01_Threads

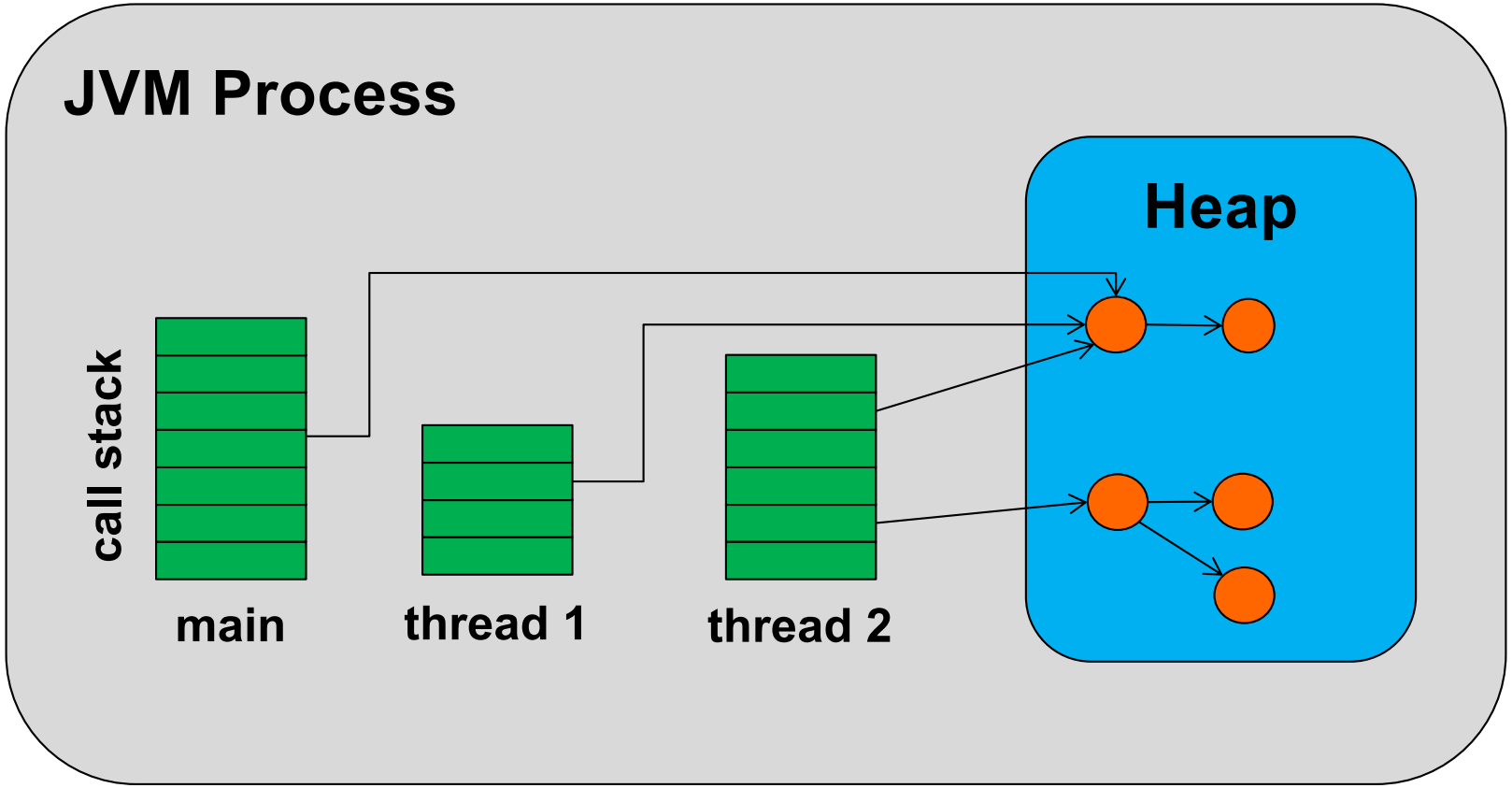
- **Processes and Threads**
- **Java Threads**

Processes and Threads

- **A process is an executable program loaded in memory**
  - has isolated address space allocated by OS
  - process switching is a rather expensive OS operation
  - communicates via OS (IPC), Files, Sockets
  - may contain multiple threads

