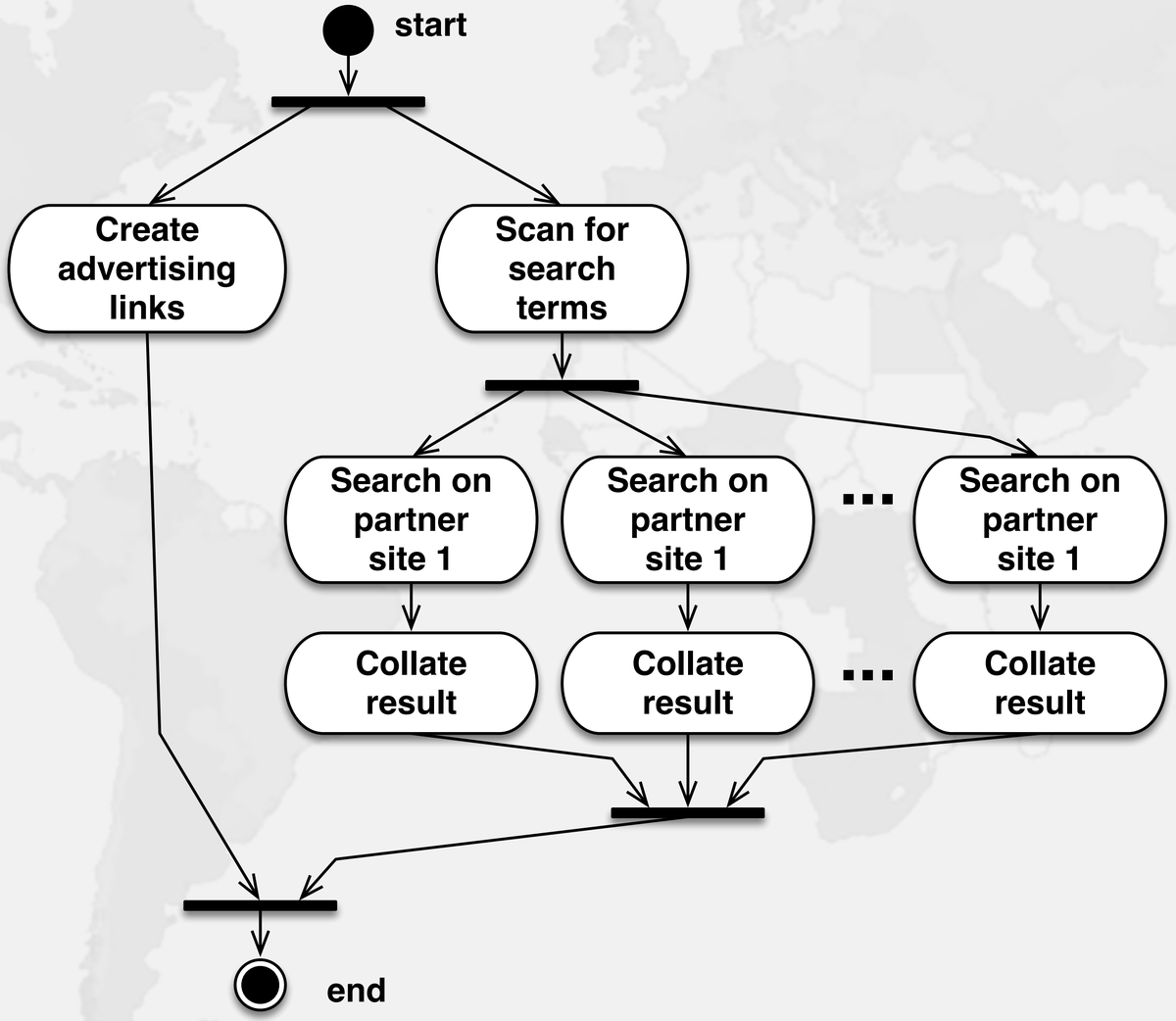
```
public class FutureRenderer extends BasicRenderer {
  private final ExecutorService executor;

  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
            .collect(Collectors.toList());
    Future<List<SearchResult>> results = executor.submit(task);
    createAdvertisingLinks(request); // 3
    results.get().forEach(this::collateResult); // 4
  }
}
```

