Parallel Programming Exercise Session 2

Spring 2025

Schedule

Motivation: Why Parallel Programming?

Theory Recap

Preparation assignment 2

Coding Remarks

Pre-Discussion assignment 2

Quiz

Why Parallel Programming?

Why Parallel Programming

- Solve problems faster
- Large problems → divided into smaller ones → executed in parallel

- Programs for Supercomputers / High-Performance Computing are highly parallel


HPE Cray
CSCS
ETH zürich
ALPS

Team RACKlette

- ETH Club about High-Performance Computing under Prof. T. Hoefler and in collaboration with CSCS
- Optimizing, compiling code for HPC clusters
- Understanding hardware and how to exploit that for speedup

https://racklette.ethz.ch/

Interested? Join us!

https://forms.gle/4zWgxXsMdd5DgCa76

Theory Recap

Terminology

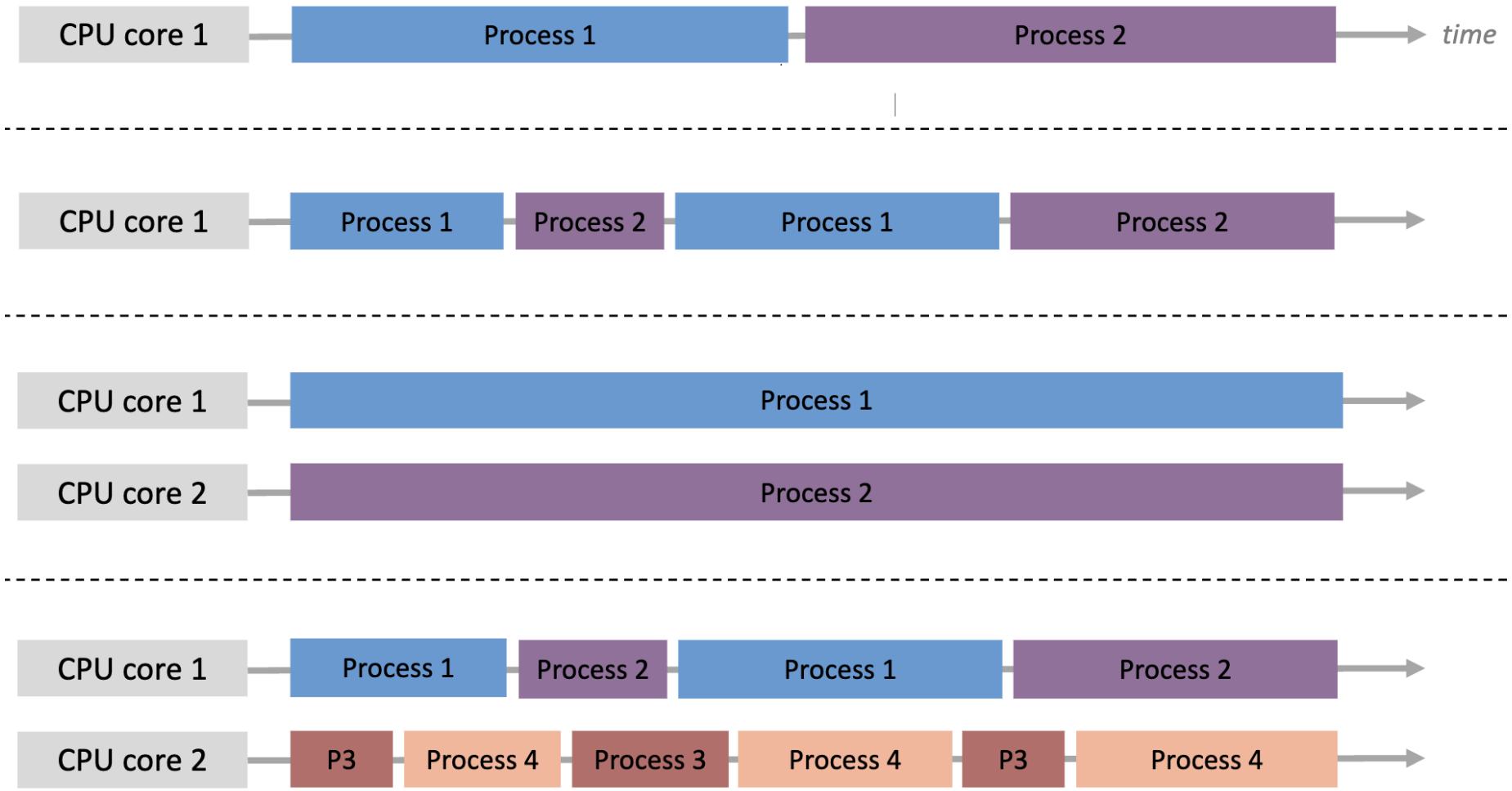
Overview:
https://cgl.ethz.ch/teaching/parallelprog25/pages/terminology.html

Sequential vs Concurrent vs Parallel

Concurrency:
Dealing with multiple things at the same time.

Parallelism:
Doing multiple things at the same time.

Sequential vs Concurrent vs Parallel



Thread Definition

An independent (i.e., capable of running in parallel) unit of computation that executes code.

Each thread is like a running sequential program,

but a thread can create other threads

that are then part of the same program.

Those threads can create more threads etc.