- **A thread is a single sequential flow of control**
  - runs in the address space of a process
  - shares address space with other threads
  - has its own execution context
    - program counter
    - call stack
  - communicates via shared memory with other threads

JVM Process Illustrated



Threading Models

- **Kernel-Level-Threads (1:1)**
  - Kernel controls threads (and processes)
  - Threads are scheduled to available CPUs by kernel
  - Used by most current JVM implementations
- **User-Level-Threads (1:n)**
  - Threads implemented and managed in a library (green threads)
  - Efficient context switches (no kernel-mode privileges)
  - Application-specific scheduling may be supported
  - Different threads may not be scheduled on different processors
- **Hybrid-Threads (m:n)**
  - User-level threads are assigned to (a smaller number of) kernel threads

Processes and Threads (Windows)

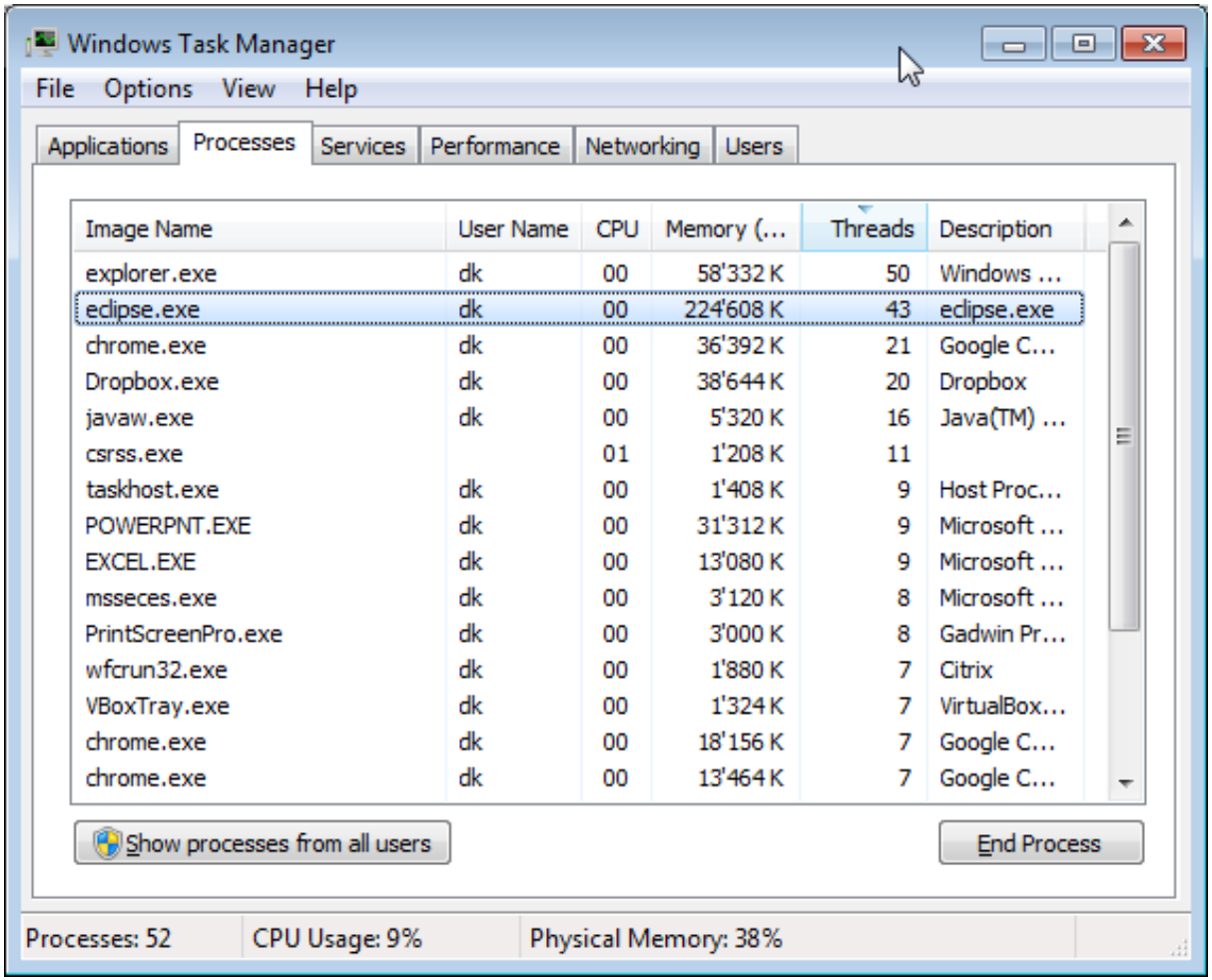


Image Name	User Name	CPU	Memory (...	Threads	Description
explorer.exe	dk	00	58'332 K	50	Windows ...
eclipse.exe	dk	00	224'608 K	43	eclipse.exe
chrome.exe	dk	00	36'392 K	21	Google C...
Dropbox.exe	dk	00	38'644 K	20	Dropbox
javaw.exe	dk	00	5'320 K	16	Java(TM) ...
csrss.exe		01	1'208 K	11	
taskhost.exe	dk	00	1'408 K	9	Host Proc...
POWERPNT.EXE	dk	00	31'312 K	9	Microsoft ...
EXCEL.EXE	dk	00	13'080 K	9	Microsoft ...
msseces.exe	dk	00	3'120 K	8	Microsoft ...
PrintScreenPro.exe	dk	00	3'000 K	8	Gadwin Pr...
wfcrun32.exe	dk	00	1'880 K	7	Citrix
VBoxTray.exe	dk	00	1'324 K	7	VirtualBox...
chrome.exe	dk	00	18'156 K	7	Google C...
chrome.exe	dk	00	13'464 K	7	Google C...

Processes and Threads (Linux)

```
 1  [||||                                   7.2%]     Tasks: 102, 252 thr, 58 kthr; 1 running
 2  [|||                                    3.9%]     Load average: 0.13 0.19 0.12
Mem[||||||||||||||||||||||||||||||5146/7935MB]     Uptime: 04:23:34
Swp[                                   0/9577MB]

  PID  PPID USER     S CPU% MEM%   TIME+  Command
 2811     1 dk       S  0.0  0.2  0:00.00 |    `- gnome-terminal
