VIRTUAL THREADS

SIMPLE YET SCALABLE CONCURRENCY IN JAVA 19

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CALLISTA

THREADS IN JAVA: PROGRAMMING MODEL FROM JDK 1.1 (1997)

```
Thread t1 = new Thread(() -> {
    ...
});
Thread t2 = new Thread(() -> {
    ...
});

t1.run();
t2.run();
```

THREADS PROGRAMMING MODEL

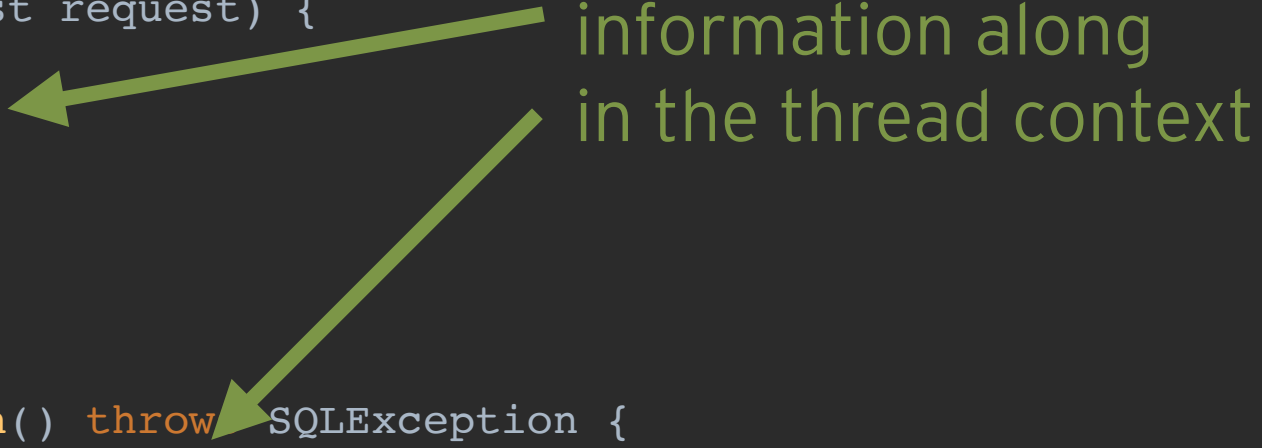
```
public ProductValue getProduct(long productId) {
  Product product = productRepository.findByProductId(productId);
  if (product != null) {
    InventoryValue inventoryValue = inventoryService.getInventory(product.getSku());
    return ProductValue.fromEntity(product, inventoryValue.getStock());
  } else {
    throw new EntityNotFoundException("Product " + productId + " not found");
  }
}
```

Illusion of "sequential flow"
Call stack variables
Call stack exception handling
Single-step debugging

