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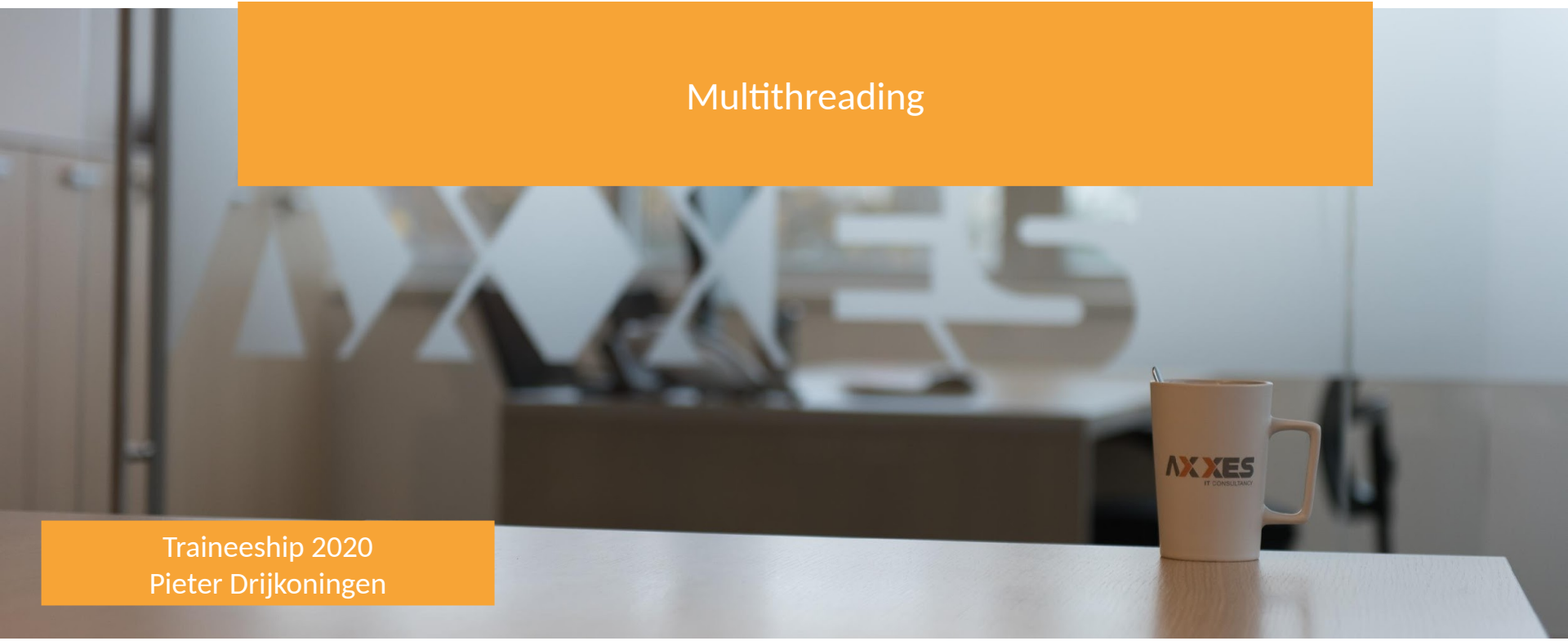
# Multithreading




Traineeship 2020
Pieter Drijkoningen

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# Inhoud

1. Intro tot multithreaded software
2. Basisbegrippen
3. Building blocks
4. ExecutorService
5. Completable Future API

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# INTRO

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# Multithreaded software

- Concurrent execution
- Hogere performantie
- Moeilijker
- Bugs moeilijk te reproduceren

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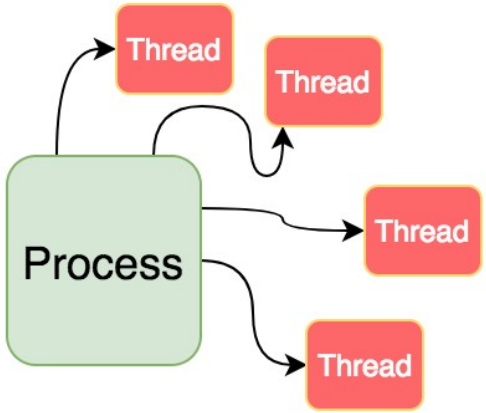
# Waarom dan?

