CS18000: Problem Solving and Object-Oriented Programming

Concurrency

(revised 10/16/23)

Video 1
History of Concurrency, Java Threads

Concurrent Programming and Synchronization

Threads

Time Slicing

- In early days -- one program ran at a time
- Along came windowed operating systems
- Giving illusion of multiple programs running at a time
- Email tool, web browser, text editor
- 1 second = 1000 milliseconds
- Time slicing -- running each program a few hundred milliseconds
- Humans are so slow that it appeared that all programs were running simultaneously

Mobile Devices

- Illusion worked well as programs became more and more complex
- Simply make the CPU run faster
- Along came mobile devices -- laptops and phones
- Run on batteries
- As the CPU runs faster, battery runs down quicker and gets very hot

Multiple Cores

- How about putting 2 or more CPUs (cores) on same chip?
- If run 2 cores at half speed, same as 1 core at full speed
- Slower cores consume less battery and generate less heat
- Now most laptops and phones have 4 or more cores
- If you have 4 apps running, they may actually be running simultaneously
- But, what if you have more than 4
- Time slicing is alive and well -- some apps are in a queue waiting to get a core

Threads

- Multiple cores can even be used to speed up one program
- A program can have more than one part (thread) running simultaneously
- What if a database is spread over 3 files?
- Run 3 threads on 3 cores ... each looking for the same item
- Program runs (approximately) 3 times faster

Sequential vs. Concurrent

- Sequential:
  - A single “thread of execution” weaves its way through your program
  - A single PC (“program counter”) identifies the current instruction being executed
- Concurrent:
  - Multiple “threads of execution” are running simultaneously through your program
  - Multiple PCs are active, one for each thread

Java Threads

- Thread class with run() method
- import java.lang.*;
- Allows creation and manipulation of threads
  - Thread t = new Thread();
- Three important methods:
  - t.start(): start the thread referenced by t
  - t.join(): “join with” (wait for) the running thread t
  - t.run(): called by start() in a different thread
- Note: Your code *does not* call run() directly; instead, the start() method calls run() as part of the new thread sequence

Example: MainThread

```
public class MainThread {
    public static void main(String[] args) {
        Thread t = Thread.currentThread();
        System.out.printf("main thread = %s\n", t);

        System.out.printf("going to sleep...\n");
        try {
            Thread.sleep(5000);
        } catch (InterruptedException e) {
            e.printStackTrace();
        }
        System.out.printf("ah, that was nice\n");

        System.out.printf("letting someone else run\n");
        Thread.yield();
        System.out.printf("back\n");
    }
}
```

How to Create Threads

- Create a class that implements the Runnable interface

```
public class MyTask implements Runnable {
    public void run() { … }
}
Thread t = new Thread(new MyTask());
```

Example: MyTask

```
public class MyTask implements Runnable {
    public static void main(String[] args) {
        MyTask m = new MyTask();
        Thread t = new Thread(m);

        t.start();
    }

    public void run() {
        System.out.printf("now in %s\n", Thread.currentThread());
    }
}
```

Video 2
Task and Domain Decomposition

Concurrent Programming and Synchronization

Runnables

Using Concurrent Processing

- How do you break down a large problem into pieces?
- Need to *decompose* the problem into pieces
- Two approaches to decomposition
  - By the tasks to be done
  - By the data to be processed

Task Decomposition

- Split task into multiple subtasks
- Each subtask runs *different code*
- Each subtask runs on its own core (processor)
- Primary benefit: responsiveness
  - GUI is one task
  - Background computation a different task
  - GUI has its own core, so is always responsive