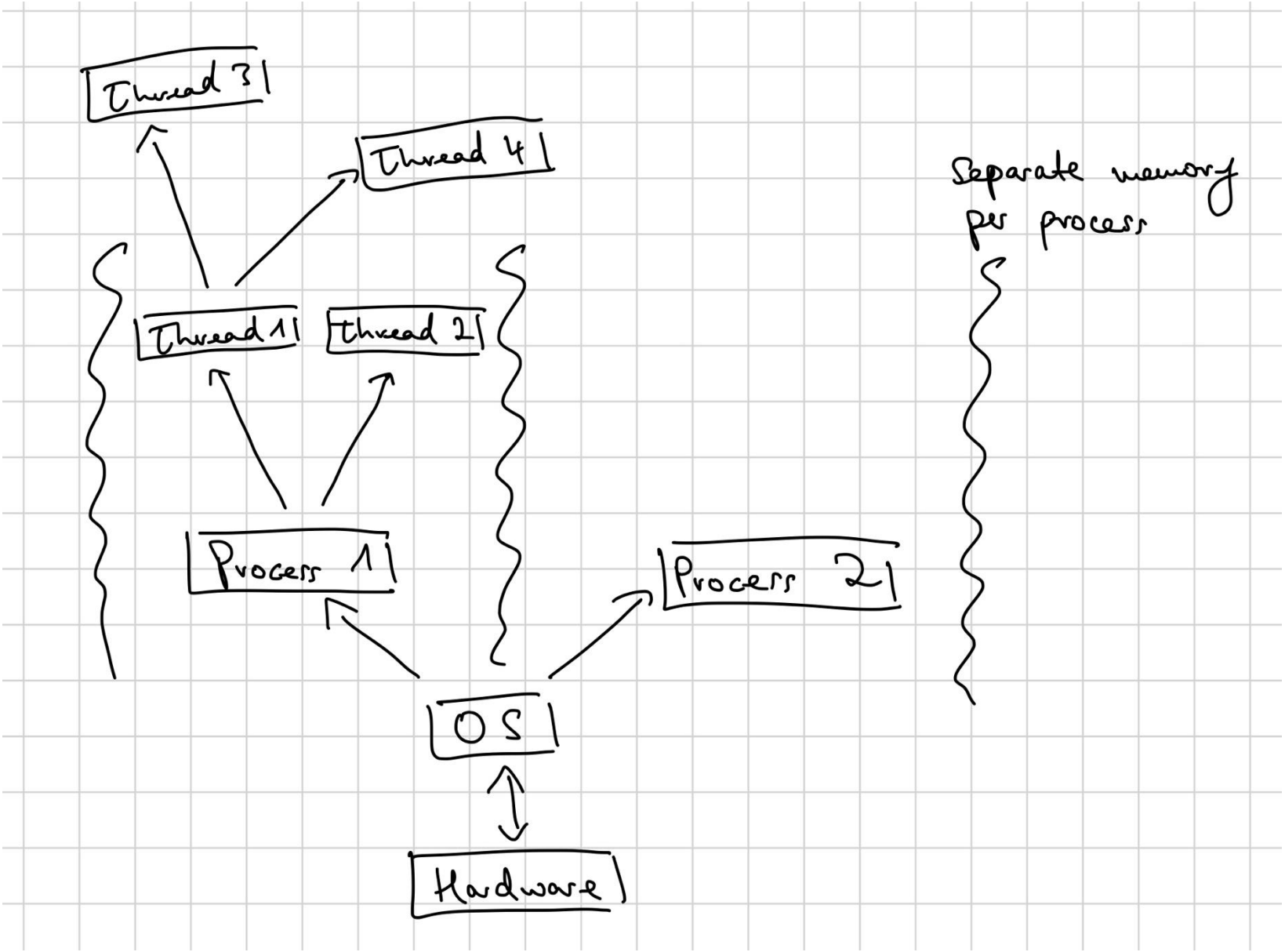
Thread Definition Advanced

Concept of threads exists on various levels:

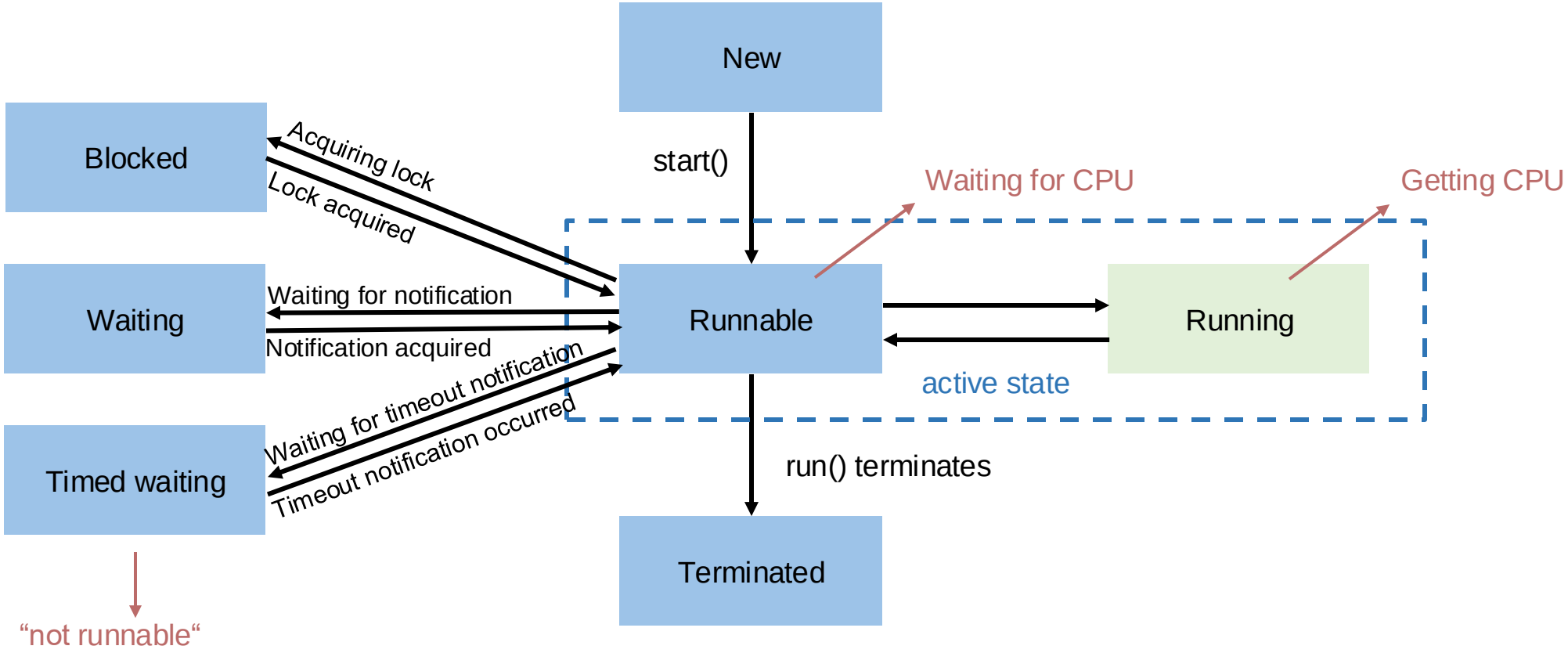
- Hardware (CPU)
- Operating systems
- Programming languages
  - Java: `Thread` class

Thread Properties (in our course)

- Threads can create other threads
- Shared memory (changes to variables by threads are visible to other Threads)
- Threads (from same class) execute same program *but* with different arguments
- Communication between threads: Writing fields of shared objects


Thread 3
Thread 4
Thread 1
Thread 2
Process 1
Process 2
OS
Hardware
Separate memory per process