- “Writing software is hard, writing concurrent software is even harder”
- Singlethreaded software ondenkbaar tegenwoordig
- Webservers, GUI applicaties, crawlers, garbage collection,…

# Threads

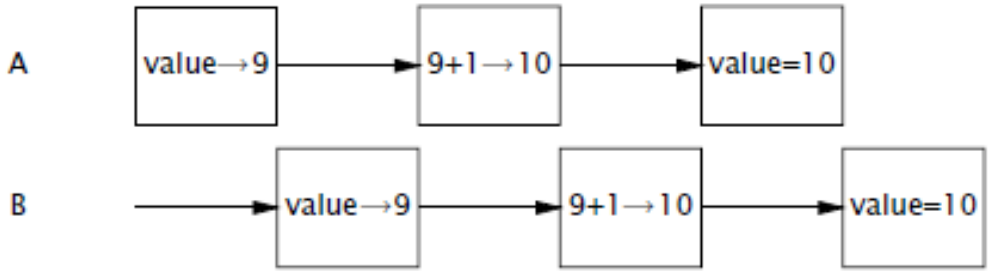
- Basic unit of scheduling
- Onderdeel van een proces
- Sequentiële uitvoering op 1 processorkern
- Hogere throughput
- Java:

  new Thread(() → doSomething()).start();



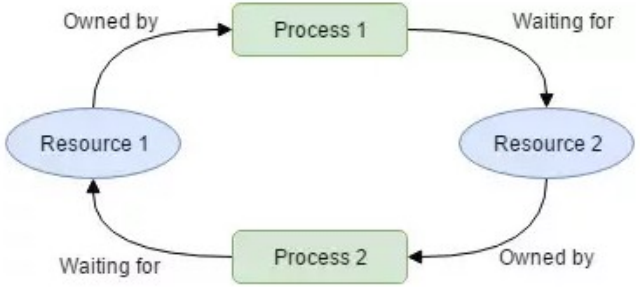
# Risico’s - Incorrectness

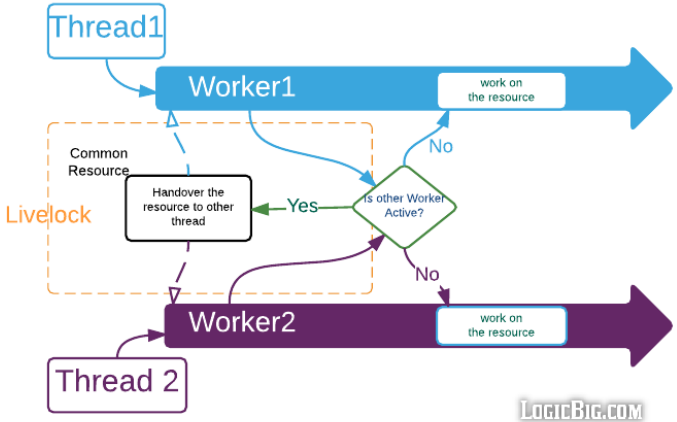
- Interleaving
- Race conditions
- *“Nothing bad ever happens”*



# Risico's - Liveness

- *"Something good eventually happens"*
- Deadlock
- Livelock
- Starvation



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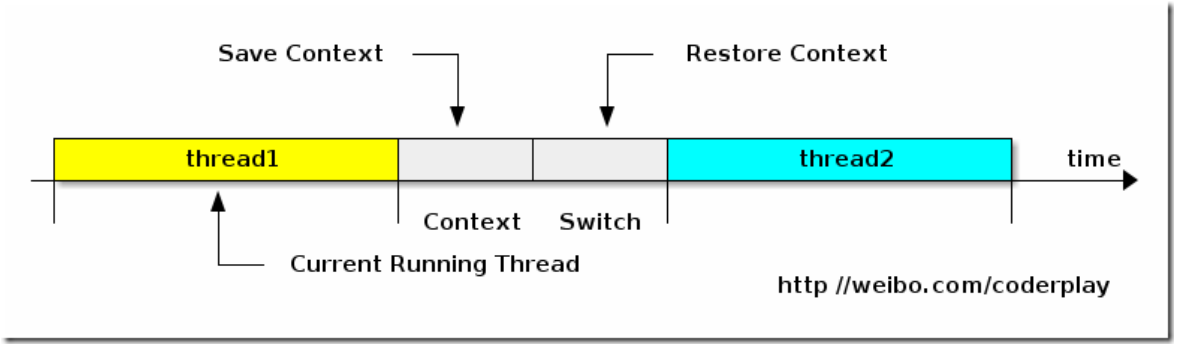
# Risico’s - Starvation

