

# Multithreading in Java

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## Problem

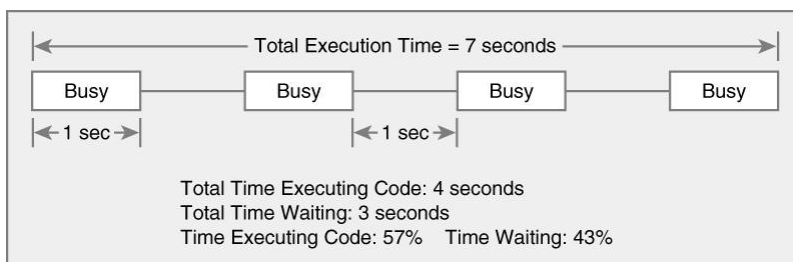
- **Multiple tasks for computer**
  - Draw & display images on screen
  - Check keyboard & mouse input
  - Send & receive data on network
  - Read & write files to disk
  - Perform useful computation (editor, browser, game)
- **How does computer do everything at once?**
  - Multitasking
  - Multiprocessing

## Multitasking (Time-Sharing)

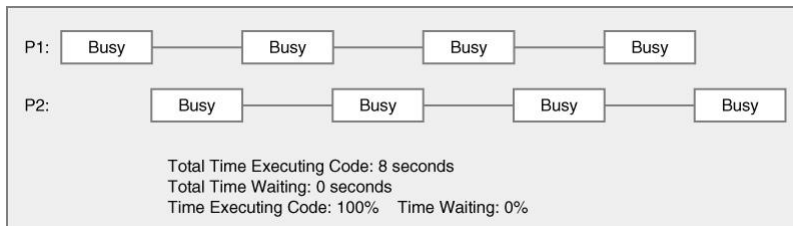
- **Approach**
  - Computer does some work on a task
  - Computer then quickly switch to next task
  - Tasks managed by operating system (scheduler)
- Computer **seems** to work on tasks concurrently
- Can improve performance by reducing waiting

## 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



4096 processor  
Cray X1

## Perform Multiple Tasks Using...

### 1. 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...

### 2. Thread

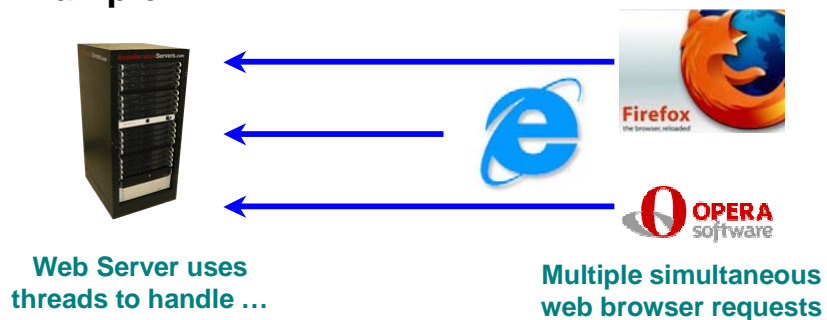
- Definition – sequentially executed stream of instructions
- Shares address space with other threads
- Has own **execution context**
  - Program counter, call stack (local variables)
- Communicate via shared access to data
- Multiple threads in process execute **same** program
- Also known as “lightweight process”

## Motivation for Multithreading

### 1. Captures logical structure of problem

- May have concurrent interacting components
- Can handle each component using separate thread
- **Simplifies programming for problem**

### ■ Example



## Motivation for Multithreading

### 2. Better utilize hardware resources

- When a thread is delayed, compute other threads
- Given extra hardware, compute threads in parallel
- **Reduce overall execution time**

### ■ Example



## Multithreading Overview

### ■ Motivation & background

### ■ Threads

- Creating Java threads
- Thread states
- Scheduling

### ■ Synchronization

- Data races
- Locks
- Wait / Notify

## 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**
  - **Thread class**

```
public class Thread extends Object { ... }
```
  - **Runnable interface**

```
public interface Runnable {  
    public void run(); // work ⇒ thread  
}
```

## Thread Class

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

    public void run(); // if no R, work for thread
    public void start(); // begin thread execution
    ...
}
```

## More Thread Class Methods

```
public class Thread extends Object {
    ...
    public static Thread currentThread()
    public String getName()
    public void interrupt()
    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

### 1. Thread class

- Extend Thread class and override the run method

#### ■ Example

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

## Creating Threads in Java

### 2. Runnable interface

- Create object implementing Runnable interface
- Pass it to Thread object via Thread constructor

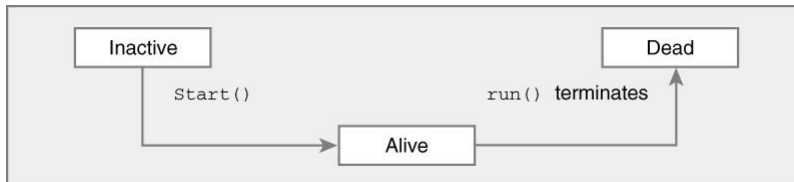
#### ■ Example

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

# Creating Threads in Java

## ■ Note

- Thread starts executing only if start() is called



- Runnable is interface
  - So it can be multiply inherited
  - Required for multithreading in applets

