

# CMSC 132: Object-Oriented Programming II

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## Threads in Java

# Problem

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- ▶ 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

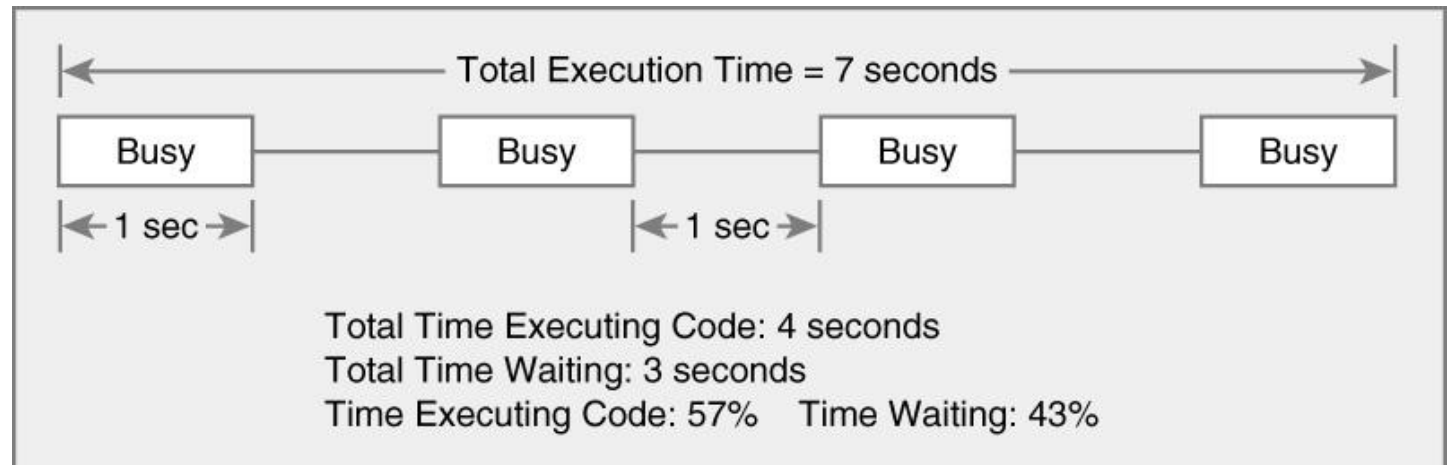
# Multitasking (Time-Sharing)

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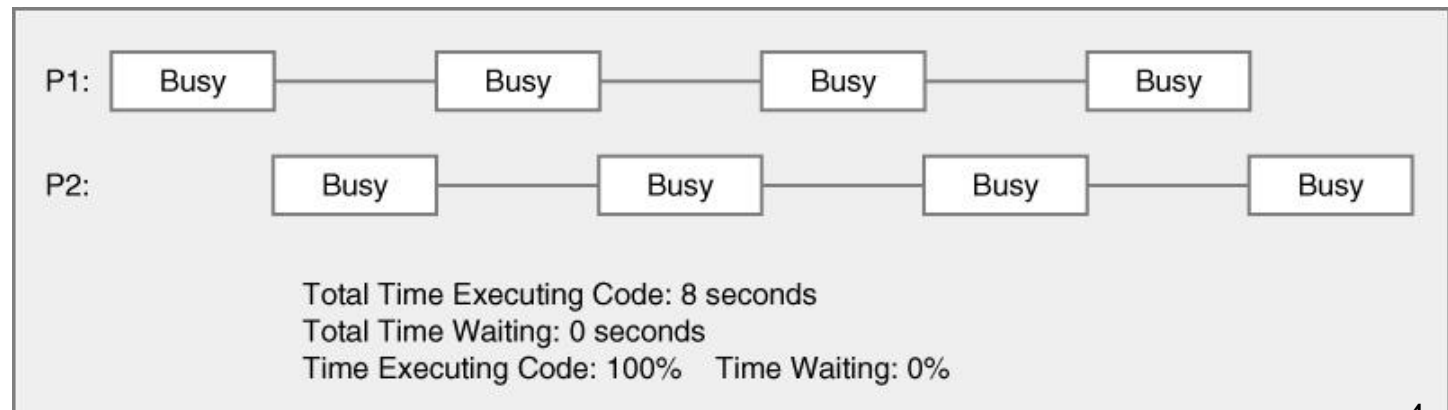
- ▶ Approach
  - Computer does some work on a task
  - Computer then quickly switch to next task
  - Tasks managed by operating system (scheduler)
- ▶ Computer **seems** to work on tasks concurrently
- ▶ Can improve performance by reducing waiting