- Eén of meerdere threads krijgen geen CPU tijd
- Teveel contention

# Risico's - Performance

- *Overhead*
- *Thread-switching*
- *Synchronisatie*



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# Demo + Oefeningen

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# Basisbegrippen

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# Thread-safety

*“A class is thread-safe if it behaves correctly when accessed from multiple threads, regardless of the scheduling or interleaving of the execution of those threads by the runtime, and with no additional synchronization or other coordination on the part of the calling code”*

*- Java Concurrency in Practice*

# Correct gedrag

- Specificatie
- Invarianten
- Postcondities

```
public class Counter {
        private int count = 0;

        public int value() {
                return count;
        }

        public void increment() {
                count++;
        }
}
```

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# State

- Waarde van een object
- Thread safety = controlled access to shared, mutable state

# Stateless

- Altijd thread-safe
- Merk op: long[] factors is state

  -> Niet shared

  -> *thread confinement*

```
public class StatelessFactorizer {

        public long[] factorize(long i) {
                long[] factors = factors(i);
                return factors;
        }

        private long[] factors(long i) {
                // Calculate factors
        }
}
```

# Stateful

- Synchronisatie nodig om thread-safe te zijn

```
public class CountingFactorizer {

        private long count = 0;

        public long getCount() { return count; }

        public long[] factorize(long i) {
                count++;
                long[] factors = factors(i);
                return factors;
        }
}
```

# Compound actions

- Read-modify-write (CountingFactorizer)
- Check-then-act (LazySingleton)
- Atomische operatie

```
public class LazySingleton {

        private LazySingleton instance = null;

        public LazySingleton getInstance() {
                if (instance == null) {
                        instance = new LazySingleton();
                }
                return instance;
        }
}
```

# Atomicity

- Ondeelbare actie
- JDK biedt enkele atomic classes aan

```
public class AtomicCountingFactorizer {

        private AtomicLong count = new AtomicLong();

        public long getCount() { return count.get(); }

        public long[] factorize(long i) {
                count.getAndIncrement();
                long[] factors = factors(i);
                return factors;
        }
}
```

```
public class CachingFactorizer {

	private AtomicLong lastValue = new AtomicLong();
	private AtomicReference<List<Long>> lastFactors = new AtomicReference<>();

	public List<Long> factorize(long i) {
		if (i == lastValue.get()) {
			return lastFactors.get();
		}
		List<Long> factors = calulateFactors(i);
		lastValue.set(i);
		lastFactors.set(factors);
		return factors;
	}
}
```

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# Locks

- Intrinsic/monitor lock
- Synchronized block/method
- mutex (**mut**ually **ex**clusive)

```
synchronized (monitor) {
        // code goes here
}

public synchronized void someMethod() {
        // code goes here
}

public void someMethod() {
        synchronized(this) {
                // code goes here
        }
}
```

```
public class CachingFactorizer {

	private AtomicLong lastValue = new AtomicLong();
	private AtomicReference<List<Long>> lastFactors = new AtomicReference<>();

	public synchronized List<Long> factorize(long i) {
		if (i == lastValue.get()) {
			return lastFactors.get();
		}
		List<Long> factors = calculateFactors(i);
		lastValue.set(i);
		lastFactors.set(factors);
		return factors;
	}
}
```

```
public class CachingFactorizer {

	private AtomicLong lastValue = new AtomicLong();
	private AtomicReference<List<Long>> lastFactors = new AtomicReference<>();

	public List<Long> factorize(long i) {
		synchronized (this) {
			if (i == lastValue.get()) {
				return lastFactors.get();
			}
		}
		List<Long> factors = factors(i);
		synchronized (this) {
			lastValue.set(i);
			lastFactors.set(factors);
		}
		return factors;
	}
}
```

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# Critical section

- Deel code dat nood heeft aan synchronized access
- Is omvat door een locking mechanism

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# Explicit locks

- Advanced API
- Reentrancy
- Fairness (longest waiting thread)

```
public class LockDemo {

        private Lock lock = new ReentrantLock();

        public void someMethod() {
                lock.lock();
                try { // code goes here }
                finally { lock.unlock(); }
        }
}
```