 2777     1 dk       S  0.0  0.0  0:00.00 `- /home/dk/tools/eclipse-3.7.1/eclipse
 2791  2777 dk       S  0.0  6.1  0:39.59 |    `- /home/dk/tools/jdk1.7.0_01/bin/java -Xms40m
 2905  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2904  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2893  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2889  2777 dk       S  0.0  6.1  0:00.03 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2880  2777 dk       S  0.0  6.1  0:00.32 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2878  2777 dk       S  0.0  6.1  0:00.61 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2877  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2872  2777 dk       S  0.0  6.1  0:00.06 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2827  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2814  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2809  2777 dk       S  0.0  6.1  0:00.01 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2806  2777 dk       S  0.0  6.1  0:00.39 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2805  2777 dk       S  0.0  6.1  0:00.02 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2804  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
 2803  2777 dk       S  0.0  6.1  0:00.00 |       `- /home/dk/tools/jdk1.7.0_01/bin/java -Xm
```

01_Threads

- **Processes and Threads**
- **Java Threads**

java.lang.Thread

- **java.lang.Thread is tightly integrated into the JVM**

```
public class Thread implements Runnable {
    /* Make sure registerNatives is the first thing <clinit> does.*/
    private static native void registerNatives();
    static { registerNatives(); }

    public synchronized void start() {
        ... start0(); ...
    }

    private native void start0();

    public static native void sleep(long millis)
                                        throws InterruptedException;

    public static native void yield();

    ...
}
```

java.lang.Thread (Native Part)