CompletableFuture

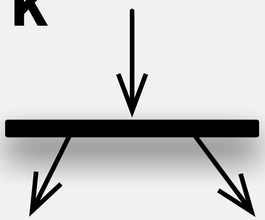
- **Convert each step into a CompletableFuture**
  - **Then combine these using *allOf()***
  - **Code is slightly faster, but a whole lot more complicated**
    - **Need separate pools for CPU and IO bound tasks**

Modeling Control Flow

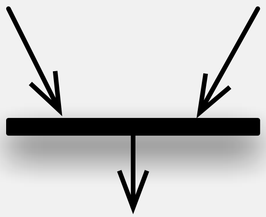
- **Our Renderer example as a UML Activity Diagram**



- **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);
  }
}
```

0.9 seconds

What about plain Thread?

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

renderPage() with native threads

threads = 11
0.5 seconds

```
public void renderPage(HttpRequest request) throws InterruptedException {
  ThreadMXBean tmb = ManagementFactory.getThreadMXBean();
  long threads = tmb.getTotalStartedThreadCount();

  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;
          })
          .collect(Collectors.toList());
  createAdvertisingThread.join();
  for (Thread searchAndCollateThread : searchAndCollateThreads) {
    searchAndCollateThread.join();
  }

  threads = tmb.getTotalStartedThreadCount() - threads;
  System.out.println("threads = " + threads);
}
```

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 ...

- **Grab our Data Structures in Java Course here**
- **https://tinyurl.com/JAX2021**

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
      .collect(Collectors.toList());
  createAdvertisingLinks(request); // 3
  results.forEach(this::collateResult); // 4
}
```

Virtual threads galore

0.5 seconds

```
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())))
        .collect(Collectors.toList());
  createAdvertisingThread.join();
  for (Thread searchThread : searchAndCollateThreads)
    searchThread.join();
}
```

How to create virtual threads

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

Structured Concurrency

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

0.5 seconds

Deadlines for ExecutorService

- **We can create virtual thread pool with deadline**

```
ExecutorService pool = Executors.newVirtualThreadExecutor(
  Instant.now().plusSeconds(1));
```

- **Our virtual threads are interrupted on timeout**
  - **We need to regularly check our interrupted status**
  - **A good approach is to then throw a CancellationException**

```
private void sleepSilently(int millis) {
  try {
    Thread.sleep(millis);
  } catch (InterruptedException e) {
    Thread.currentThread().interrupt();
    throw new CancellationException("interrupted");
  }
}
```

- **No easy way currently to know which task timed out**

Structured Concurrency with Deadline

0.3 seconds
TimeoutException

```
Collection<Future<?>> futures = new ConcurrentLinkedQueue<>();
try (ExecutorService mainPool = Executors.newVirtualThreadExecutor(
    Instant.now().plusMillis(300))) {
  Stream.of(
      mainPool.submit(() -> createAdvertisingLinks(request)), // 3
      mainPool.submit(() -> {
        List<SearchTerm> terms = scanForSearchTerms(request); // 1
        try (ExecutorService searchAndCollatePool =
                 Executors.newVirtualThreadExecutor()) {
          terms.stream()
              .map(term -> searchAndCollatePool.submit( // 2 & 4
                  () -> collateResult(term.searchOnPartnerSite())))
              .forEach(futures::add);
        }
      })
  ).forEach(futures::add);
}
if (futures.stream().anyMatch(Future::isCancelled))
  throw new TimeoutException("Timed out");
```

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
  - Loom: LinkedTransferQueue, SynchronousQueue, SelectorImpl, Object.wait()

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
  - -XX:+UseBiasedLocking to enable it again
  - Please report if turning it on makes a big difference

