Multithreading in Java

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Problem

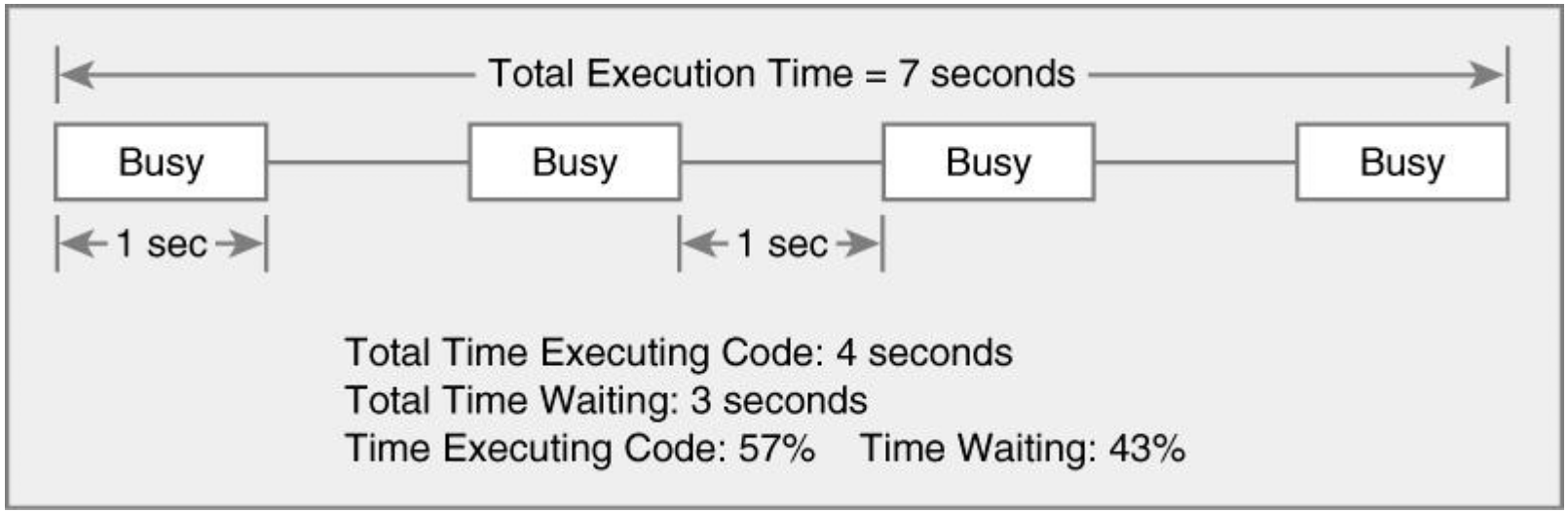
- Multiple tasks for computer
  - Draw & display images on screen
  - Check keyboard & mouse input
  - Send & receive data on network
  - Read & write files to disk
  - Perform useful computation (editor, browser, game)
- How does computer do everything at once?
  - Multitasking
  - Multiprocessing

Multitasking (Time-Sharing)

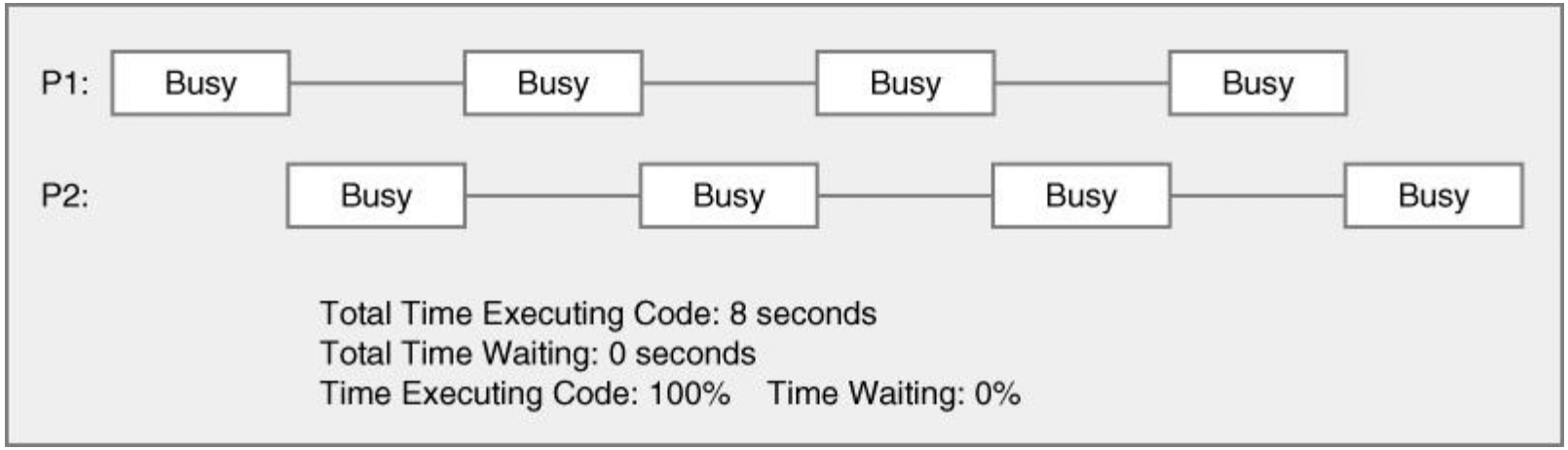
- Approach
  - Computer does some work on a task
  - Computer then quickly switch to next task
  - Tasks managed by operating system (scheduler)
- Computer seems to work on tasks concurrently
- Can improve performance by reducing waiting