- **openjdk/hotspot/src/os/linux/vm/os_linux.cpp**

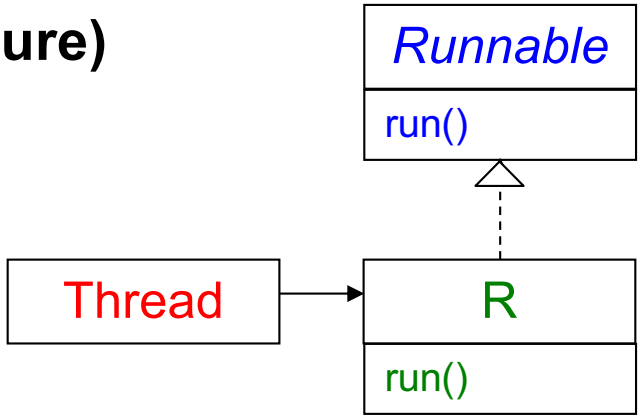
```
...
# include <pthread.h>
...
bool os::create_thread(Thread* thread, ThreadType thr_type,
                                                    size_t stack_size) {
    ...
    OSThread* osthread = new OSThread(NULL, NULL);
    if (osthread == NULL) {    return false;  }
    ...
    pthread_t tid;
    int ret = pthread_create(&tid, &attr, (void* (*)(void*)) java_start,
                                                                thread);
...
}
```

Source: http://download.java.net/openjdk/jdk7/

Thread creation

```
interface Runnable {
  public void run();
}
```

- **java.lang.Thread** = **Worker (Infrastructure)**
- **java.lang.Runnable** = **Work (Task)**




```
public class R implements Runnable {
   private int nr;
   public R(int nr) { this.nr = nr; }
   @Override
   public void run() {
      for(int i = 0; i < 10; i++) {
         System.out.println(
             "Hello" + nr + " " + i);
      }
   }
}
```

```
Runnable r = new R(1);
Thread   t = new Thread(r);
```

- run has no parameters
- run returns no result
- run does not declare any checked exception

Starting the Thread

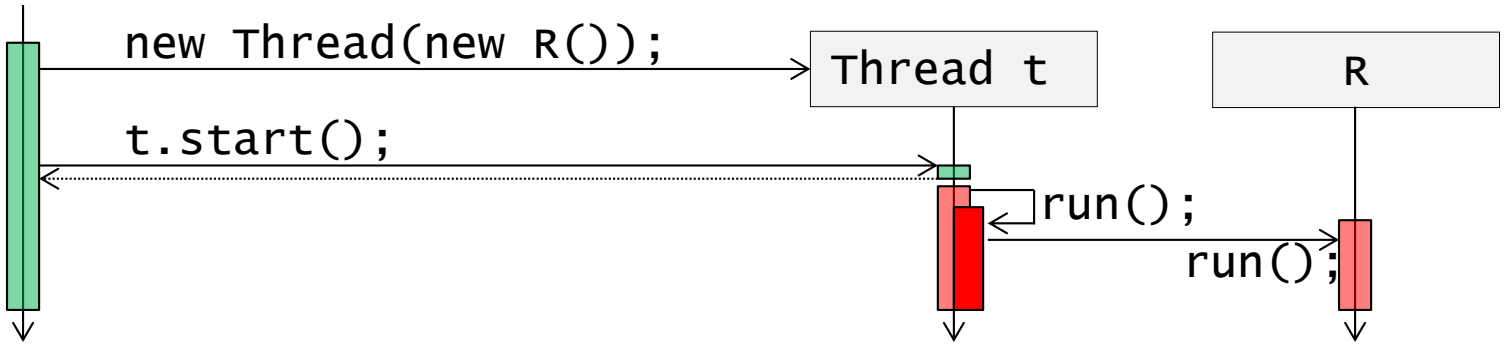
- **Thread t = new Thread(r);**
  - constructor initializes the thread object
- **t.start()**
  - activates the thread and returns immediately
  - concurrently executes the thread object's run method
  - when run() returns, the thread terminates

```
public class Test {
   static void main(String[] args) {
      Thread t1 = new Thread(new R(1));
      Thread t2 = new Thread(new R(2));
      t1.start();
      t2.start();
   }
}
```

```
Hello1 0
Hello2 0
Hello1 1
Hello2 1
Hello2 2
Hello2 3
Hello2 4
Hello2 5
Hello2 6
Hello2 7
Hello2 8
Hello2 9
Hello1 2
Hello1 3
Hello1 4
Hello1 5
Hello1 6
Hello1 7
Hello1 8
Hello1 9
Process
Exit...
```

Thread.start() and Thread.run()