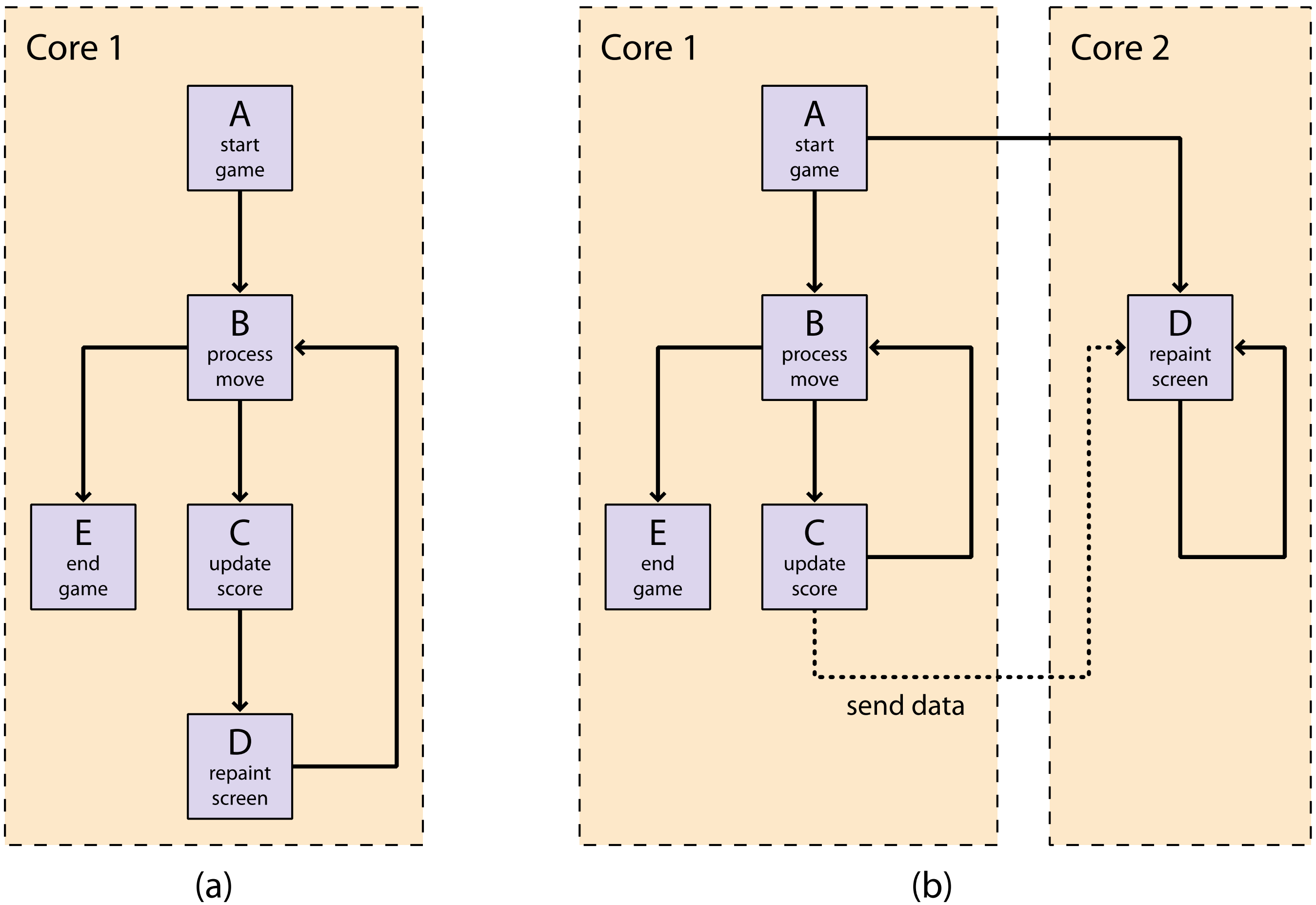
Domain Decomposition

- Domain:
  - Input examined by the problem
- Divide domain into pieces (subdomains)
- Each subtask runs the
  - *same code* but
  - *on different input*
- Each subdomain is given to a task running on a different core
- Primary benefit: raw speed

Examples: Task Decomposition

- Updating the screen of a video game
  - One task processes player moves
  - One task updates the display
  - Two tasks communicate as necessary
- Can a student register for a class?
  - One task determines if student has pre-reqs
  - One task decides if student has class at same time
  - One task determines if a seat is available in class
  - Combine results when each task is done

