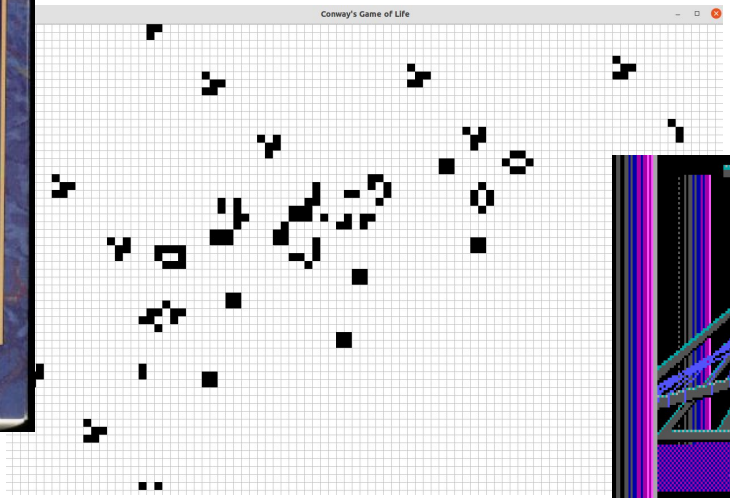
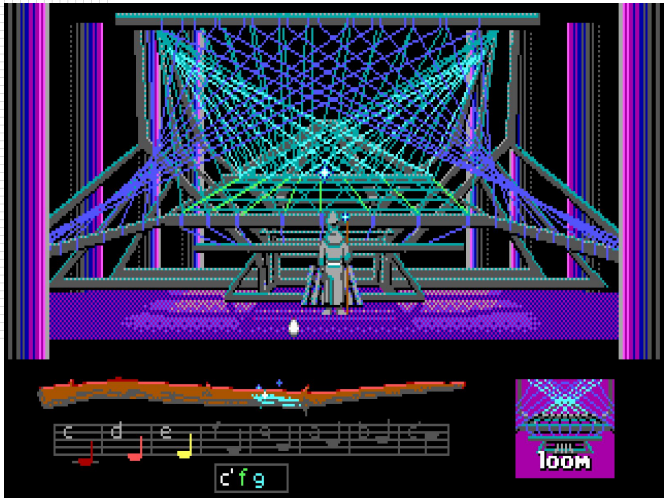
Game of Loom 2: life and dead(lock) of a virtual thread



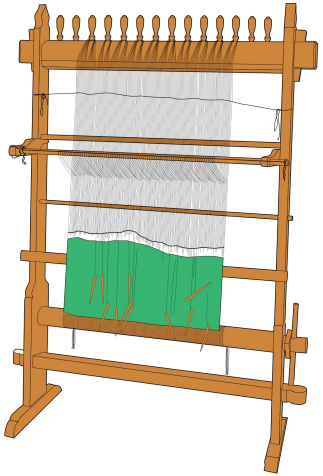


by Mario Fusco

@mariofusco

Where did we leave? A recap on virtual threads …

- **Virtual threads** make a better use of OS threads **getting rid of the 1:1 relationship** with operating system threads
  - Many virtual threads can be **multiplexed** on the same platform thread (**carrier**)



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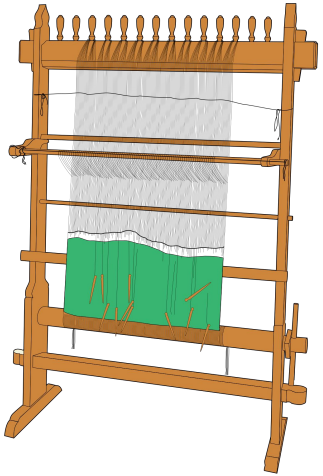
- When a virtual thread calls a blocking operation the JDK performs a **nonblocking OS call** and automatically **suspends** the virtual thread **until the operation finishes**
  - Virtual threads perform **blocking calls without consuming resources**, thus allowing to **write asynchronous** code in a way that **looks synchronous**
  - What virtual threads are really good for is … **waiting**



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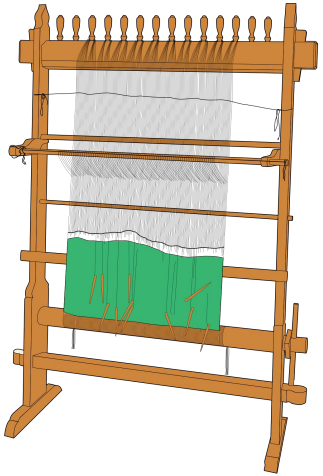
  - What virtual threads are really good for is … **waiting**
- Virtual threads are **lightweight**
  - 200-300B metadata
  - Pay-as-you-go **stack** (allocated on heap)
  - Some ns (or below 1µs) for **context switch** (in **user space**)




VIRTUAL THREADS
LIGHTYEAR
VIRTUAL THREADS EVERYWHERE
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YOU WANT VIRTUAL THREADS
EVERYBODY WANT VIRTUAL THREADS
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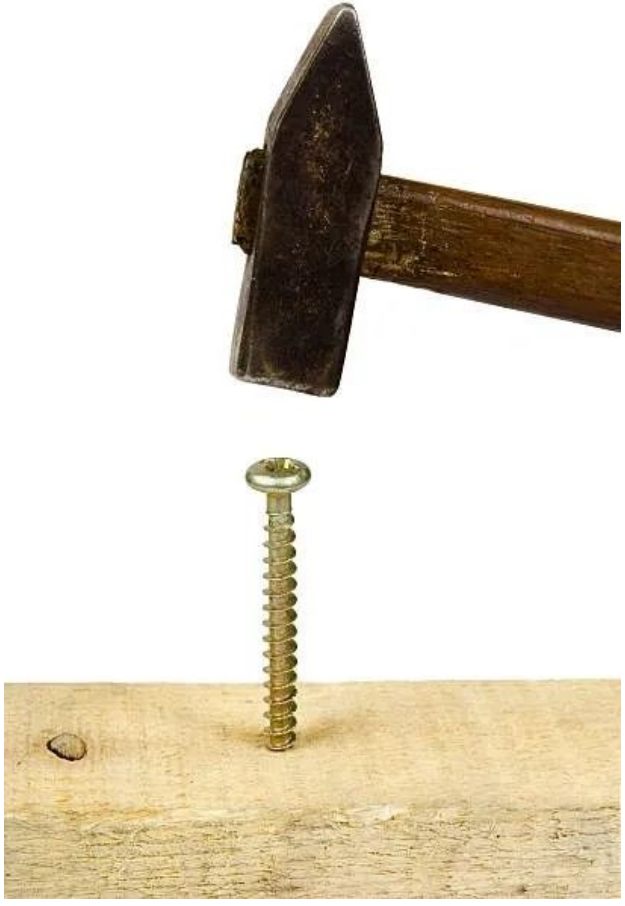
Should we really use virtual threads *EVERYWHERE*?



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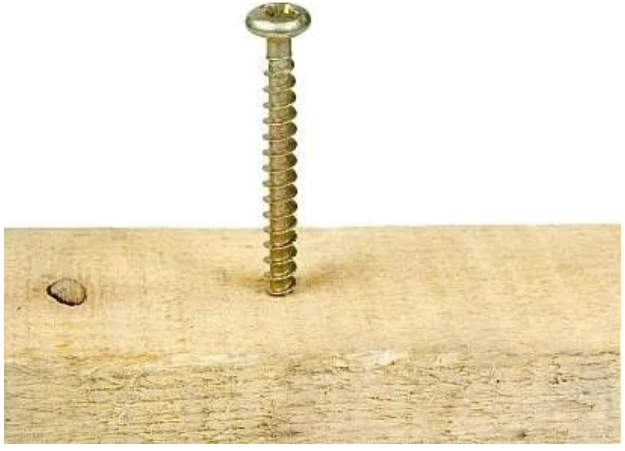
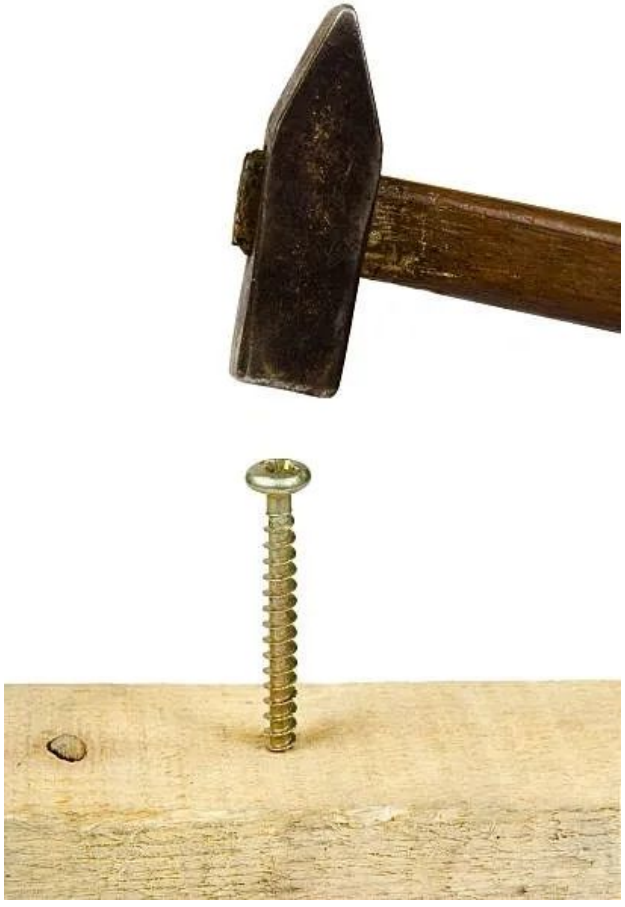


