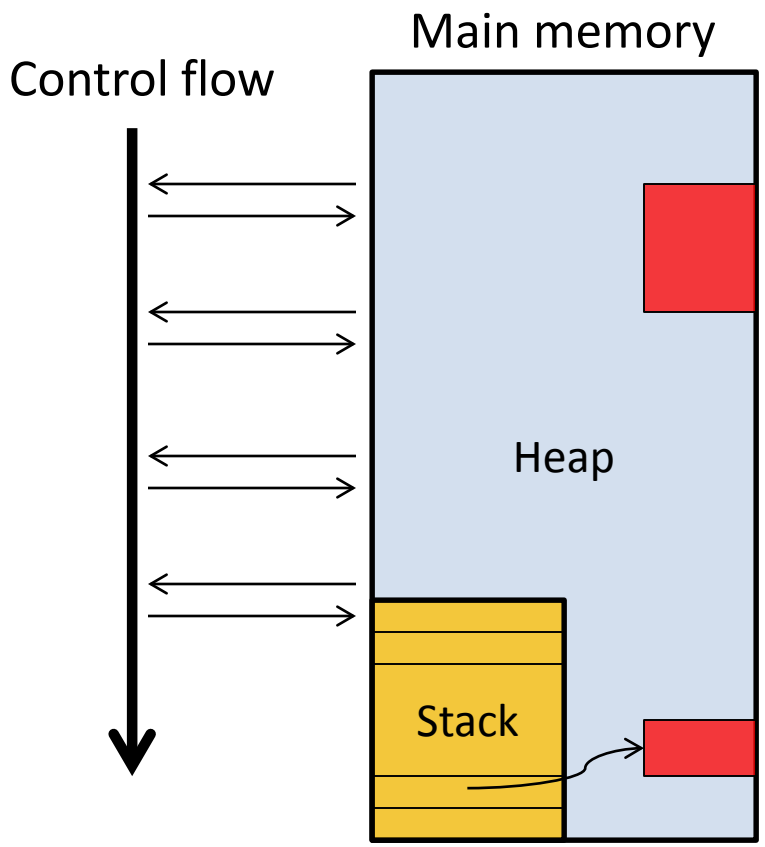
CMSC 433 Fall 2016
Section 0101
Rance Cleaveland

UNIVERSITY OF MARYLAND

Lecture 2
Introduction to Concurrency

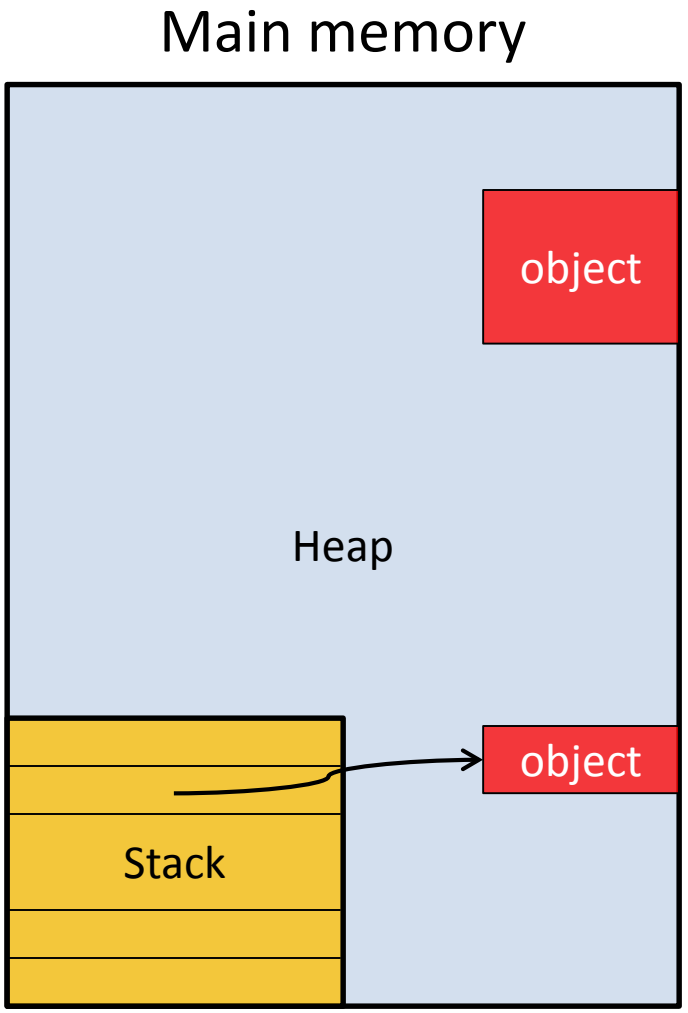
Running a Sequential Program

- Executable
  Machine instructions to be performed
- Program counter
  Next instruction to be executed
- Stack
  Current variable definitions
- Heap
  Dynamically allocated data structures
- Control flow
  Sequence of instructions performed during an execution