= fairly simple

THREADS PROGRAMMING MODEL: THREAD CONTEXT

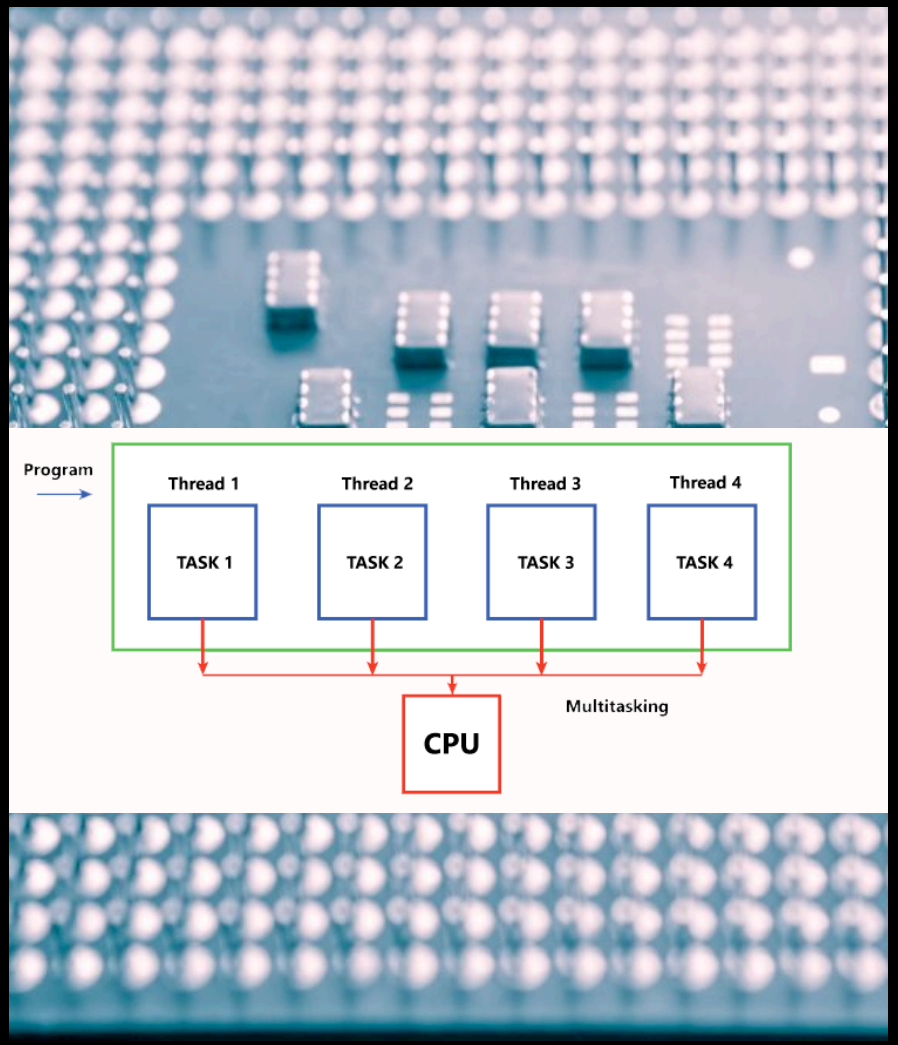
```
private static final InheritableThreadLocal<String> currentTenant =
  new InheritableThreadLocal<>();

...

public void preHandle(WebRequest request) {
  String tenantId = …;
  currentTenant.set(tenantId);
}


...

public Connection getConnection() throws SQLException {
  String tenantId = currentTenant.get();
  ...
}
```



PLATFORM / OS THREADS

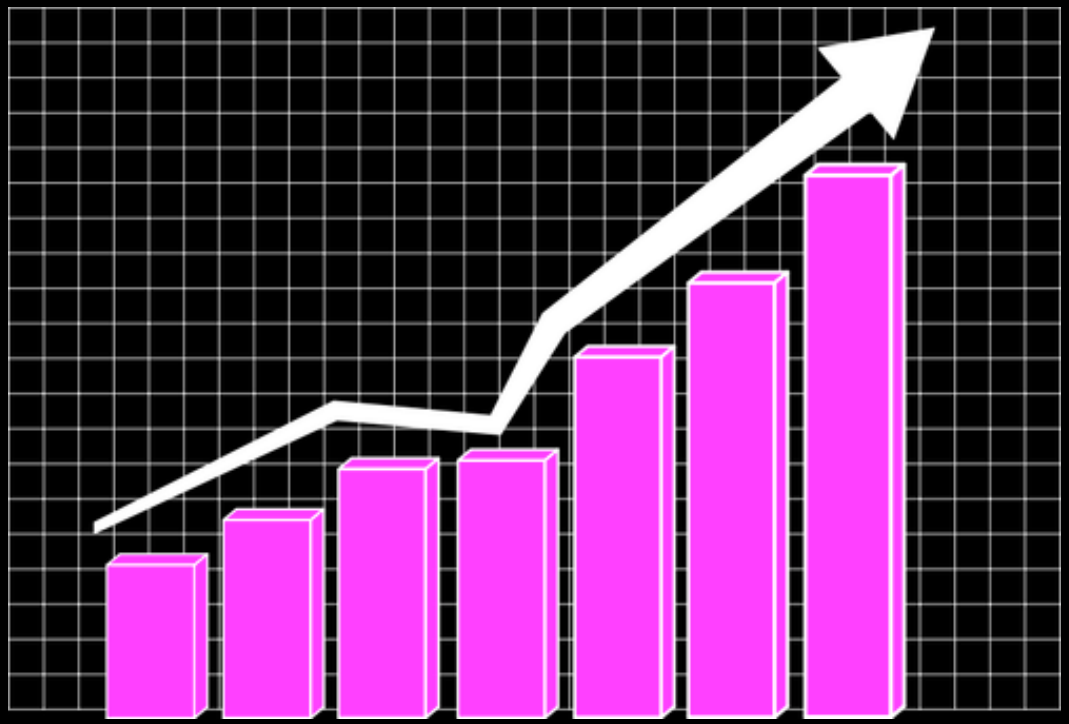
- Reliable scheduling mechanism

- Thread stacks are monolithic blocks of memory
- Relatively expensive, and hence limited



INTERNET SCALE

- 1999:
  - The Internet had 280 million users
- 2005:
  - 1 billion Internet users.
  - Facebook had 5.5 million users.
- 2014:
  - 2.95 billion Internet users.
  - Facebook 1.3 billion users.
  - Twitter 270 million users.
- 2022
  - 5 billion Internet users.
  - Facebook 2.9 billion users.

