Prepare for what *Loom*s ahead

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java training

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- The Java Specialists' Newsletter
  - 319 editions, published since 2000
  - www.javaspecialists.eu
- Please say "hi" after talk and during conference :-)
  - Ich beiße nicht!
  - Afterwards heinz@javaspecialists.eu

When is Loom Coming?

- **Virtual threads were fully released in Java 21**
- **Structured Concurrency & Scoped Values in Java 24 preview**
  - **Not ready yet, hopefully for Java 25 - LTS**

Why do we need Virtual Threads?

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

Parallel Computing

- Solving a problem on many CPUs in parallel
  - Large problem is broken into smaller ones, solved in parallel
  - Focus is on solving problems faster
  - Communication overhead reduces speedup possibilities
- Typically used on large number of cores
  - Few threads per core
- Java: ForkJoin or parallel streams
- Examples: Weather prediction, financial trend analysis

Concurrent Computing

- Interacting tasks may execute concurrently
  - Independent tasks simplify architecture
  - Do something useful during wait time (IO, Locks, etc.)
  - Focus on task interaction (memory integrity, progress)
  - Does not always scale well with native threads
- Can be used on any number of cores
- Java: Structured concurrency, virtual threads
- Examples: Blocking IO, background tasks

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

4.3 seconds

- **Sequential processing is the simplest**

```
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

```
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
  }
}
```

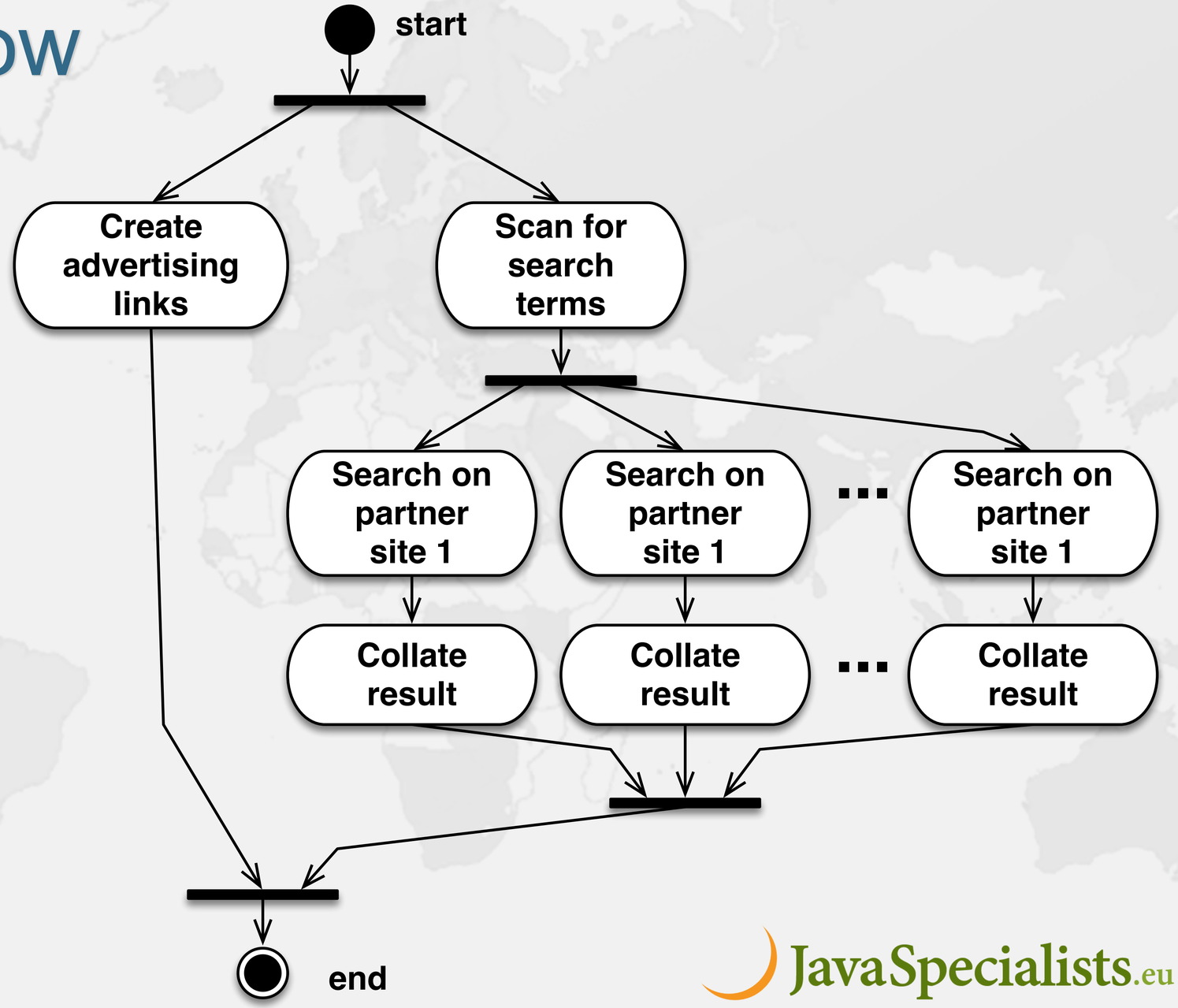
4.1 seconds

CompletableFuture

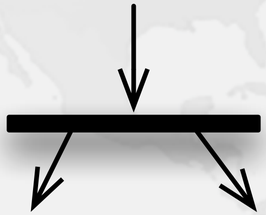
- **Convert each step into a CompletableFuture**
  - **Then combine these using *allOf()***
  - **Code is slightly faster, but a whole lot more complicated**
    - **Need separate pools for CPU and IO bound tasks**

Modeling Control Flow

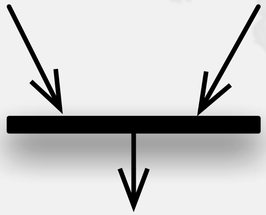
- Renderer example as UML Activity Diagram



- 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 platform threads