Java Memory Model

- Stack
  - Local variables
  - Method parameters
- Heap
  - Objects!
  - Every call to new allocates space on heap
- Class-typed variables reference heap or null



More on Main Memory (MM)

- Naively, MM is a table:
  - Each address can store a value
  - Each address refers to one memory location (no copies)

Address	Value
0000	‘a’
0001	37
0002	NULL

- In reality, several copies of a given address are possible
  - Caches
  - Registers
  - …
- Why? *Performance*
  - Higher-speed memory is more expensive
  - Copying frequently used data into high-speed memory (register, cache) improves performance while containing cost

Concurrent Programs

- Multiple control flows!
- Programs with multiple control flows can be
  - Concurrent
  - Parallel
  - Distributed
- Control flows are either
  - Processes
  - Threads

Concurrent vs. Parallel vs. Distributed

- Concurrent

  # of control flows unrelated to # of physical processors

- Parallel

  # of control flows ≤ # of physical processors; each flow has its own processor

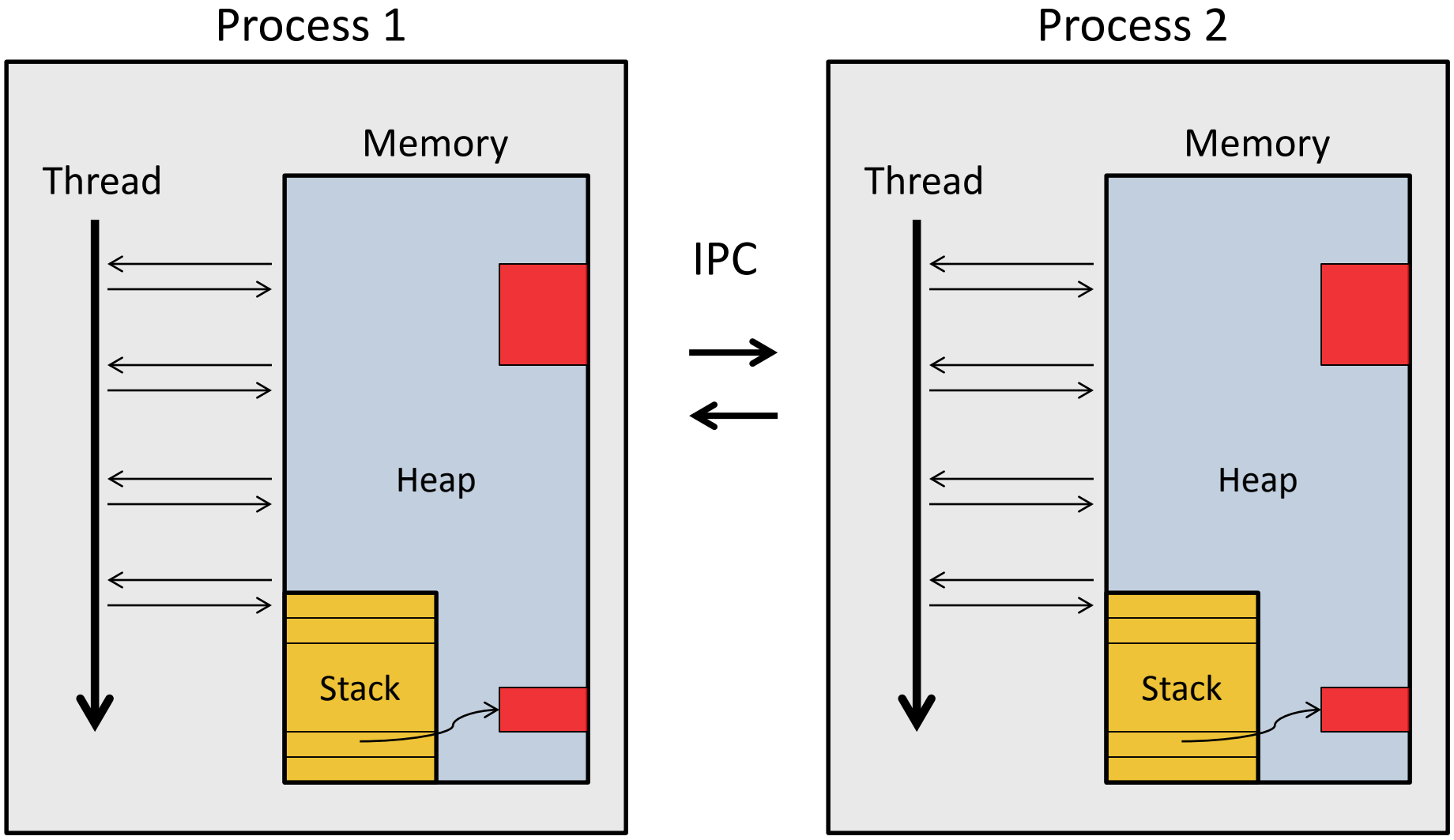
- Distributed

  Multiple machines connected via network

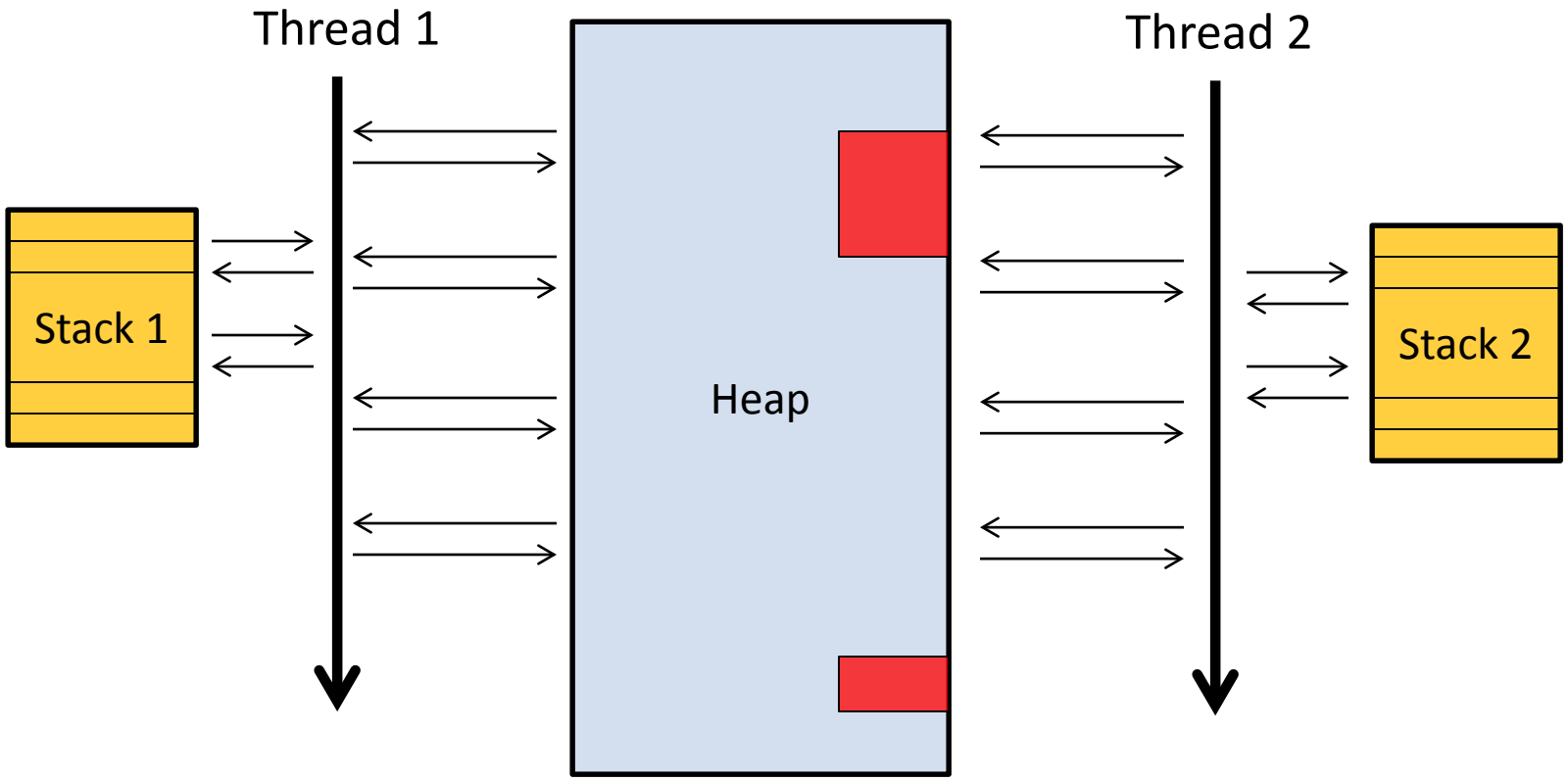