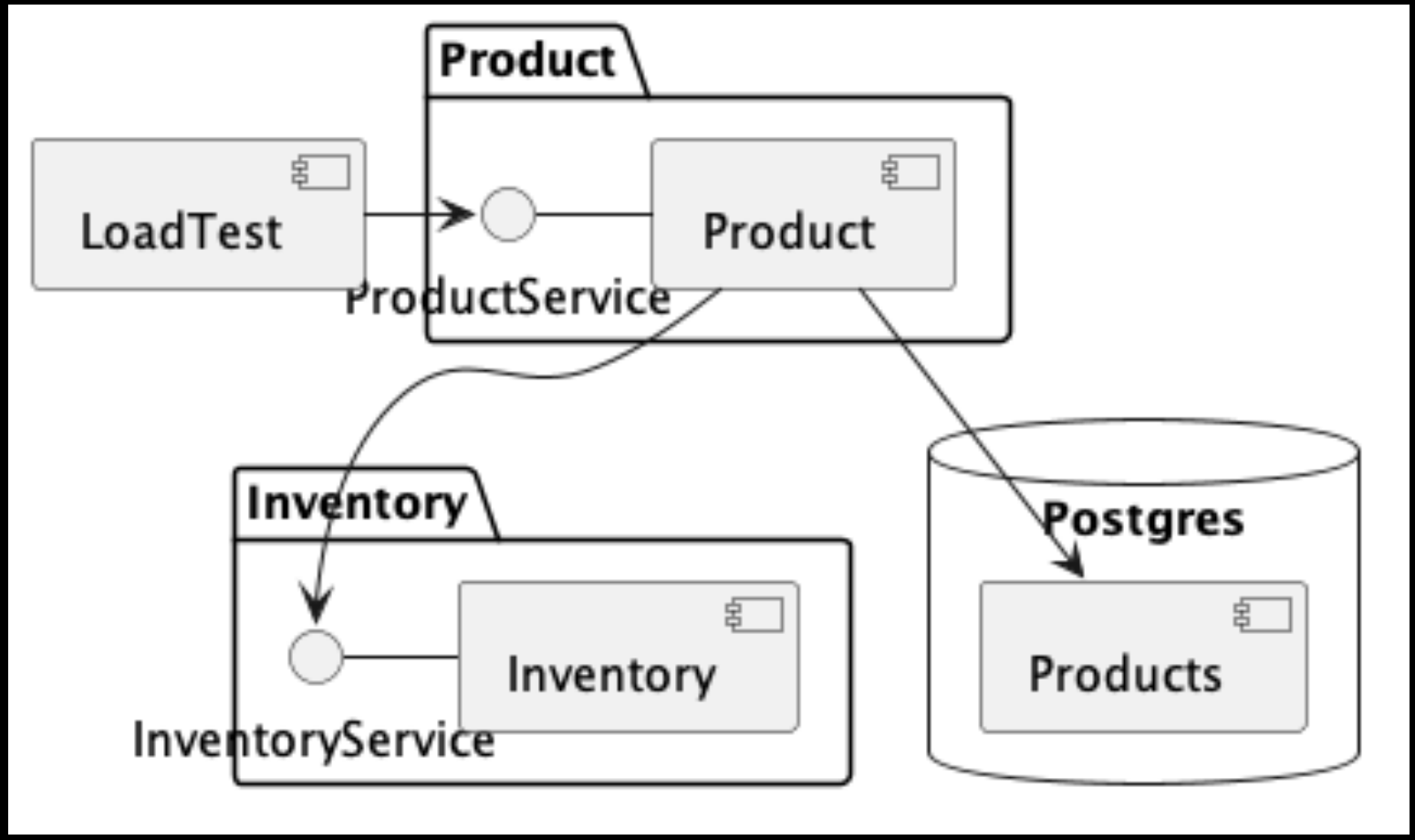


HTTPS://WWW.STATISTA.COM/STATISTICS/617136/DIGITAL-POPULATION-WORLDWIDE/

THREAD PER TASK

```
@GetMapping(value = "/products/{productId}")
public ResponseEntity<ProductValue> getProduct(@PathVariable long productId) {
  try {
    ProductValue product = productService.getProduct(productId);
    return new ResponseEntity<>(product, HttpStatus.OK);
  } catch (EntityNotFoundException e) {
    throw new NotFoundException(e.getMessage());
  }
}
```