```
public void renderPage(HttpRequest request)
    throws InterruptedException {
  Thread createAdvertisingThread =
      new Thread(() -> createAdvertisingLinks(request)); // 3
  createAdvertisingThread.start();
  List<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();
}
```

0.5 seconds

Started 11 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 a ForkJoinPool
    - Carriers are always daemon threads

Configuring Carrier Threads

- # threads is Runtime.getRuntime().availableProcessors()
  - Configure size with `jdk.virtualThreadScheduler.parallelism`
  - Can temporarily increase due to ManagedBlocker
    - Configure with `jdk.virtualThreadScheduler.maxPoolSize`
- Moved off carrier threads when blocking on IO
  - Also with waiting on synchronizers from java.util.concurrent

Before we continue ...

- **A small gift for you - coupon expires at 13:30**
  - **Be sure to enable emails**

`tinyurl.com/wjax2024-3`

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
}
```

tinyurl.com/wjax2024-3

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

tinyurl.com/wjax2024-3

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

Using ExecutorService - Unstructured

0.5 seconds

```
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())));
      }
    });
  }
}
```

Structured Concurrency (preview)

- **Better approach for describing concurrent flows**
  - **https://openjdk.org/jeps/480 new JEP coming soon**
  - **Idioms are still being developed, e.g.**

```
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
  }
}
```

0.5 seconds

InterruptedException

- Long-running methods should check if "interrupted"
  - And avoid "swallowing" InterruptedException
- StructuredDemo

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, CountDownLatch, Semaphore, etc.
  - 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

Things to know about Virtual Threads

- Future now has: resultNow(), exceptionNow(), state()
  - See demo TimeoutInPool
- Java networking IO is interruptible on virtual threads
  - In the past, we had to close the socket, stop() didn't work
- Reflection rewritten to avoid native code (JEP 416)
- Thread dump does not pause application
  - $ jcmd <pid> Thread.dump_to_file -format=json <file>
- Stack depth same as the JVM native threads

Things to know about Virtual Threads

- Unlike old threads, virtual threads aren't GC roots
- Since Java 20, Thread.stop() throws an UnsupportedOperationException
- ThreadGroup does not enumerate virtual threads
- Virtual Thread that cannot be unblocked are GCed
  - Caused dumb demos to appear to create billions of threads

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**

```
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();
```

no output

Object.wait() calles wait(0L)

```
public final void wait(long timeoutMillis) throws InterruptedException {
    long comp = Blocker.begin();
    try {
        wait0(timeoutMillis);
    } catch (InterruptedException e) {
        Thread thread = Thread.currentThread();
        if (thread.isVirtual())
            thread.getAndClearInterrupt();
        throw e;
    } finally {
        Blocker.end(comp);
    }
}
```

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
- Synchronized is fine for guarding memory
  - Debug with jdk.tracePinnedThreads=full or short