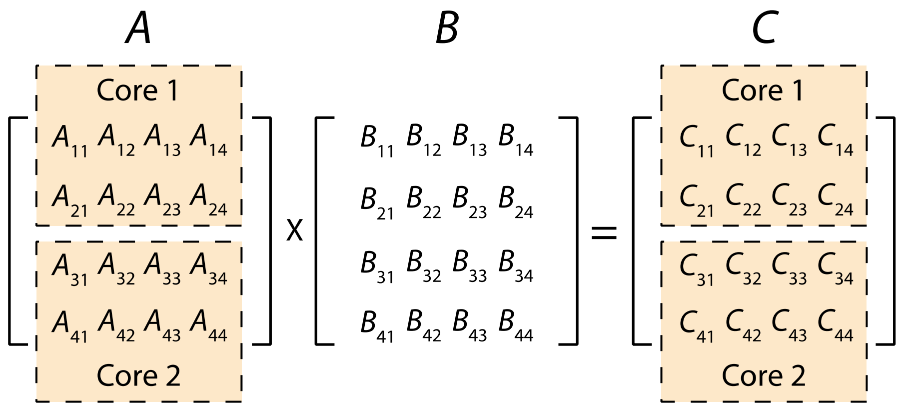
Task Decomposition Example: Video Game Updates



Examples: Domain Decomposition

- Factoring a large number
  - Trial divide up to square root of number
  - Assign blocks of trial divisors to separate tasks
  - First task to divide with 0 remainder stops process
- Finding words in a word search puzzle
  - Divide word list into subsets
  - Assign each subset to a separate task
  - Tasks search the puzzle grid, recording hits

Domain Decomposition Example: Matrix Multiplication



Using domain decomposition to compute the matrix product A x B.

The top half is computed on Core 1 and the bottom half on Core 2.

Task Decomposition

```
public class Model implements Runnable {
    // This run method keeps track of where the characters are, what
    // direction they are moving and at what speed
    public void run() {…}
}

public class View implements Runnable {
    // This run method updates the GUI showing where each character is
    // right now
    public void run() {…}
}
```

Task Decomposition

```
public class Game {
    public static void main(String[] args) {
    // Thread data keeps track of where the characters are, what direction they
    // are moving and at what speed
        Thread data = new Thread(new Model (…));
    // Thread gui updates the GUI showing each character
        Thread gui = new Thread(new View (…));

   // Start the data thread.  It will receive information from the GUI about use
   // of controls, mouse clicks, etc.
        data.start();
   // Start the gui thread.  It will receive information from Model class methods
   // about where the characters are, what direction they are moving and at what
   // speed
         gui.start();
         …
    }
}
```

Video 1
Synchronization Using join()

Concurrent Programming and Synchronization

Synchronization

Unpredictability in Thread Execution

- Thread execution may be interrupted
  - “Time slicing” of threads (and processes) prevents one thread from “hogging” the CPU
  - Higher priority activities may interrupt the thread: e.g., I/O
- Multiple threads do not always proceed at the same rate
- Coordination of multiple threads a challenge
- Java provides low-level and high-level tools to deal with *synchronization of threads*

Example: Interleave (1)

```
public class Interleave implements Runnable {
    private char c;

    public Interleave(char c) {
        this.c = c;
    }

    public void run() {
        for (int i = 0; i < 100; i++) {
            System.out.printf("%c", c);
            for (int j = 0; j < 1000; j++)
                Math.hypot(i, j);
        }
        System.out.printf("%c", Character.toUpperCase(c));
    }

// ... continued on next slide ...
```

Example: Interleave (2)

```
// ... continued from previous slide ...

    public static void main(String[] args) {
      while (true) {
        Thread t1 = new Thread(new Interleave('a'));
        Thread t2 = new Thread(new Interleave('b'));
        t1.start();
        t2.start();

        try {
            t1.join();
            t2.join();
        } catch (InterruptedException e) { …. }
        System.out.println();
      }
    }
}
```

Join: Wait for a Thread to Finish

- A simple kind of synchronization
- For Thread `t`:

```
t.join();
```

- Blocks the “current thread”—the one that called t.join()—until Thread t completes (returns from run())
- join() may throw an InterruptedException, so generally is in try-catch clause