# Multitasking Can Aid Performance

## ▶ Single task



## ▶ Two tasks



# Multiprocessing (Multithreading)

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- ▶ 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

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## ▶ 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

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## ▶ 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

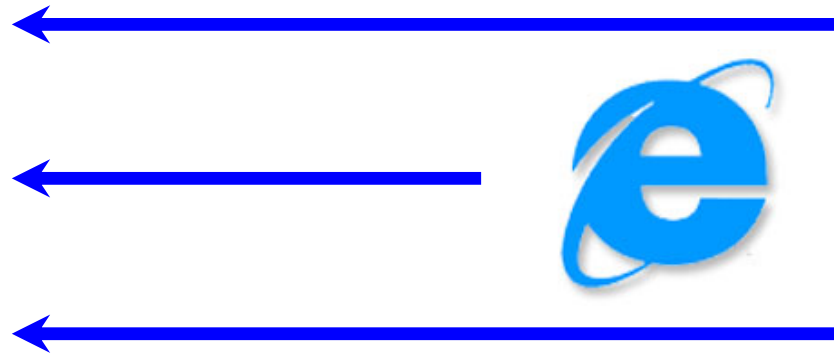
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- ▶ Captures logical structure of problem
  - May have concurrent interacting components
  - Can handle each component using separate thread
  - Simplifies programming for problem

- ▶ Example



**Web Server uses threads to handle ...**



**Multiple simultaneous web browser requests**



# Motivation for Multithreading

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- ▶ 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

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- ▶ **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

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

# Extending Thread class

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- 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

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- ▶ 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

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```
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