Biased Locking Turned Off

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

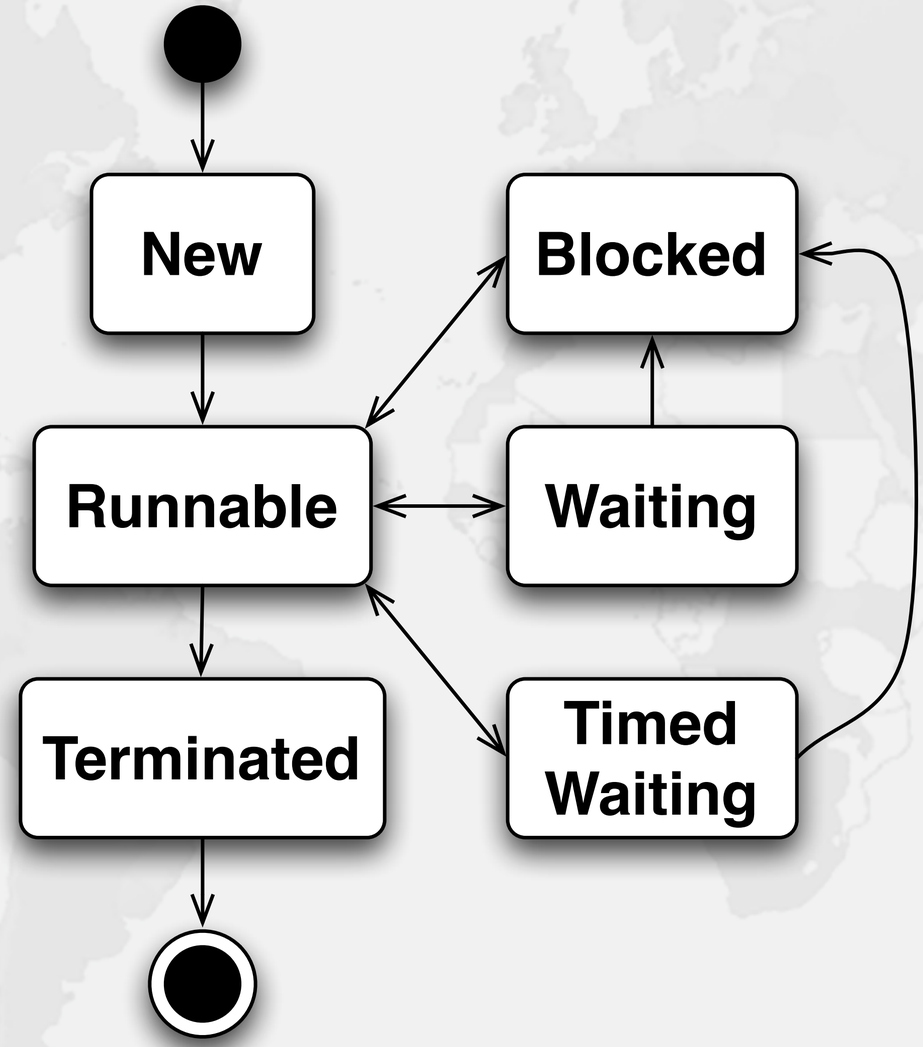
Rather do not use ThreadLocal

- Virtual threads do support ThreadLocal
  - However, it is costly
  - Virtual threads not reused
    - ThreadLocals often do not make sense
- Rather use Scoped Values - preview
  - https://openjdk.org/jeps/487