- **Thread.start()**
  - starts a new thread of control to execute the run() method of the Thread object and returns immediately



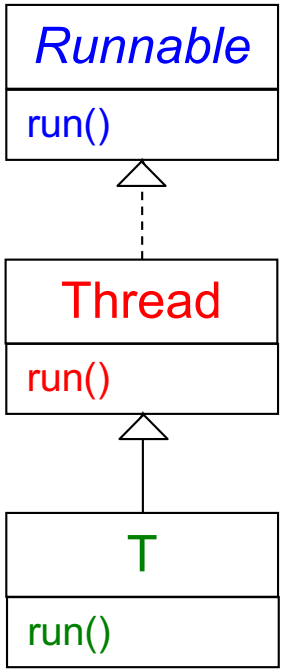
- **Thread.run()**
  - contains the code to be executed by this thread
  - Default implementation in class Thread invokes run method on target runnable

```
public void run() {
   if (target != null) {
      target.run();
   }
}
```

Alternative Thread Definition

- **Class Thread implements Runnable**
  - Method **run** can be implemented in subclass of Thread

```
public class T extends Thread {
   private int nr;
   public T(int nr) { this.nr = nr; }
   @Override
   public void run() {
      for (int i=0; i<10; i++) {
         System.out.println("Hello" +
                                 nr + " " + i);
      }
   }
}
```



  - If a thread is created without an argument implementing *Runnable*, then the Thread's run method is used.

```
new T(1).start(); new T(2).start();
```

Java 8 Thread Definition

- **Pass a function literal to the thread**

```
public class Test1 {

  public static void main(String[] args) throws Exception {
    Thread t1 = new Thread(() -> do(System.out, "1"));
    Thread t2 = new Thread(() -> do(System.err, "2"));
    t1.start();
    t2.start();
  }

  private static void do(PrintStream p, String name) {
    for (int i = 0; i < 1000; i++) {
      p.println("Hello" + name + " " + i);
    }
  }
}
```

Extending Thread vs. Implementing Runnable

- **Extending Thread**
  - Okay for simple experiments
  - Easy access to Thread methods

```
getName();
```

- **Implementing Runnable separately**
  - Separation of concerns
    - Task definition
    - Task execution
  - Allows subclassing, i.e. no multiple subclassing problems
  - You cannot miss to implement run
  - Also easy access to Thread methods thanks to static imports

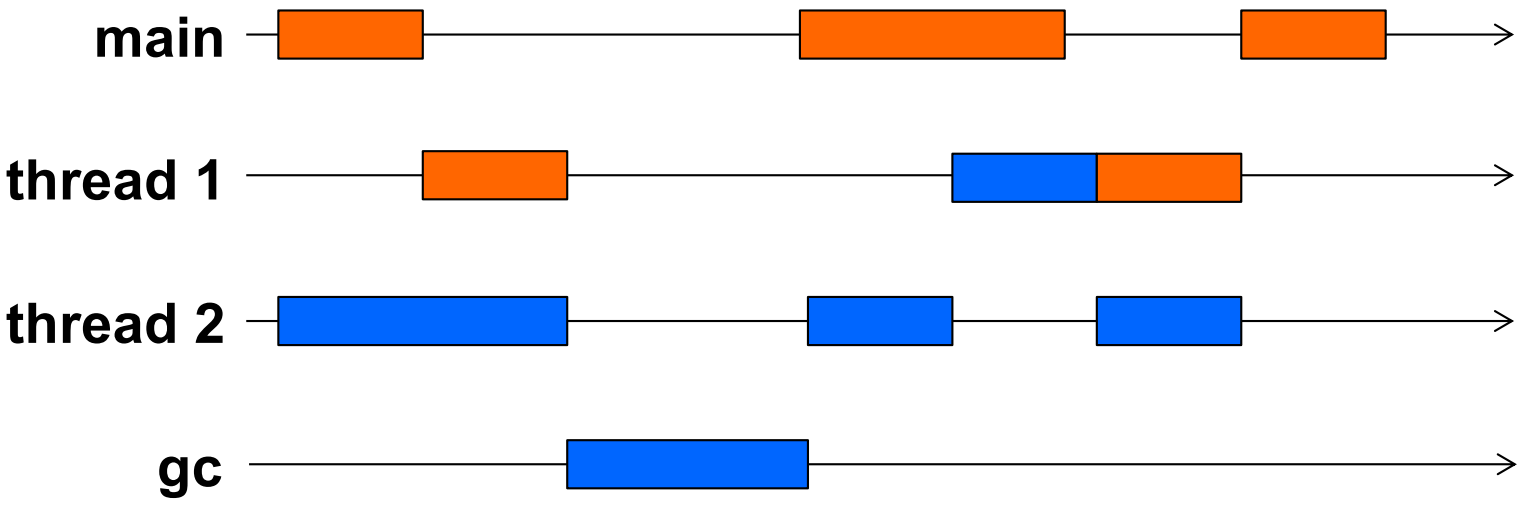
```
import static java.lang.Thread.*;
currentThread().getName();
```