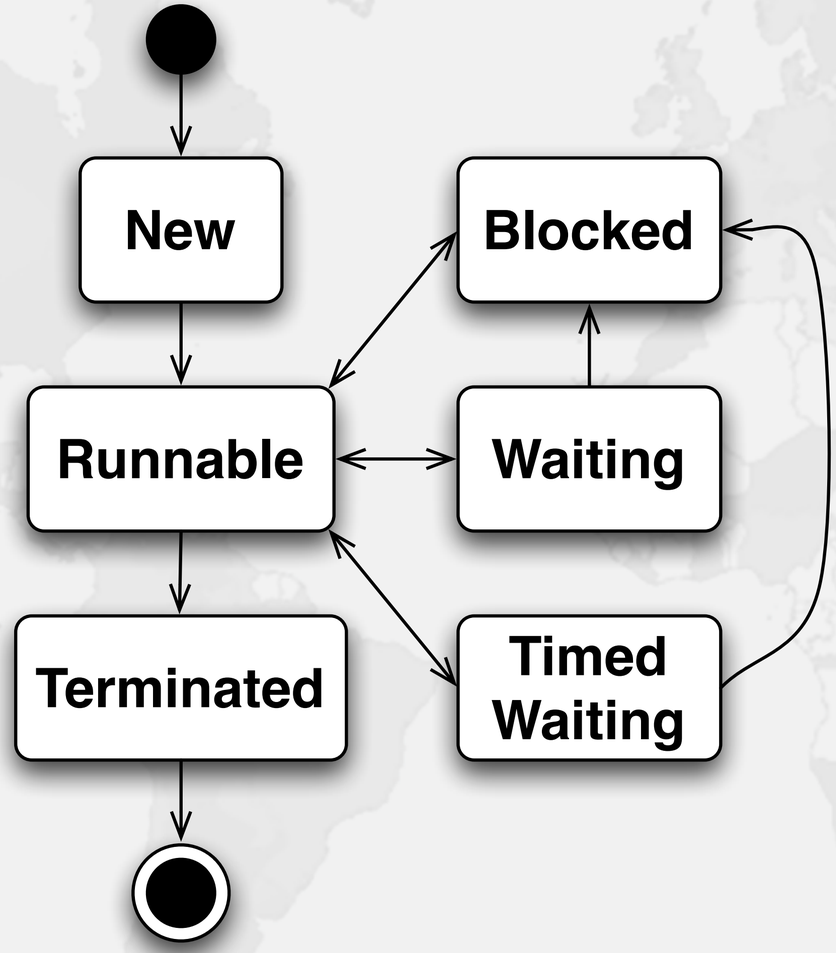
Rather do not use ThreadLocal

- **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)**

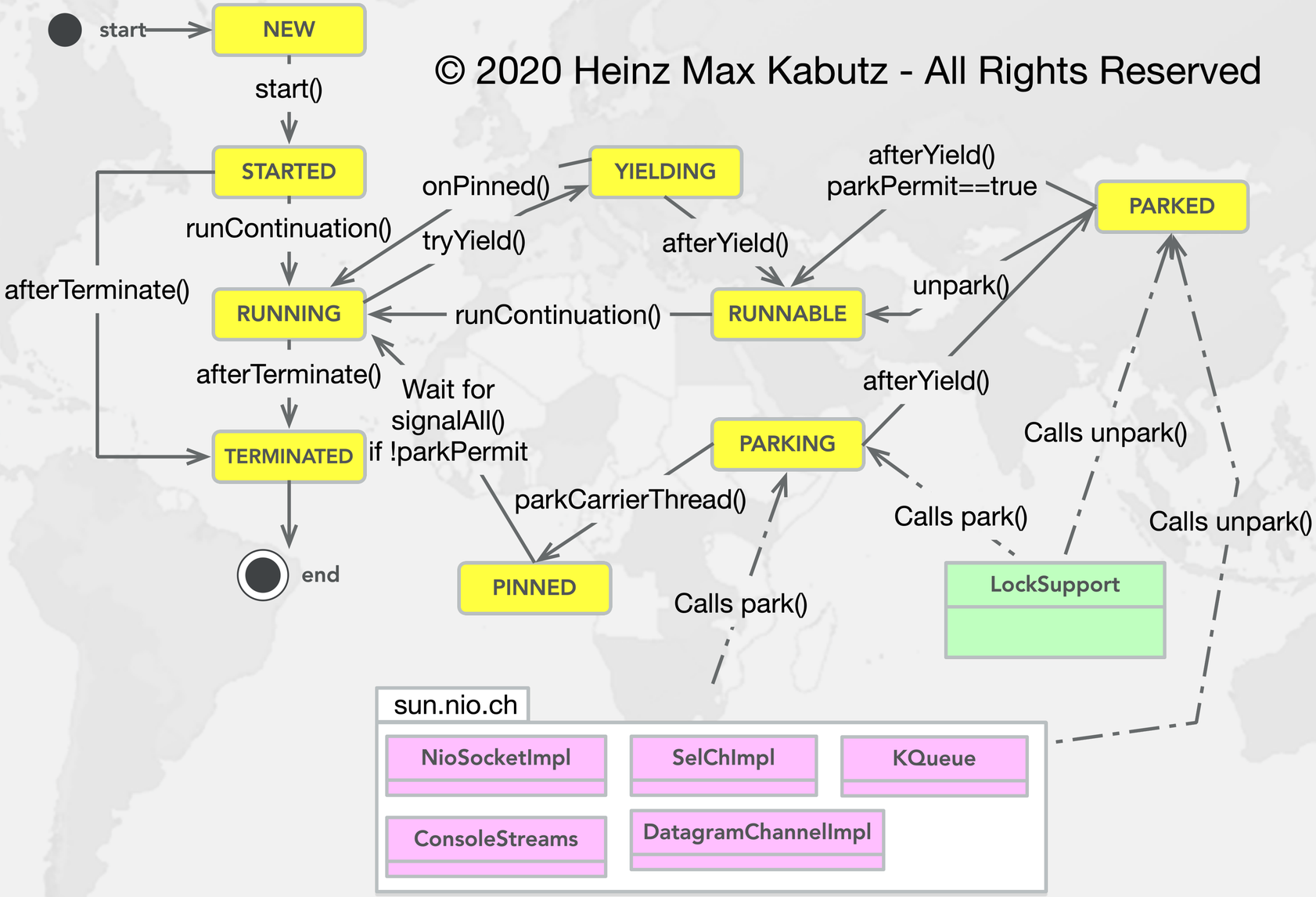
```
public class ThreadLocalTest {
  private static final ThreadLocal<DateFormat> df =
      ThreadLocal.withInitial(() ->
          new SimpleDateFormat("yyyy-MM-dd") {
            {
              System.out.println("Making SimpleDateFormat");
            }
          });

  public static void main(String... args) throws Exception {
    Runnable task = () -> {
      try {
        for (int i = 0; i < 3; i++) {
          System.out.println(df.get().parse("2020-05-04"));
        }
      } 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 2020
Mon May 04 00:00:00 EEST 2020
Mon May 04 00:00:00 EEST 2020

Disallowing Thread Locals
Making SimpleDateFormat
Mon May 04 00:00:00 EEST 2020
Making SimpleDateFormat
Mon May 04 00:00:00 EEST 2020
Making SimpleDateFormat
Mon May 04 00:00:00 EEST 2020
```