- Not ideal for CPU-bound task

Lack of fairness due to the fact that virtual threads are **not pre-emptive**

Overall performance concerns caused by overhead of virtual threads scheduler

Should we really use virtual threads *EVERYWHERE*?



- Not ideal for CPU-bound task
  - **Lack of fairness** due to the fact that virtual threads are **not pre-emptive**
  - **Overall performance** concerns caused by overhead of virtual threads scheduler
- **Not virtual-threads friendly** frameworks & tools
  - Use of `synchronize` can lead to **pinning**
  - Use of **ThreadLocal**

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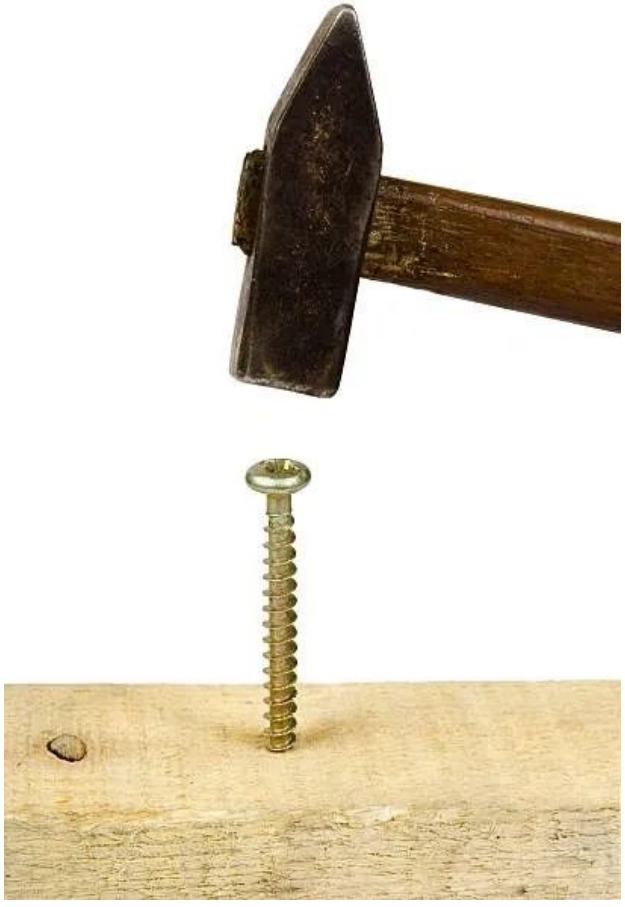

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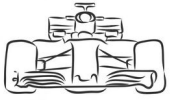
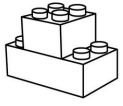
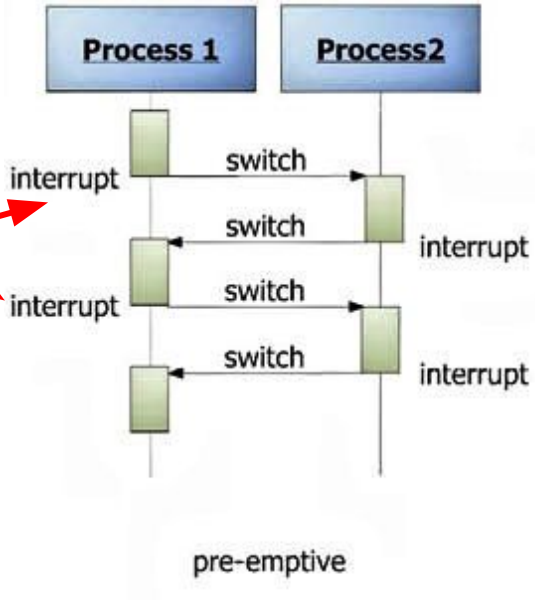
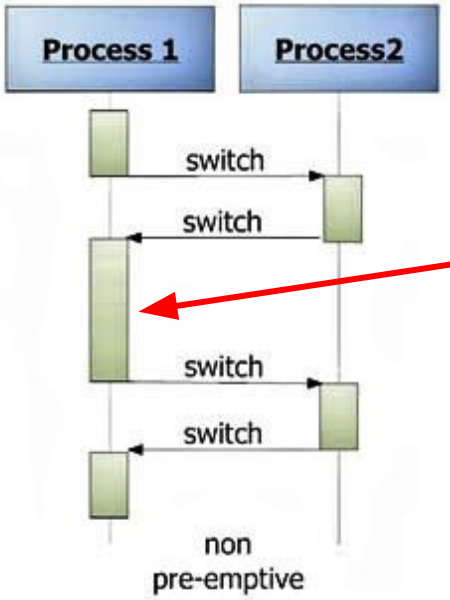
  -  **Overall performance** concerns caused by overhead of virtual threads scheduler
- **Not virtual-threads friendly** frameworks & tools
  -  Use of `synchronize` can lead to **pinning**
  -  Use of **ThreadLocal**
- **Poorly customizable**
  -  **Carrier** native thread pool is **not pluggable** (but for a very good reason)

Lack of fairness in CPU bound tasks

Virtual Threads are **not pre-emptive**, they cannot be descheduled while running heavy calculations without ever calling a JDK's blocking methods, so they are **not a good fit for CPU-bound** tasks when **fairness** is key

Interrupts the processing of a task and transfers the CPU to another process





Non-preemptive operation usually proceeds towards completion uninterrupted

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Virtual Threads are **not pre-emptive**, they cannot be descheduled while running heavy calculations without ever calling a JDK's blocking methods, so they are **not a good fit for CPU-bound** tasks when **fairness** is key

The cost of a continuation

In Project Loom, the word **continuation** means **delimited continuation**, also sometimes called a **coroutine**. It can be thought of as sequential code that may suspend or yield execution at some point by itself and can be resumed by a caller.

When a virtual thread hits a blocking call its continuation is **suspended** and the JVM **unmounts** the thread from its carrier …