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# ReadWrite locks

- Multiple readers
- Single writer

```
public class ReadWriteLockDemo {

        private ReadWriteLock lock = new ReentrantReadWriteLock();
        private Lock readLock = lock.readLock();
        private Lock writeLock = lock.writeLock();
}
```

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# Oefeningen

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# Building Blocks

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# Synchronized Collections

- Elke public method synchronized
- Wel threadsafe, niet performant
- Compound actions vereisen nog steeds externe synchronisatie

```
Collections.synchronizedList(new ArrayList<>());
Collections.synchronizedSet(new HashSet<>());
Collections.synchronizedMap(new HashMap<>());
```

```
public Object getLast(List list) {
        int lastIndex = list.size() - 1;
        return list.get(lastIndex);
}
```

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# Concurrent Collections

- Java 1.5
- java.util.concurrent package
- Collection implementaties optimized voor concurrent access

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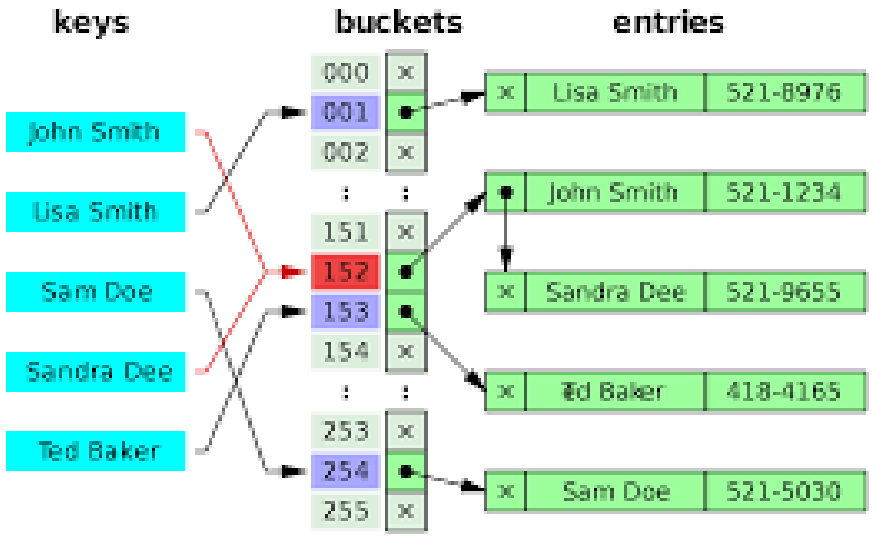
# CopyOnWriteArrayList/HashSet

- Geen locking voor reads
- Bij write wordt een kopie gemaakt
- Optimized voor collecties die veel vaker uitgelezen dan aangepast worden

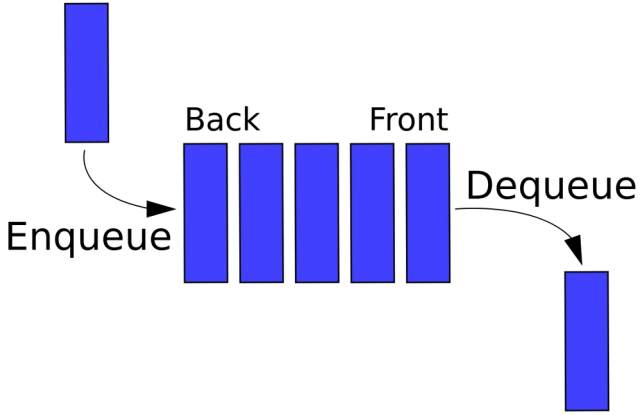
# ConcurrentHashMap

- Geen locking voor reads
- 16 concurrent writers mogelijk
- Geen custom compound actions mogelijk
- put-if-absent, remove-if-equal, replace-if-equal zijn voorzien



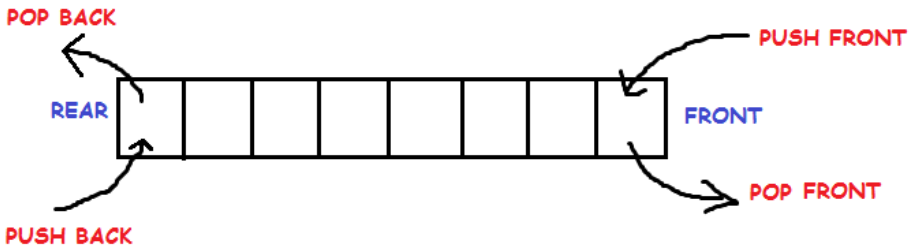
# Queue & BlockingQueue

- Collectie om elementen te queuen en op andere thread uit te lezen
- FIFO
- offer() en poll()
- put() en take()