DEMO: EXAMPLE SYSTEM

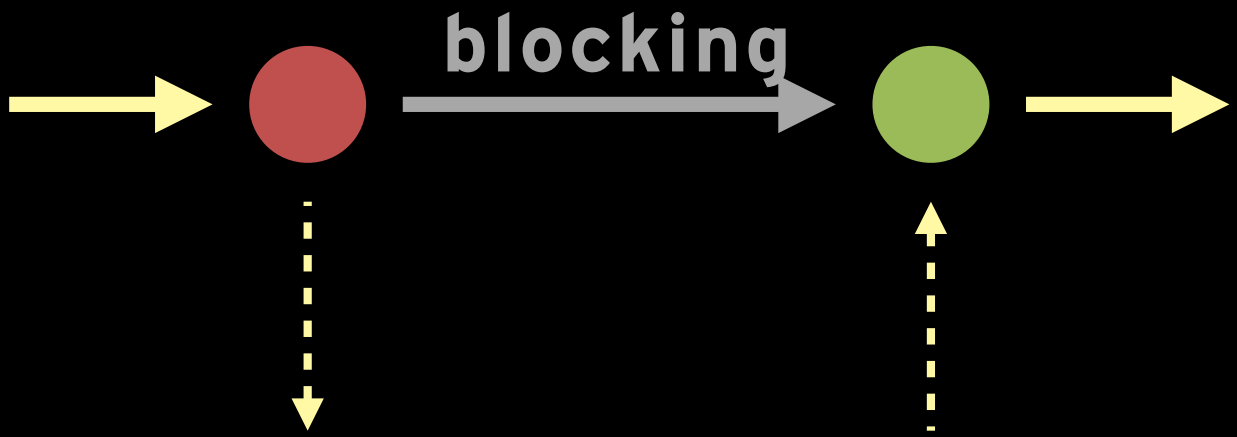


https://github.com/callistaenterprise/cadec-2023-virtual-threads.git

BLOCKING THREADS

Blocking!