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…

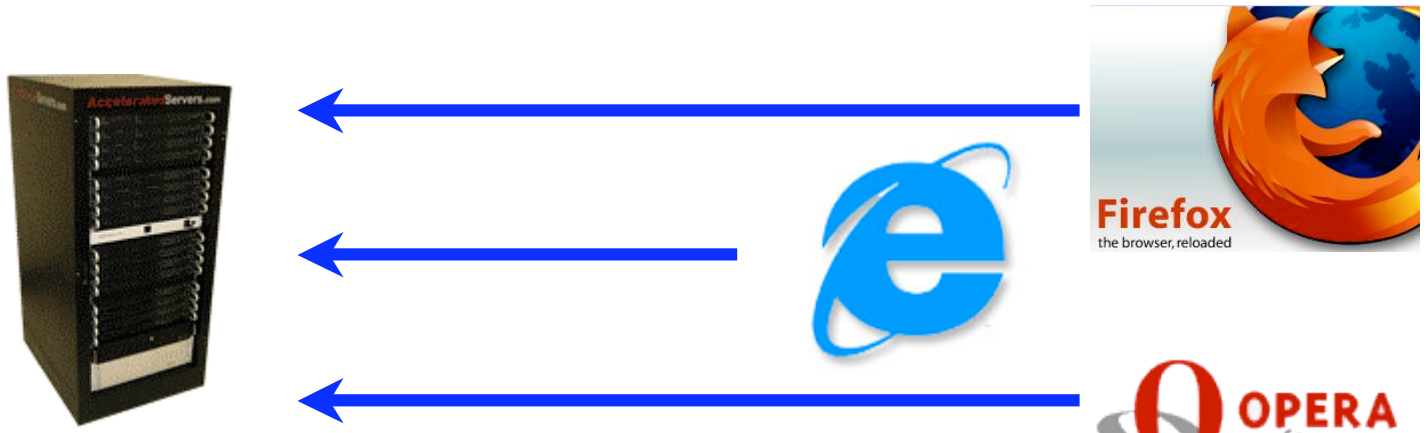
- **Process**
  - Definition – executable program loaded in memory
  - Has own address space
    - Variables & data structures (in memory)
  - Each process may execute a different program
  - Communicate via operating system, files, network
  - May contain multiple threads

Perform Multiple Tasks Using…

- **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

- 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

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

- You have to specify the work you want the thread to do
- Define a class that implements the Runnable interface

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

- Put the work in the run method
- Create an instance of the worker class and create a thread to run it
  - or hand the worker instance to an executor

Thread Class

```
public class Thread {

    public Thread(Runnable R);    // Thread ⇒ R.run()
    public Thread(Runnable R, String name);

    public void start();   // begin thread execution
    ...
}
```

More Thread Class Methods

```
public class Thread {
    …
   public String getName();
    public void interrupt();
    public boolean isAlive();
    public void join();
    public void setDaemon(boolean on);
    public void setName(String name);
    public void setPriority(int level);

   public static Thread currentThread();

    public static void sleep(long milliseconds);
    public static void yield();
}
```

