CMSC 132: Object-Oriented Programming II

Threads in Java

Problem

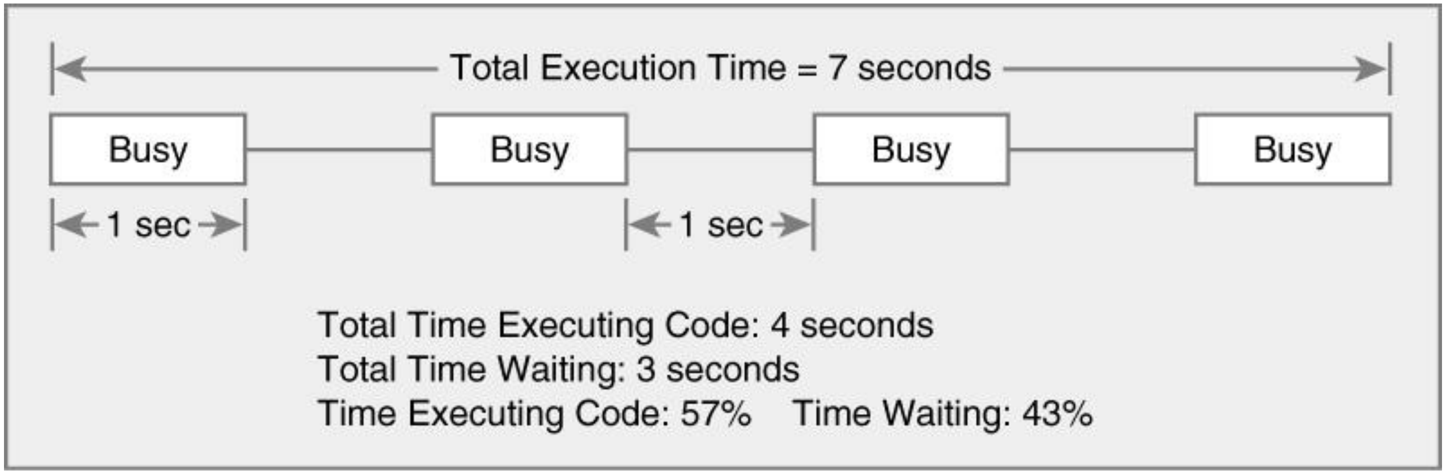
- Multiple tasks for computer
  - Draw & display images on screen
  - Check keyboard & mouse input
  - Send & receive data on network
  - Read & write files to disk
  - Perform useful computation (editor, browser, game)
- How does computer do everything at once?
  - Multitasking
  - Multiprocessing

Multitasking (Time-Sharing)

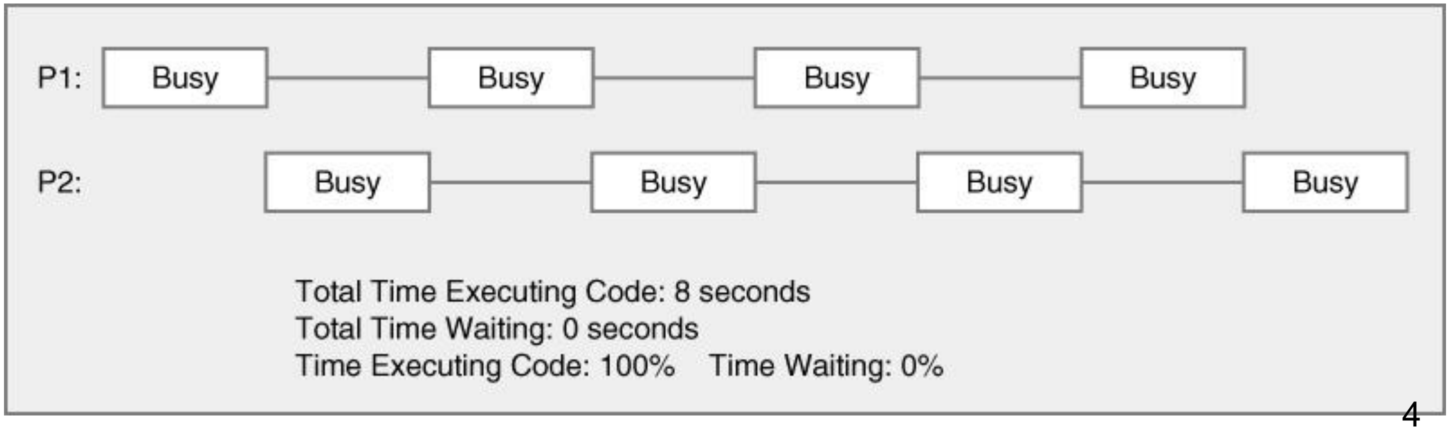
- Approach
  - Computer does some work on a task
  - Computer then quickly switch to next task
  - Tasks managed by operating system (scheduler)
- Computer seems to work on tasks concurrently
- Can improve performance by reducing waiting