Join using Try-Catch Clause

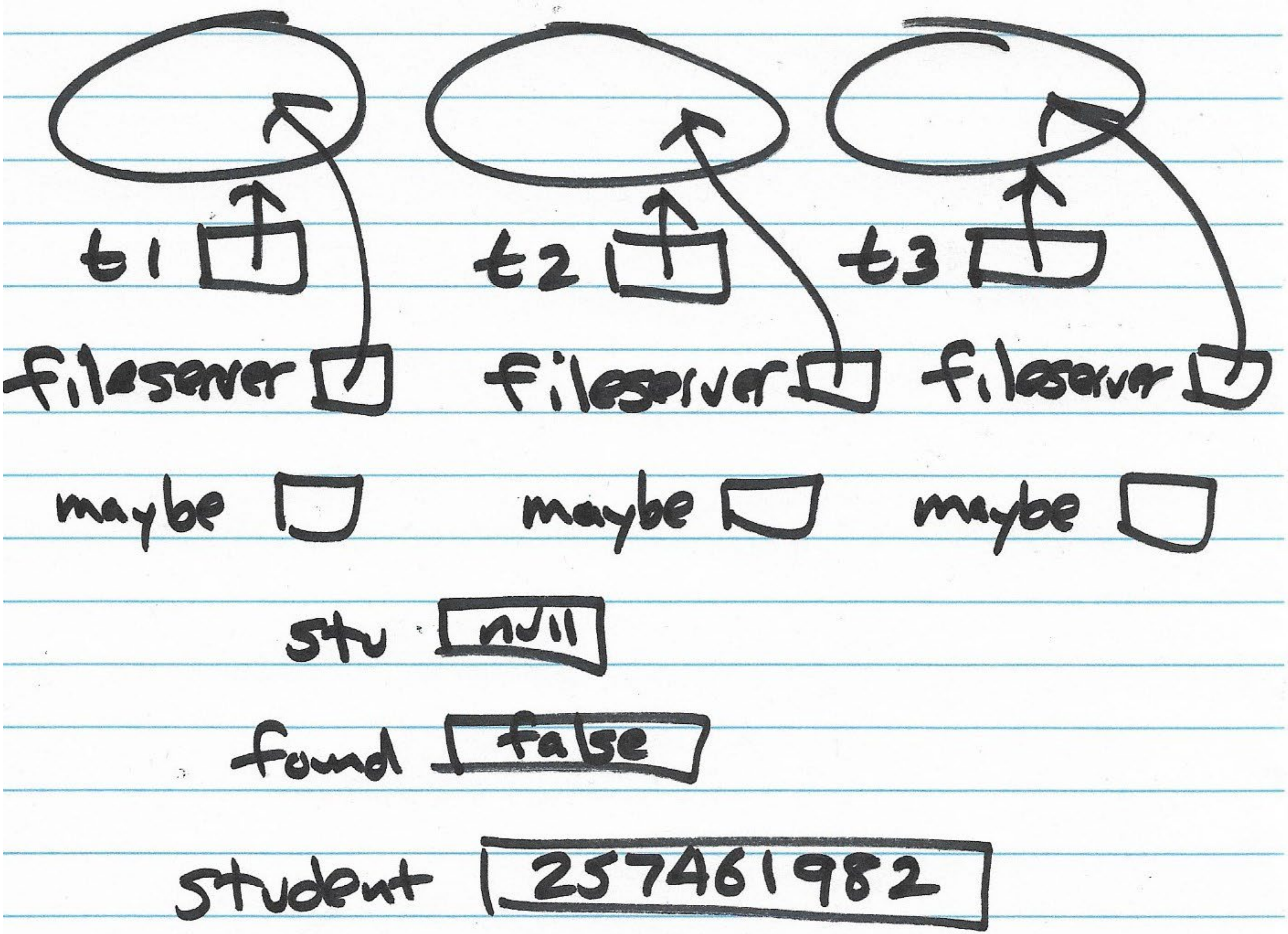
```
try {
    t.join();
} catch (InterruptedException e) {
    e.printStackTrace(); // example
};
```

Search for a Student using Threads

```
public class FindStudent implements Runnable {
    private static Student stu = null; // stu will be returned
    private static boolean found = false; // haven’t found stu yet
    private static int student; // who we are looking for
    private Fileserver fileserver; // where to look
    private Student maybe = null; // maybe this is the one

    public FindStudent (Fileserver f) {fileserver=f;};

    public Student search (int student) throws
                StudentNotFoundException {
        this.student = student;
        Thread t1 = new Thread (new FindStudent (fileserver1));
        Thread t2 = new Thread (new FindStudent (fileserver2));
        Thread t3 = new Thread (new FindStudent (fileserver3));
```



t1
t2
t3
fileserver
fileserver
fileserver
maybe
maybe
maybe
stu
null
found
false
student
257461982