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```
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()  
}
```

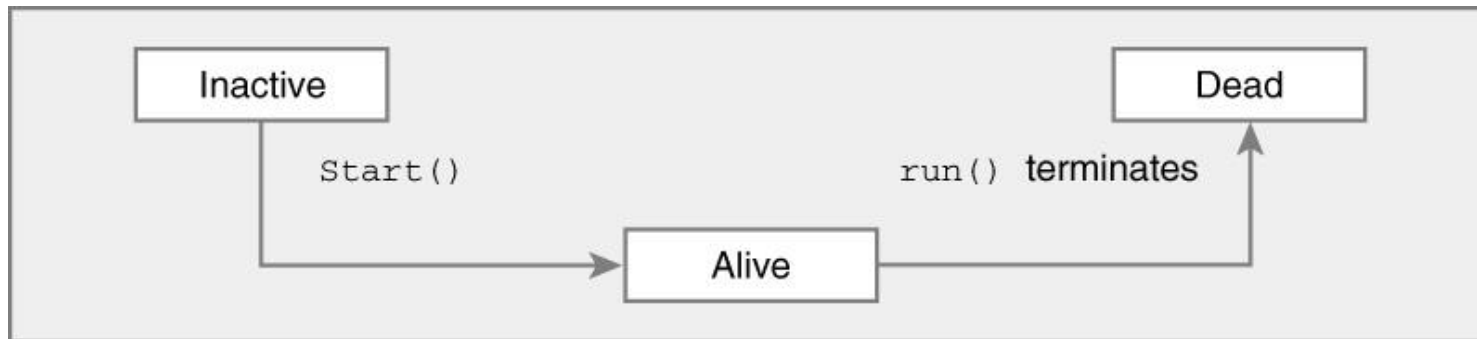


# Creating Threads in Java

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## ► 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**

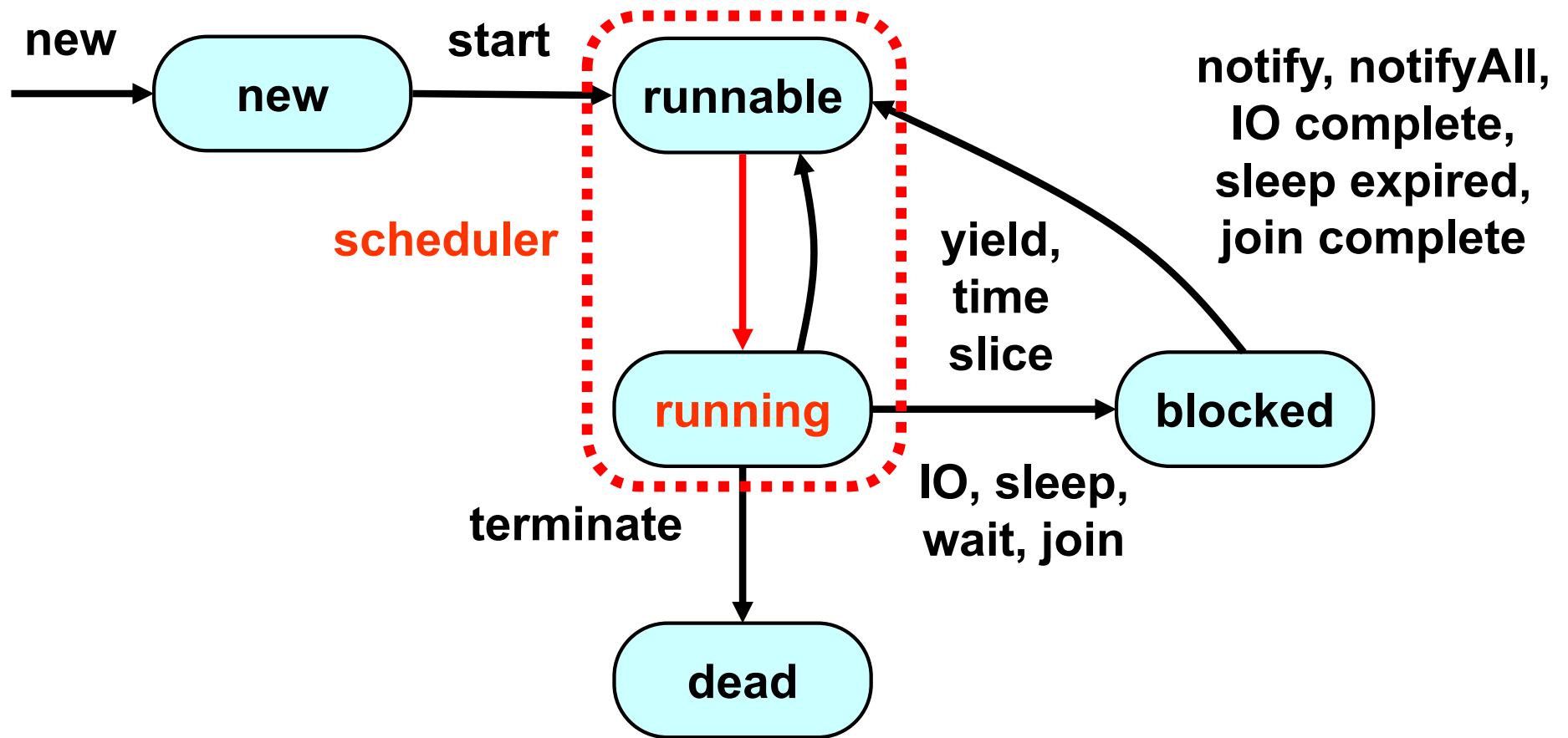
# Threads – Thread States

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- ▶ 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

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- ▶ 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