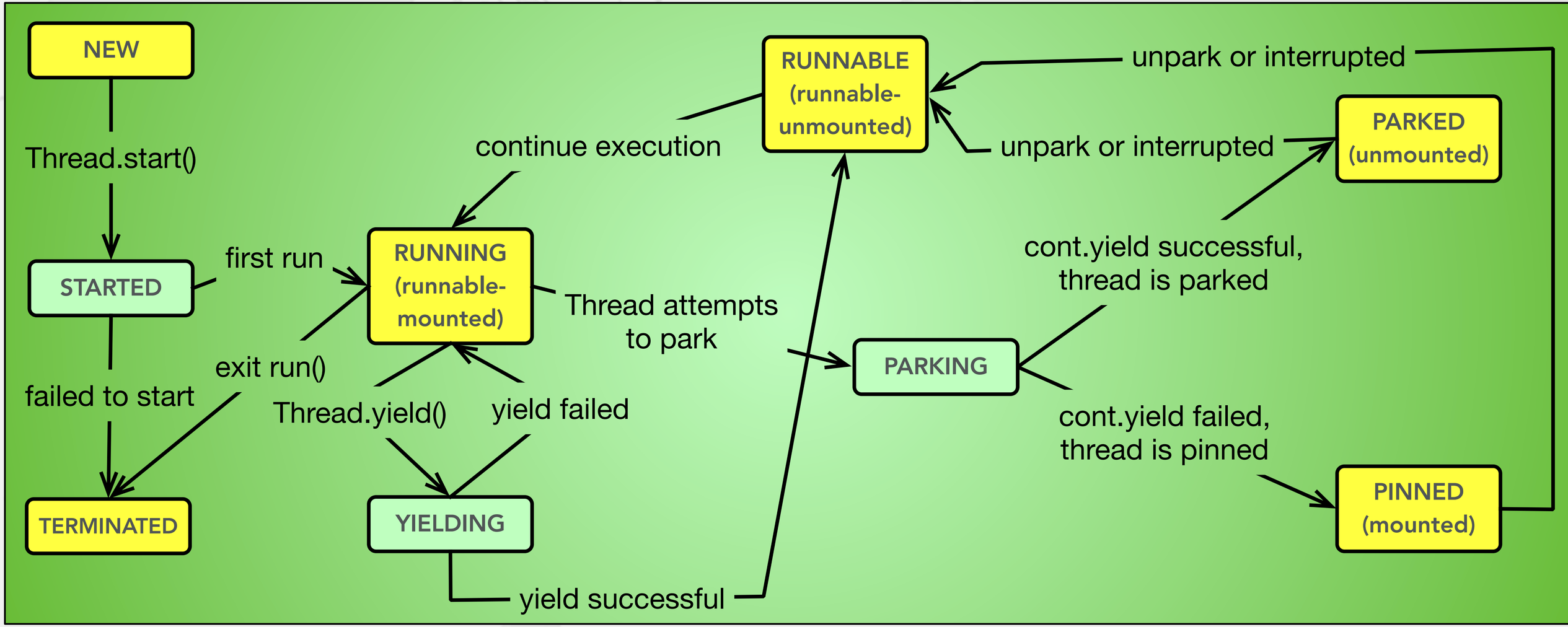
Naming

- 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



Virtual thread states

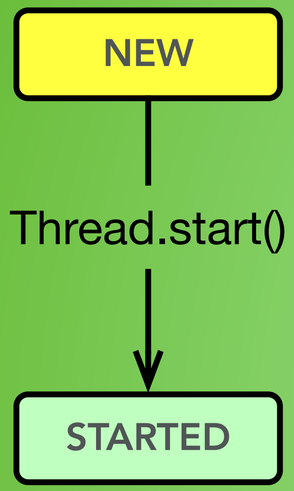


java.lang.VirtualThread States

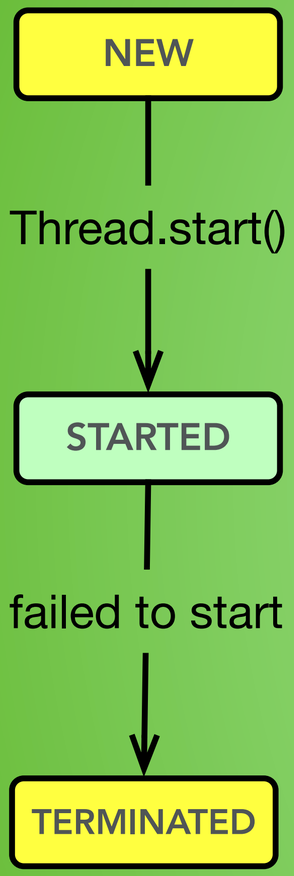
NEW

```
Thread.ofVirtual().unstarted(() -> {})
```