Multitasking Can Aid Performance

- Single task



- Two tasks



Multiprocessing (Multithreading)

- Approach
  - Multiple processing units (multiprocessor)
  - Computer works on several tasks in parallel
  - Performance can be improved

Dual-core AMD Athlon X2

32 processor Pentium Xeon

Titan at ORNL

Perform Multiple Tasks Using Processes

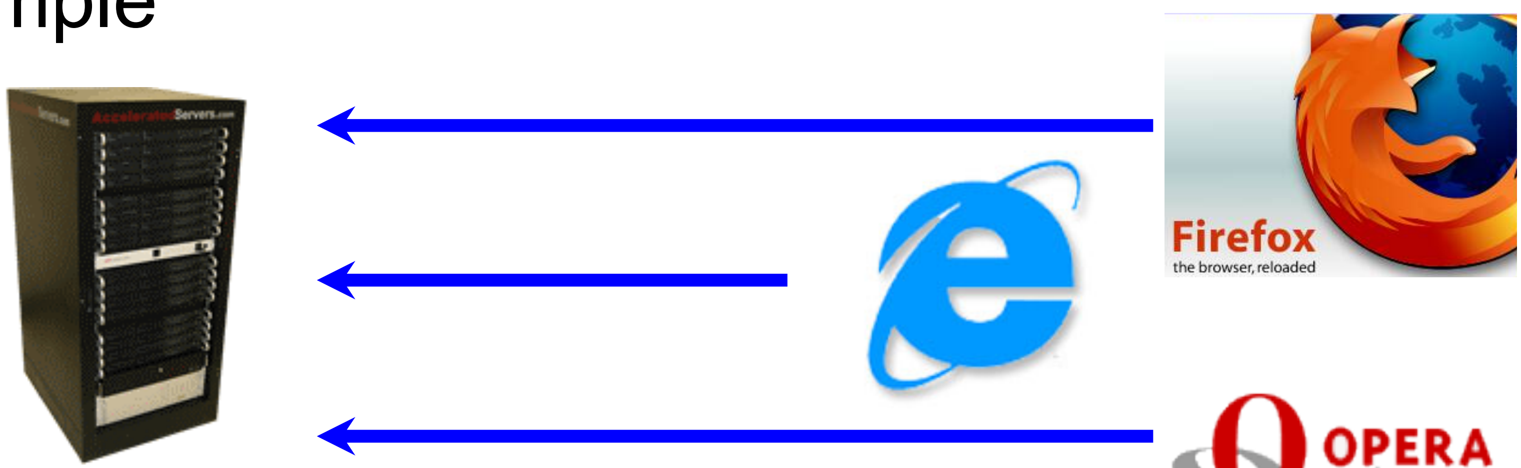
- Process
  - Definition → executable program loaded in memory
  - Has own address space
    - Variables & data structures (in memory)
  - Each process may execute a different program
  - Communicate via operating system, files, network
  - May contain multiple threads

Perform Multiple Tasks Using Threads

- Thread
  - Sequentially executed stream of instructions
  - Has own execution context
    - Program counter, call stack (local variables)
  - Communicate via shared access to data
  - Also known as “lightweight process”

Motivation for Multithreading

- Captures logical structure of problem
  - May have concurrent interacting components
  - Can handle each component using separate thread
  - Simplifies programming for problem
- Example



Web Server uses threads to handle …

Multiple simultaneous web browser requests

Motivation for Multithreading

- Better utilize hardware resources
  - When a thread is delayed, compute other threads
  - Given extra hardware, compute threads in parallel
  - Reduce overall execution time
- Example

Multiple simultaneous web browser requests…

Handled faster by multiple web servers

Programming with Threads

- Concurrent programming
  - Writing programs divided into independent tasks
  - Tasks may be executed in parallel on multiprocessors
- Multithreading
  - Executing program with multiple threads in parallel
  - Special form of multiprocessing