Processes vs. Threads

- Processes
  - Possess own heap
  - Communicate via *IPC* (= inter-process communication) mechanisms
    - Sockets
    - Message passing
    - Etc.
- Threads
  - Contained within processes
  - Possess own stack, program counter
  - Share heap with other threads in same process
  - Communicate via shared memory
- Historically
  - Process management handled by operating system
  - Processes were single-threaded

(Single-Threaded) Processes



Multi-threaded Process



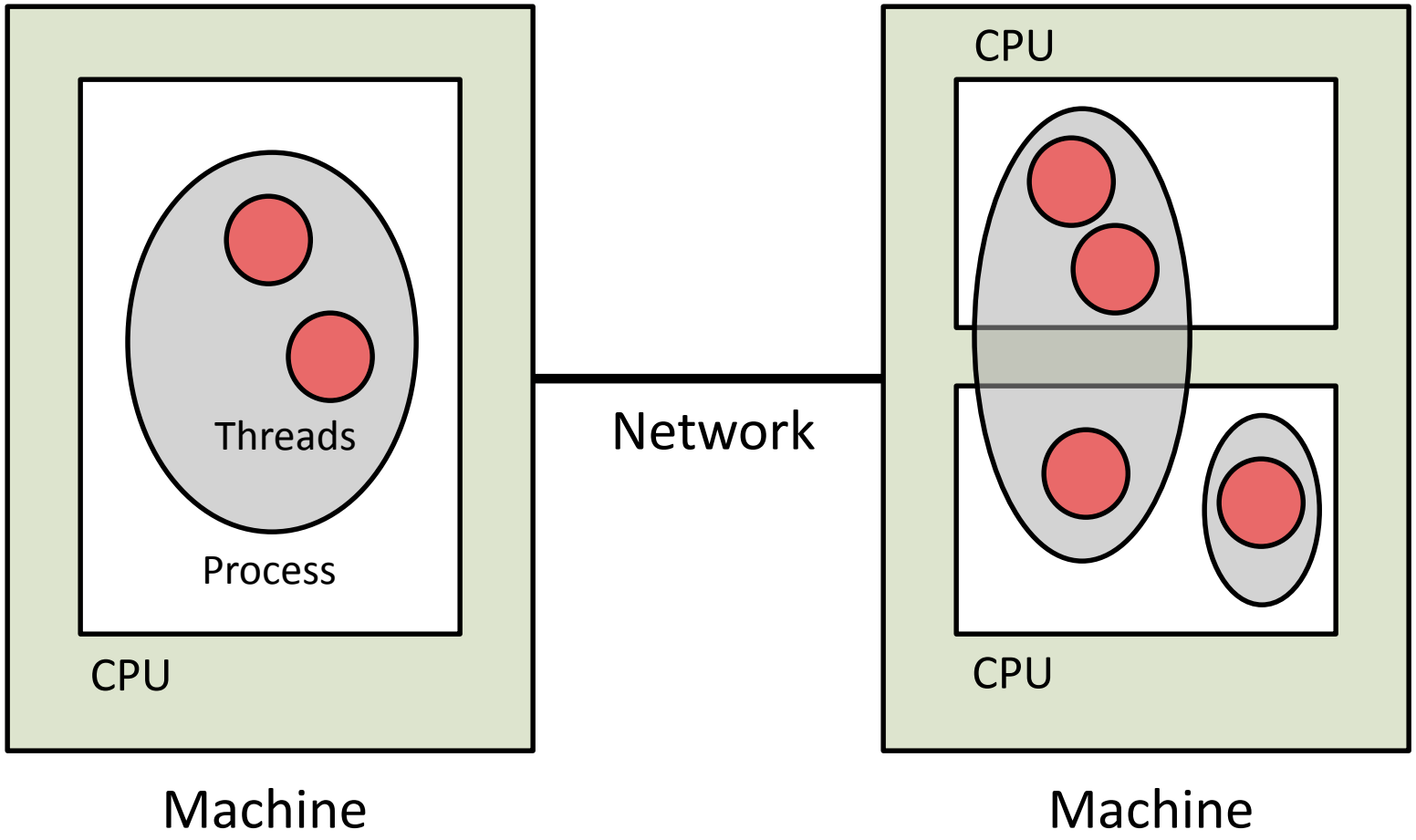
Running a Multi-Process / Multi-Threaded Application