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**

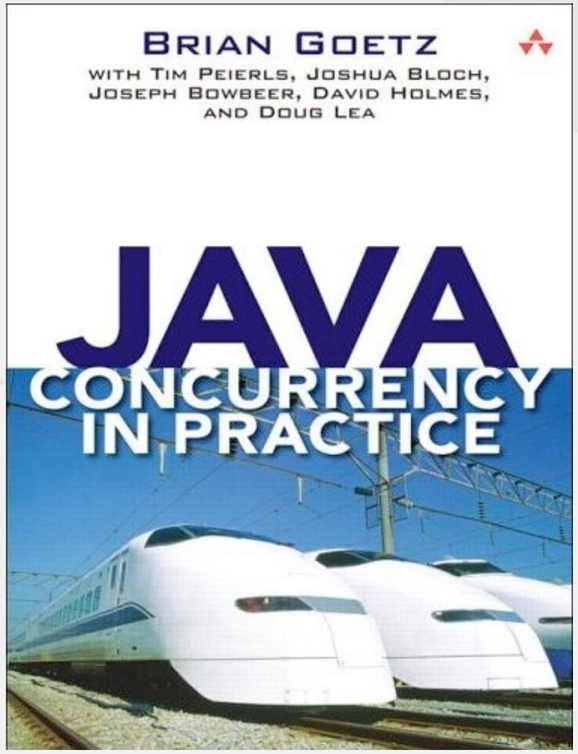
Memory overhead of IO Streams

	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**

Education is Key



- Concurrency Specialist Course
  - https://www.javaspecialists.eu/courses/concurrency/
- Only Java concurrency course officially endorsed by Brian Goetz, author of Java Concurrency in Practice
- Taught remotely anywhere in the world
- Includes all the latest Java concurrency constructs
  - Virtual threads and Project Loom on request
- Don't forget gift: https://tinyurl.com/JAX2021

Extreme Java - Concurrency Performance

- **3 day course run online live**
- **https://extreme-java-camp.de/**

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Questions?

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