Life cycle of a Thread



Daemon vs non-daemon threads

Daemon threads
low priority threads

Non-daemon / user threads
high priority threads

JVM process stops when all non-daemon threads terminate

Daemon vs non-daemon threads

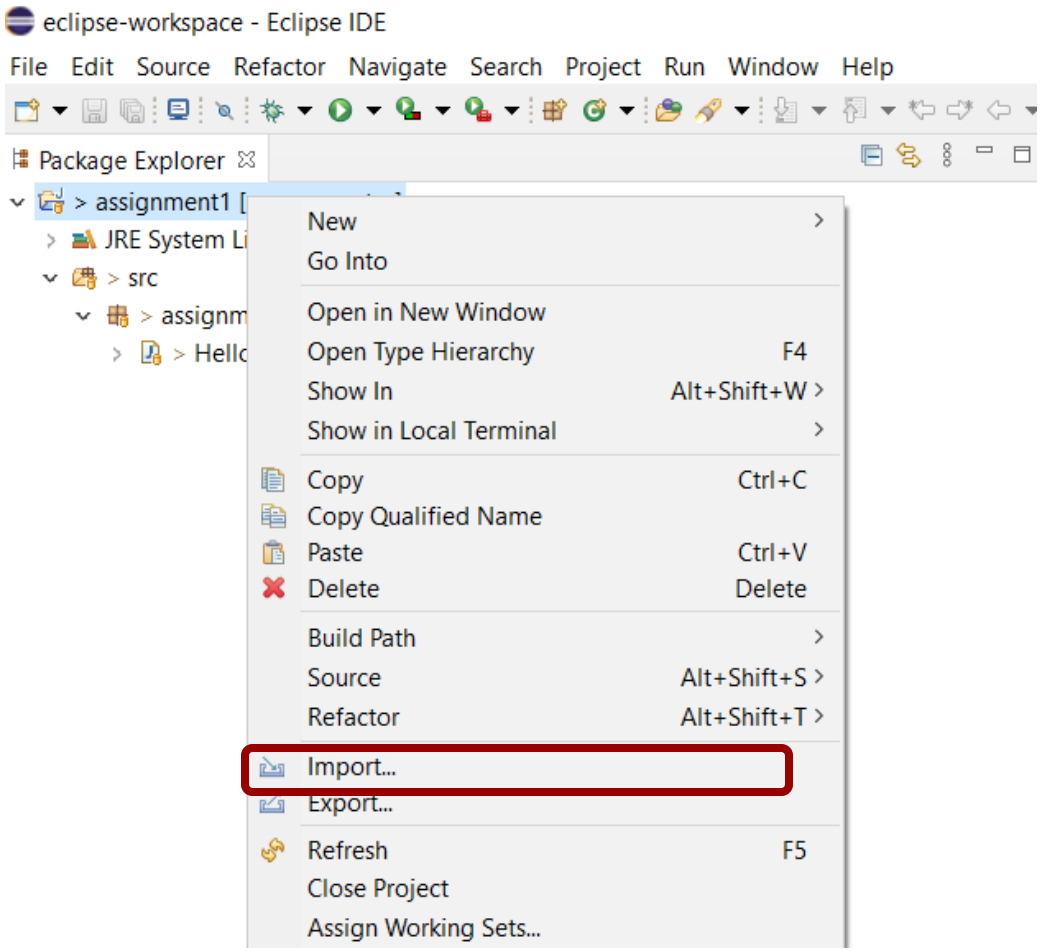
- Creating a new thread from a daemon thread leads to a daemon thread
- Creating a new thread from a non-daemon thread leads to a non-daemon thread
- Manually set daemon / non-daemon status before .start() with .setDaemon([true | false])
- Check if a thread is daemon with .isDaemon();

Preparation Exercise 2

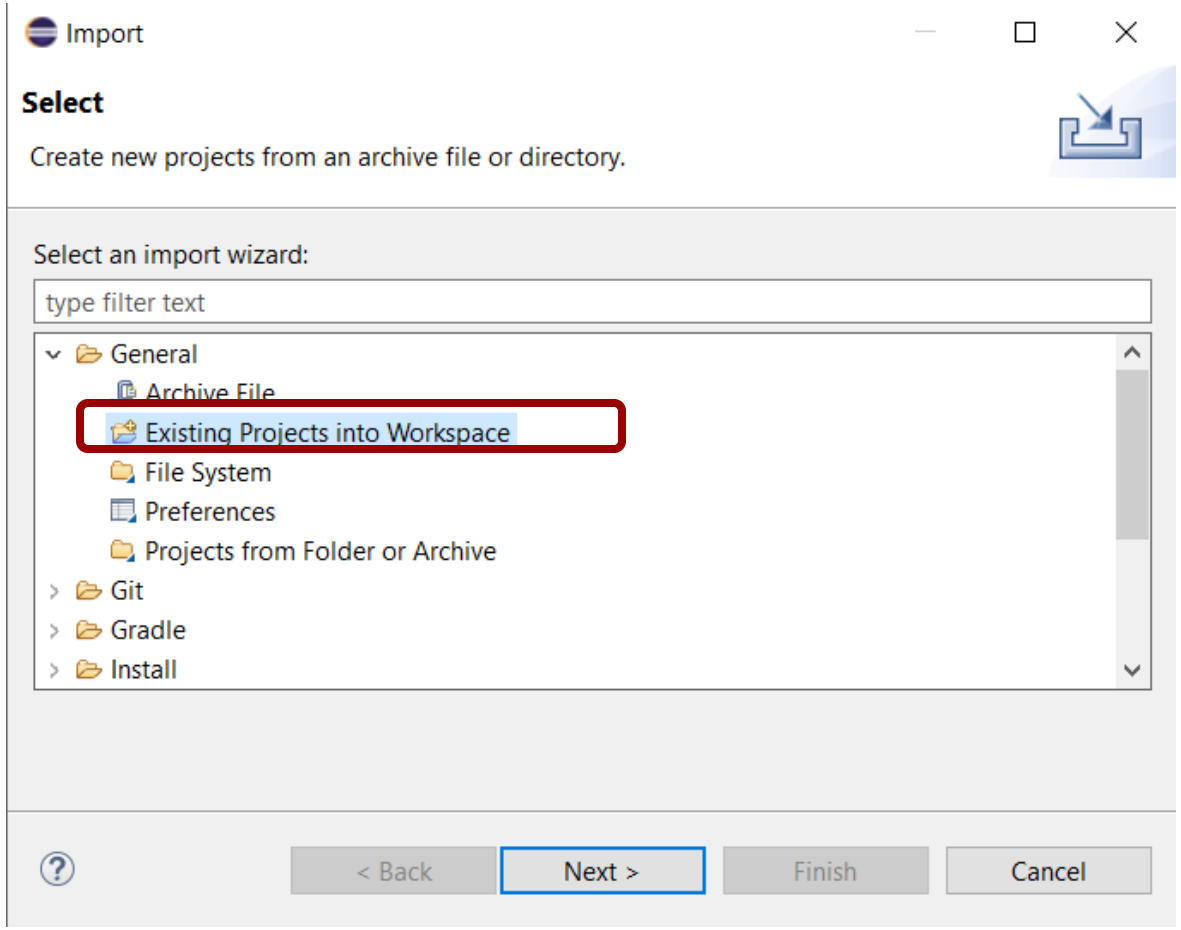
Preparations

1. Import assignment2.zip in Eclipse
2. Run the projects unit-tests in Eclipse
3. Understand output of unit-tests
    - Did the test fail or succeed?
    - Why did the test fail?
4. Start coding and keep checking if tests pass