- Execution requires processor
- Running a thread requires using a processor
- What decides which thread gets which processor?
  - Scheduler (part of operating system)!
  - Scheduling policy decides which threads run when
  - Pre-emptive schedulers can interrupt one thread and let another run on a given processor
    - Interrupted thread is "suspended": its stack, program counter are saved so that thread can be re-activated later
    - Stack, program of new thread are loaded and new thread activated
    - This is called a *context switch*

Threads, Processes and Processors

- Do processes run on single machine? Yes
- Do processes run on a single processor? Not necessarily
  - Different threads can run on different processors
  - Scheduler makes this decision
- Do threads run on a single processor?
  - Usually
  - Some schedulers support *thread migration* (why?)

A Reference Model for Distributed / Parallel / Concurrent Programs



Language Support for Concurrency

- Many languages support concurrency!

  C, C++, C#, OCaml, Java, Scala, Erlang, Python, …
- Traditionally: process / thread management handled via system calls to operating system
  - Not part of core language (e.g. C)
  - Platform-specific, non-portable, since different OS's have different mechanisms
- Modern languages (e.g. Java, Scala, Erlang) include mechanisms for thread management directly

Java Concurrency

- Support for multi-threading, processes
  - Process = running instance of Java Virtual Machine
  - Objects live on heap, can be shared by threads in same process
- Every Java program has at least one thread: `main`
- This course: focus is on thread programming

Java Threads Are Objects

- Object class is `Thread`, which is part of java.lang package (automatically imported!)
- Thread objects include:
  - `public void run()` executed when thread is launched
  - `public void start()` to launch the thread
  - Other methods that we will study later
  - Constructors, of which more later, but here are two:
    - `Thread()` create a thread
    - `Thread(String name)` create a thread with the given name

Thread Creation in Java

- Create an object `t` in class `Thread` with desired functionality in `run()` method
- Invoke `t.start()`
- This starts a thread that runs the `t.run()` method!

"Desired Functionality in `run()`"?

- Two approaches
  - Subclassing from `Thread`
  - Implementing `Runnable` interface
- In the former: override `run()`
- In the second
  - Define a class implementing the Runnable interface
  - Use relevant constructor in Thread on objects in this class

```
Thread (Runnable target)
Thread (Runnable target, String name)
```

Thread Implementation via Subclassing (Inheritance)

```
public class HelloWorldThread extends Thread {
  public void run() {
    System.out.println ("Thread says Hello World!");
  }
}
```

New class `HelloWorldThread` is introduced

- Extends Thread class
- Uses overriding to redefine `run ( )` method to do what we want

Thread Implementation via Runnable

```
public class HelloWorldRunnable implements Runnable {
  public void run() {
    System.out.println ("Runnable says Hello World!");
  }
}
```

- `Runnable` is an interface in java.lang containing only: `public void run()`
- This class implements `Runnable` by providing each object with a `run()` method
- Constructor for `Thread` class can now be called with objects in this class

Thread Creation

```
Thread h1 = new HelloWorldThread ();
Thread h2 = new Thread (new HelloWorldRunnable ());
h1.start();
h2.start();
```

- `h1` is thread object created from subclass of `Thread`
- `h2` is thread object created from `Runnable` object
- Output is two instances of “Hello World!”

Subclassing or Runnable?

	Subclassing	Runnable
PROS	• Easy access to Thread methods when implementing run () • No need for creating intermediate object	• Can inherit from another class besides Thread when creating Runnable object • Protects other Thread methods (e.g. start())
CONS	• Cannot inherit from another class • Danger of overriding other methods in Thread class (e.g. start())	• Harder to access non-static Thread methods when defining Runnable objects • Must create intermediate Runnable object in order to create Thread

Thread States

- What happens if we do the following?

```
Thread h1 = new HelloWorldThread ();
h1.start();
h1.start();
```

- Answer

```
Exception in thread "main"
java.lang.IllegalThreadStateException
```

- What?
  - Not every method is legal on every `Thread` object
  - The *state* of the object determines this validity
  - In this case, you cannot start a thread that has already been started

Thread States?