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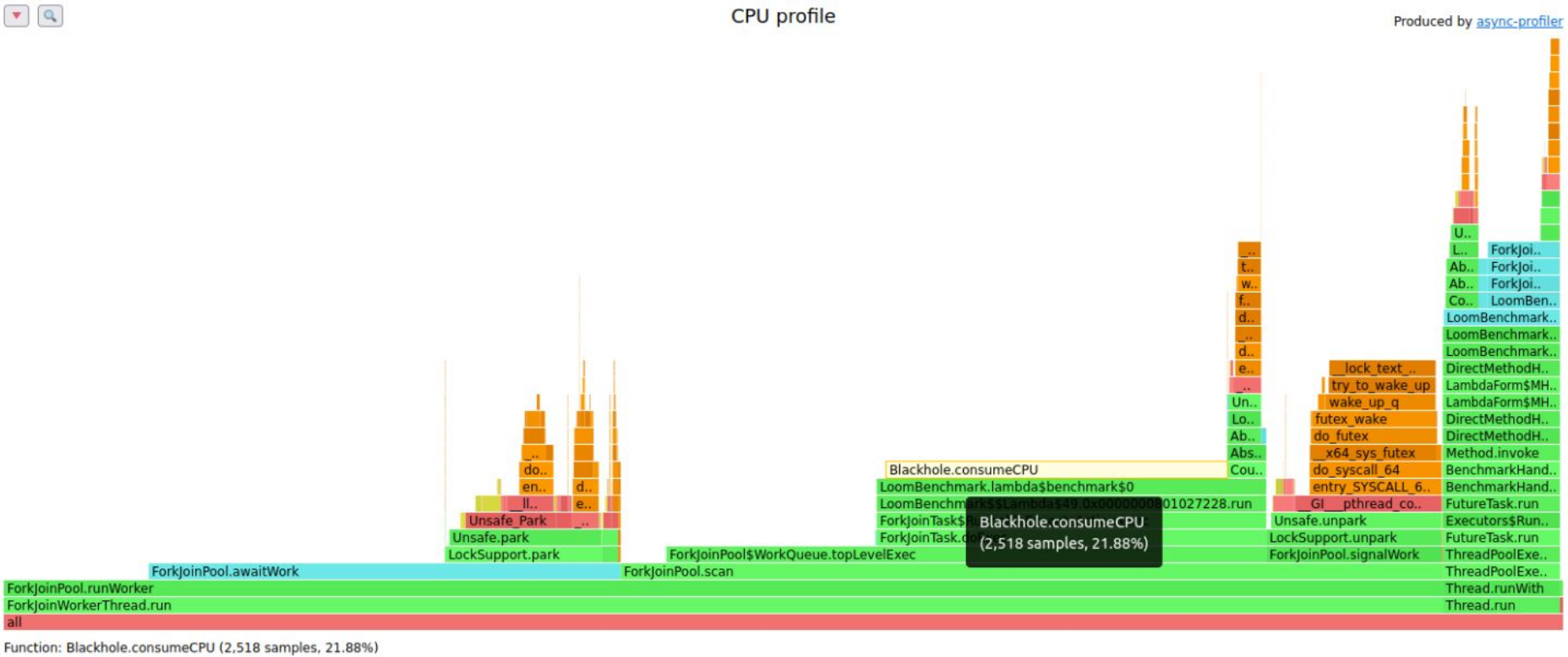
When a virtual thread hits a blocking call its continuation is **suspended** and the JVM **unmounts** the thread from its carrier …

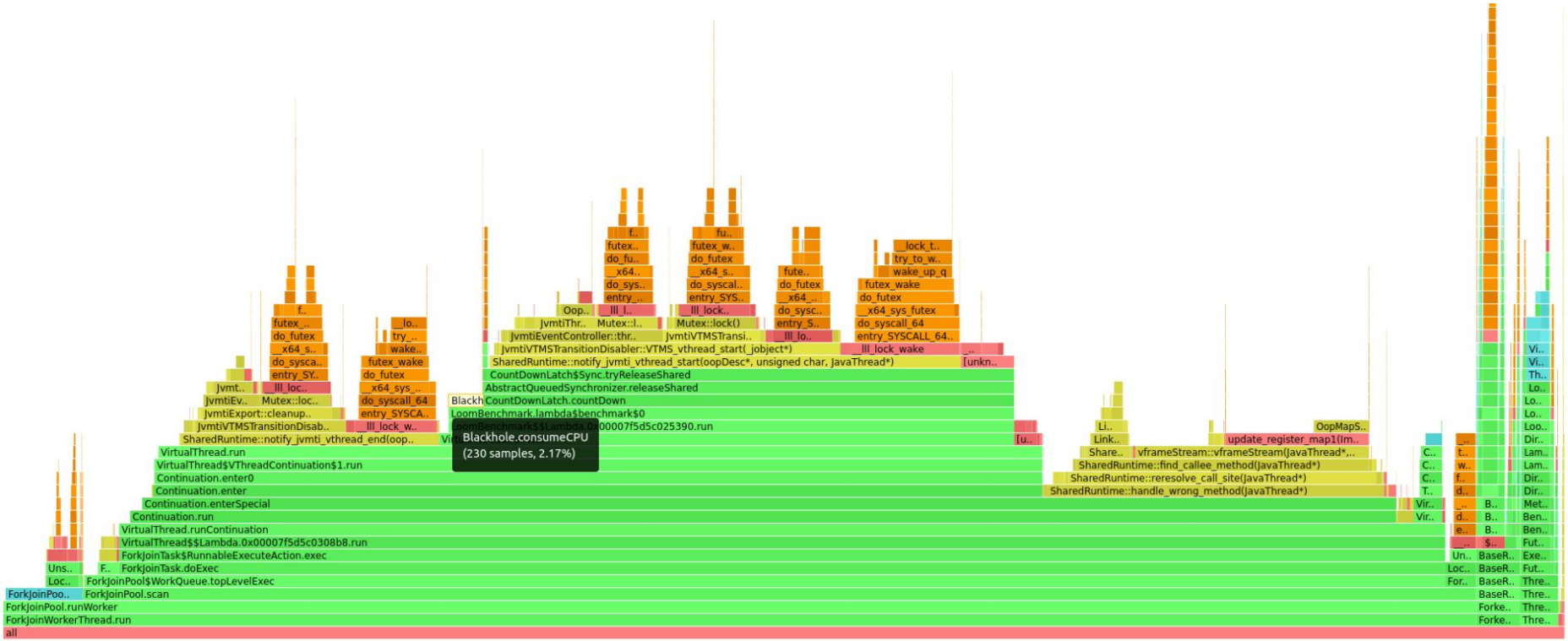
… but this also has a cost!

Native Threads Execution



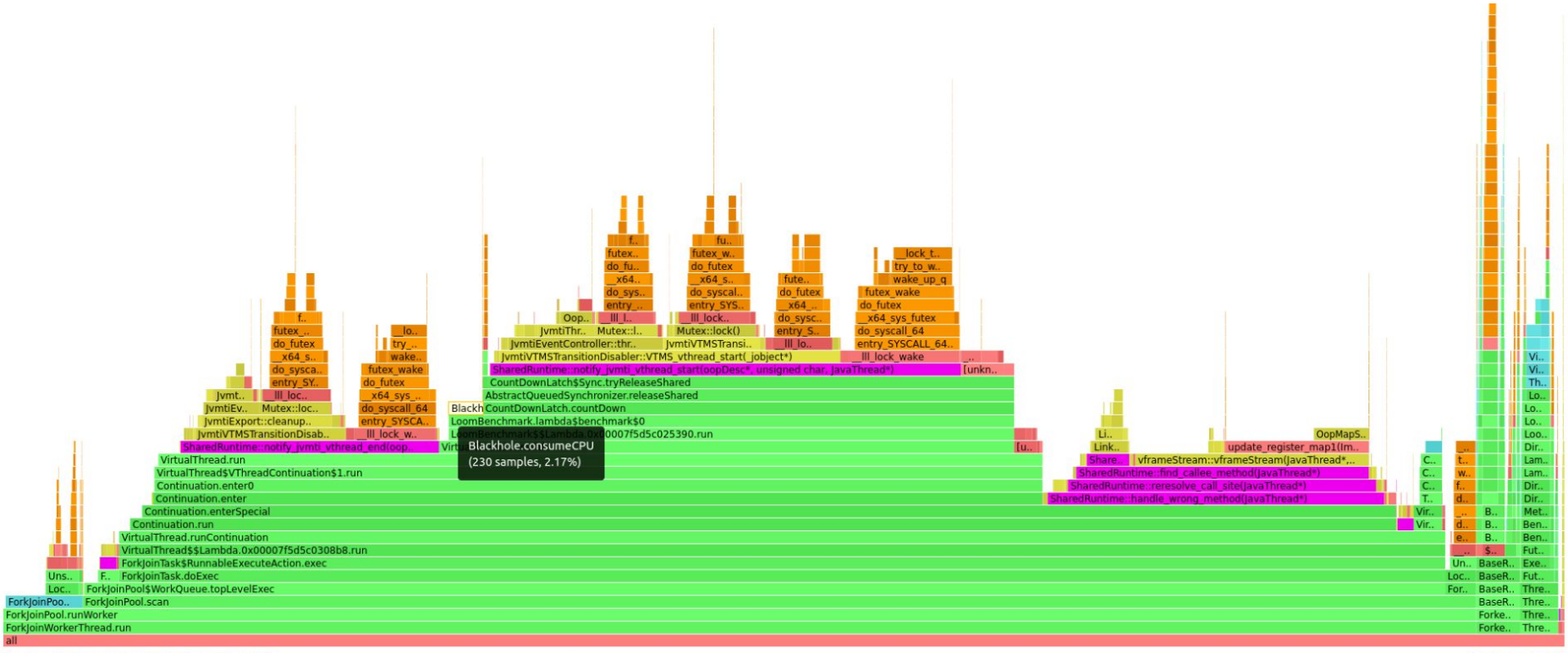
Function: Blackhole.consumeCPU (2,518 samples, 21.88%)

Virtual Threads Execution - The cost of a continuation



Function: Blackhole.consumeCPU (230 samples, 2.17%)

Virtual Threads Execution - The cost of a continuation



ThreadLocals as thread scoped variables

```
enum RightsLevel { ADMIN, GUEST }

record Principal(RightsLevel rights) {
   public boolean canOpen() {
       return rights == RightsLevel.ADMIN;
   }
}

record Request(boolean authorized) { }

class Server {
   final static ThreadLocal<Principal> PRINCIPAL =
                               new ThreadLocal<>();

   String serve(Request request) {
       var level = request.authorized() ?
            RightsLevel.ADMIN : RightsLevel.GUEST;
       PRINCIPAL.set( new Principal(level) );
       return Application.handle( request );
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```

```
static class DBConnection {
   static DBConnection open() {
       var principal = Server.PRINCIPAL.get();
       if (!principal.canOpen())
            throw new IllegalArgumentException();
       return new DBConnection();
   }

   String doQuery() {
       return "Result";
   }
}

static class Application {
   public static String handle(Request request) {
       return DBConnection.open().doQuery();
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ThreadLocals as thread scoped variables

A ThreadLocal is a construct that allows us to store data accessible only by a specific thread.