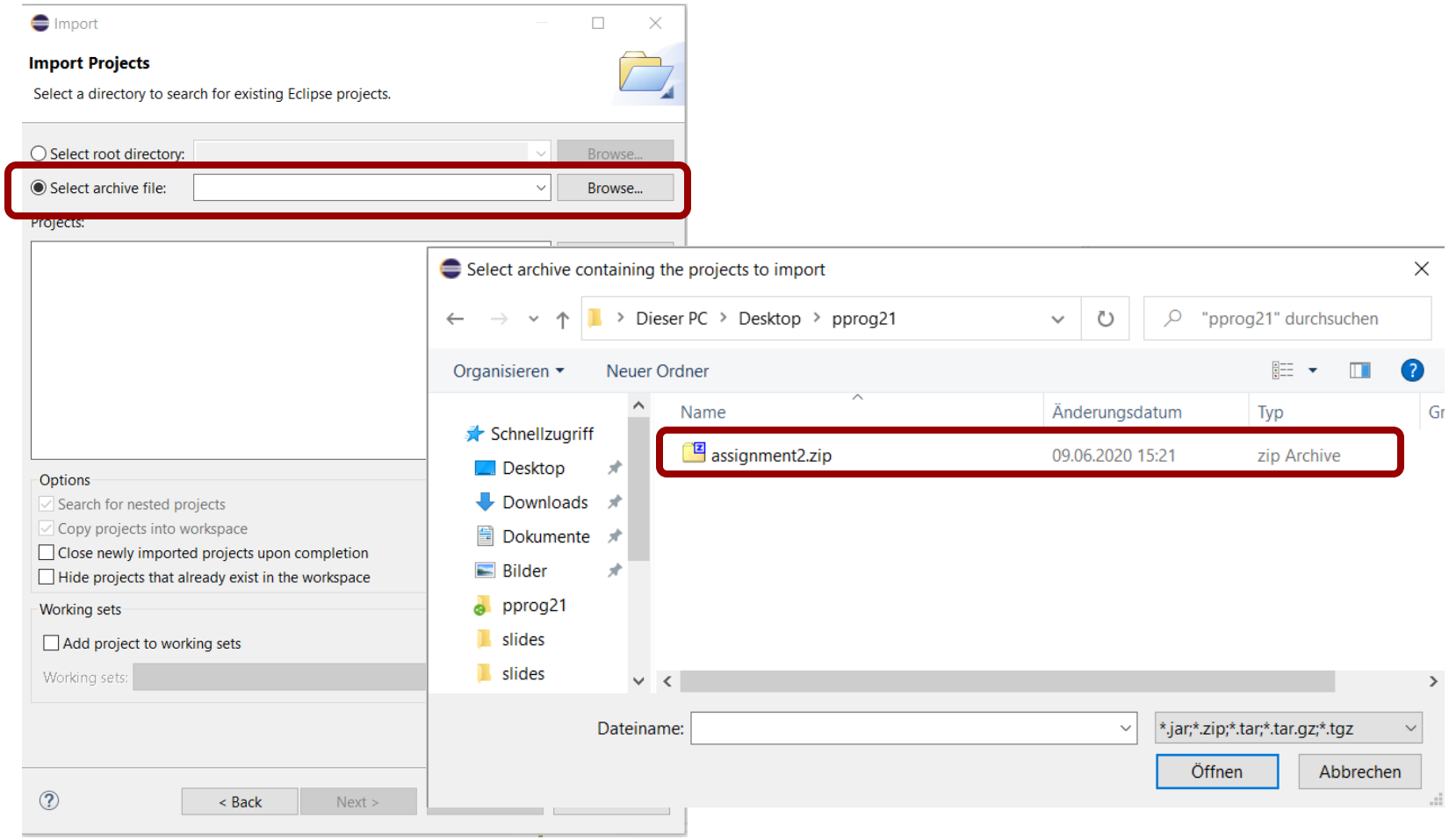
Eclipse: import project



Eclipse: import project

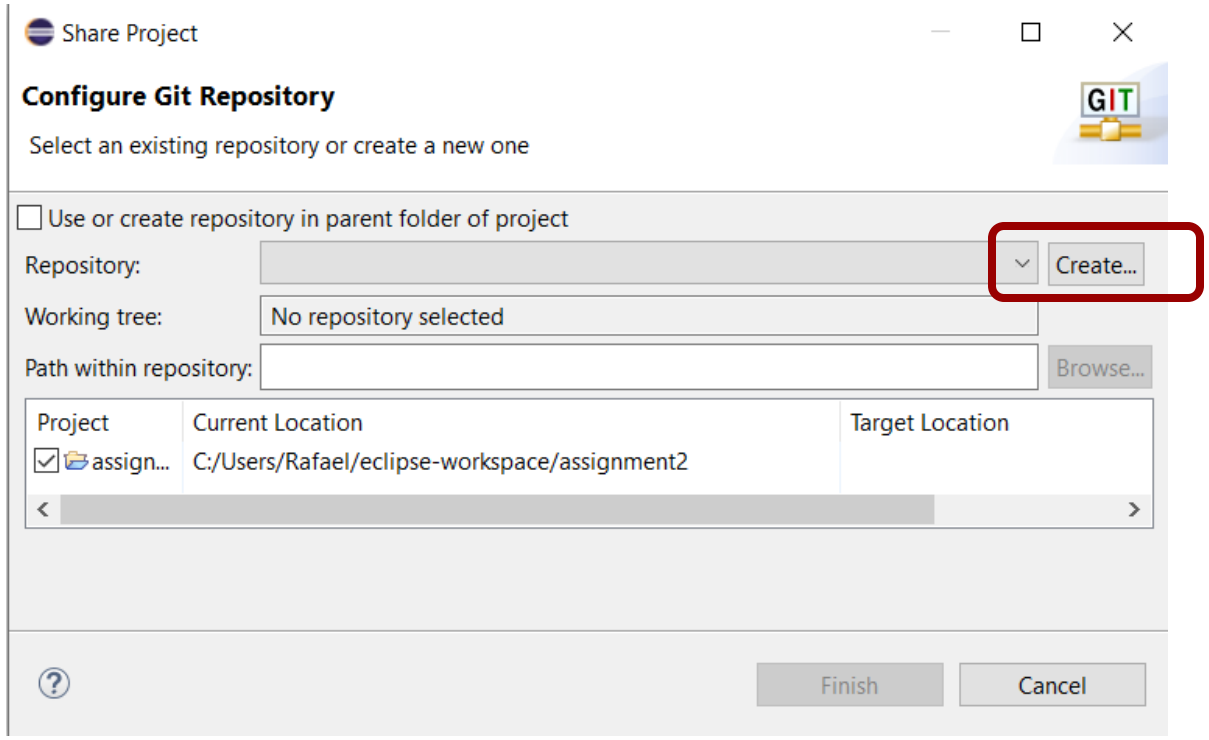


Eclipse: import project

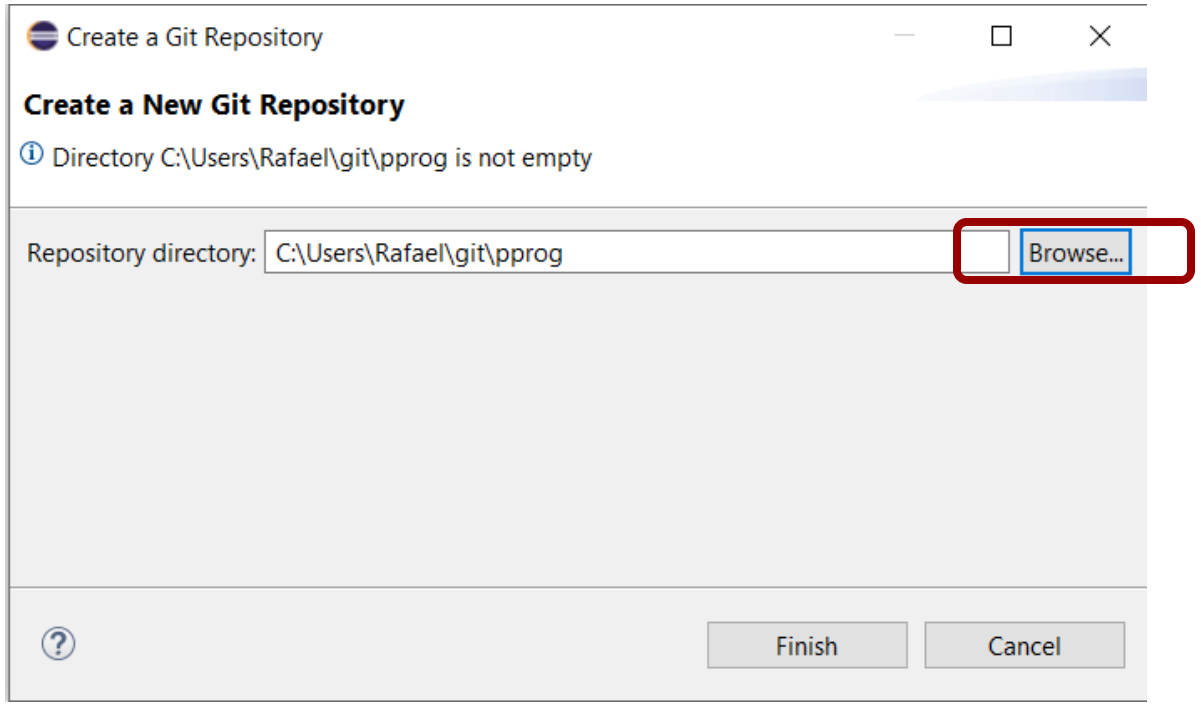


Eclipse: add to git

Team -> Share Project ...