Creating Threads in Java

- Two approaches to create threads
  - Extending Thread class (**NOT RECOMMENDED**)
  - Runnable interface approach (**PREFERED**)

Extending Thread class

- We overload the Thread class run() method
- The run() methods defines the actual task the thread performs
- Example

```
public class MyThread extends Thread {
    public void run( ) {
        …          // work for thread
    }
}
MyThread t = new MyThread( ) ;// create thread
t.start( );                // begin running thread
…               // thread executing in parallel
```

Runnable interface

- Define a class (worker) that implements the Runnable interface

  public interface Runnable {
      public void run(); // work done by thread
  }

  - Create thread to execute the run() method
    - Alternative 1: Create thread object and pass worker object to Thread constructor
    - Alternative 2: Hand worker object to an executor
  - Example

```
public class Worker implements Runnable {
    public void run( )  { // work for thread }
}
Thread t = new Thread(new Worker( )); // create thread
t.start();                        // begin running thread
…                          // thread executing in parallel
```

Extending Thread Approach Not Recommended

- Not a big problem for getting started
  - But a bad habit for industrial strength development
- Methods of worker and Thread class intermixed
- Hard to migrate to more efficient approaches
  - Thread Pools

Thread Class

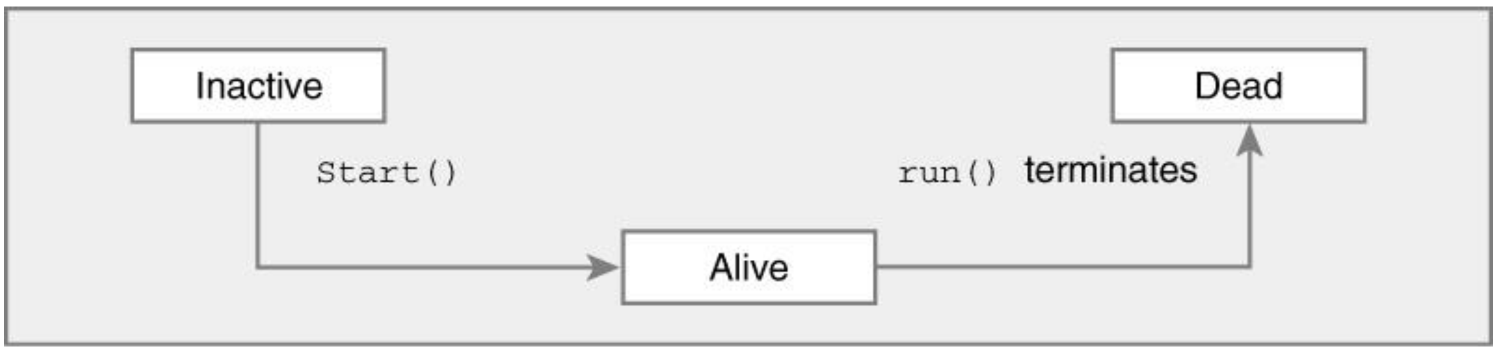
```
public class Thread extends Object implements
   Runnable {
    public Thread();
    public Thread(String name);   // Thread name
    public Thread(Runnable R);
    public Thread(Runnable R, String name);

    public void run();        // if no R, work for thread
    public void start();      // thread gets in line so it
   eventually it can run
    ...
}
```

More Thread Class Methods

```
public class Thread extends Object {
    …
    public static Thread currentThread()
    public String getName()
    public void interrupt()   // alternative to stop (deprecated)
    public boolean isAlive()
    public void join()
    public void setDaemon()
    public void setName()
    public void setPriority()
    public static void sleep()
    public static void yield()
}
```

Creating Threads in Java

- Note
  - Thread eventually starts executing only if start() is called



  - Runnable is interface
    - So it can be implemented by any class
    - Required for multithreading in applets
  - Do not call the run method directly