## Threads – Thread States

### ■ Java thread can be in one of these states

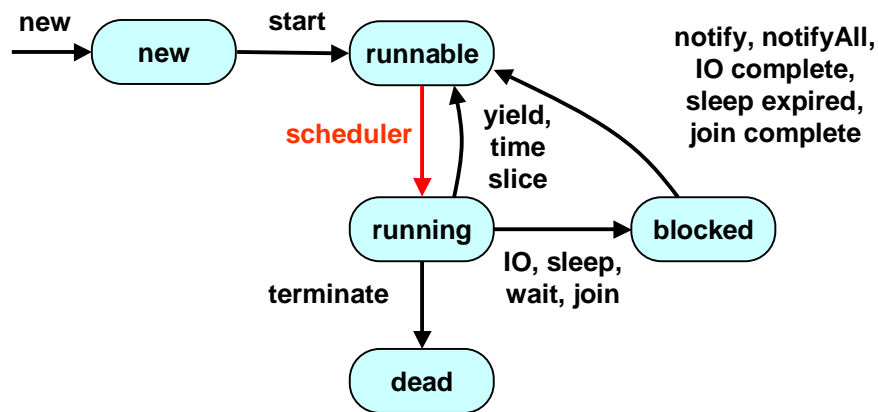
- New – thread allocated & waiting for start()
- Runnable – thread can begin execution
- Running – thread currently executing
- Blocked – thread waiting for event (I/O, etc.)
- Dead – thread finished

### ■ 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()...

## Threads – Thread States

### ■ State diagram



## Daemon Threads

### ■ Java threads types

- **User**
- **Daemon**
  - Provide general services
  - Typically never terminate
  - Call `setDaemon()` before `start()`

### ■ Program termination

1. All user threads finish
2. Daemon threads are terminated by JVM
3. Main program finishes

# Threads – Scheduling

## ■ Scheduler

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

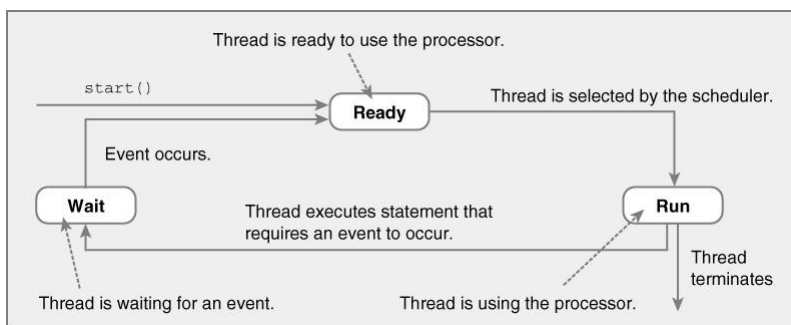
## ■ Scheduling policy

- Nonpreemptive (cooperative) scheduling
- Preemptive scheduling

# Threads – Non-preemptive Scheduling

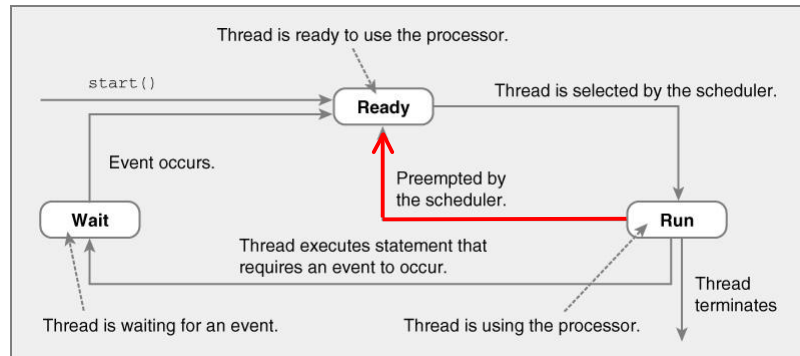
## ■ Threads continue execution until

- 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



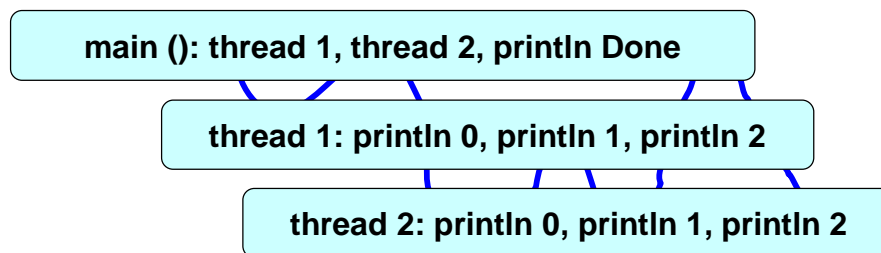
## Java Thread Example

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

## 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



## Data Races

```
public class DataRace extends Thread {
    static int x;
    public void run() {
        for (int i = 0; i < 100000; i++) {
            x = x + 1;
            x = x - 1;
        }
    }
    public static void main(String[] args) {
        x = 0;
        for (int i = 0; i < 100000; i++)
            new DataRace().start();
        System.out.println(x); // x not always 0!
    }
}
```

## Thread Scheduling Observations

- Order thread is selected is **indeterminate**
  - Depends on scheduler
- Thread can block indefinitely (starvation)
  - If other threads always execute first
- Thread scheduling may cause **data races**
  - Modifying same data from multiple threads
  - Result depends on thread execution order
- Synchronization
  - Control thread execution order
  - Eliminate data races