Scheduling

- **Scheduling**
  - Per CPU core only one thread is running at any given time
  - Scheduling = Allocation of CPU time to threads
- **Threading Models**
  - Cooperative Threading
    - threads decide, when they should give up the processor to other threads yield(); sleep(1000); blocking *I/O Operations*
  - Preemptive Threading
    - JVM interrupts threads at any time (time sliced)
    - no thread can unfairly hog the processor
- **JVM specification does not mandate a threading model!**
  - Exotic Java implementations may implement cooperative scheduling
  - For the rest of the course, we assume a preemptive threading model

Scheduling Illustrated

- **Four threads scheduled on two CPU cores**
  - time on core 1 time on core 2



Thread API: Controlling Threads

- **void start()**
  - Starts this thread
- **void run()**
  - The code to be executed concurrently by this thread
- **static void sleep(long millis[, int nanos])**
  - Causes the calling thread to sleep for the specified number of ms
- **static void yield( )**
  - A hint to the scheduler that the current thread is willing to yield its current use of a processor. The scheduler is free to ignore this hint.
- **void join([long millis])**
  - Waits (at most millis milliseconds) for this thread to terminate
- **void setDaemon(boolean)**
  - Marks this thread as either a daemon or a user thread

Thread.join

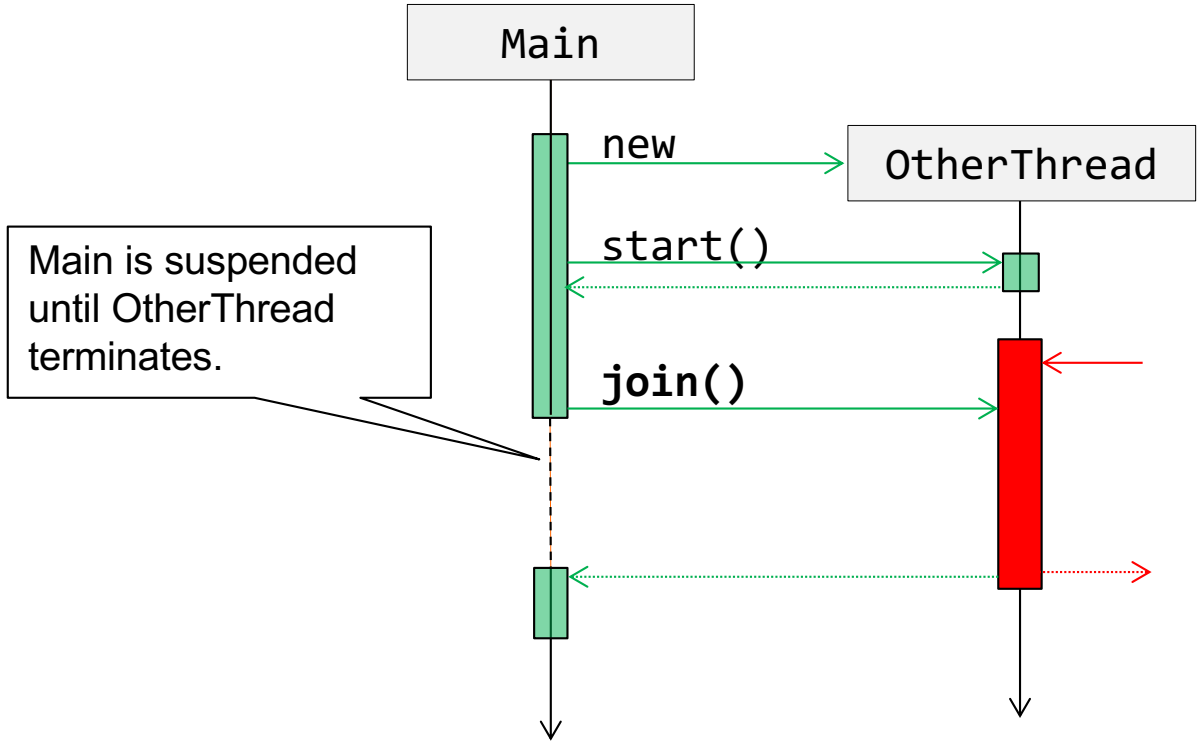
- **Example:**

```
public class Test1 {
   static void main(String[] args){
      Thread t1 = new Thread(new R(1));
      Thread t2 = new Thread(new R(2));
      t1.start();
      t2.start();
      System.out.println("done");
   }
}
```