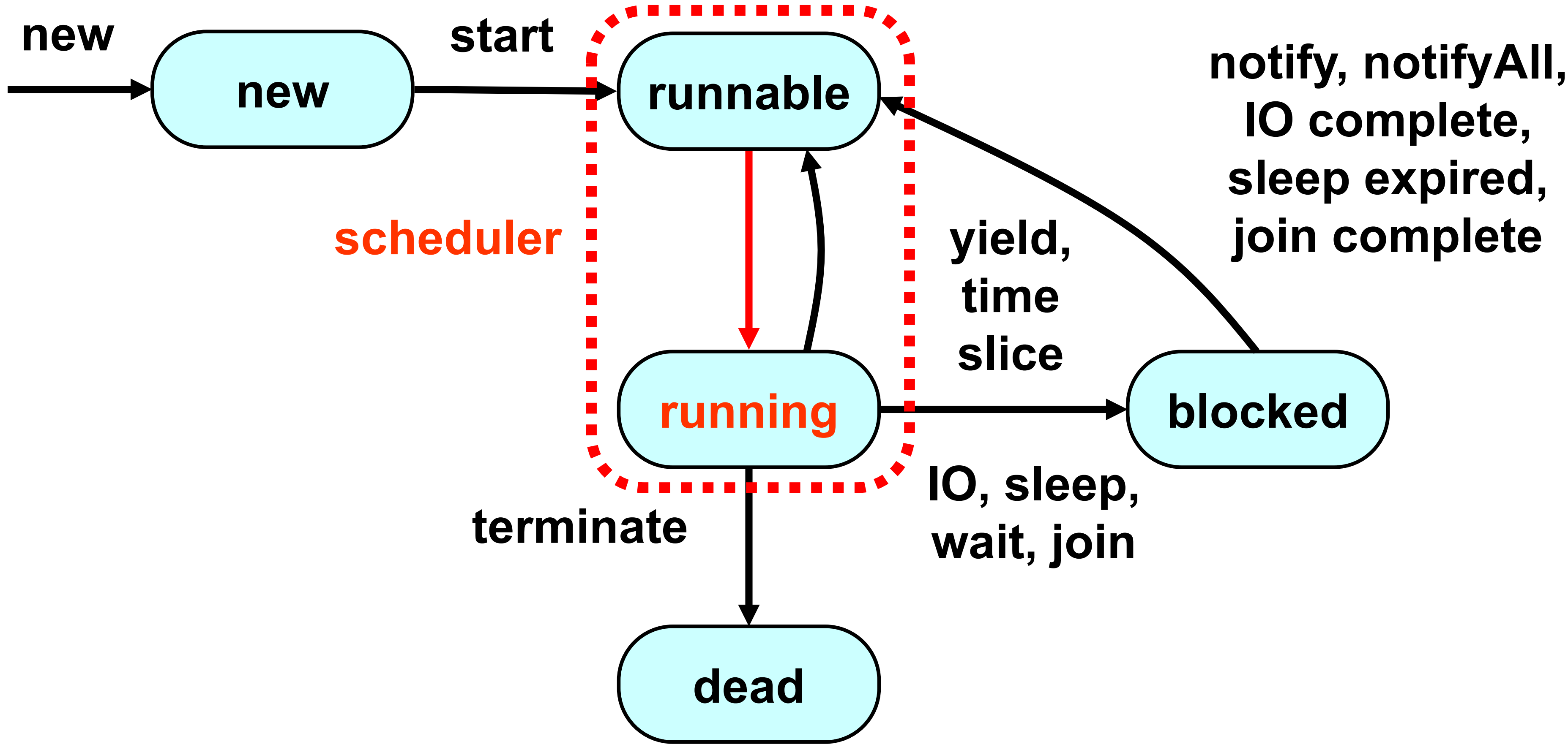
Threads – Thread States

- Java thread can be in one of these states
  - New → thread allocated & waiting for start()
  - Runnable → thread can begin execution
  - Running → thread currently executing
  - Blocked → thread waiting for event (I/O, etc.)
  - Dead → thread finished
- Transitions between states caused by
  - Invoking methods in class Thread
    - new(), start(), yield(), sleep(), wait(), notify()…
  - Other (external) events
    - Scheduler, I/O, returning from run()…
- In Java states defined by Thread.State

  http://docs.oracle.com/javase/7/docs/api/java/lang/Thread.State.html

Threads – Thread States

- State diagram



Running is a logical state → indicates runnable thread is actually running

Daemon Threads

- Java threads types
  - User
  - Daemon
    - Provide general services
    - Typically never terminate
    - Call setDaemon() before start()
- Program termination
  - All user threads finish
  - Daemon threads are terminated by JVM