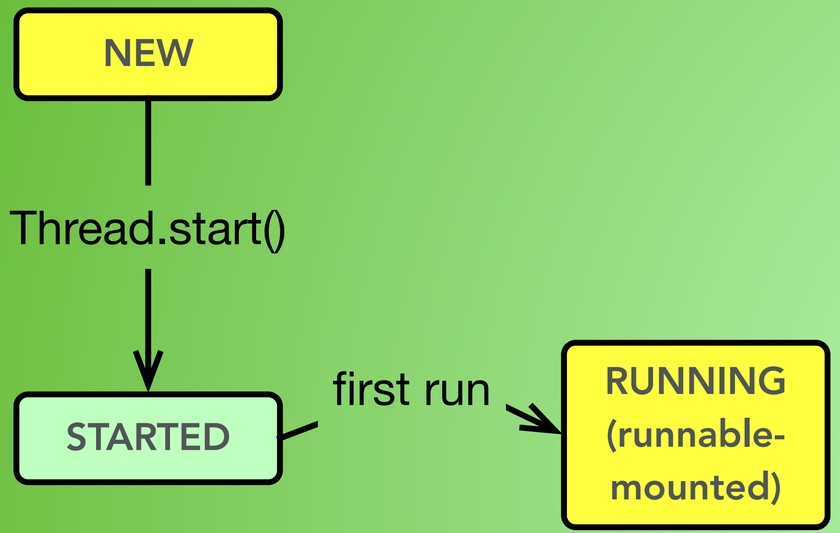
STARTED is a transient state



Might go straight to TERMINATED



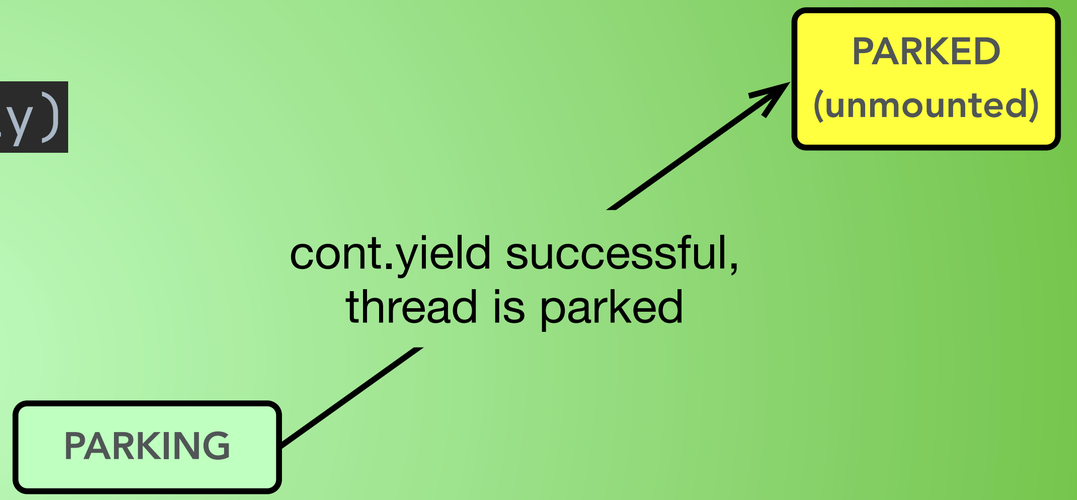
More likely to go to RUNNING



A blocking method goes to PARKING

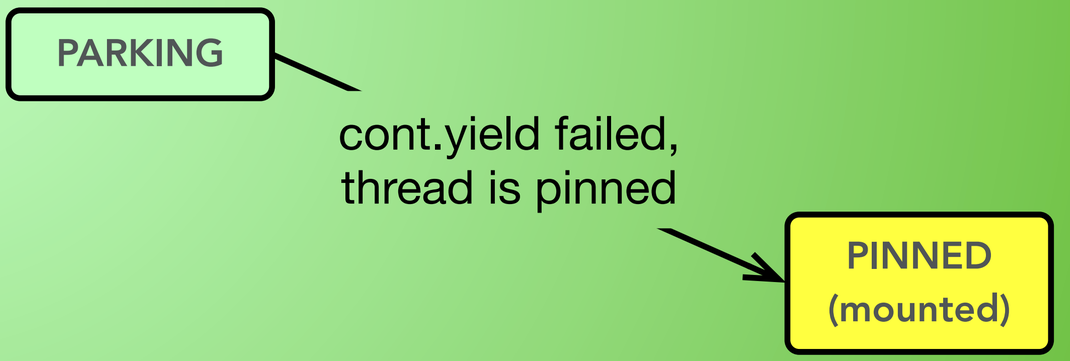
If successful, go to PARKED

```
Thread.startVirtualThread(
        semaphore::acquireUninterruptibly)
```