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static class Application {
   public static String handle(Request request) {
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```

ThreadLocals as (virtual) thread scoped variables

```
public static void main(String[] args) {
   var server = new Server();

   var authorized = Thread.ofVirtual().name("Authorized").unstarted(() -> callServer(server, true));
   var notAuthorized = Thread.ofVirtual().name("NOT Authorized").unstarted(() -> callServer(server, false));

   authorized.start();
   notAuthorized.start();

   try { Thread.sleep(1000L); } catch (InterruptedException e) { throw new RuntimeException(e); }
}

private static void callServer(Server server, boolean auth) {
   var result = server.serve(new Request(auth));
   System.out.println( "thread " + Thread.currentThread().getName() + " got result " + result );
}
```

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Exception in thread "NOT Authorized" java.lang.IllegalArgumentException
    at org.mfusco.loom.experiments.threadlocal.ThreadLocalMain$DBConnection.open(ThreadLocalMain.java:48)
    at org.mfusco.loom.experiments.threadlocal.ThreadLocalMain$Application.handle(ThreadLocalMain.java:41)

thread Authorized got result Result
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ThreadLocals as (virtual) thread scoped variables

So? Everything is fine, right?
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ThreadLocal with virtual threads?

ThreadLocals as (virtual) thread scoped variables

So? Everything is fine, right?
What is the problem to use
ThreadLocal with virtual threads?

- That we can have a **huge number of virtual threads**, and each virtual thread will have its own ThreadLocal
  - The **memory footprint** of the application may quickly become **very high**
  - ThreadLocal will be **useless in a one-thread-per-request scenario** since data won't be shared between different requests

ScopedValues to the rescue

```
class Server {
   final static ThreadLocal<Principal> PRINCIPAL = new ThreadLocal<>();

   String serve(Request request) {
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ScopedValues to the rescue (still preview in JDK 21)

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   }
}
```


```java
class Server {
   final static ScopedValue<Principal> PRINCIPAL =
                                       ScopedValue.newInstance();

   String serve(Request request) {
       var level = request.authorized() ?
                           RightsLevel.ADMIN : RightsLevel.GUEST;
       try {
           return ScopedValue.where(PRINCIPAL, new Principal(level))
                             .call(() -> Application.handle(request));
       } catch (Exception e) { throw new RuntimeException(e); }
   }
}
```

ThreadLocals as Cache / Objects Pool ???

Do ScopedValues cover all the possible typical usage patterns of ThreadLocals?

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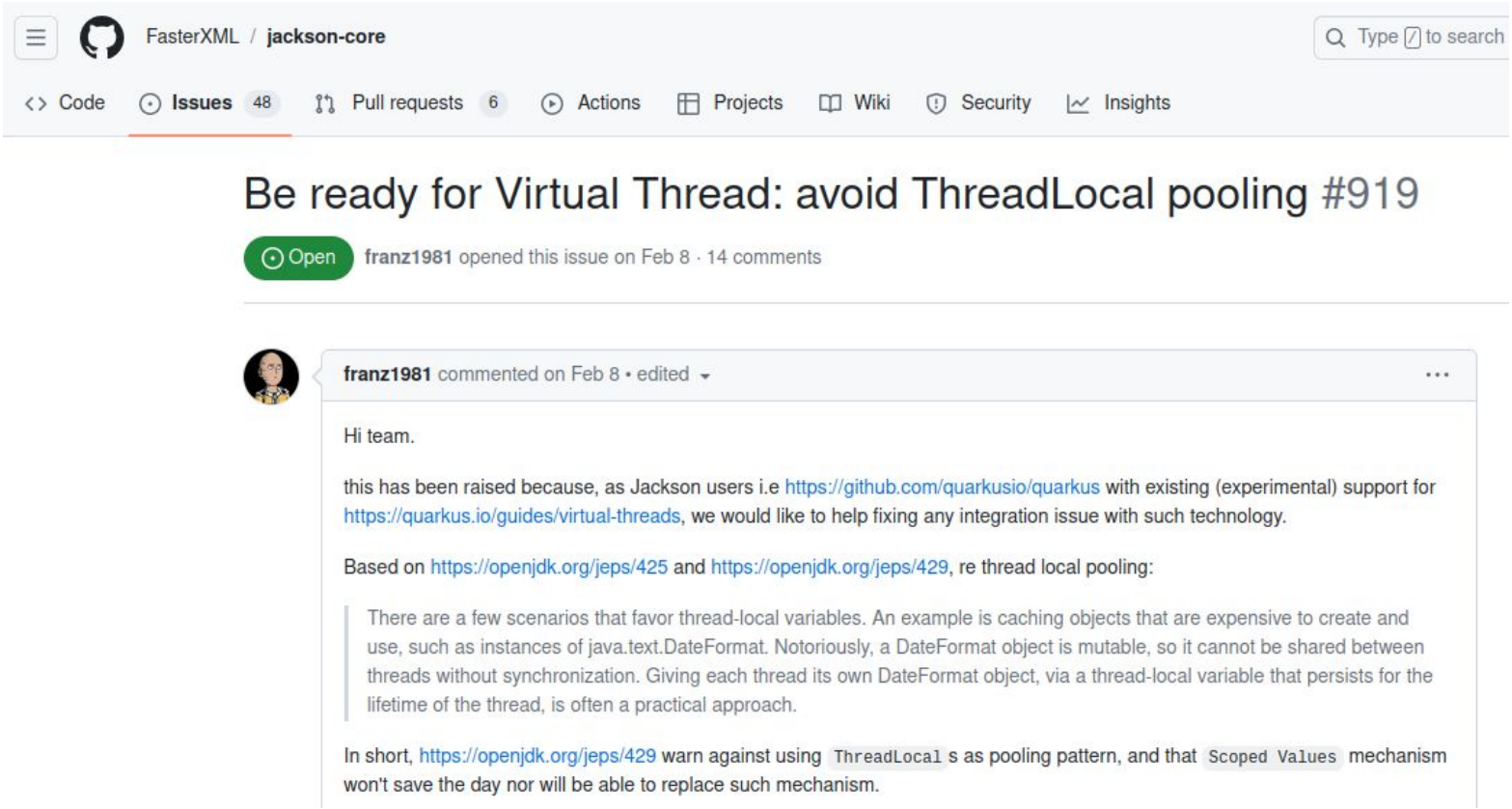
ThreadLocals as Cache / Objects Pool into the wild …



FasterXML / jackson-core

Type / to search

Code | Issues 48 | Pull requests 6 | Actions | Projects | Wiki | Security | Insights

Be ready for Virtual Thread: avoid ThreadLocal pooling #919

Open **franz1981** opened this issue on Feb 8 · 14 comments

franz1981 commented on Feb 8 • edited

Hi team.