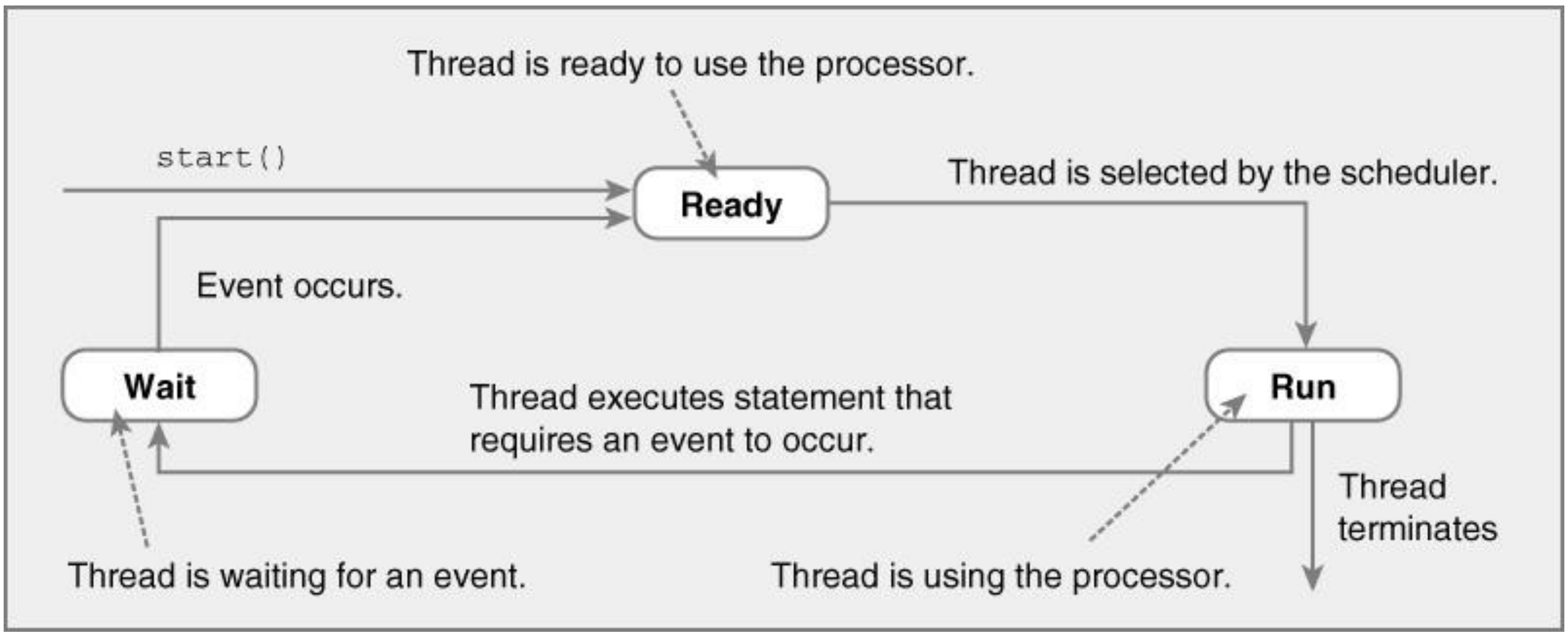
Threads – Scheduling

- Scheduler
  - Determines which runnable threads to run
    - When context switching takes place
  - Can be based on thread priority
  - Part of OS or Java Virtual Machine (JVM)

- Scheduling policy
  - Non-preemptive (cooperative) scheduling
  - Preemptive scheduling