- Accessible via method `Thread.State getState()`
- `Thread.State` is an enumerated type recording state of thread object
  - `NEW`
    A thread that has not yet started is in this state.
  - `RUNNABLE`
    A thread executing in the Java virtual machine is in this state.
  - `BLOCKED`
    A thread that is blocked waiting for a monitor lock is in this state.
  - `WAITING`
    A thread that is waiting indefinitely for another thread to perform a particular action is in this state.
  - `TIMED_WAITING`
    A thread that is waiting for another thread to perform an action for up to a specified waiting time is in this state.
  - `TERMINATED`
    A thread that has exited is in this state.

[Quoted from http://docs.oracle.com/javase/6/docs/api/java/lang/Thread.State.html]

Thread State Example Revisited

```
Thread h1 = new HelloWorldThread (); // state is NEW
h1.start(); // state is RUNNABLE
h1.start(); // Error!
```

- When `h1` is created, its state is `NEW`
- After `h1.start()` is called, the state is `RUNNABLE`
- `h1.start()` can only be called when state is `NEW`!

More on Thread States

- Some `Thread` methods (e.g. start) only applicable when object is in correct state
- The states `NEW`, `RUNNABLE`, `TERMINATED` are probably easiest to understand
- We will learn about the states `BLOCKED`, `WAITING`, `TIMED_WAITING` later

Other Thread State Methods

- `boolean isAlive()`
  - Returns `true` if thread has been started but is not terminated
  - `t.isAlive()` equivalent to
    `(t.getState() != NEW) && (t.getState() != TERMINATED)`
- `void join()`
  - Blocks until thread terminates, then terminates
  - `t.join()` very similar to
    `while (t.isAlive ()) { }`
- `void join(int millis)`

  Like `t.join()` except that if `t` has not terminated in millis milliseconds, then `t.join(millis)` nevertheless terminates

Threads and Process Termination

- A process (JVM) terminates when "there is nothing left that has to be done"
- When does this hold?
  - When the main thread terminates?
  - When all threads terminate?
  - When "the important" threads terminate?
- Java answer: when all *user threads* terminate

User Threads vs. Daemon Threads

- In Java, every thread object is by default a *user thread*
- A Java process can terminate if and only if all user threads (including, but not only, main) have terminated
- Threads may be changed to *daemon threads* using method `setDaemon(boolean on)`
  - If the only nonterminated threads are daemons, then the JVM will terminate
  - Daemon threads should only be used for "background work" (e.g. updating status bars, etc.) needed while "useful" computation is being performed
- `setDaemon()` is only valid if thread state is `NEW`; otherwise, `IllegalThreadStateException` thrown