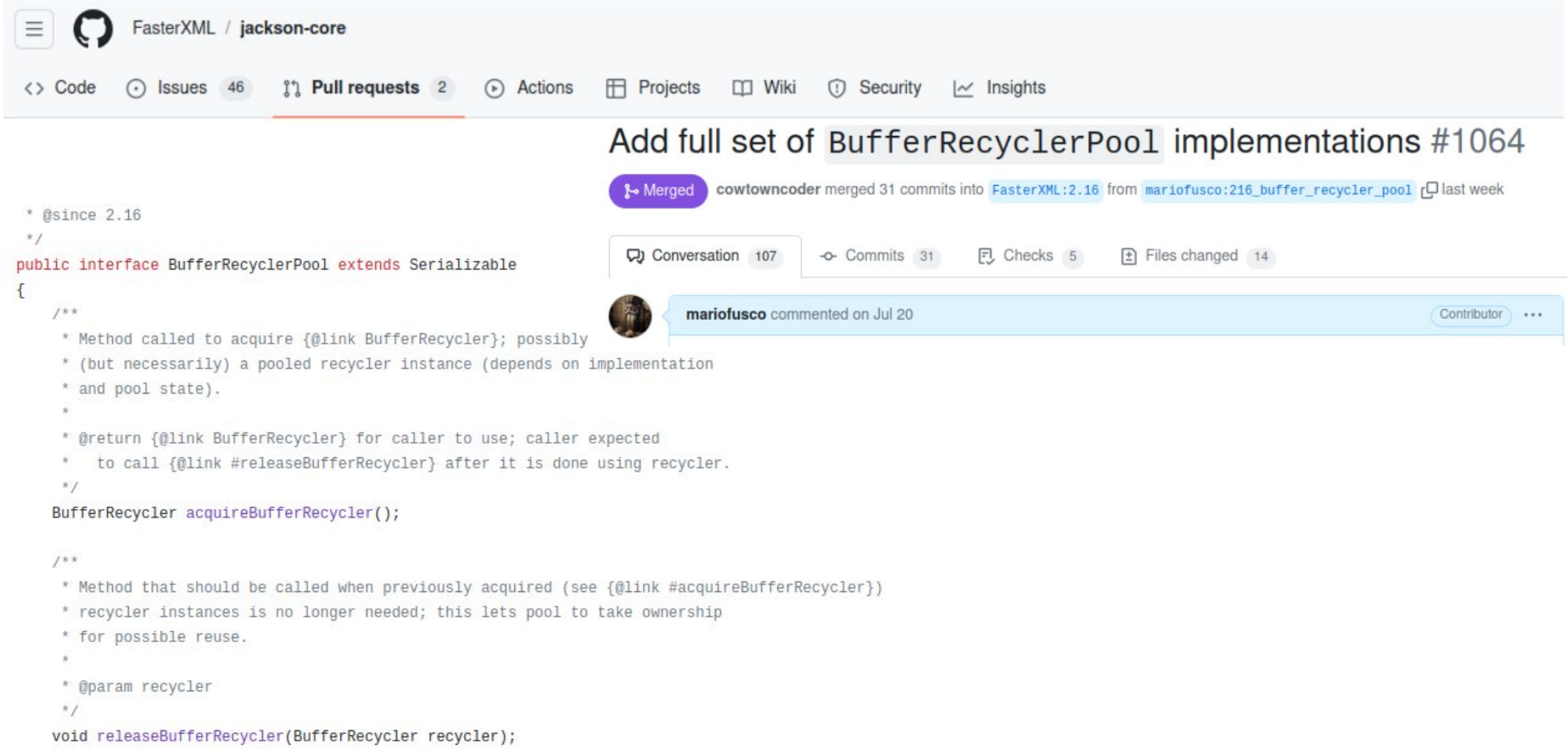
this has been raised because, as Jackson users i.e https://github.com/quarkusio/quarkus with existing (experimental) support for https://quarkus.io/guides/virtual-threads, we would like to help fixing any integration issue with such technology.

Based on https://openjdk.org/jeps/425 and https://openjdk.org/jeps/429, re thread local pooling:

> There are a few scenarios that favor thread-local variables. An example is caching objects that are expensive to create and use, such as instances of java.text.DateFormat. Notoriously, a DateFormat object is mutable, so it cannot be shared between threads without synchronization. Giving each thread its own DateFormat object, via a thread-local variable that persists for the lifetime of the thread, is often a practical approach.

In short, https://openjdk.org/jeps/429 warn against using `ThreadLocal`s as pooling pattern, and that `Scoped Values` mechanism won't save the day nor will be able to replace such mechanism.

… and the fix 🎉



FasterXML / jackson-core

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Add full set of `BufferRecyclerPool` implementations #1064

Merged **cowtowncoder** merged 31 commits into `FasterXML:2.16` from `mariofusco:216_buffer_recycler_pool` last week

Conversation 107 | Commits 31 | Checks 5 | Files changed 14

mariofusco commented on Jul 20 — Contributor

```
 * @since 2.16
 */
public interface BufferRecyclerPool extends Serializable
{
    /**
     * Method called to acquire {@link BufferRecycler}; possibly
     * (but necessarily) a pooled recycler instance (depends on implementation
     * and pool state).
     *
     * @return {@link BufferRecycler} for caller to use; caller expected
     *   to call {@link #releaseBufferRecycler} after it is done using recycler.
     */
    BufferRecycler acquireBufferRecycler();

    /**
     * Method that should be called when previously acquired (see {@link #acquireBufferRecycler})
     * recycler instances is no longer needed; this lets pool to take ownership
     * for possible reuse.
     *
     * @param recycler
     */
    void releaseBufferRecycler(BufferRecycler recycler);
```

Plugging a different thread pool as carriers

Can we outperform the default Fork/Join pool based carrier thread pool?

Plugging a different thread pool as carriers

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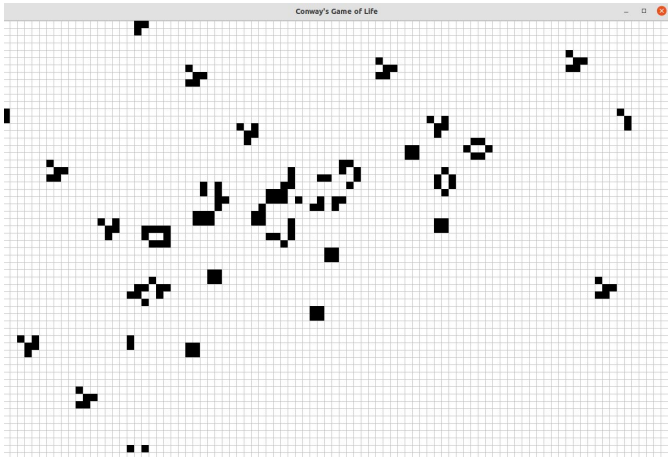
Let’s put at work Game of Life again!



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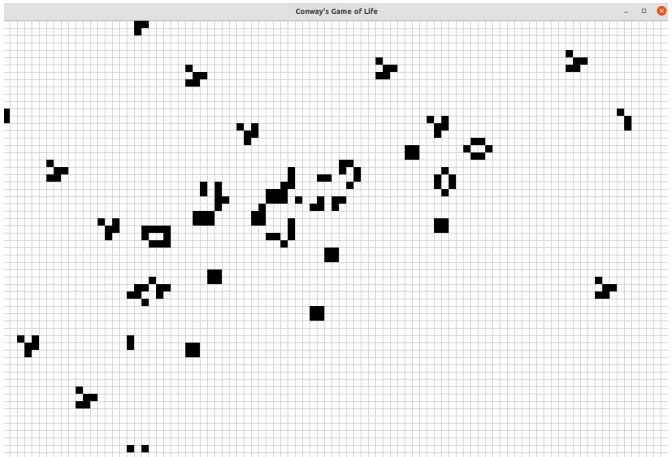

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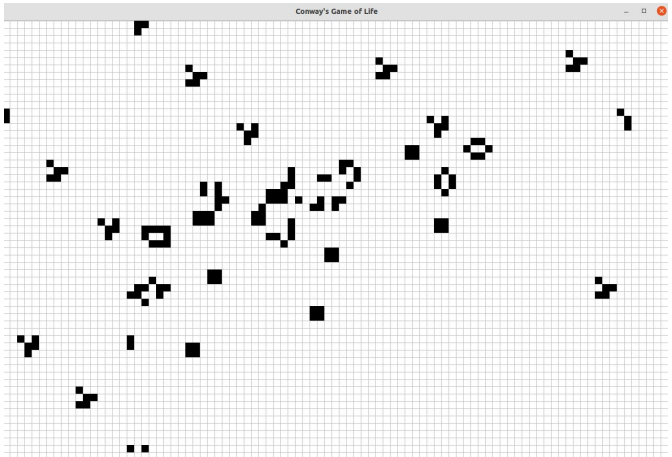
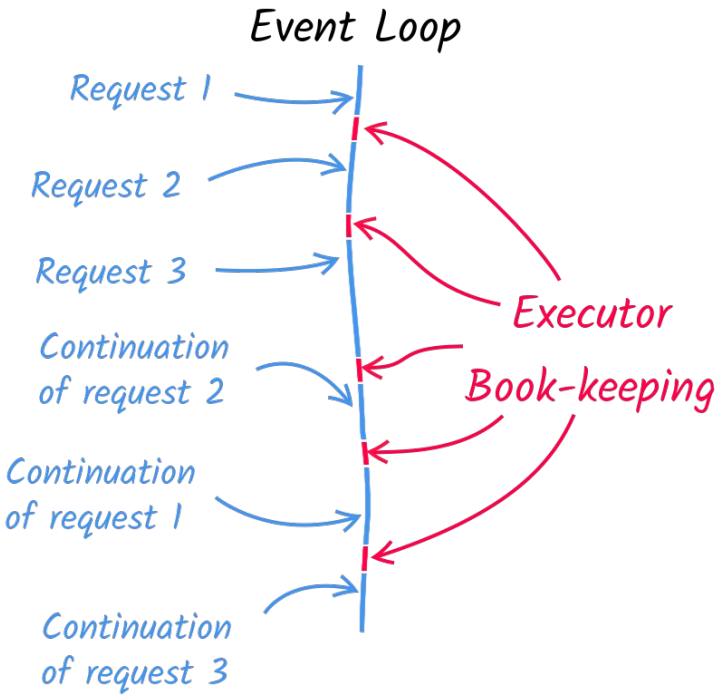



```
Benchmark                                (executionStrategy)   Mode  Cnt    Score   Error  Units
GameOfLifeBenchmark.benchmark                         Native  thrpt   40   40.317 ± 0.353  ops/s
GameOfLifeBenchmark.benchmark                 ForkJoinVirtual  thrpt   40  244.639 ± 1.419  ops/s
GameOfLifeBenchmark.benchmark  FixedCarrierPoolVirtual  thrpt   40  129.525 ± 5.346  ops/s
GameOfLifeBenchmark.benchmark     PinnedCarrierVirtual  thrpt   40   59.071 ± 1.532  ops/s
```