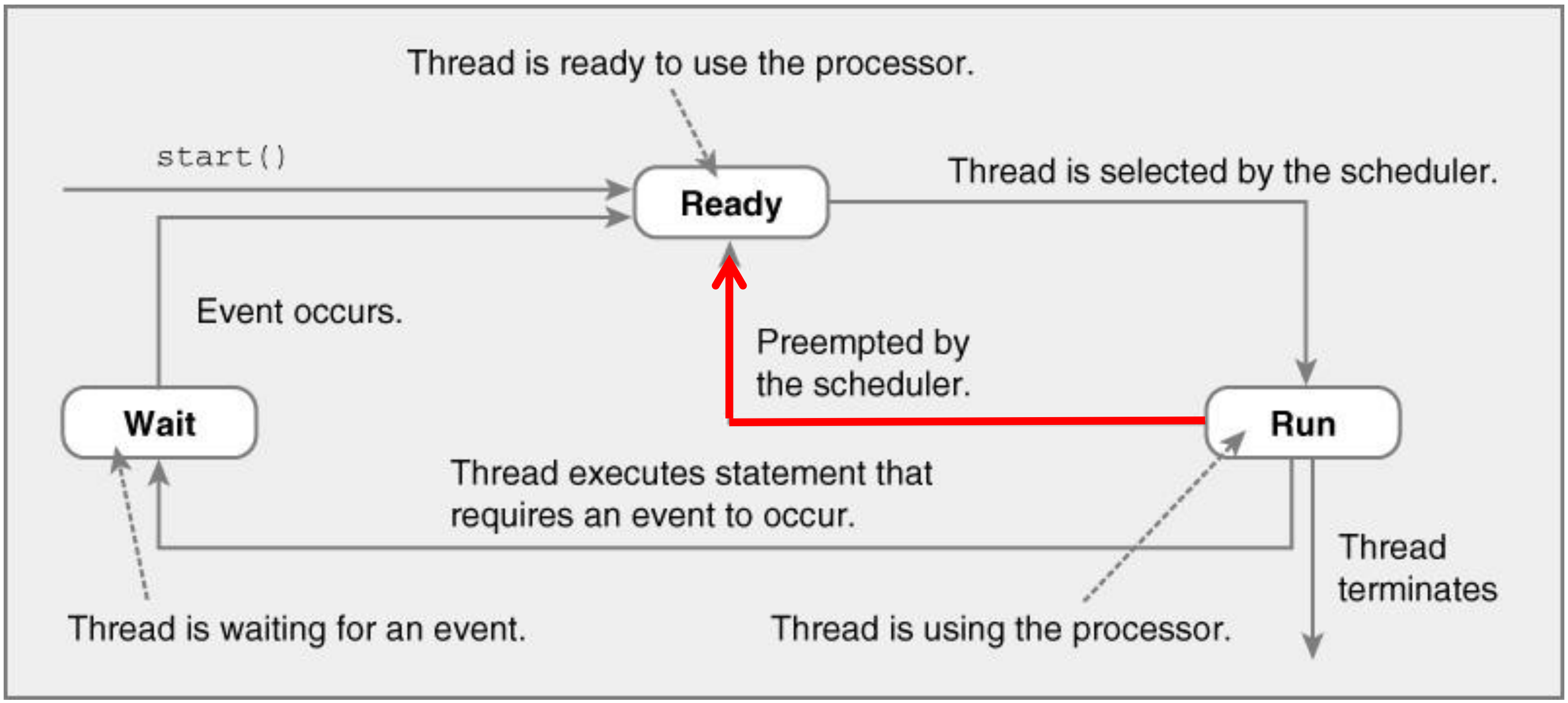
Threads – Non-preemptive Scheduling

- Threads continue execution until
  - Thread terminates
  - Executes instruction causing wait (e.g., IO)
  - Thread volunteering to stop (invoking yield or sleep)



Threads – Preemptive Scheduling

- Threads continue execution until
  - Same reasons as non-preemptive scheduling
  - Preempted by scheduler



Thread Scheduling Observations

- Order thread is selected is indeterminate
  - Depends on scheduler
- Scheduling may not be fair
  - Some threads may execute more often
- Thread can block indefinitely (starvation)
  - If other threads always execute first
- Your code should work correctly regardless the scheduling policy in place