Search for a Student using Threads

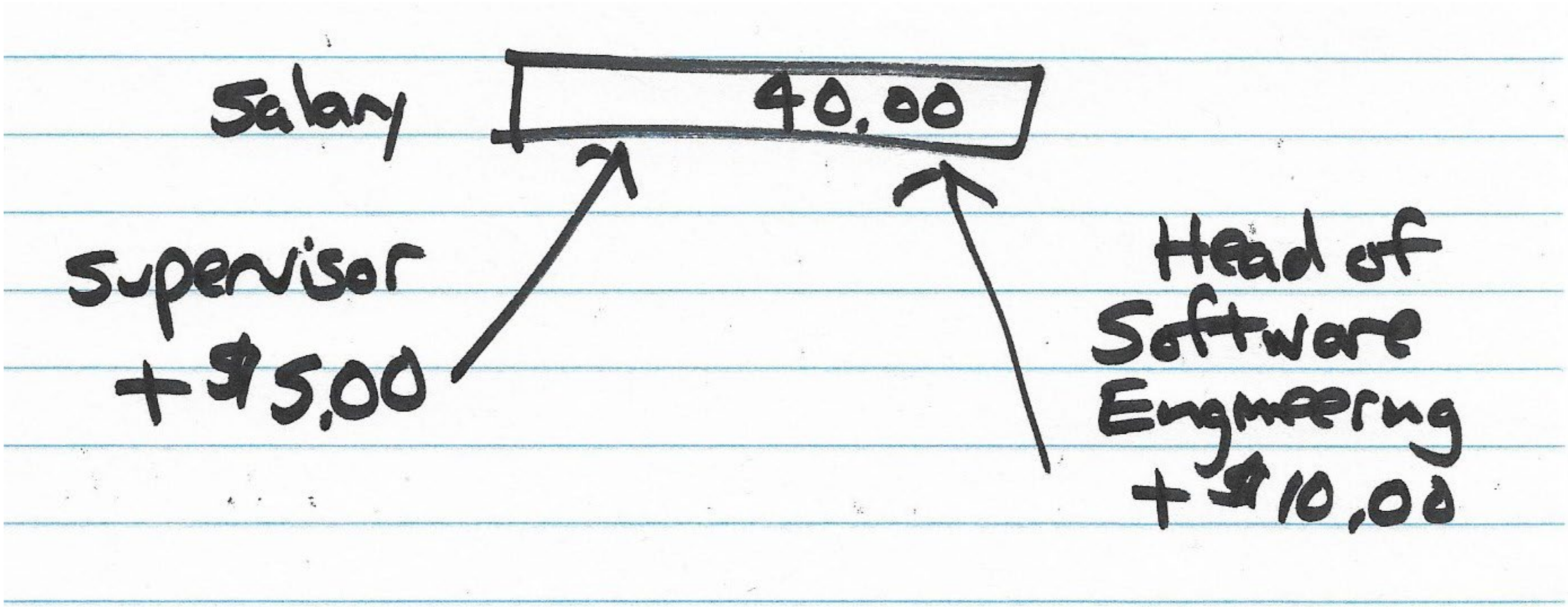
```
    t1.start();
    t2.start();
    t3.start();
    try {
        t1.join();
        t2.join();
        t3.join();
    } catch (InterruptedException e) { …. }

    if (found)
        return stu;
    else
        throw new StudentNotFoundException
        (Integer.toString(student));
}
```

Search for a Student using Threads

```
public void run() {
    while (more to read on fileserver) {
        if (found) return;
        // read the next Student object, maybe points to it
        …
        if (maybe.getID() == student) {
            stu = maybe;
            found = true;
        }
}
```

Video 2
Race Conditions


Salary
40,00
Supervisor
+ $5,00
Head of
Software
Engineering
+ $10,00

Synchronization Problem: Race Condition

- As threads “race” through execution, their instructions are interleaved at the nanosecond level
  - Byte codes within a thread always executed in relative order, as expected
  - Byte codes between threads not executed in predictable absolute order
- Causes problems when accessing and updating shared data