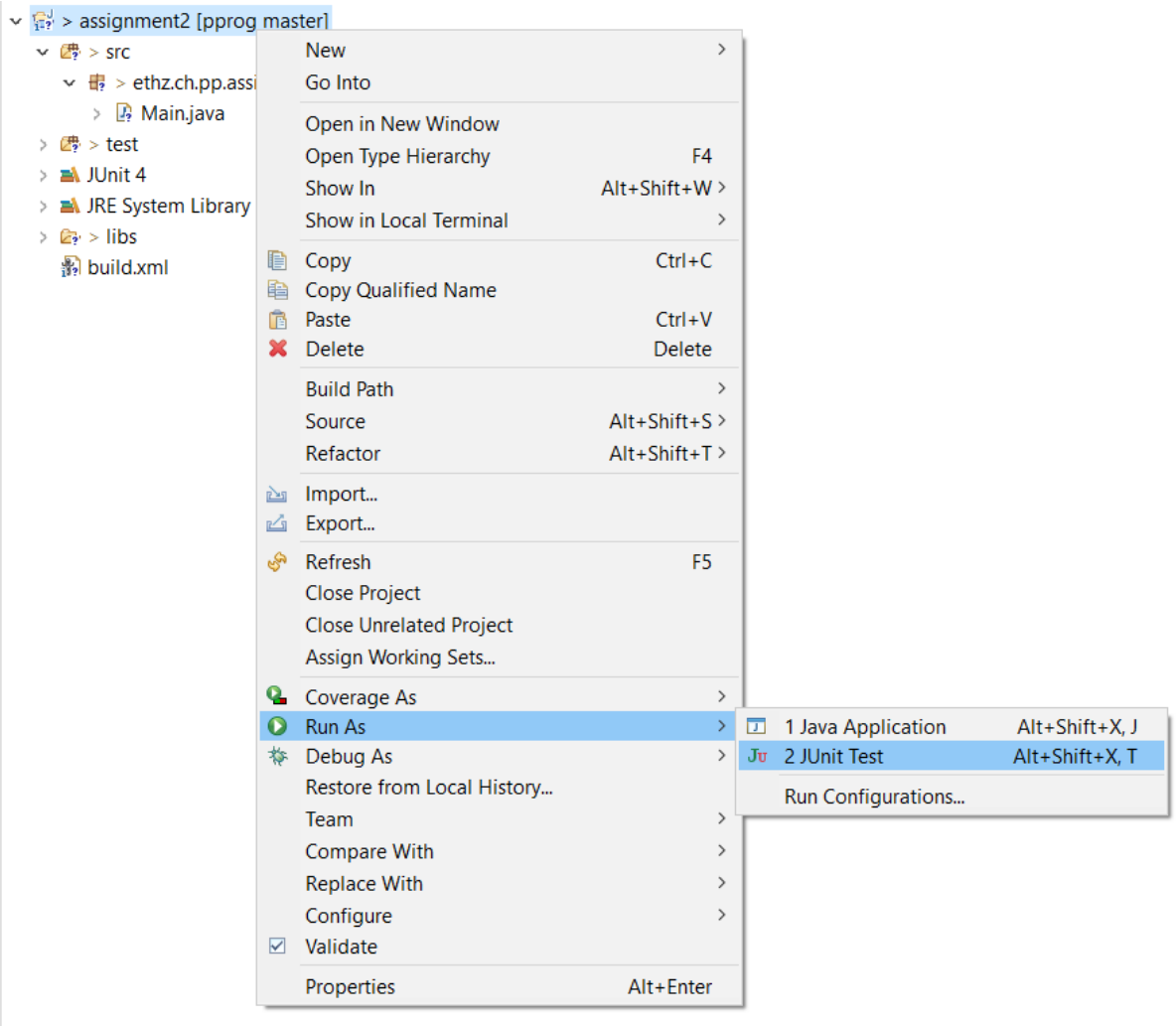


Eclipse: add to git



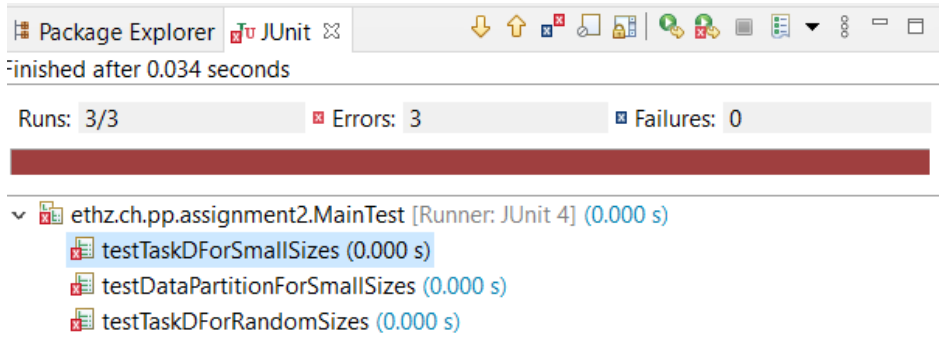
Important: Select same directory as for assignment 1
If you don't have a repo yet, contact your TA

Eclipse: running JUnit tests (1)

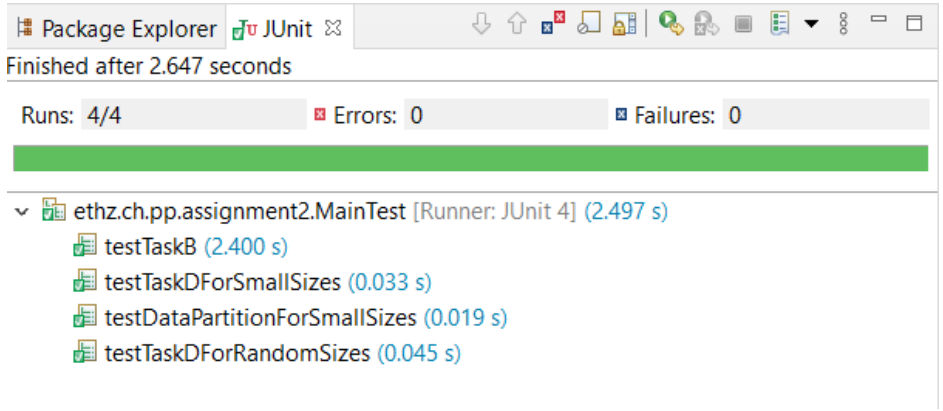


Eclipse: running JUnit tests (2)

Template



Your solution (ideally)



Coding Remarks

Code Style

- Try to make your code as readable as possible
- Include high-level comments that explain why you are doing something (much better than a line-by-line commentary of your code)

Code Style / Errors

Keep attention what Eclipse reports:

HelloWorld.java | *HelloWorld.java

```
1  package asdf;
2
3  public class HelloWorld {
4
5      public static void main(String[] args) {
6          // TODO Auto-generated method stub
7          String myString = "Foo" + "Bar" + " " + 123;
8
9      }
10
11 }
12
```

The value of the local variable myString is not used

4 quick fixes available:

- Remove 'myString' and all assignments
- Remove 'myString', keep assignments with side effects
- Add @SuppressWarnings 'unused' to 'myString'
- Add @SuppressWarnings 'unused' to 'main()'

Press 'F2' for focus

Java Doc (https://docs.oracle.com/en/java/javase/21/docs/api/index.html)

OVERVIEW MODULE PACKAGE CLASS USE TREE DEPRECATED INDEX HELP

Java SE 15 & JDK 15

SEARCH: Search

Java® Platform, Standard Edition & Java Development Kit
Version 15 API Specification

This document is divided into two sections:

Java SE

The Java Platform, Standard Edition ... pose computing. These APIs are in modules whose names start with `java`.

JDK

The Java Development Kit (JDK) APIs are specific to the JDK and will not necessarily be available in all implementations of the Java SE Platform. These APIs are in modules whose names start with `jdk`.

We will use Java SE

All Modules | Java SE | JDK | Other Modules

Modules

Module	Description