So why we may want to plug a different carrier?
The Quarkus use case - Reactive ≅ Virtual Threads



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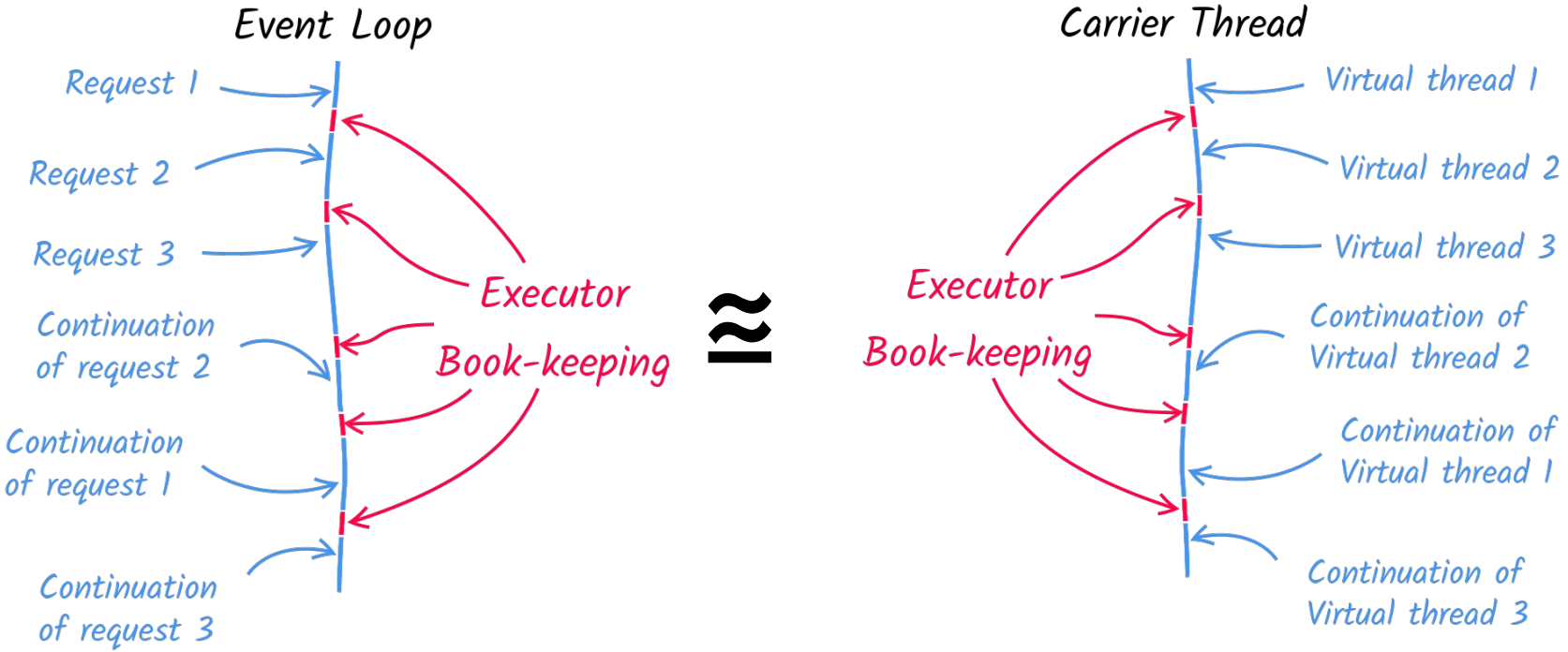

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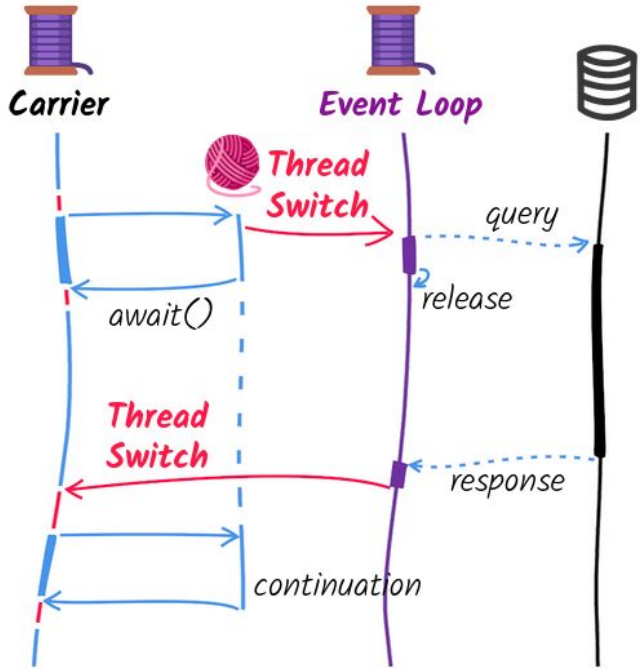
The Quarkus use case - The Event Loop as carrier

```
@RunOnVirtualThread
```



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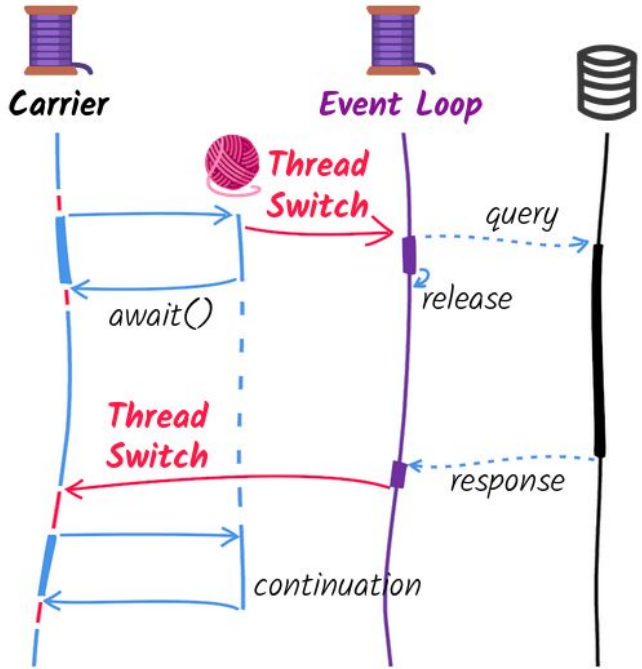
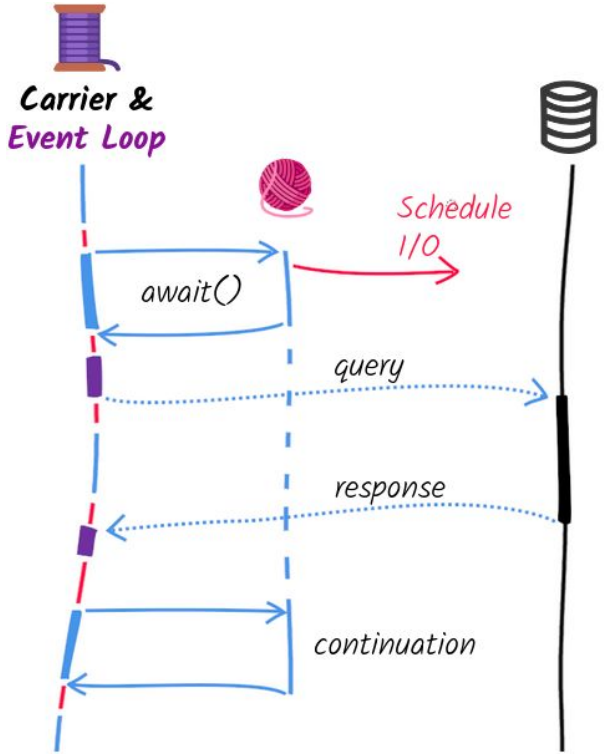
The Quarkus use case - The Event Loop as carrier

