Threads and Concurrency in Java: Part 1

Concurrency

- What every computer engineer needs to know about concurrency:

  Concurrency is to untrained programmers

  as matches are to small children.

  It is all too easy to get burned.

Concurrency: What

- Concurrency means that there are multiple agents running at the same time and interacting.

Concurrency: Where

- Sources of concurrency:
  - We have concurrency when we have interacting processes running on different computers (e.g. Apache –a web server– on mona.engr.mun.ca and Firefox –a web browser– on paradox.engr.mun.ca)

Concurrency : Where

- We also have concurrency when we have interacting processes running on the same computer. E.g. Firefox and Windows Explorer.
  - Every interactive program is part of a concurrent system: the user is a concurrent agent.
- Furthermore we can have multiple “threads of control” within one OS process.
  - A.K.A. multithreading

- Concurrency can be intermachine, interprocess, or multithreading.

Concurrency : Where

- These slides concentrate on intraprocess concurrency in Java.

Concurrency: Why

- Reasons for using concurrency
  - Speed. Multiple threads can be run on multiple processors (or multiple cores). This *may* give a speed advantage.
  - Distribution. We may wish different parts of a system to be located on different machines for reasons of convenience, security, reliability , ….

Concurrency: Why

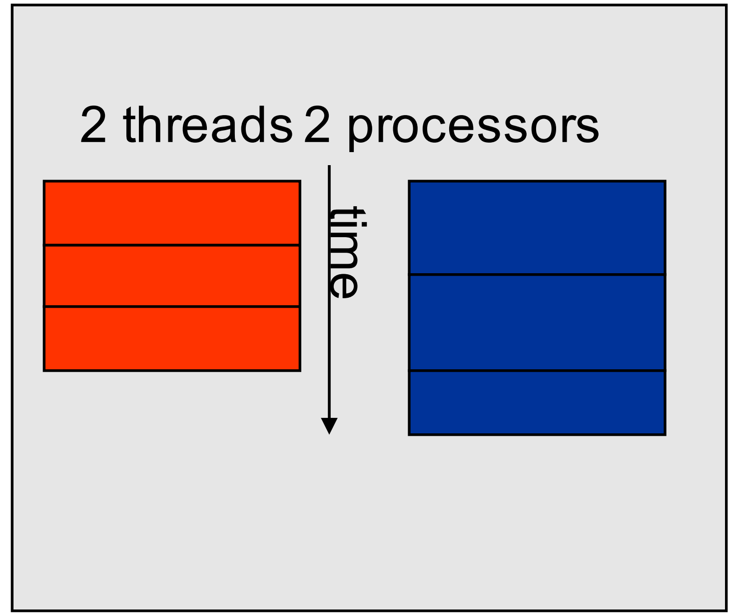
- Reasons for using concurrency
  - Asynchrony. It is easiest to deal with multiple sources of events by having one thread dedicated to each stream of incoming or outgoing events.
    - For example, a web browser may use one thread to deal with input from the user and one thread for each server it is currently interacting with.
    - Likewise a web server will typically dedicate at least one thread to each current session.

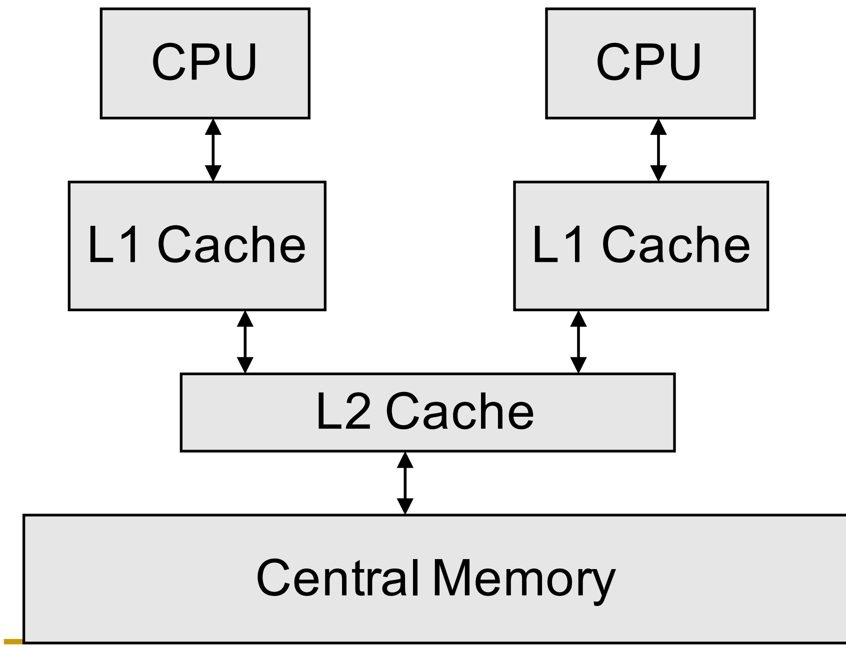
Threads

- Each thread has its own
  - program counter
  - registers
  - local variables and stack
- All threads share the same heap (objects)