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## ▶ Scheduler

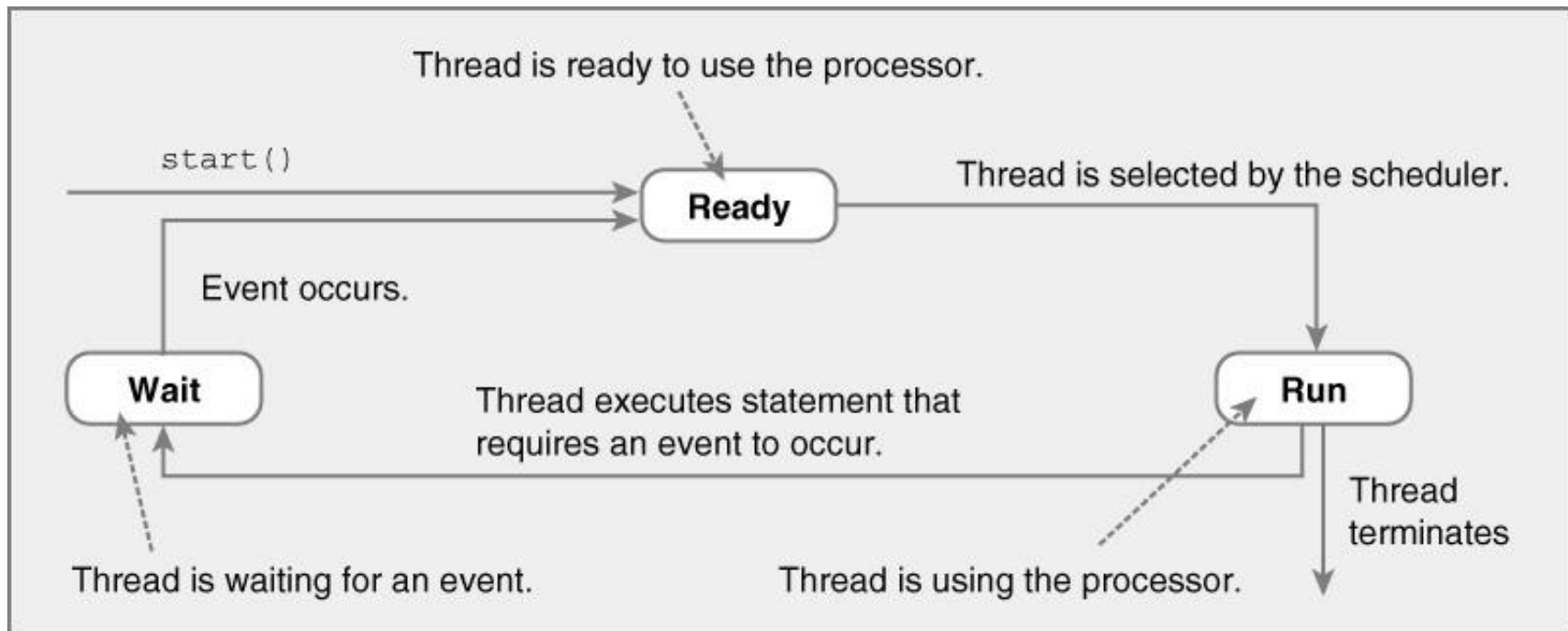
- Determines which runnable threads to run
  - When **context switching** takes place
- Can be based on thread **priority**
- Part of OS or Java Virtual Machine (JVM)

## ▶ Scheduling policy

- Non-preemptive (cooperative) scheduling
- Preemptive scheduling

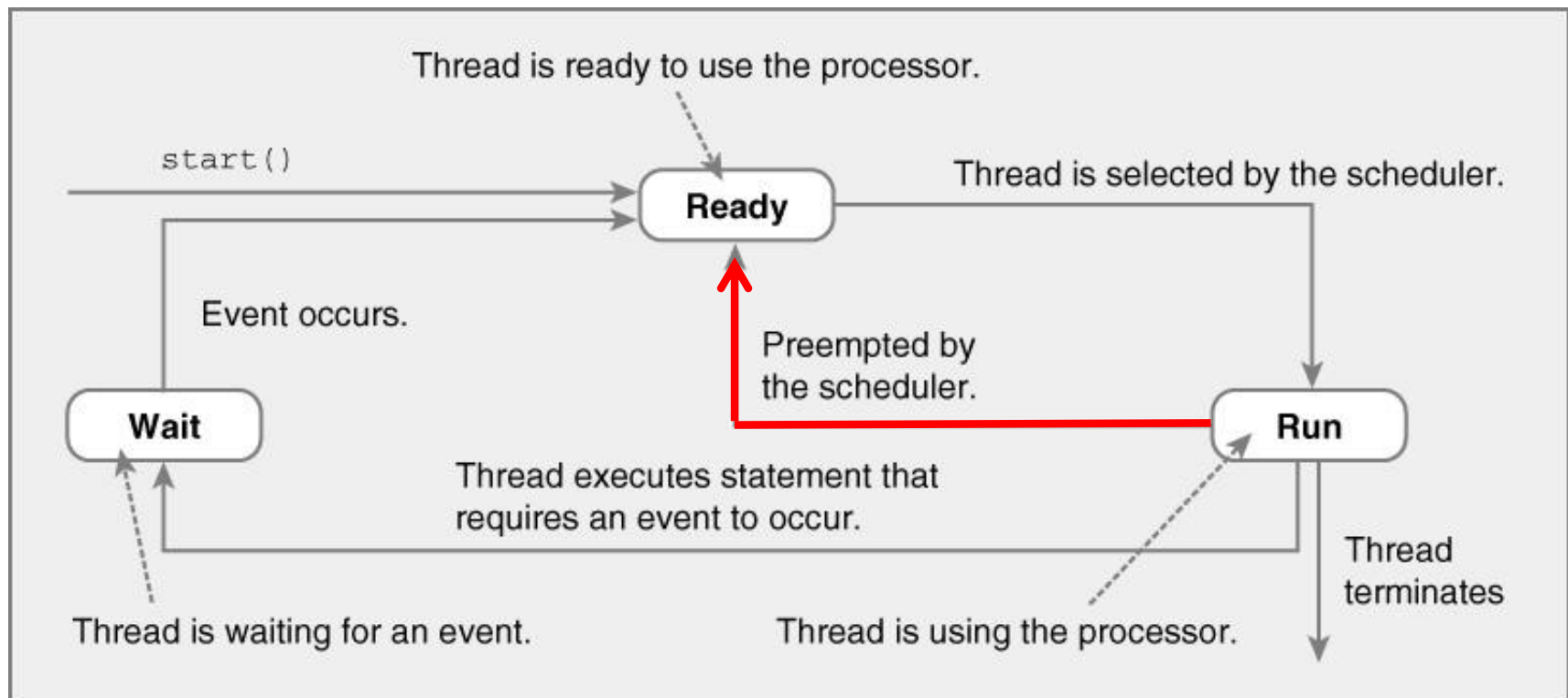
# Threads – Non-preemptive Scheduling

- ▶ 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

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- ▶ 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");
    }
}
```