Creating Threads in Java

- **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
```

Alternative (Not Recommended)

- **Directly extend Thread class**

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

Why not recommended?

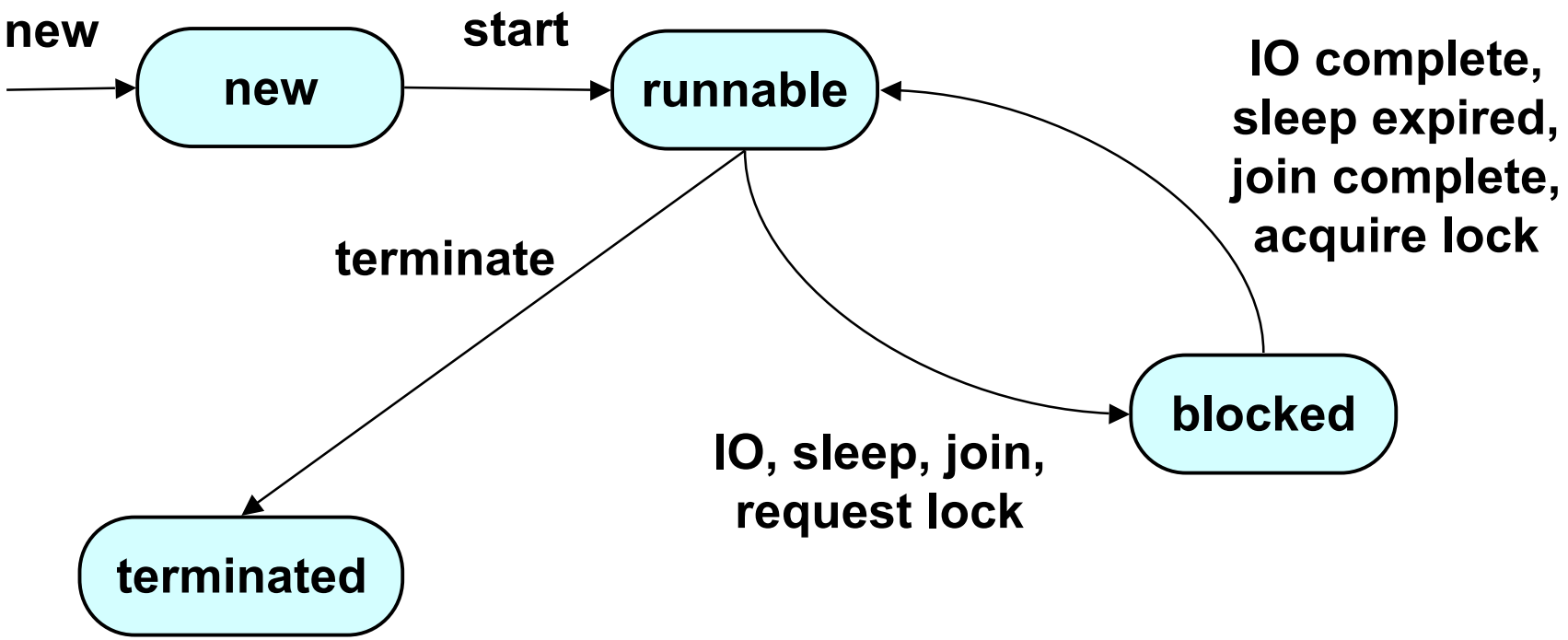
- Not a big problem for getting started
  - but a bad habit for industrial strength development
- The methods of the worker class and the Thread class get all tangled up
- Makes it hard to migrate to Thread Pools and other more efficient approaches

Threads – Thread States

- Java thread can be in one of these states
  - New – thread allocated & waiting for start()
  - Runnable – thread can execute
  - Blocked – thread waiting for event (I/O, etc.)
  - Terminated – thread finished
- Transitions between states caused by
  - Invoking methods in class Thread
    - start(), yield(), sleep()
  - Other (external) events
    - Scheduler, I/O, returning from run()…

Threads – Thread States

- State diagram



Threads – Scheduling

- **Scheduler**
  - Determines which runnable threads to run
  - Can be based on thread priority
  - Part of OS or Java Virtual Machine (JVM)
  - Many computers can run multiple threads simultaneously (or nearly so)

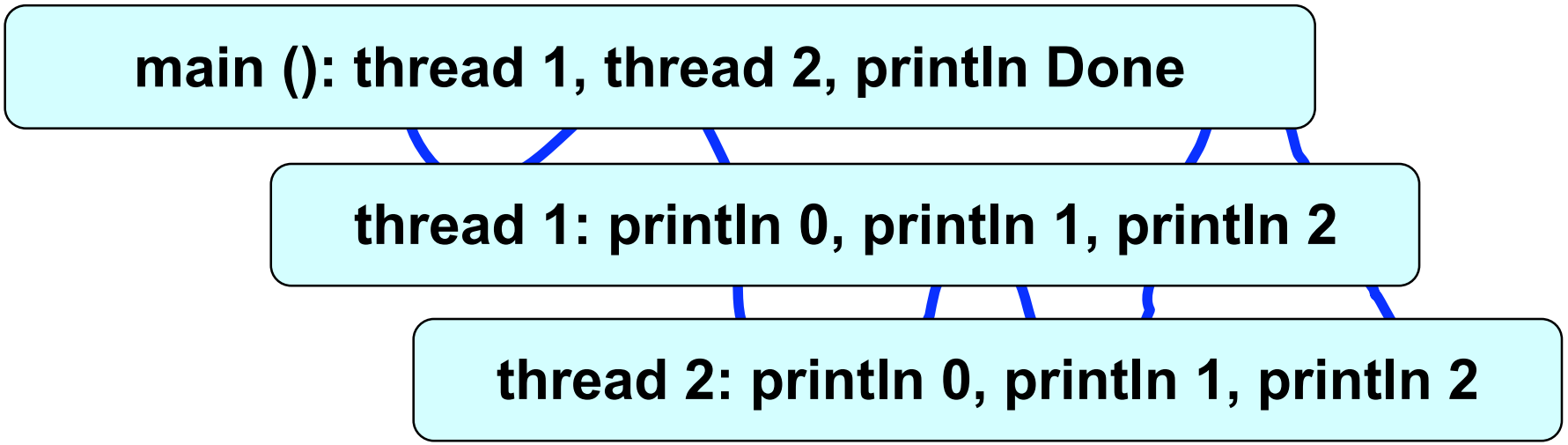
Java Thread Example