Concurrency: How Multiple processors

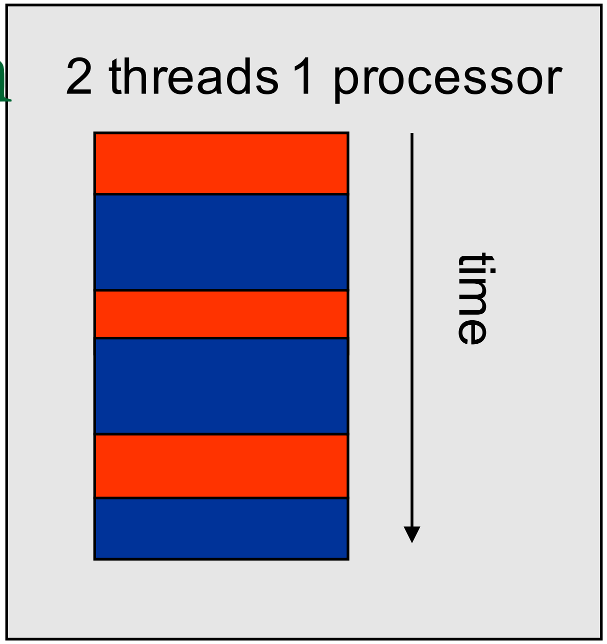
- Multiprocessor (and mulitcore)



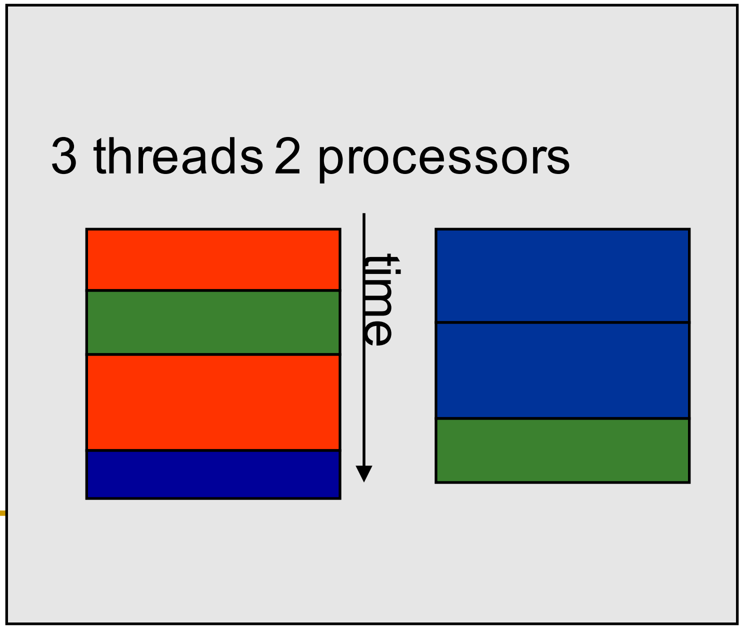


Concurrency: How
Time slicing implementation

- Single processor
  - The CPU is switched between threads at unpredictable times