Example: RaceCondition (1)

```
public class RaceCondition implements Runnable {
    private static int counter;

    public static void main(String[] args) {
        counter = 0;

        Thread t1 = new Thread(new RaceCondition());
        Thread t2 = new Thread(new RaceCondition());

        t1.start();
        t2.start();

        try {
            t1.join();
            t2.join();
        } catch (InterruptedException e) { e.printStackTrace(); }

        System.out.printf("counter = %d\n", counter);
    }
    // ... run() method on next slide ...
}
```

Example: RaceCondition (2)

```
public void run() {
    for (int i = 0; i < 10000; i++) {
        counter++;
    }
}
```

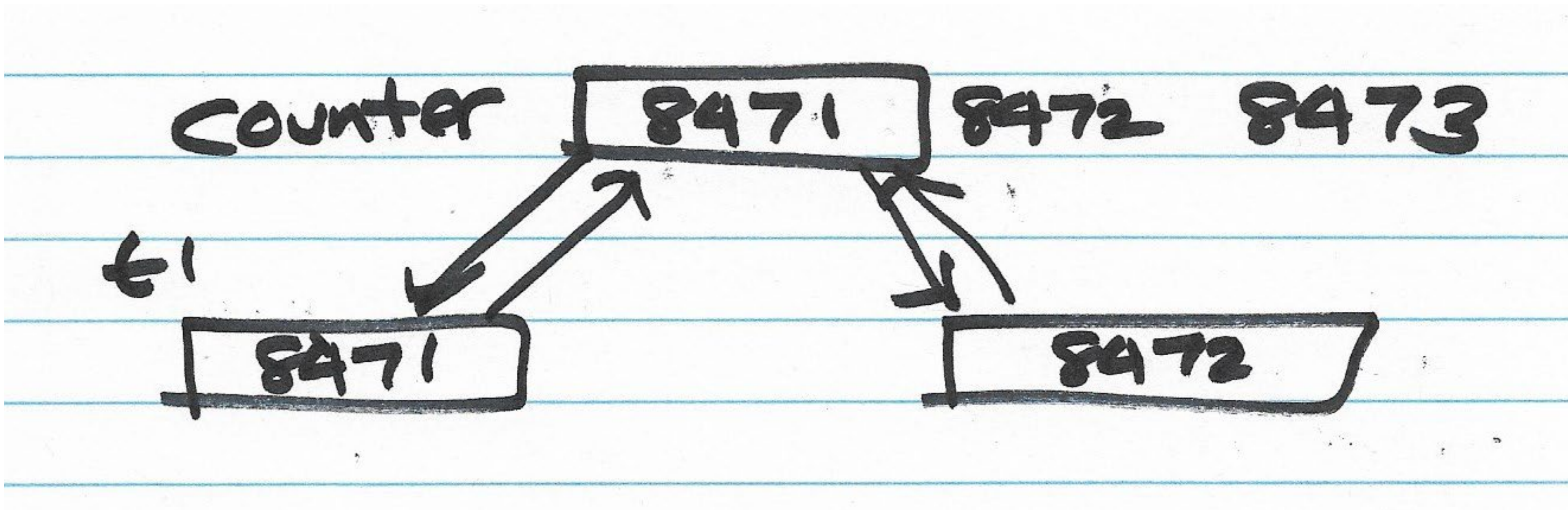
Two Threads Updating a Counter

- Thread 1

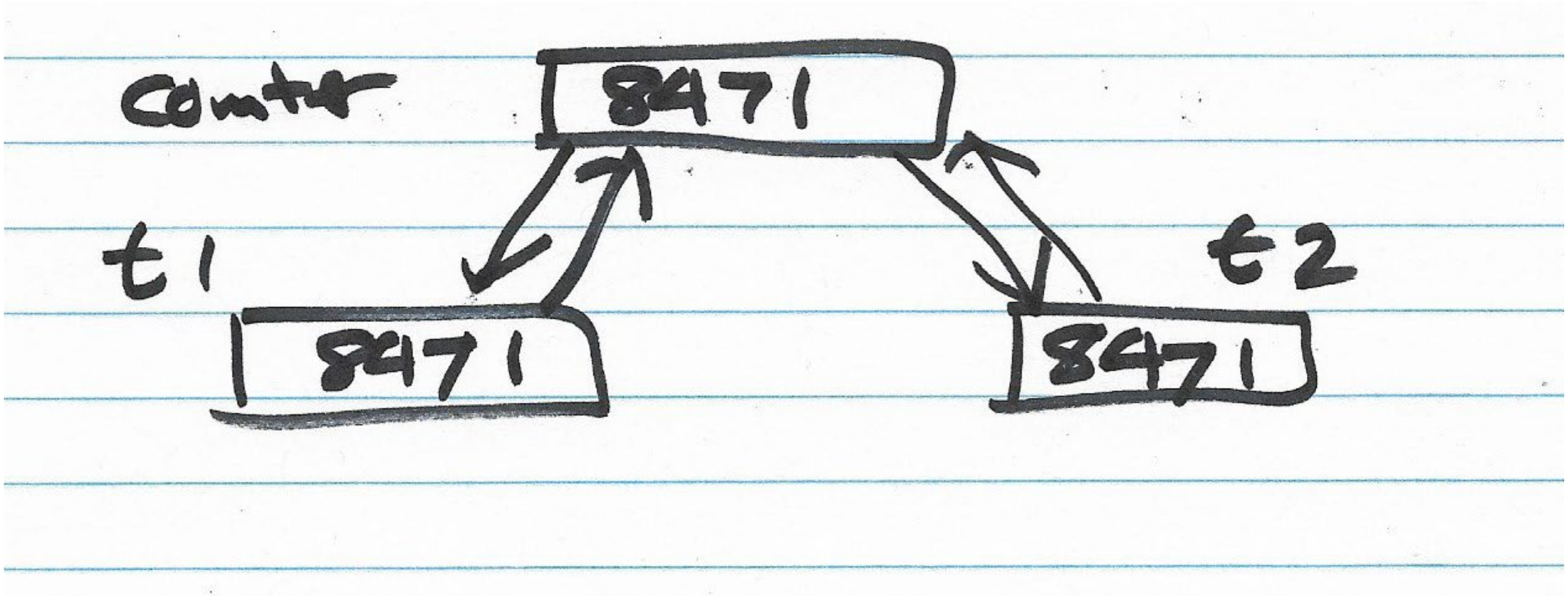
```
int t1 = counter;
t1 = t1 + 1;
counter = t1;
```

- Thread 2

```
int t2 = counter;
t2 = t2 + 1;
counter = t2;
```



Counter
8471
8472 8473
t1
8471
8472


counter
8471
t1
8471
t2
8471

Solution: Synchronize Threads

- Java keyword “synchronized”
- Allows two or more threads to use a common object to avoid race conditions
- Syntax:

```
synchronized (object) {
    statements;  // modify shared data here
}
```

- Among all threads synchronizing using the same object, only one thread can be “inside” the block of statements at a time

Example: NoRaceCondition (1)

```
public class NoRaceCondition implements Runnable {
    private static int counter = 0;
    private static Object gateKeeper = new Object();

    public static void main(String[] args) {
        Thread t1 = new Thread(new NoRaceCondition());
        Thread t2 = new Thread(new NoRaceCondition());
        t1.start();
        t2.start();
        try {
            t1.join();
            t2.join();
        } catch (InterruptedException e) { e.printStackTrace(); }
        System.out.printf("counter = %d\n", counter);
    }

    public void run() {
        for (int i = 0; i < 10000; i++) {
            synchronized (gateKeeper) { counter++; }
        }
    }
}
```