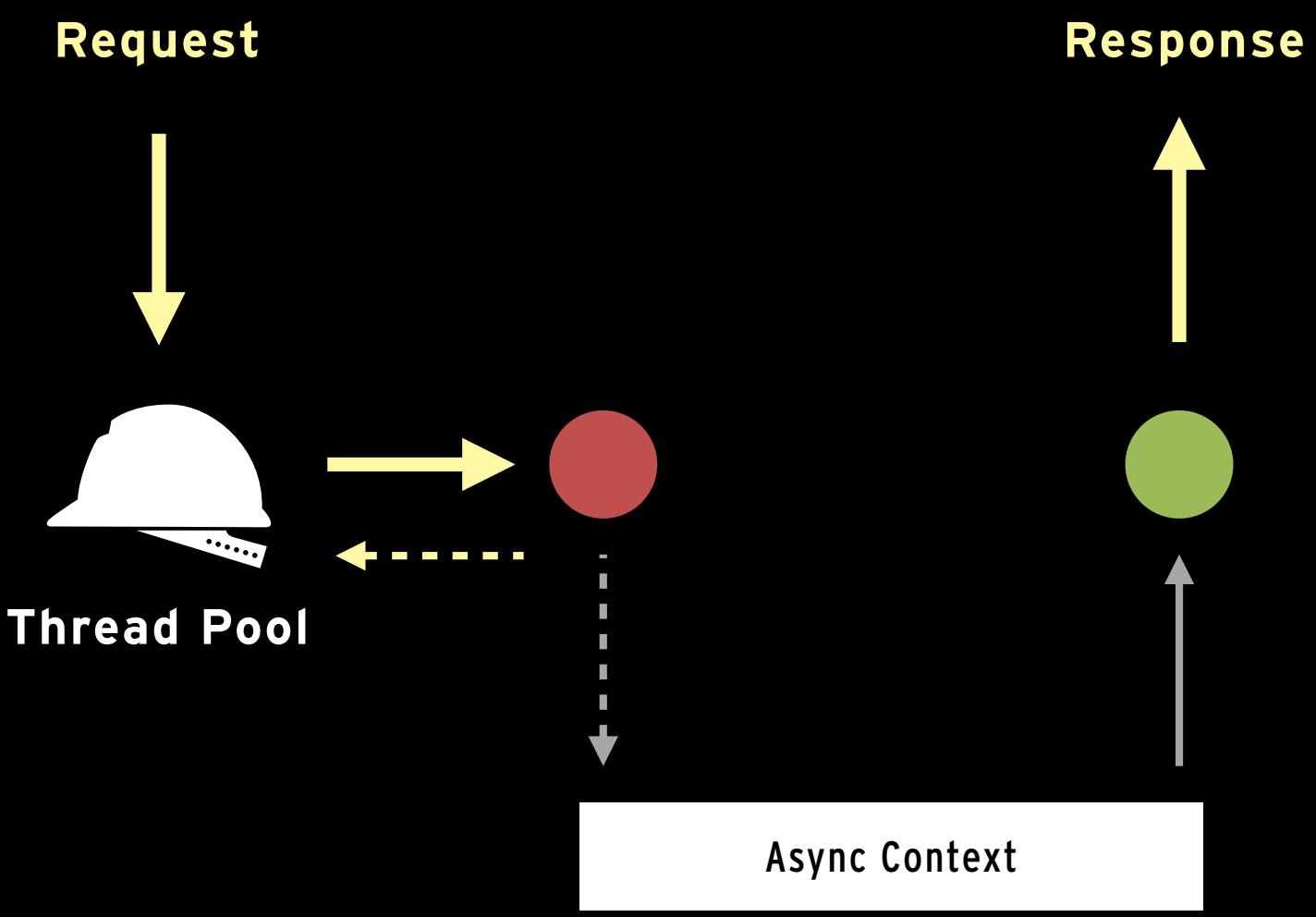
```
public ProductValue getProduct(long productId) {
  // Database call will block
  Product product = productRepository.findByProductId(productId);
  if (product != null) {
    // Rest call will block
    InventoryValue inventoryValue = inventoryService.getInventory(product.getSku());
    return ProductValue.fromEntity(product, inventoryValue.getStock());
  } else {
    throw new EntityNotFoundException("Product " + productId + " not found");
  }
}
```



LITTLE'S LAW

$$T = N / d$$

NON-BLOCKING / ASYNC PROGRAMMING MODEL



NON-BLOCKING PROGRAMMING MODEL: Callbacks

```
public void getProduct(long productId, ProductServiceCallback callback) {
  productRepository.findById(productId, product -> {
    inventoryService.getInventory(product.getSku(), inventory -> {
      ProductValue result = ProductValue.fromEntity(product, inventory.getStock());
      callback.handle(result);
    });
  });
}
```

NON-BLOCKING PROGRAMMING MODEL: `CompletableFuture`

```
public CompletableFuture<ProductValue> getProduct(long productId) {
  return productRepository.findById(productId).thenCompose(product -> {
    return inventoryService.getInventory(product.getSku()).thenApply(inventory -> {
      return ProductValue.fromEntity(product, inventory.getStock());
    });
  });
}
```

NON-BLOCKING PROGRAMMING MODEL: RxJava

```
public Single<ProductValue> getProduct(long productId) {
  return productRepository.findById(productId).flatMap(product ->
      inventoryService.getInventory(product.getSku()).map(inventory ->
          ProductValue.fromEntity(product, inventory.getStock())
      )
  );
}
```

NON-BLOCKING PROGRAMMING MODEL: Spring WebFlux

```
public Mono<ProductValue> getProduct(long productId) {
  return productRepository.findById(productId).flatMap(product ->
      inventoryService.getInventory(product.getSku()).map(inventory ->
          ProductValue.fromEntity(product, inventory.getStock())
      )
  );
}
```

NON-BLOCKING PROGRAMMING MODEL: Shortcomings

```
public Mono<ProductValue> getProduct(long productId) {
  return productRepository.findById(productId).flatMap(product ->
      inventoryService.getInventory(product.getSku()).map(inventory ->
          ProductValue.fromEntity(product, inventory.getStock())
      )
  );
}
```