# Deque & BlockingDeque

- Deque = Double-ended Queue
- offerFirst/Last() en pollFirst/Last()
- putFirst/Last() en takeFirst/Last()

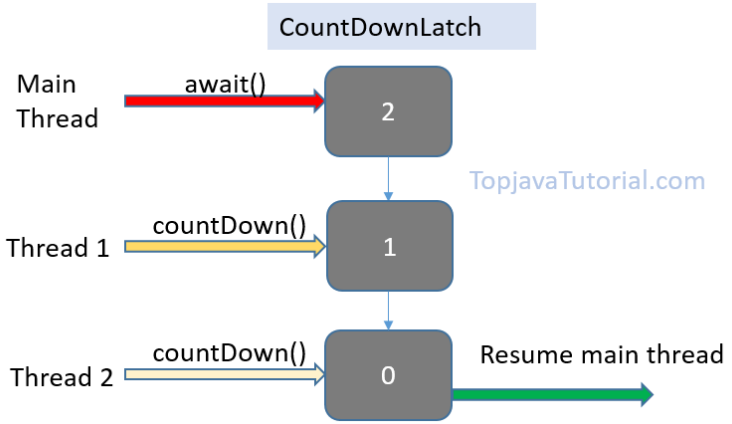


# Synchronizers

- Bewaken toegang tot resources
- Hebben state en logica om te bepalen of een thread door mag of moet wachten

# Latch

- Gesloten tot een bepaalde *terminal state* bereikt wordt
- Daarna continu open
- new CountDownLatch(2);



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# Semaphore

- Beheert een aantal virtual permits
- Handig om connection pools af te schermen
- Intrinsic lock = semaphore met 1 permit

```
Semaphore semaphore = new Semaphore(10);
semaphore.acquire();
try {
        // some code
} finally {
        semaphore.release();
}
```

# Barrier

- Om te wachten tot andere threads een bepaald punt bereikt hebben
- Barrier action
- Simulaties

```
CyclicBarrier barrier = new CyclicBarrier(2);
new Thread(() -> {
        barrier.await();
        // more code
}.start();
new Thread(() -> {
        barrier.await();
        // more code
}.start();
```

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# Demo + Oefeningen

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# Executor Framework

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# Tasks

- Discrete unit of work
- Task boundaries
- Onafhankelijk
- Execution policy

# Sequential Execution Policy

- Single-threaded
- Geen thread-safety nodig
- Slechte performantie

```
public class WebServer {

        public static void main(String[] args) {
                ServerSocket socket = new ServerSocket(80);
                while (true) {
                        Socket request = socket.accept();
                        handleRequest(request);
                }
        }

        public static void handleRequest(Socket request) {};
}
```

# Unbounded Thread Creation

- Nieuwe thread per task
- Submitting los van verwerking
- Veel overhead
- Instabiel

```
public class WebServer {

        public static void main(String[] args) {
                ServerSocket socket = new ServerSocket(80);
                while (true) {
                        Socket request = socket.accept();
                        new Thread(() -> handleRequest(request)
                                .start();
                }
        }

        public static void handleRequest(Socket request) {};
}
```

# Thread pooling

- Collectie van long-living threads
- Threads zijn herbruikbaar

```
public class WebServer {

    public static void main(String[] args) {
        ExecutorService executor = Executors.newFixedThreadPool(50);
        ServerSocket socket = new ServerSocket(80);
        while (true) {
            Socket request = socket.accept();
            executor.submit( () -> handleRequest(request)).start();
        }
    }
}
```

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# ExecutorService

- Abstractie van thread pools
- API voor asynchrone tasks
- Uitgebreide execution policies:
  - Max concurrent tasks
  - Volgorde
  - Queue size
  - Task hooks
- Ingebouwd shutdown mechanisme

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# Executors

- Factory methods voor ExecutorServices

```
ExecutorService executor = Executors.newSingleThreadExecutor();
ExecutorService executor = Executors.newFixedThreadPool(4);
ExecutorService executor = Executors.newCachedThreadPool();
ScheduledExecutorService executor = Executors.newScheduledThreadPool(4);
```