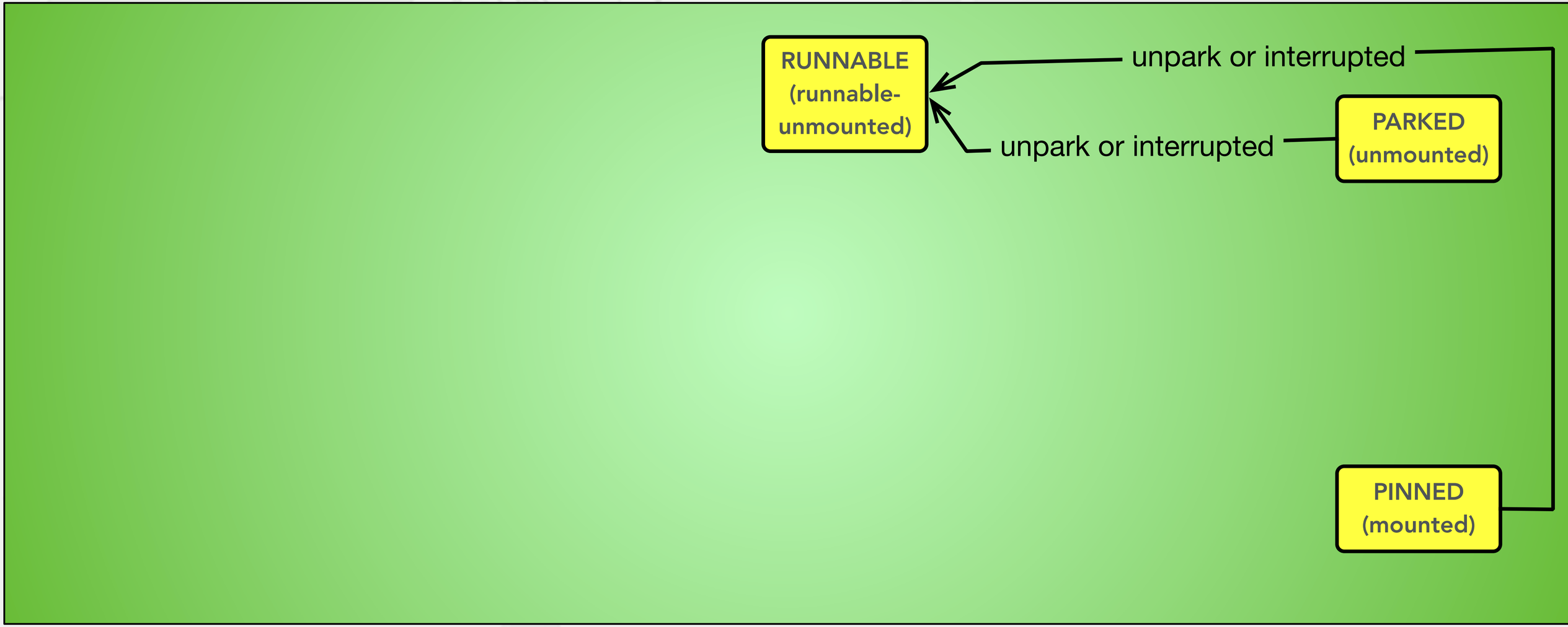


If not successful, go to PINNED

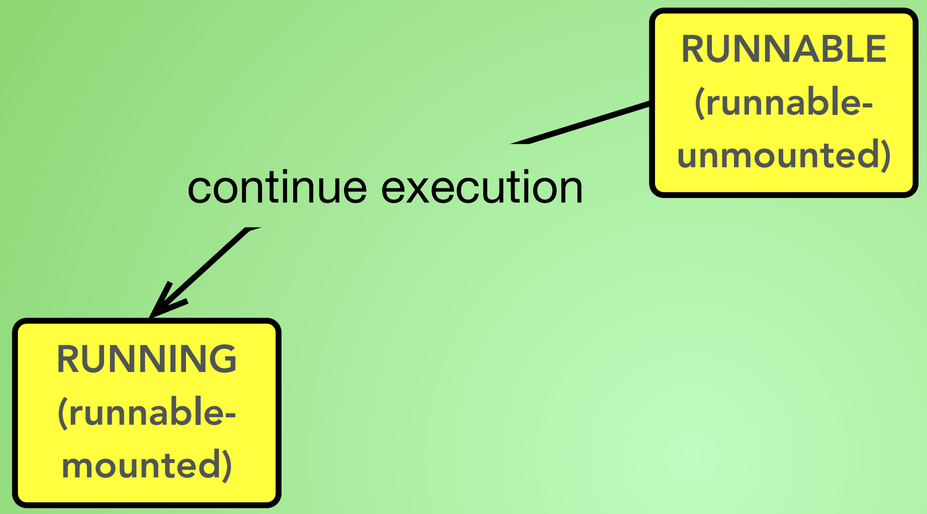
```
Thread.startVirtualThread(() -> {
    synchronized (semaphore) {
        semaphore.acquireUninterruptibly();
    }
});
```