Obscure syntax
No sequential flow
No ThreadLocal = Complexity
Akward error handling
No single-step debugging

IMPACTS ALL APIS: e.g. JDBC/HIBERNATE/JPA -> R2DBC

```
import io.r2dbc.spi.ConnectionFactory;

  ...

  @Bean
 public ConnectionFactory connectionFactory() {
    ConnectionFactory connectionFactory =  ConnectionFactoryBuilder.build();
    return new TenantAwareConnectionFactory(connectionFactory);
  }

  @Bean
  @Primary
  ReactiveTransactionManager connectionFactoryTransactionManager() {
    return new R2dbcTransactionManager(connectionFactory());
  }
```

OpenJDK

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JEP Process

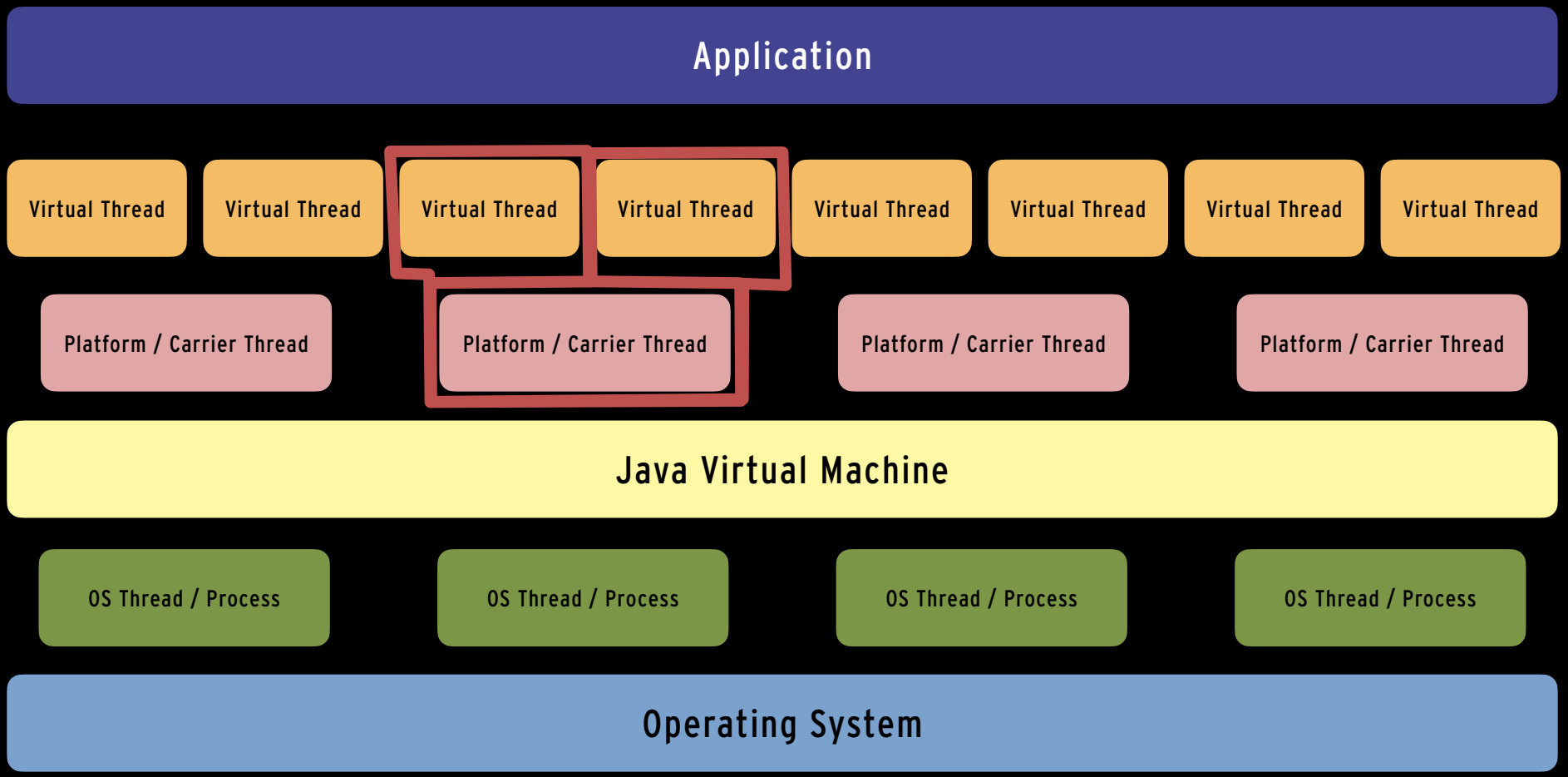
Source code
Mercurial
GitHub

Tools
Mercurial
Git
jtreg harness

JEP 425: Virtual Threads (Preview)