@RunOnVirtualThread





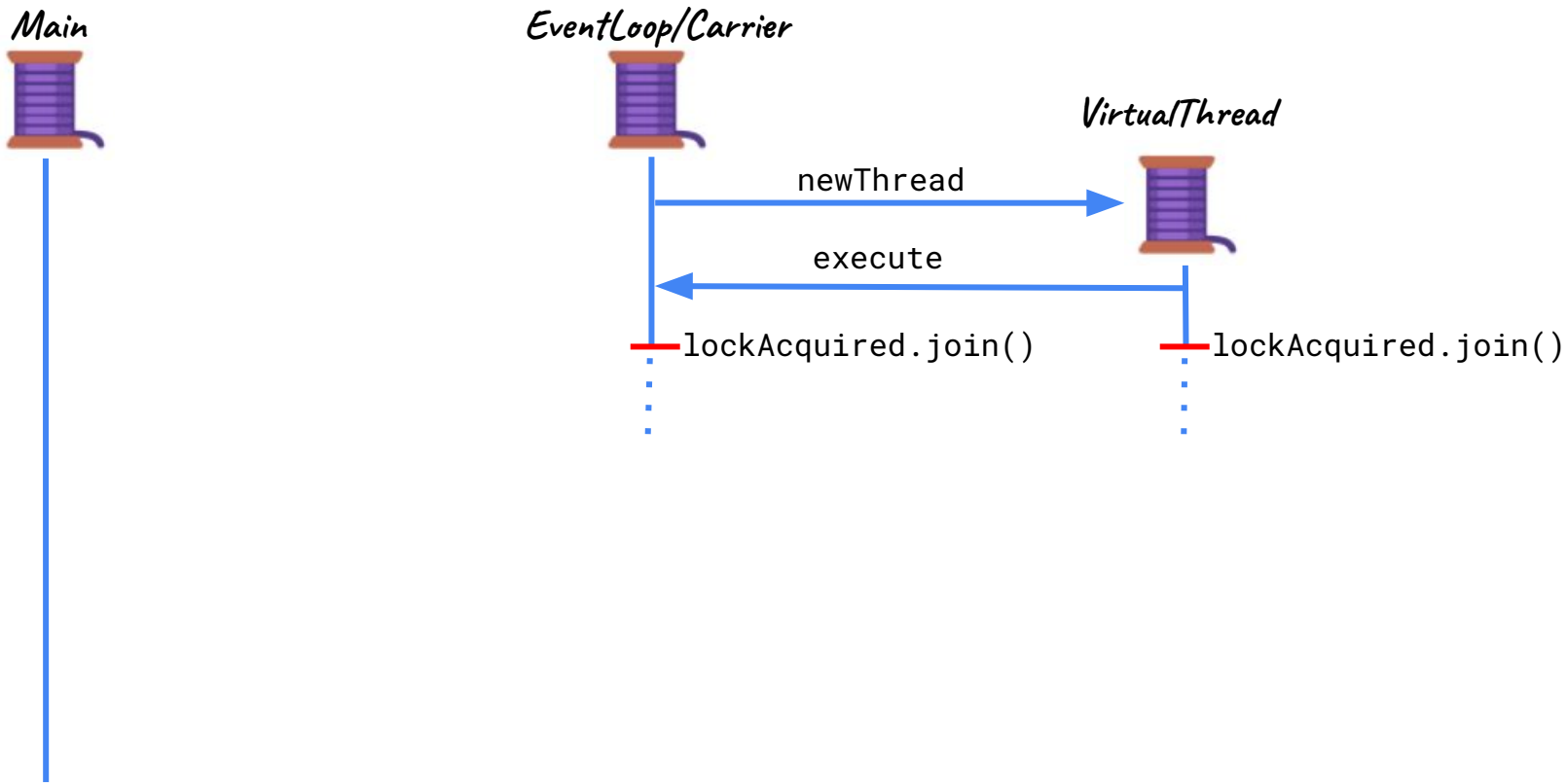
Why not using the event-loop as carrier thread???

- No (more) API to do that in Loom - API removed in fall 2021

Why not using the event-loop as carrier thread???

- No (more) API to do that in Loom - API removed in fall 2021
- It lead to…. **deadlocks!**

What’s going on ??? 🤔



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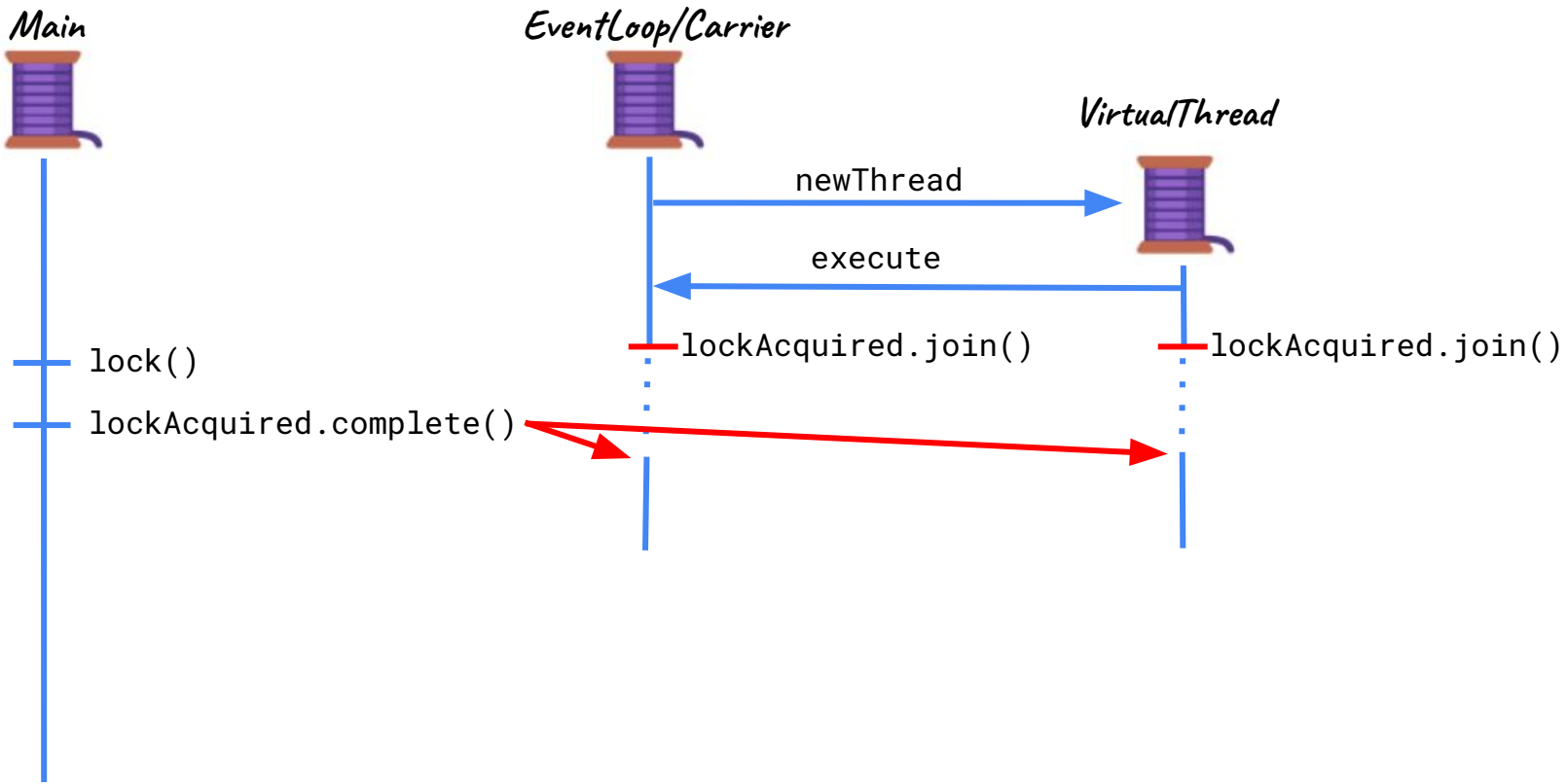