  – What is the output?

Thread.join

- **Illustrated**



Thread.join

- **Example:**

```
public class Test1 {
   static void main(String[] args) throws Exception{
      Thread t1 = new Thread(new R(1));
      Thread t2 = new Thread(new R(2));
      t1.start();
      t2.start();
      t1.join(); // waits until t1 has terminated
      t2.join(); // waits until t2 has terminated
      System.out.println("done");
   }
}
```

Thread.setDaemon

- **Daemon Threads**
  - Daemon threads run in the background
  - If only daemon threads are active, the process stops
  - setDaemon() must be called before start()

```
public class Test1 {
   static void main(String[] args){
      Thread t1 = new Thread(new R(1));
      Thread t2 = new Thread(new R(2));
      t2.setDaemon(true);
      t1.start();
      t2.start();
   }
}
```

  - What is the output?

JVM: Start and Termination

- **On JVM start up**
  - An initial non-daemon thread which calls the *main* method is started
- **The JVM continues to execute threads until either**
  - Runtime.*getRuntime().exit(n);* has been called and the security manager has permitted the exit operation to take place
  - All threads that are not daemon threads have died, either by
    - returning from the call to the run method
    - throwing an exception that propagates beyond the run method

Uncaught Exception Handlers

- **Uncaught exception handlers**
  - Allows to detect whether threads die due to an uncaught exception