```
public class ThreadExample implements Runnable {
    public void run() {
        for (int i = 0; i < 3; i++)
            System.out.println(i);

    }
    public static void main(String[] args) {
     new Thread(new ThreadExample()).start();
     new Thread( 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



Daemon Threads

- Why doesn't the program quit as soon as Done is printed?
- Java threads types
  - User
  - Daemon
    - Provide general services
    - Typically never terminate
    - Call setDaemon() before start()
- Program termination
  - If all non-daemon threads terminate, JVM shuts down

Might not see different interleavings

- The threads in that example are too short
- Each started thread will probably complete before the next thread starts

- Let's make more threads that run longer

Data Races

```
public class DataRace implements Runnable {
 static volatile int x;
 public void run() {
    for (int i = 0; i < 10000; i++) {
       x++;
       x--;
    }
 }
 public static void main(String[] args) throws Exception {
     Thread [] threads = new Thread[100];
     for (int i = 0; i < threads.length; i++)
        threads[i] = new Thread(new DataRace());
     for (int i = 0; i < threads.length; i++)
        threads[i].start();
     for (int i = 0; i < threads.length; i++)
        threads[i].join();
     System.out.println(x);    // x not always 0!
 }
}
```

Why volatile

- We'll spend more time on volatile later
- But volatile tells the compiler:
  - other threads might see reads/writes of this variable
  - don't change/reorder eliminate the reads and writes

- An optimizing compiler should, if it sees
  - x++; x--;
- replace it with a no-op
  - if x isn't volatile

Thread Scheduling Observations

- Order thread is selected is indeterminate
  - Depends on scheduler, timing, chance
- Scheduling is not guaranteed to be fair
- Some schedules/interleavings can cause unexpected and bad behaviors

- Synchronization
  - can be used to control thread execution order

Using Synchronization

```
public class DataRace implements Runnable {
 static volatile int x;
 static Object lock = new Object();
 public void run() {
    for (int i = 0; i < 10000; i++)
       synchronized(lock) {
         x++;  x--;
    }
 }
 public static void main(String[] args) throws Exception {
     Thread [] threads = new Thread[100];
     for (int i = 0; i < threads.length; i++)
        threads[i] = new Thread(new DataRace());
     for (int i = 0; i < threads.length; i++)
        threads[i].start();
     for (int i = 0; i < threads.length; i++)
        threads[i].join();
     System.out.println(x);    // x always 0!
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