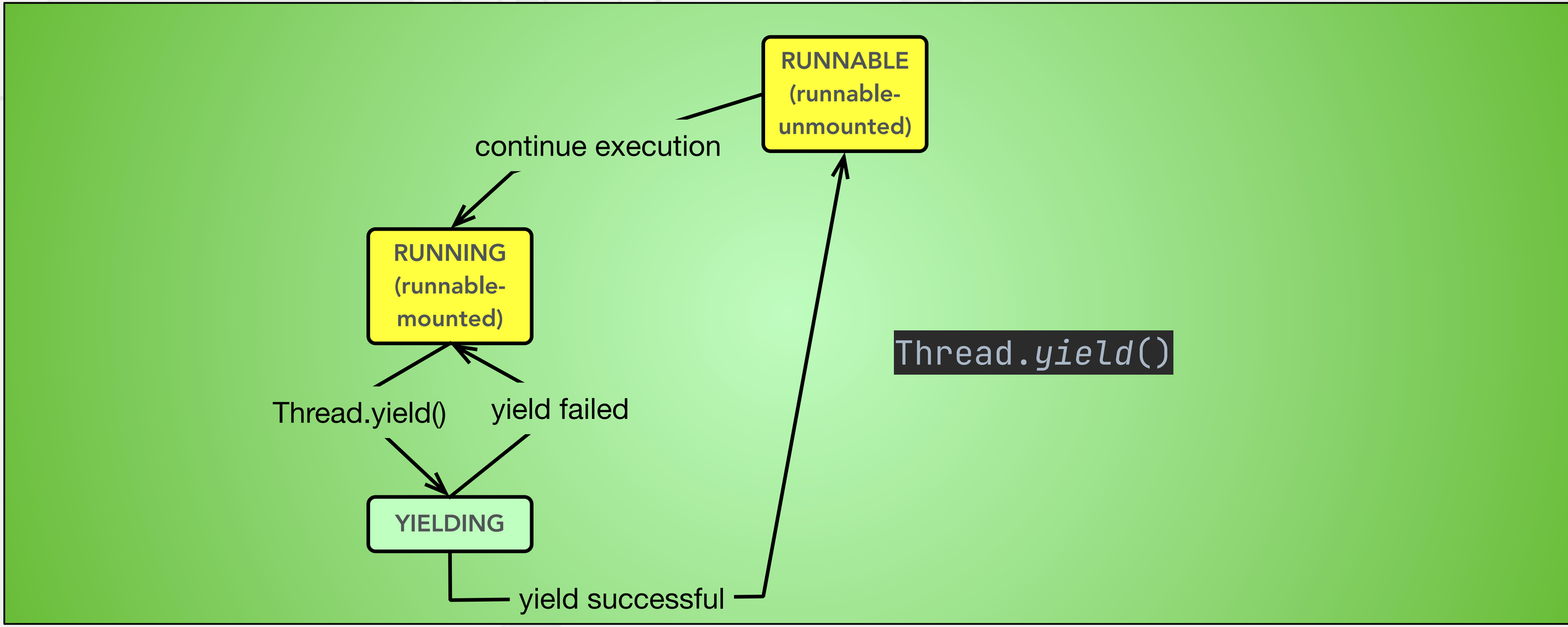
Unpark or interrupt goes to RUNNABLE



RUNNABLE back to RUNNING

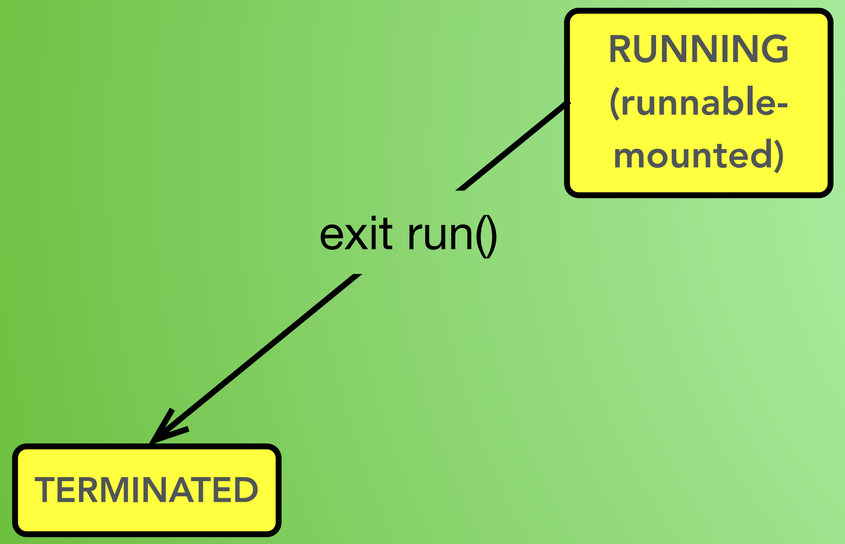


Can try to Thread.yield()