Authors	Ron Pressler, Alan Bateman
Owner	Alan Bateman
Type	Feature
Scope	SE
Status	Candidate
Component	core-libs
Discussion	loom dash dev at openjdk dot java dot net
Effort	XL
Reviewed by	Alex Buckley, Brian Goetz, Chris Hegarty
Created	2021/11/15 16:43
Updated	2022/04/11 11:03
Issue	8277131

VIRTUAL THREADS



VIRTUAL THREADS: SAME PROGRAMMING MODEL

```
Thread.startVirtualThread(() -> {
   ...
});


var executor = Executors.newVirtualThreadPerTaskExecutor();
executor.submit(() -> {
   ...
});
```

VIRTUAL THREADS IN SPRING BOOT 3

```
@Bean
AsyncTaskExecutor applicationTaskExecutor() {

  ExecutorService executorService = Executors.newVirtualThreadPerTaskExecutor();
  return new TaskExecutorAdapter(executorService::execute);

}
```

VIRTUAL THREADS IN TOMCAT 10.1.X

```
@Bean
TomcatProtocolHandlerCustomizer<?> protocolHandlerExecutorCustomizer() {

  return protocolHandler ->
    protocolHandler.setExecutor(Executors.newVirtualThreadPerTaskExecutor());

}
```

BEST PRACTICES: DON'T USE `synchronised`

- The current implementation of virtual threads cause `synchronised` blocks to be *pinned* to the underlying carrier thread, which may cause blocking
- Use `ReentrantLock` instead, if needed

```
private final ReentrantLock REENTRANT_LOCK = new ReentrantLock();

public InventoryValue getInventory(String sku) {
  try {
    REENTRANT_LOCK.lock();
    ...
  } finally {
    REENTRANT_LOCK.unlock();
  }
}
```

```
  <jvmArguments>-Djdk.tracePinnedThreads=full</jvmArguments>
```

BEST PRACTICES: DON'T USE THREAD POOLS

- Virtual Threads are cheap - don't try to reuse them
- Use `Semaphores` instead, if there is a need to limit use of other scarce resources

```
private final Semaphore INVENTORY_SEMAPHORE;

public InventoryServiceImpl(@Value("${inventory.session.max:1000}") int permits) {
  INVENTORY_SEMAPHORE = new Semaphore(permits);
}

public InventoryValue getInventory(String sku) {
  try {
    INVENTORY_SEMAPHORE.acquire();
    ...
 } finally {
    INVENTORY_SEMAPHORE.release();
  }
}
```

BEST PRACTICES: DON'T OVERUSE `ThreadLocal`

- While Virtual Threads are plentiful, multiple or heavy-weight ThreadLocal variables may alter the equation and become a bottleneck
- Harmless when used wisely

```
private static final InheritableThreadLocal<String> currentTenant =
    new InheritableThreadLocal<>();

...

public Connection getConnection() throws SQLException {
    String tenantId = currentTenant.get();
    ...
}
```

VIRTUAL THREADS: CURRENT STATUS

- First Preview release in Java 19:

```
<plugin>
    <groupId>org.apache.maven.plugins</groupId>
    <artifactId>maven-compiler-plugin</artifactId>
    <configuration>
        <compilerArgs>--enable-preview</compilerArgs>
    </configuration>
</plugin>
```

- Second Preview in Java 20 (March 2023), final release in Java 21? (September 2023)
- Fully functional support in Spring Boot 3 / Spring Framework 6
- Fully functional support in Tomcat 10.1
- Fully functional support in Oracle JDBC 21c
- Preliminary support in Quarkus, Microsoft JDBC
- Ongoing work in many supporting libraries/frameworks (HikariCP, PostgresJDBC, …)

SUMMARY

- Virtual Threads allow applications using the familiar "Thread-per-Task" model to achieve the **same high scalability** as Async/ Non-blocking applications, but **without the complexity of a new programming model** and developer experience.

- The Reactive stack may **still be a better option** when the unique features of e.g. Reactive Streams (**parallellism, back-pressure, cancellation** etc.) are required.

Time for questions?

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