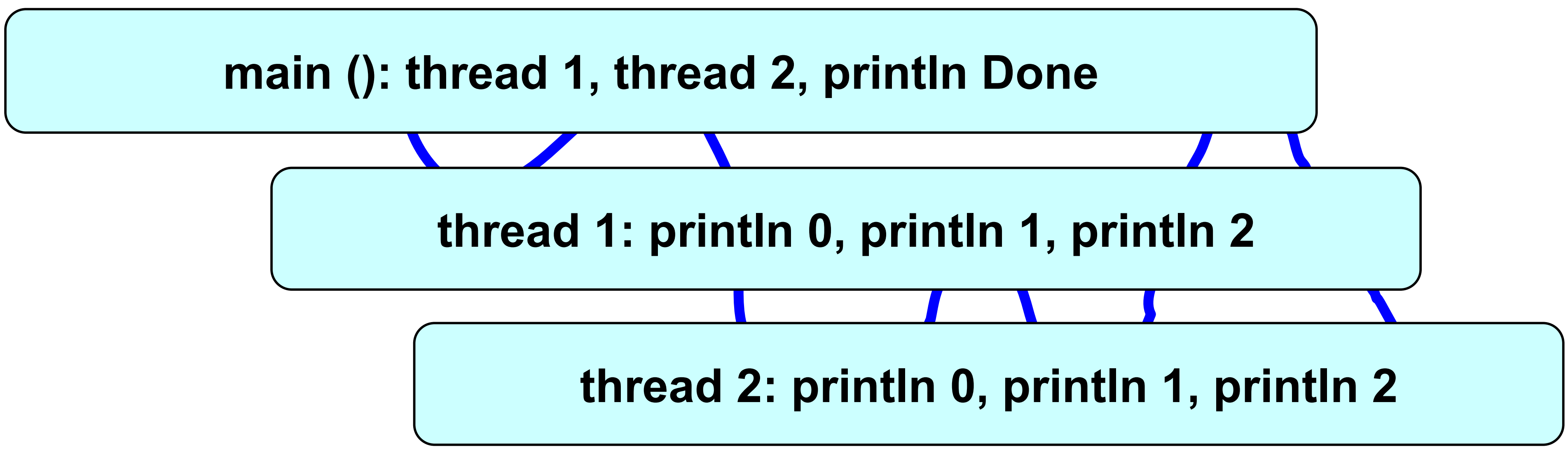
Java Thread Example

```
public class ThreadNoJoin extends Thread {
    public void run() {
      for (int i = 0; i < 3; i++) {
        try {
            sleep((int)(Math.random() * 5000)); // 5 secs
        } catch (InterruptedException e) {
            e.printStackTrace();
        }
         System.out.println(i);
      }
    }
    public static void main(String[] args) {
        Thread t1 = new ThreadNoJoin();
        Thread t2 = new ThreadNoJoin();
        t1.start();
        t2.start();
        System.out.println("Done");
    }
}
```

To understand this example better, let's assume we want to make a sandwich

Java Thread Example – Output

- Possible outputs
  - 0,1,2,0,1,2,Done // thread 1, thread 2, main()
  - 0,1,2,Done,0,1,2 // thread 1, main(), thread 2
  - Done,0,1,2,0,1,2 // main(), thread 1, thread 2
  - 0,0,1,1,2,Done,2 // main() & threads interleaved



Thread Class – join( ) Method

- Can wait for thread to terminate with join( )
- Method prototype
  - public final void join( )
    - Returns when thread is done
    - Throws InterruptedException if interrupted

Java Thread Example (Join)

```
public class ThreadJoin extends Thread {
  public void run() {
    for (int i = 0; i < 3; i++) {
      try {
        sleep((int)(Math.random()*5000));// 5 secs
      }catch (InterruptedException e) {
          e.printStackTrace(); }
      System.out.println(i);
    }
  }
public static void main(String[] args) {
   Thread t1 = new ThreadJoin();
   Thread t2 = new ThreadJoin();
   t1.start();
   t2.start();
   try { t1.join();
          t2.join();
    } catch (InterruptedException e) { e.printStackTrace(); }
   System.out.println("Done");
  }
}
```

About Join

- Important: You will limit the concurrency level if you do not start/join correctly
- Suppose you want to run many threads concurrently. **Start them all and then execute the join for each one**. **Do not start one thread, then join on that thread, start the second one, join on that thread, etc.**
- The following is WRONG!

```
t1.start()
t1.join()
t2.start()
t2.join()
```

- Feel free to use arrays, sets, etc., to keep track of your threads

Terminating Threads

- A thread ends when the run() method ends
- Sometimes we may need to stop a thread before it ends
  - For example, you may have created several threads to find a problem solution and once one thread finds it, there is no need for the rest
- How to stop thread?
  - **Using stop() method** → WRONG! This is a deprecated method. Using it can lead to problems when data is shared
  - **Using interrupt() method**
    - This method does not stop the thread. Instead, it notifies the thread that it should terminate. The method sets a boolean variable in the thread and that value can be checked by the thread (by using the method interrupted())
    - It is up to the thread to terminate or not
    - public void run() {

```
 while(!Thread.interrupted()) {
      // work
  }
  // release resource, cleaning tasks
}
```

Thread Example

- Swing uses a single-threaded model
- Long computations in the EDT freezes the GUI
- Example: Progress Bar Example

Example

- x = 0 initially. Then these threads are executed:

```
T1  y = x;        T2  z = x;
    x = y+1;          x = z+2;
```