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# Runnable/Callable/Future

- Runnable en Callable zijn abstractie van een asynchrone taak
- Callable geeft een resultaat terug
- Future is abstractie van het resultaat van een asynchrone operatie

```
ExecutorService ex = Executor.newSingleThreadExecutor();
Runnable runnable = () -> doSomething();
Future<?> future = ex.submit(runnable);
future.get();
```

```
ExecutorService ex = Executor.newSingleThreadExecutor();
Callable<String> callable = () -> return “Hello world!”;
Future<String> future = ex.submit(callable);
String result = future.get();
```

# CompletionService

- ExecutorService + BlockingQueue
- Resultaat van de taak wordt op queue gezet

```
ExecutorService executor = Executors.newSingleThreadExecutor();
CompletionService cs = new ExecutorCompletionService(executor);
for (int i = 0; i < 100; i++) {
        Callable<Image> callable = () -> loadImage(i);
        cs.submit(callable);
}
List<Image> images = new ArrayList<>();
for (int i = 0; i < 100; i++) {
        Image image = cs.take();
        images.add(image);
}
```

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# ThreadPoolExecutor

- Standaard implementatie van ExecutorService
- Zelf instantiëren -> volledige controle over configuratie
- RejectedExecutionPolicy: AbortPolicy (default), DiscardPolicy, CallerRunsPolicy,…
- Hooks: beforeExecute(), afterExecute(), terminated()

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# ThreadPoolExecutor

```
public class CustomThreadPoolExecutor extends ThreadPoolExecutor {

    public CustomThreadPoolExecutor() {
        super(2, 2, 0L, SECONDS, new ArrayBlockingQueue<>(4));
    }

    @Override
    public void beforeExecute(Thread t, Runnable r) { // custom logic }

    @Override
    public void afterExecute(Thread t, Runnable r) { // custom logic }
}
```

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# Oefeningen

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# CompletableFuture API

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# CompletableFuture API

- Java 8
- Verbetering op Future interface
- Volledig framework voor asynchrone operaties te beheren

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# CompletableFuture - Callbacks

```
Future<String> future = new FutureTask(() -> “Hello!”);
future.run();
String result = future.get();
System.out.println(result);
```

```
CompletableFuture.supplyAsync(() -> “Hello!”)
                 .thenAccept(result -> System.out.println(result));
```

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# CompletableFuture - Chaining

```
Future<String> future = new FutureTask(() -> “Hello”);
future.run();
future = new FutureTask(() -> future.get() + “ world!”);
future.run();
System.out.println(future.get());
```

```
CompletableFuture.supplyAsync(() -> “Hello!”)
                .thenCompose(result -> CompletableFuture.supplyAsync(() -> result + “ world!”))
                .thenAccept(result -> System.out.println(result));
```

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# CompletableFuture - Combining

```
FutureTask<String> f1 = new FutureTask(() -> “Hello Alice!”);
FutureTask<String> f2 = new FutureTask(() -> “Hello Bob!);
f1.run();
f2.run();
System.out.println(f1.get());
System.out.println(f2.get());


CompletableFuture<Void> future = CompletableFuture.allOf(
        CompletableFuture.supplyAsync(() -> “Hello Alice!”),
        CompletableFuture.supplyAsync(() -> “Hello Bob!”)
);
```

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# CompletableFuture - Combining

```
List<CompletableFuture<String>> futures = Arrays.asList(
        CompletableFuture.supplyAsync(() -> “Hello Alice!”),
        CompletableFuture.supplyAsync(() -> “Hello Bob!”)
);
CompletableFuture.allOf(futures.toArray(new CompletableFuture[0]))
                .thenAccept(v -> {
                        futures.stream()
                                .map(Future::get)
                                .forEach(result -> System.out.println(result))
                });
```

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# CompletableFuture - Exception Handling

```
Future<String> future = new FutureTask(() -> {
        methodThatMightFail();
}

try {
        future.get()
} catch (Exception ex) {
        // exception handling goes here
}
```

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# CompletableFuture - Exception Handling

```
CompletableFuture.supplyAsync(() -> methodThatMightFail())
        .exceptionally(ex -> {
            System.out.println(ex.getMessage();
            return “default value”);
        })
        .thenAccept(result -> System.out.println(result);
```

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# Oefeningen

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# Feedback

https://forms.office.com/Pages/ResponsePage.aspx?id=tsPR7Ye-u0OS1HqRHFzuFzf05V3wFXZIsWm671aH0uFUNjQ0Wk5OVlFTOFdTSlNWOVMwTVRMWjFIRS4u