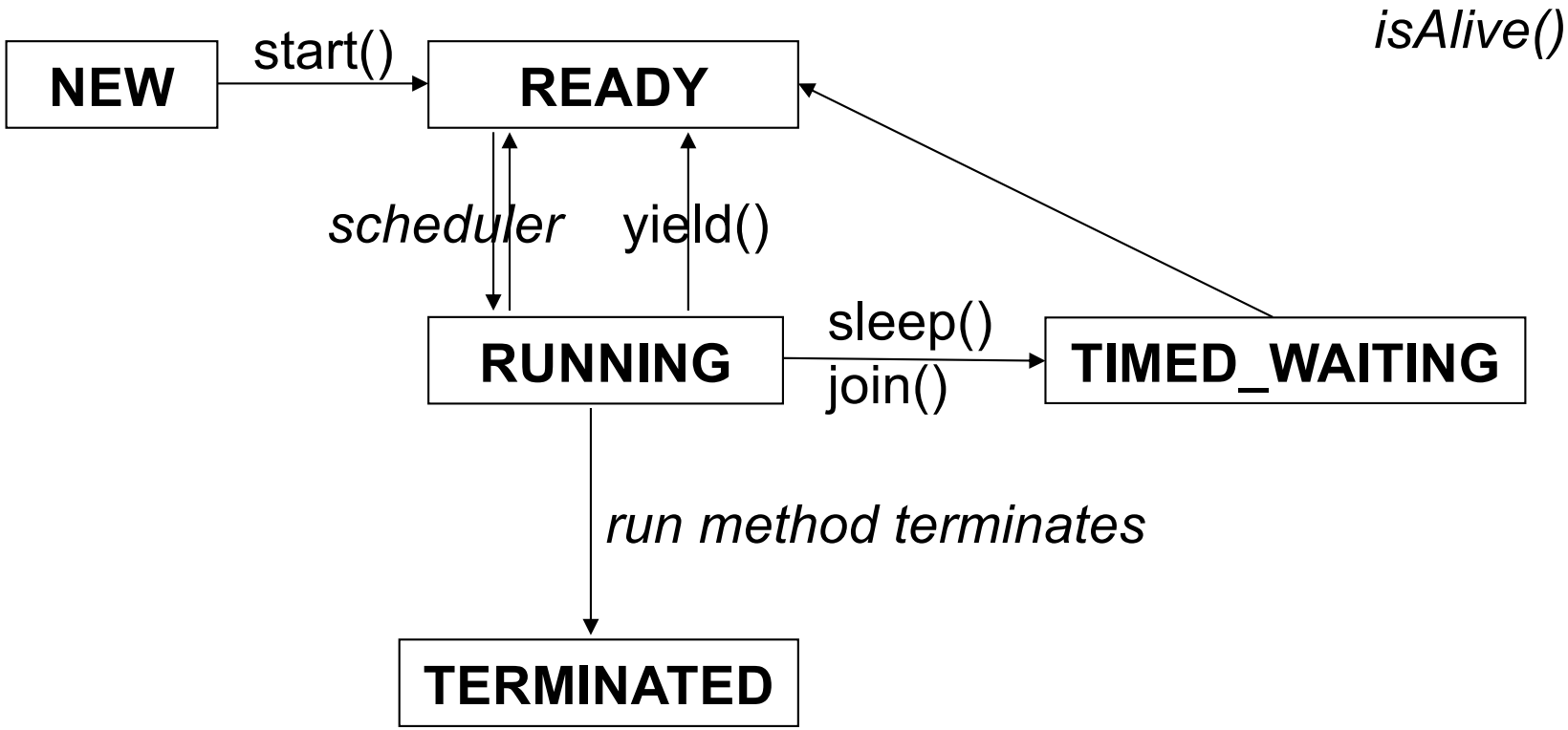
```
interface UncaughtExceptionHandler {
   void uncaughtException(Thread t, Throwable e);
}
```

  - Handling uncaught exceptions
    - Default behavior: print stack trace to System.err
    - Report message in application log
    - Try to restart the thread
    - Shut down the application
  - Install Custom Exception Handlers (called before default behavior)
    - Thread.setUncaughtExceptionHandler [instance method]
    - Thread.setDefaultUncaughtExceptionHandler [static method]

Thread API: Gathering Information

- **static Thread currentThread()**
  - Returns a reference to the currently executing thread object
- **long getId()**
  - Returns the unique identifier of this thread
- **String getName()**
  - Returns this thread's name
- **boolean isDaemon()**
  - Tests if this thread is a daemon thread
- **State getState()**
  - Returns the state of this thread
- **boolean isAlive()**
  - Tests if this thread is alive (i.e. started and not yet terminated)

Thread State



Thread Priority

- **Thread Priorities**

```
public void setPriority(int priority);
public int  getPriority();
```

  - A new thread inherits its priority from the thread that *created* it
  - Must be in the range 1..10
    - Thread.MIN_PRIORITY = 1; // minimum priority that a thread can have
    - Thread.NORM_PRIORITY = 5; // default priority
    - Thread.MAX_PRIORITY = 10; // maximum priority that a thread can have
  - Priorities map on to some machine-specific values
    - Linux: "nice" values | Windows: local thread priorities
  - Main issue:

A JVM is free to implement priorities in any way it chooses, including ignoring the value!

Summary

- **Thread**
  - Mean to execute multiple control flows concurrently within a process
  - Communicates via shared memory with other threads
- **Thread scheduling is non deterministic in common JVMs**
- **Thread construction is preferably be done by implementing java.lang.Runnable separately (not by subclassing Thread)**
- **Use Thread.start() to start a newly created thread**
- **Use Thread.join() to wait for a thread to terminate**
- **Don't rely on thread priorities**
  - Never use priorities to support synchronization or waiting strategies