- What is the value of x afterward   3 1 2

```
T1  y = x;    T2
    x = y+1;
                  z = x;
                  x = z+2;
```

```
T1            T2  z = x;
                  x = z+2;
    y = x;
    x = y+1;
```

```
T1  y = x;    T2
                  z = x;
                  x = z+2;
    x = y+1;
```

```
T1            T2  z = x;
    y = x;
    x = y+1;
                  x = z+2;
```

Data Races

- That was an example of a data race
  - Threads are "racing" to read, write x
  - The value of x depends on who "wins" (3, 1, 2)
- Languages rarely specify who wins data races
  - The outcome is nondeterministic
- So programmers restrict certain outcomes
  - Synchronization with locks, condition variables
- And they often mess up
  - Leading to bugs that are hard to track down…

Thread API Concepts

- Thread management
  - Creating, killing, joining (waiting for) threads
  - Sleeping, yielding, prioritizing
- Synchronization
  - Controlling order of execution, visibility, atomicity
  - Locks: Can prevent data races, but watch out for deadlock!
  - Condition variables: supports communication between threads

- Most languages have similar APIs, details differ

Synchronization Example

```
public class Example extends Thread {
  private static int cnt = 0;
  public void run() {
    synchronized (this) {
      int y = cnt;
      cnt = y + 1;
    }
  }
  …
}
```

Acquires *the lock associated w/ current object; only succeeds if lock not held by another thread, otherwise blocks*

Releases *the lock*

Condition Variables

- A condition variable represents a set of threads waiting for a condition to become true
  - Implemented, at least conceptually, as a wait set
- Since different threads may access the variable at once, we protect the wait set with a lock
  - Thus avoiding possible data races

Synchronization, the traditional way

```
public class Example extends Thread {
  private static int cnt = 0;
  static Object lock = new Object();
  public void run() {
    synchronized (lock) {
      int y = cnt;
      cnt = y + 1;
    }
  }
  ...
}
```

Object uses as a ***Lock***

Acquires *the intrinsic lock; only succeeds if lock not held by another thread, otherwise blocks*

Releases *the lock when exiting block*

Synchronization, with explicit Locks

```
public class Example extends Thread {
  private static int cnt = 0;
  static Lock lock = new ReentrantLock();
  public void run() {
    lock.lock();
    int y = cnt;
    cnt = y + 1;
    lock.unlock();
  }
  ...
}
```

Lock, *for protecting the shared state*

Acquires *the lock; only succeeds if lock not held by another thread, otherwise blocks*

Releases *the lock*

Producer / Consumer Solution

```
Lock lock = new ReentrantLock();
Condition ready = lock.newCondition();
boolean bufferReady = false;
Object buffer;
```

```
void produce(Object o) {
    lock.lock();
    while (bufferReady)
      ready.await();
    buffer = o;
    bufferReady = true;
    ready.signalAll();
    lock.unlock();
  }
```

```
Object consume() {
    lock.lock();
    while (!bufferReady)
      ready.await();
    Object o = buffer;
    bufferReady = false;
    ready.signalAll();
    lock.unlock();
    return o;   }
```

- Uses single condition per lock (like intrinsics)

Producer / Consumer Solution

```
Lock lock = new ReentrantLock();
Condition producers = lock.newCondition();
Condition consumers = lock.newCondition();
boolean bufferReady = false;
Object buffer;
```

```
void produce(Object o) {
    lock.lock();
    while (bufferReady)
      producers.await();
    buffer = o;
    bufferReady = true;
    consumers.signalAll();
    lock.unlock();
  }
```

```
Object consume() {
    lock.lock();
    while (!bufferReady)
      consumers.await();
    Object o = buffer;
    bufferReady = false;
    producers.signalAll();
    lock.unlock();
    return o; }
```

- Uses 2 conditions per lock for greater efficiency

Producer / Consumer Solution

```
Lock lock = new ReentrantLock();
Condition producers = lock.newCondition();
Condition consumers = lock.newCondition();
boolean bufferReady = false;
Object buffer;
```

```
void produce(Object o) {
    lock.lock();
    while (bufferReady)
      producers.await();
    buffer = o;
    bufferReady = true;
    consumers.signal ();
    lock.unlock();
  }
```

```
Object consume() {
    lock.lock();
    while (!bufferReady)
      consumers.await();
    Object o = buffer;
    bufferReady = false;
    producers.signal ();
    lock.unlock();
    return o; }
```

- Wakes up only one thread: More efficient, still!