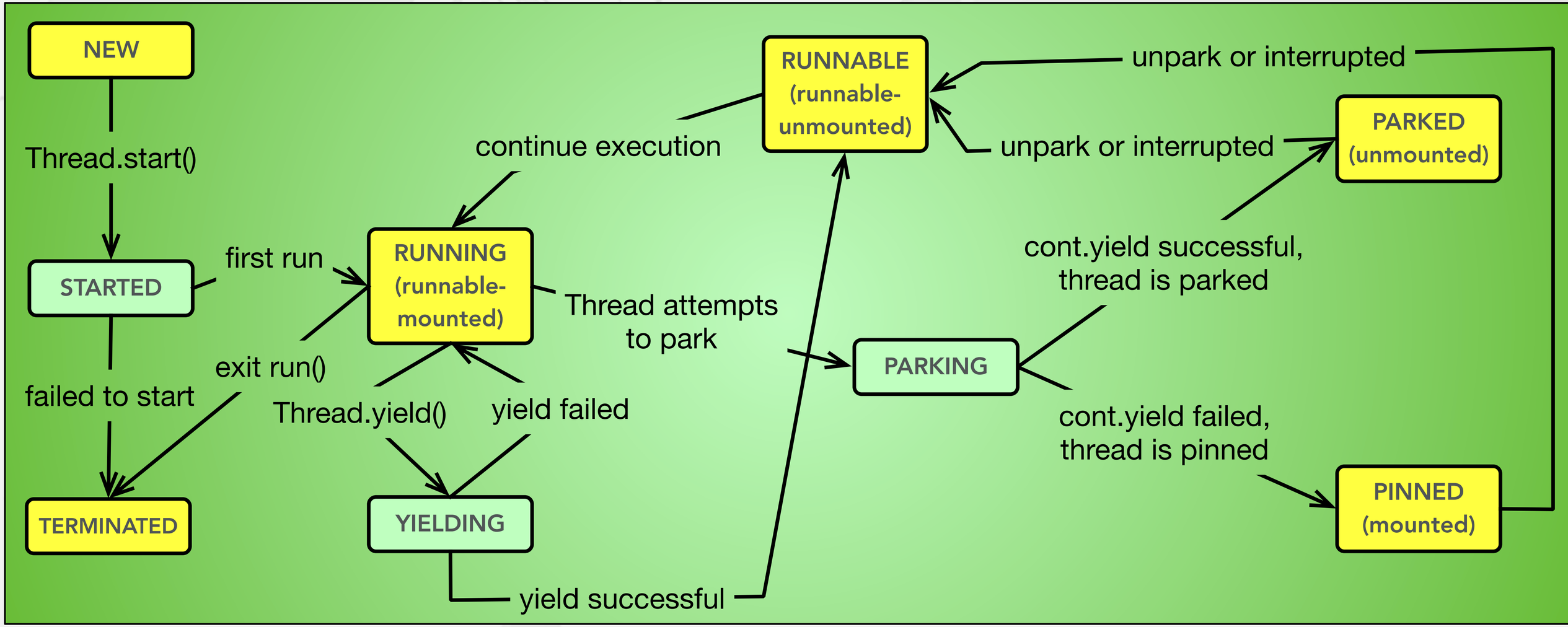


When done, we go to TERMINATED

```
Thread terminated = Thread.ofVirtual().start(() -> {});
terminated.join();
```



Full State Machine



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!**

Parallel Programming with Loom?

- **Loom for concurrent programming, not parallelism**
  - **Best not to do CPU intensive work in virtual threads**
    - **Use platform threads and ForkJoin or parallel streams**

Trick Question

- **How long will this take to execute?**

```
public class ParallelismPuzzle {
  public static void main(String... args) {
    long time = System.nanoTime();
    try {
      ForkJoinPool.commonPool().submit(() -> {
        long until = System.currentTimeMillis() + 1000;
        while (System.currentTimeMillis() <= until) ;
      }).join();
    } finally {
      time = System.nanoTime() - time;
      System.out.printf("time = %dms%n", (time / 1_000_000));
    }
  }
}
```

How long?

- Either about one second
  - This is the expected answer
- Or forever
  - If -Djava.util.concurrent.ForkJoinPool.common.parallelism=0

How long will this take?

- **Obviously depends on common pool parallelism**

```
public class ParallelStreamPuzzle {
  public static void main(String... args) {
    long time = System.nanoTime();
    try {
      IntStream.range(0, Runtime.getRuntime().availableProcessors())
          .parallel()
          .forEach(i -> {
            System.out.println(Thread.currentThread());
            long until = System.currentTimeMillis() + 1000;
            while (System.currentTimeMillis() <= until) ;
          });
    } finally {
      time = System.nanoTime() - time;
      System.out.printf("time = %dms%n", (time / 1_000_000));
    }
  }
}
```

How long?

- Either about one second
  - This is the expected answer
- Or longer, but not forever, even with
  - -Djava.util.concurrent.ForkJoinPool.common.parallelism=0

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
      - Example from Spar during lockdown
      - If a permit is lost due to an exception, parallelism is reduced

Don't forget ... almost at the end ...

tinyurl.com/wjax2024-3

When will Loom be ready?

- **Virtual threads in Java 21, JEP 444**
  - **Some parts still in preview stage in Java 24:**
    - **Structured concurrency (JEP TBD) and Scoped Values (JEP 487)**
- **Java has different levels of readiness**
  - **Part of the JDK**
  - **Preview feature - mostly done, supported by all vendors**
  - **Experimental feature - not necessarily in all Java runtimes**
  - **Incubator**