More on Thread Termination

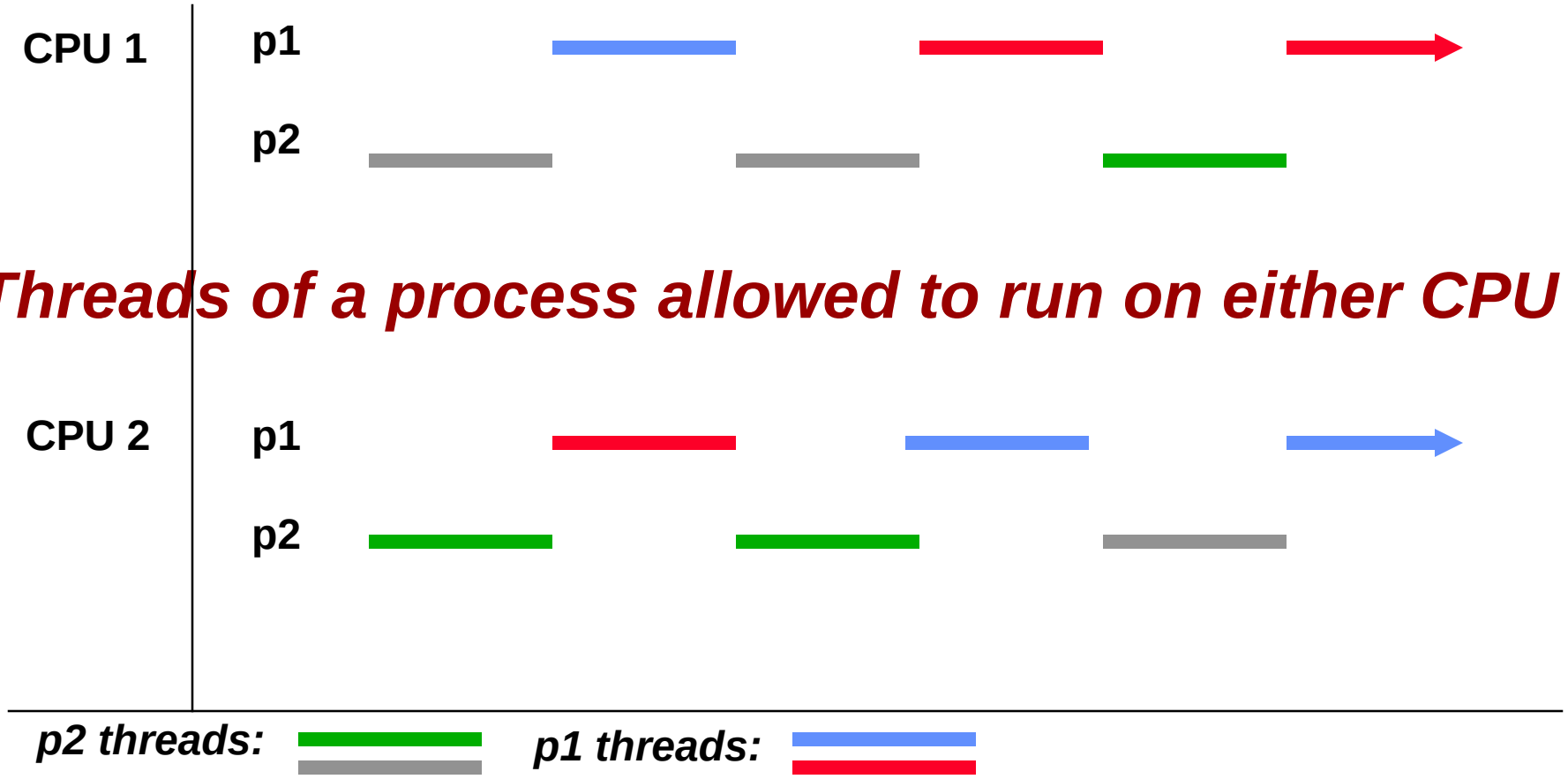
- When a thread object terminates, the object still remains!
  - Thread state is `TERMINATED` …
  - … but object still exists

Thread Execution

- Once threads are started, what determines when they are eligible for execution?
- Answer: scheduler!
  - Operating system routine responsible for allocating processor time to threads
  - If there are more processors than threads, could allocate each thread to its own processor
  - If there are more threads than processors, *time-slicing* may be needed to *interleave* access to processors
    - Each thread executes for a while, then is pre-empted
    - Exact scheme also takes account of priorities, also whether or not threads are blocked
    - What if thread is in the middle of something "atomic"?

Scheduling Example (1)

Scheduling Example (2)



Methods for Interacting with Scheduler

- `void setPriority(int newPriority)`
  Set priority to given value (must be between MIN_PRIORITY and MAX_PRIORITY: see below)
- `int getPriority()`
  Return priority value
- `static void yield()`
  "Hint" to scheduler that thread can give up processor
- `static void sleep(int millis)`
  Block for millis milliseconds
- `static int MIN_PRIORITY`
  Smallest (lowest) priority
- `static int MAX_PRIORITY`
  Largest (highest) priority
- `static int NORM_PRIORITY`
  Default priority

InterruptedException

- Thrown by some `Thread` methods (e.g. `sleep()`)
  - Raised when a thread is interrupted while sleeping
  - We will see about interruptions later
- When you call such a method, you must either
  - Catch the exception, e.g.

```
try { … sleep (1000);…}
catch (InterruptedException e) { … }
```

  - … or include a `throws` directive in your method declaration, e.g.

```
public void myMethod (…) throws
InterruptedException {…}
```

currentThread()

`static Thread currentThread()`

- Returns thread of current execution
- Useful when implementing thread operations via `Runnable`, as you can get access to thread info at runtime