java.base	Defines the foundational APIs of the Java SE Platform.
java.compiler	Defines the Language Model, Annotation Processing, and Java Compiler APIs.
java.datatransfer	I... plications.
java.desktop	I... for accessibility, audio, imaging, printing, and JavaBeans.
java.instrument	...nning on the JVM.
java.logging	I...
java.management	Defines the Java Management Extensions (JMX) API.
java.management.rmi	Defines the RMI connector for the Java Management Extensions (JMX) Remote API.
java.naming	Defines the Java Naming and Directory Interface (JNDI) API.
java.net.http	Defines the HTTP Client and WebSocket APIs.
java.prefs	Defines the Preferences API.
java.rmi	Defines the Remote Method Invocation (RMI) API.
java.scripting	Defines the Scripting API.
java.se	Defines the API of the Java SE Platform.
java.security.jgss	Defines the Java binding of the IETF Generic Security Services API (GSS-API).
java.security.sasl	Defines Java support for the IETF Simple Authentication and Security Layer (SASL).
java.sql	Defines the JDBC API.
java.sql.rowset	Defines the JDBC RowSet API.
java.transaction.xa	Defines an API for supporting distributed transactions in JDBC.
java.xml	Defines the Java API for XML Processing (JAXP), the Streaming API for XML (StAX), the Simple API for XML (SAX), and the W3C Document Object Model (DOM) API.

Java Doc (https://docs.oracle.com/en/java/javase/21/docs/api/index.html)

OVERVIEW MODULE PACKAGE CLASS USE TREE DEPRECATED INDEX HELP Java SE 15 & JDK 15

MODULE: DESCRIPTION | MODULES | PACKAGES | SERVICES SEARCH: Search

Module java.base

Defines the foundational APIs of the Java SE Platform.

Providers:

The JDK implementation of this module provides an implementation of the jrt file system provider to enumerate and read the class and resource files in a run-time image. The jrt file system can be created by calling `FileSystems.newFileSystem(URI.create("jrt:/"))`.