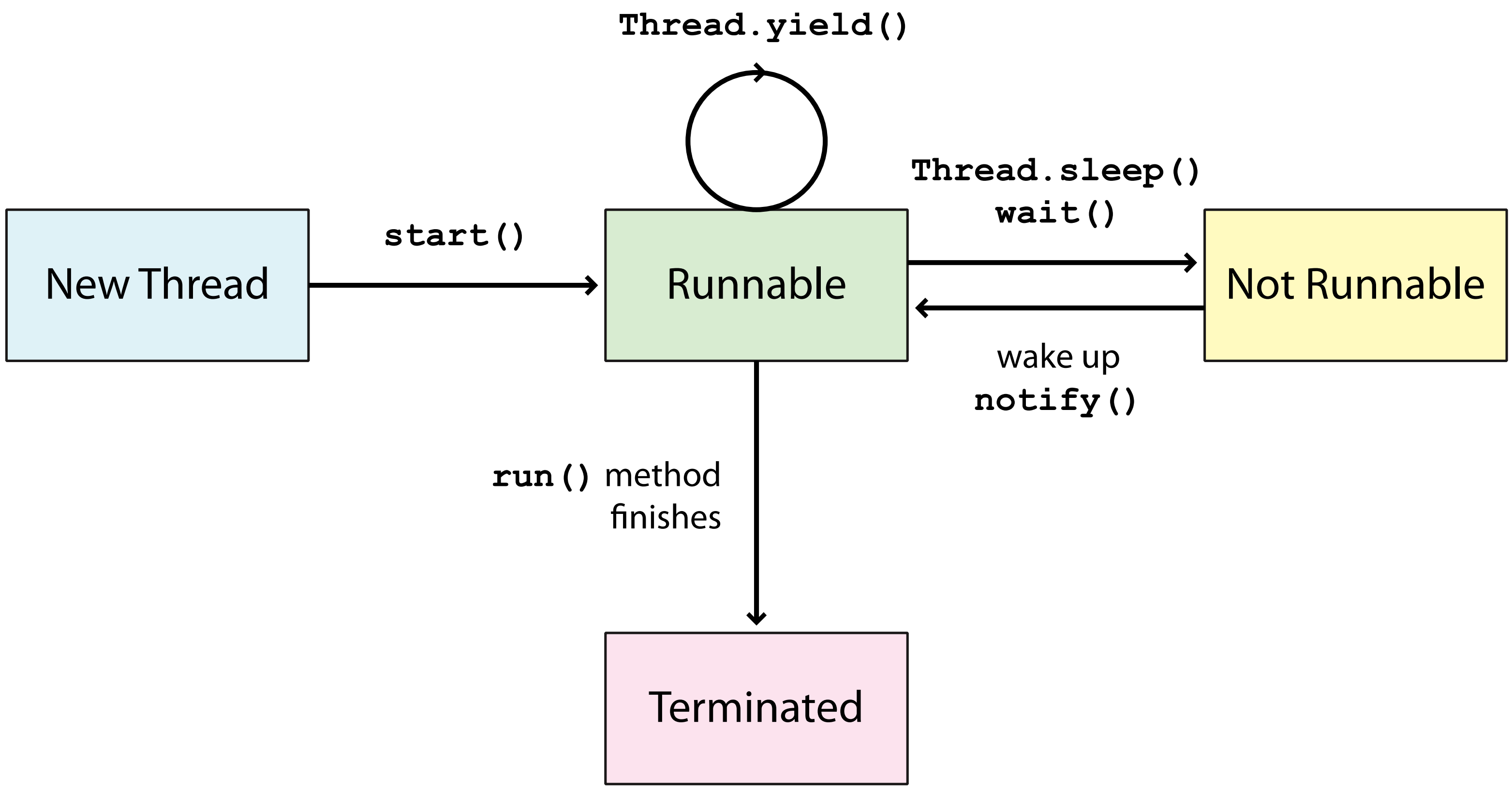
Shared Memory Architecture

- Two paradigms for supporting concurrent or parallel processing
- Message Passing: processes
  - Messages sent between separate processes
  - Generally, one process per program
  - May run on different physical computers
- Shared Memory: threads
  - Single program
  - All threads share the same memory space
  - This approach is what we are using in Java

Thread States

- A Java thread goes through several states in its lifetime:
  - New thread: created but not yet started
  - Runnable: started and available to be run
  - Not Runnable: sleeping, waiting for i/o, etc.
  - Terminated: returned from the run() method
- t.sleep(n) puts the current thread to sleep for n milliseconds; allows other threads to run
- t.yield() "gives up" the CPU, letting another thread run

Thread States



```
t1.start();
t2.start();
t3.start();
t4.start();
t5.start();

try {
    t1.join();
    t2.join();
    t3.join();
    t4.join();
    t5.join();
} catch (InterruptedException e) { …. }
```