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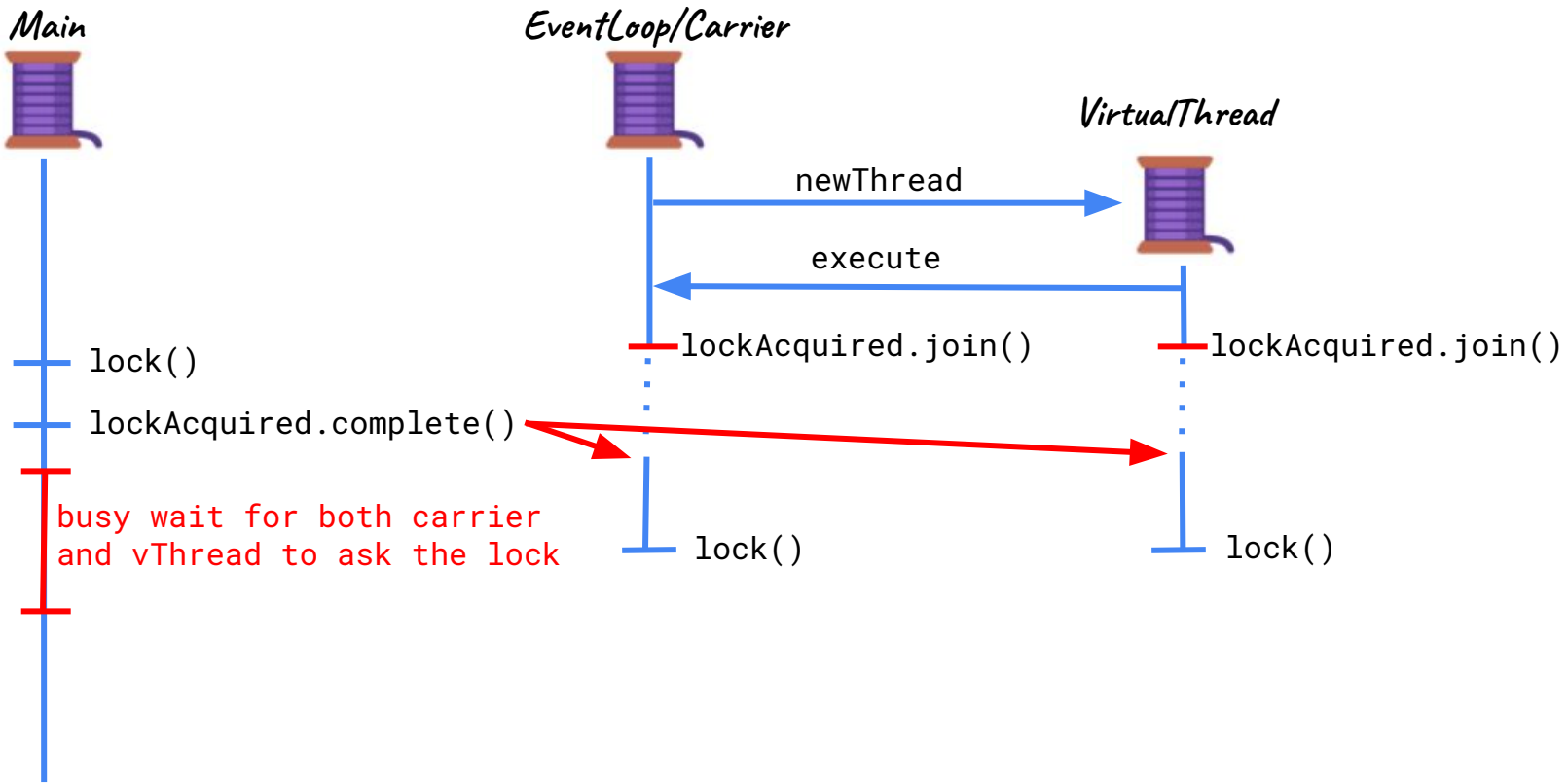

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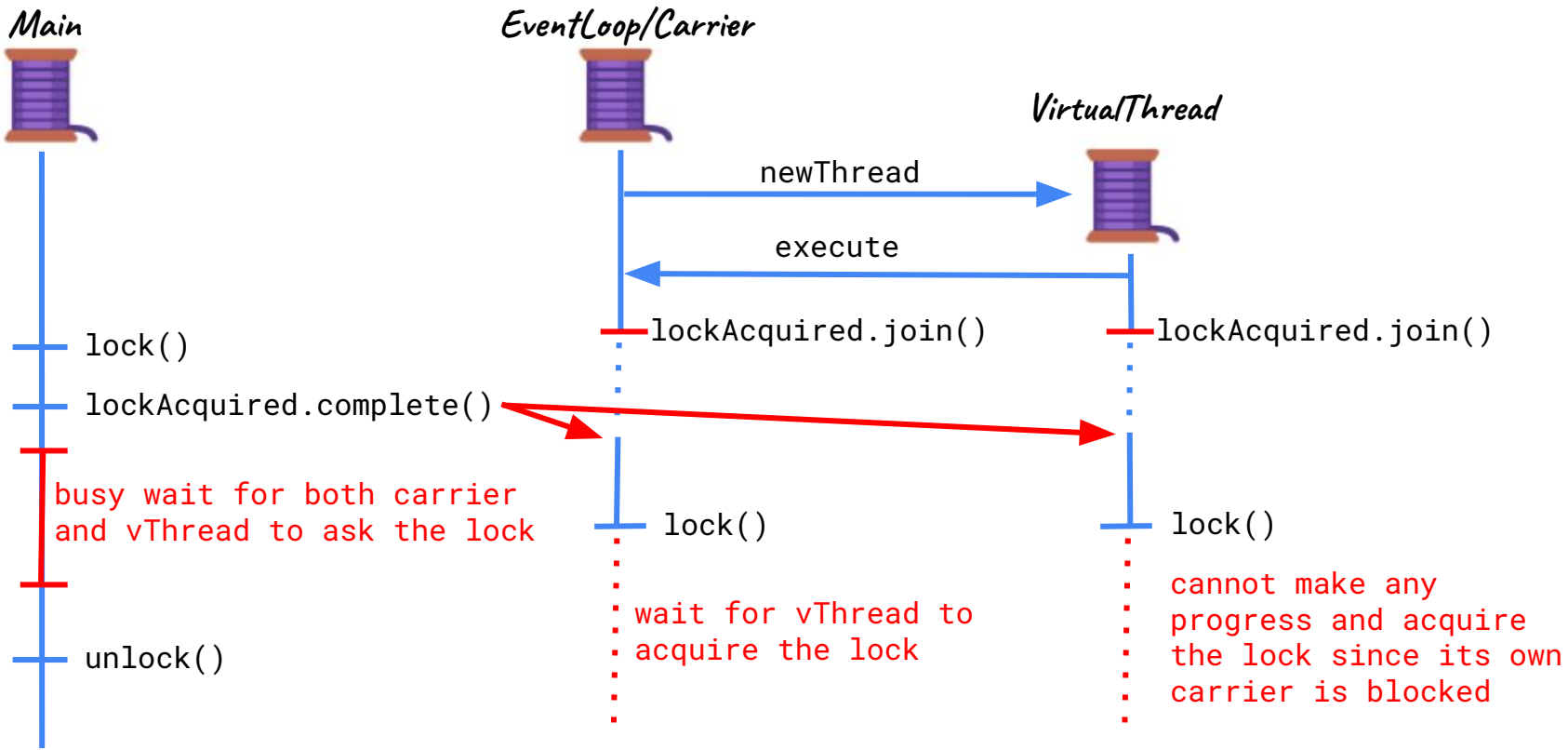

Conclusions

- Virtual threads are **not faster** threads ⇒ they don't magically execute more instructions per second than native ones do.
- Virtual threads are **not drop in replacement** for native threads ⇒ they are a different (new) tool and you have to **know their features and characteristics** in order to use them appropriately.
- Virtual threads are generally **not a good fit** for CPU bound tasks ⇒ **lack of fairness** and the performance **cost of coroutines** can be problematic.
- What virtual threads are really good for is **waiting** ⇒ their goal is **maximizing the utilization of external resources** and then **improving throughput**, without affecting readability.

Learn More

Quarkus Virtual Threads

- REST / HTTP
- Hibernate, Bean Validation, Transactions
- Kafka, AMQP, JMS
- gRPC
- Scheduled tasks
- Event Bus
- ...