Module Graph:

java.base

Tool Guides:

java launcher, keytool

Since:

9

Packages

Exports

Package	Description
java.io	Provides for system input and output through data streams, serialization and the file system.
java.lang	Provides cl gramming language.
java.lang.annotation	Provides lib ation facility.
java.lang.constant	Cl e entities such as classes or method handles, and classfile entities such as constant pool entries or `invokedynamic` call sites.
java.lang.invoke	The `java.lang.invoke` package provides low-level primitives for interacting with the Java Virtual Machine.
java.lang.module	Classes to support module descriptors and creating configurations of modules by means of resolution and service binding.
java.lang.ref	Provides reference-object classes, which support a limited degree of interaction with the garbage collector.
java.lang.reflect	Provides classes and interfaces for obtaining reflective information about classes and objects.
java.lang.runtime	The `java.lang.runtime` package provides low-level runtime support for the Java language.
java.math	Provides classes for performing arbitrary-precision integer arithmetic (`BigInteger`) and arbitrary-precision decimal arithmetic (`BigDecimal`).
java.net	Provides the classes for implementing networking applications.
java.net.spi	Service-provider classes for the `java.net` package.
java.nio	Defines buffers, which are containers for data, and provides an overview of the other NIO packages.

Packages

Java Doc (https://docs.oracle.com/en/java/javase/21/docs/api/index.html)

OVERVIEW MODULE PACKAGE CLASS USE TREE DEPRECATED INDEX HELP Java SE 15 & JDK

SEARCH: Search

Module java.base

Package java.util

Contains the collections framework, some internationalization support classes, a service loader, properties, random number generation, string parsing and scanning classes, base64 encoding and decoding, a bit array, and several miscellaneous utility classes. This package also contains legacy collection classes and legacy date and time classes.

Java Collections Framework

For an overview, API outline, and design rationale, please see:

- **Collections Framework Documentation**

For a tutorial and programming guide with examples of use of the collections framework, please see:

- **Collections Framework Tutorial**

Since:
1.0

Interface Summary

Interface	Description
Collection<E>	The root interface in the *collection hierarchy*.
Comparator<T>	A comparison function, which imposes a *total ordering* on some collection of objects.
Deque<E>	A linear collection that supports element insertion and removal at both ends.
Enumeration<E>	An object that implements the Enumeration interface generates a series of elements, one at a time.
EventListener	A tagging interface that all event listener interfaces must extend.
Formattable	The `Formattable` interface must be implemented by any class that needs to perform custom formatting using the `'s'` conversion specifier of `Formatter`.
Iterator<E>	An iterator over a collection.
List<E>	An ordered collection (also known as a *sequence*).
ListIterator<E>	An iterator for lists that allows the programmer to traverse the list in either direction, modify the list during iteration, and obtain the iterator's current position in the list.
Map<K,V>	An object that maps keys to values.
Map.Entry<K,V>	A map entry (key-value pair).
NavigableMap<K,V>	A `SortedMap` extended with navigation methods returning the closest matches for given search targets.
NavigableSet<E>	A `SortedSet` extended with navigation methods reporting closest matches for given search targets.
Observer	Deprecated. *This interface has been deprecated.*
PrimitiveIterator<T,T_CONS>	A base type for primitive specializations of `Iterator`.

Classes

Java Doc (https://docs.oracle.com/en/java/javase/21/docs/api/index.html)

OVERVIEW MODULE PACKAGE CLASS USE TREE DEPRECATED INDEX HELP Java SE 15 & JDK 1

SUMMARY: NESTED | FIELD | CONSTR | METHOD DETAIL: FIELD | CONSTR | METHOD SEARCH: Search

the element previously at the specified position

Throws:

`IndexOutOfBoundsException` - if the index is out of range (`index < 0 || index >= size()`)

add

```
public boolean add(E e)
```

Appends the specified element to the end of this list.

Specified by:

`add` in interface `Collection<E>`

Specified by:

`add` in interface `List<E>`

Overrides:

`add` in class `AbstractList<E>`

Parameters:

`e` - element to be appended to this list

Returns:

`true` (as specified by `Collection.add(E)`)

add

```
public void add(int index,
                E element)
```

Inserts the specified element at the specified position in this list. Shifts the element currently at that position (if any) and any subsequent elements to the right (adds one to their indices).

Specified by:

`add` in interface `List<E>`

Overrides:

`add` in class `AbstractList<E>`

Parameters:

`index` - index at which the specified element is to be inserted

`element` - element to be inserted

Throws:

`IndexOutOfBoundsException` - if the index is out of range (`index < 0 || index > size()`)

remove

Method Signature

Semantic description what the method does

Parameter description

Possible occurring errors

Pre-Discussion Exercise 2

Task A

To start with, print to the console "Hello Thread!" from a new thread. How do you check that the statement was indeed printed from a thread that is different to the main thread of your application? Furthermore, ensure that your program (i.e., the execution of main thread) finishes only after the thread execution finishes.

Task A: How to create and start a new thread?

option 1: Extend class Thread

```
class ConcurrWriter extends Thread { …
     public void run() { … }
}
ConcurrWriter writerThread = new ConcurrWriter();
writerThread.start();   // calls ConcurrWriter.run()
```

option 2: Implement Runnable

```
public class ConcurrReader implements Runnable {
     …
     public void run() { …
           … code here executes concurrently with caller … }
}

ConcurrReader readerThread = new ConcurrReader();
Thread t = new Thread(readerThread);
t.start();   // calls ConcurrReader.run() automatically
```

Demo

Task B

Description: Our goal in this exercise will be to parallelize the execution of the following loop defined in `computePrimeFactors` method:

```
for (int i = 0; i < values.length; i++) {
  factors[i] = numPrimeFactors(values[i]);
}
```

which computes the number of prime factors for each element in an given array. For example, for number `12` the number of prime factors is `numPrimeFactors(12) = 3` since `12 = 2*2*3`. The implementation of `numPrimeFactors` is already provided for you in the assignment template and should not be changed.

Task B

Run the method computePrimeFactors in a single thread other than the main thread. Measure the execution time of sequential execution (on the main thread) and execution using a single thread. Is there any noticeable difference?

Task C

Design and run an experiment that would measure the overhead of creating and executing a thread.