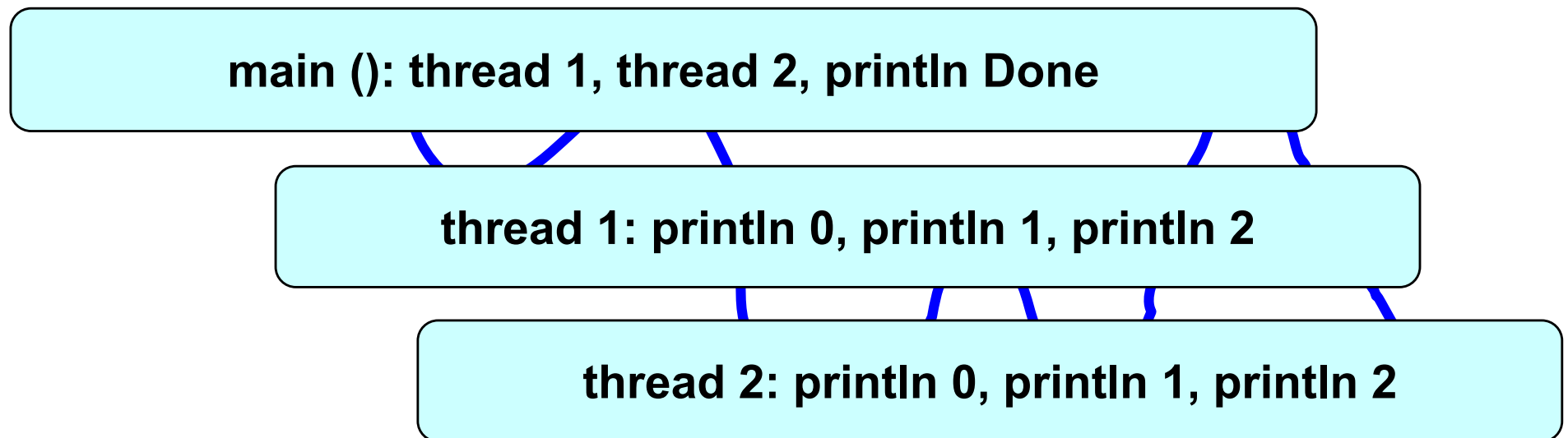
To understand this example better, let's assume we want to make a sandwich

# Java Thread Example – Output

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## ► 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

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- ▶ 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

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- ▶ 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

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- ▶ 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

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

# Example

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- ▶  $x = 0$  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

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- ▶ 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

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- ▶ 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)

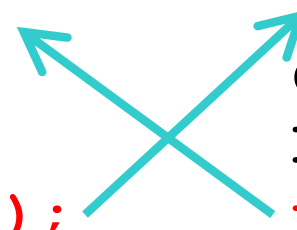
# Producer / Consumer Solution

---

```
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!