Task C

option 1: Measures real time elapsed including time when the thread is not running.

```
long time = System.nanoTime();
//compute something
time =  System.nanoTime() - time;
```

option 2: Measures thread cpu time excluding time when the thread is not running.

```
ThreadMXBean tmxb = ManagementFactory.getThreadMXBean();
long time = tmxb.getCurrentThreadCpuTime();
//compute something
time = tmxb.getCurrentThreadCpuTime()-time;
```

Task C

Measured execution time not always the same

→ Average over multiple runs (the more the better)

→ Calculate variance

Task D

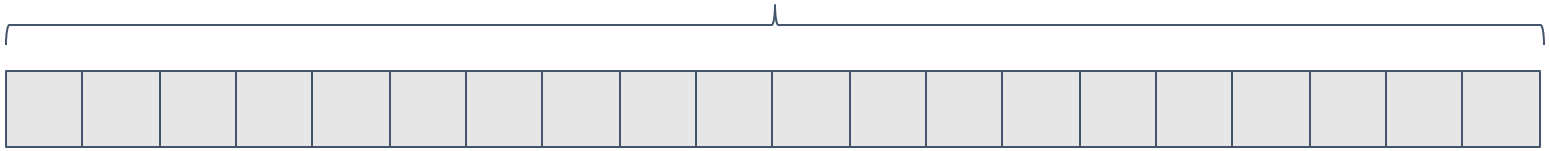
Before you parallelize the loop in Task E, design how the work should be split between the threads by implementing method PartitionData. Each thread should process roughly equal amount of elements. Briefly describe you solution and discuss alternative ways to split the work.

Task D: Split the work between the threads

PartitionData(int length, int numPartitions) { … }

length (20)

Input



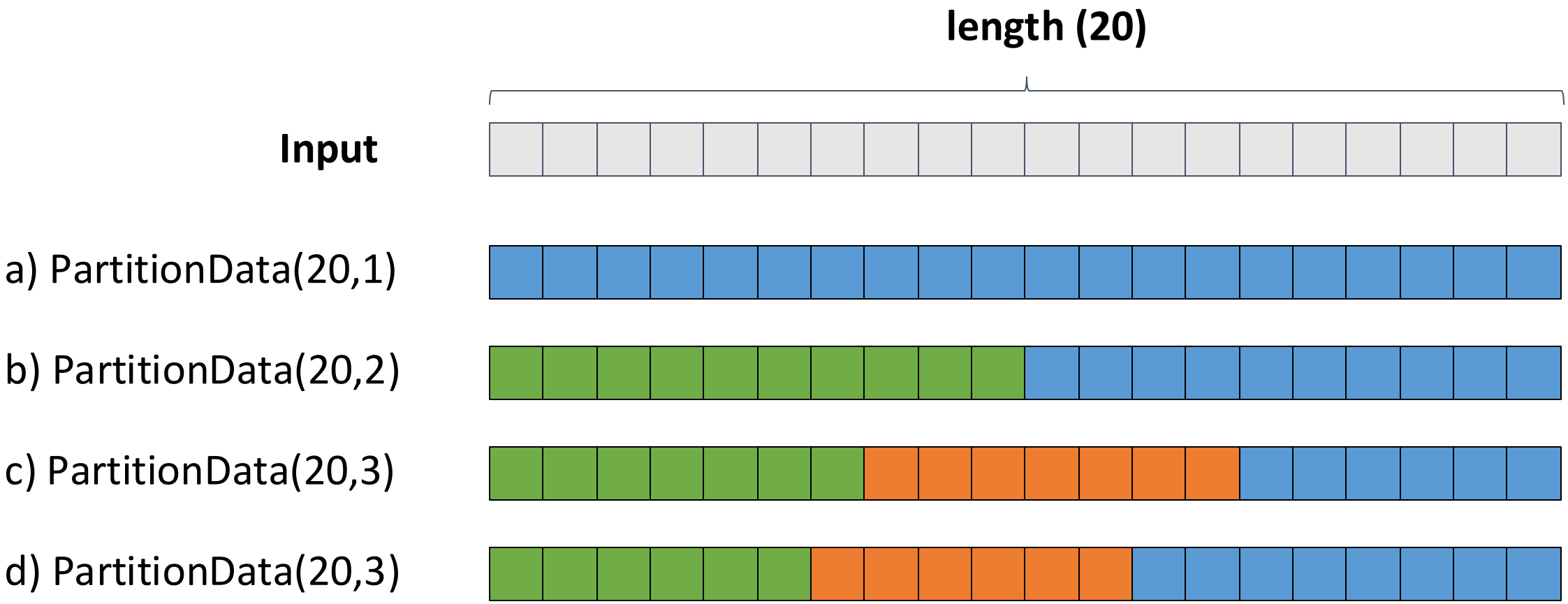
a) PartitionData(20,1) ?

b) PartitionData(20,2) ?

c) PartitionData(20,3) ?

Task D: Split the work between the threads

PartitionData(int length, int numPartitions) { … }



both c) and d) are correct solutions for this exercise

Task D

Several ways with different performance depending on task and data

If input is random: Splitting the input into half works well

If input is sorted: 1. half finishes faster than 2. half
→ maybe split on odd/even indices

Task D

- What about (length>0 and numPartitions>0) and length<numPartitions?
  - ??
  - ??
- And (length<=0 or numPartitions<=0)?
  - ??
  - ??

```
PartitionData(int length, int numPartitions) {  …  }
```

Task D

- What about (length>0 and numPartitions>0) and length<numPartitions?
  - Throw an exception?
  - Return m = min(m,n) splits?
- And (length<=0 or numPartitions<=0)?
  - Throw an exception?
  - Create a default return value (e.g. new ArraySplit[0])?
- In any case, write your assumptions in JavaDoc

```
PartitionData(int length, int numPartitions) {  …  }
```

Task E

Parallelize the loop execution in computePrimeFactors using a configurable number of threads.

Task F

Think of how would a plot that shows the execution speed-up of your implementation, for n = 1, 2, 4, 8, 16, 32, 64, 128 threads and the input array size of 100, 1000, 10000, 100000 look like.

Task G

Measure the execution time of your parallel implementation for n = 1, 2, 4, 8, 16, 32, 64, 128 threads and the input array size of input.length = 100, 1000, 10000, 100000. Discuss the differences in the two plots from task F and G.

Speedup

Sub-linear: usually

Super-linear: not possible in theory, *but*

- Modern hardware properties (local/remote memory)
- Bug (this course assumes this)

Past Exam Task

Kreuzen Sie alle korrekten Aussagen über das Erstellen von Java `Threads` an.

Mark all correct statements regarding the creation of Java `Threads`.

- ◯ Beim Aufteilen eines Workloads sollte man soviele Threads erstellen wie möglich, bis nur noch elementare Operationen pro Thread ausgeführt werden.

  When splitting a workload, as many threads as possible should be created until only elementary operations are performed per thread.

- ◯ Um eine eigene Thread-Klasse in Java zu definieren kann man das Runnable-Interface implementieren.

  To define a custom thread class in Java, one can implement the Runnable interface.

- ◯ Um eine eigene Thread-Klasse in Java zu definieren kann man die Thread-Klasse erweitern.

  To define a custom thread class in Java, one can extend the Thread class.

- ◯ Threads werden fast ausschliesslich genutzt um eine rekursive Implementation zu beschleunigen.

  Threads are used almost exclusively to speed up a recursive implementation.

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Rep. Exam, FS 2023

QUIZ