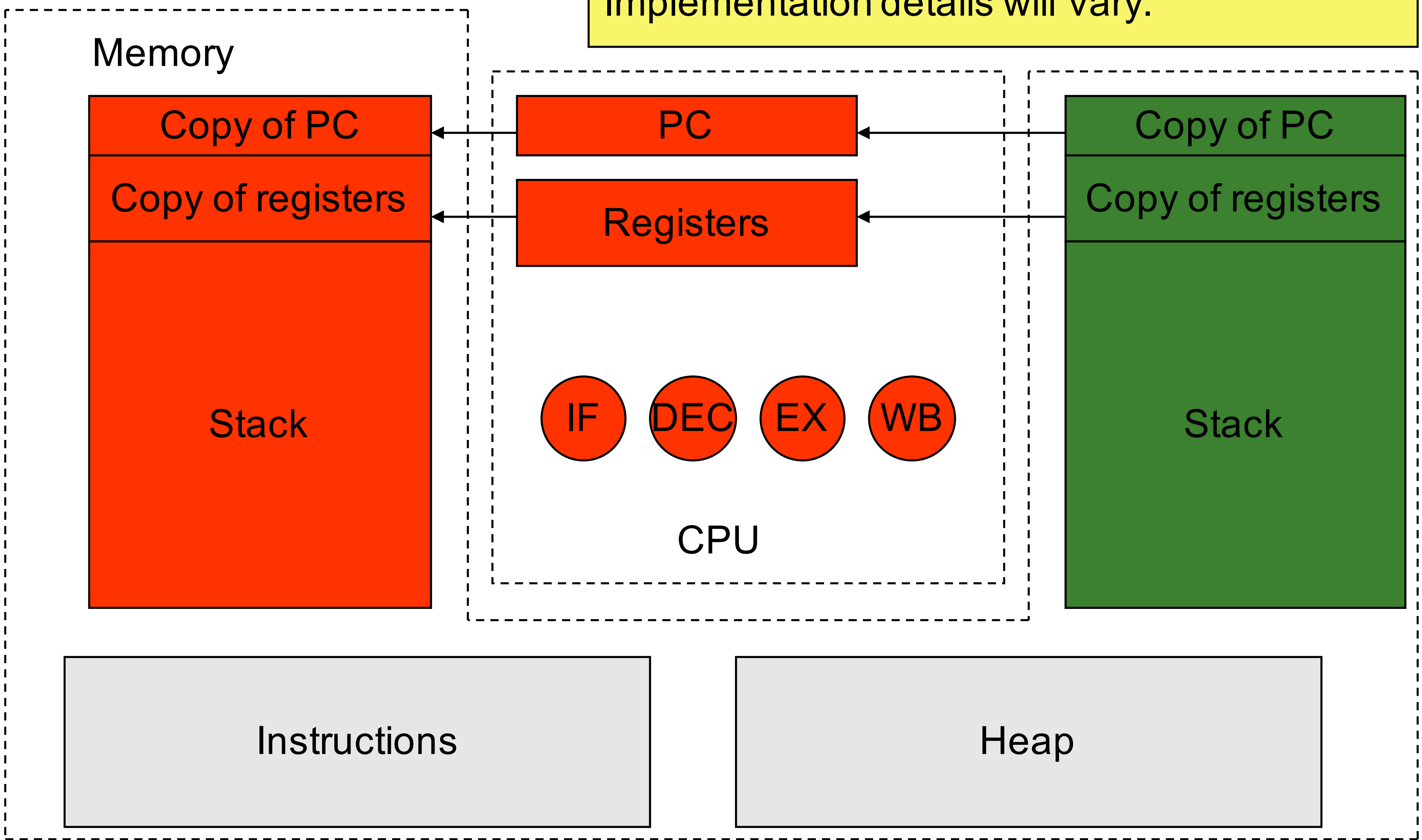


- Multiple processor
  - Thread may occasionally migrate



Context switch

Previously saved PC and register values are fetched.
Implementation details will vary.



Thread Objects in Java

- In Java, threads are represented by objects of class java.lang.Thread.
- The *run* method contains the actual code for the thread to execute.

```
public class ThreadExample extends Thread {
    private String message;

    ThreadExample( String message ) {
        this.message = getName() + ": " + message;
    }

    @Override public void run() {
        for( int i=0 ; i<20 ; ++i )
            System.out.println( message );
    }
}
```

Starting a new thread

- Calling t.*start*() starts a new thread
  - which executes the t.*run*()

```
public class ThreadExampleMain {
      public static void main(String[] args) {
          ThreadExample thread0 = new ThreadExample("Hi");
          ThreadExample thread1 = new ThreadExample("Ho");

          thread0.start();
          thread1.start();
          System.out.println(
                 Thread.currentThread().getName() +
                 ": Main is done");
      }
   }
```

Output for example

- Possible output for example:

  Thread-1: Ho

  Thread-1: Ho

  Thread-0: Hi

  main: Main is done

  Thread-1: Ho

  Thread-0: Hi

  … (and so on for another 35 lines)

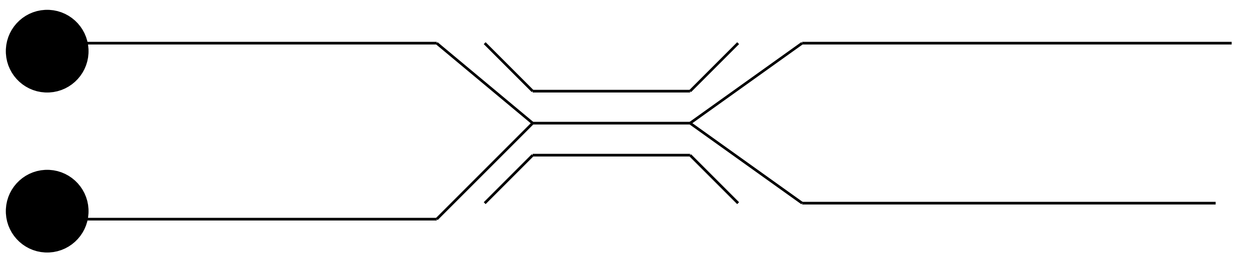
  - When t.*run*() completes the thread stops.
  - When all threads have stopped the program exits

Race Conditions

- A system has a <u>race condition</u> when its correctness depends the order of certain events, but the order of those events is not sufficiently controlled by the design of the system.

Race Conditions

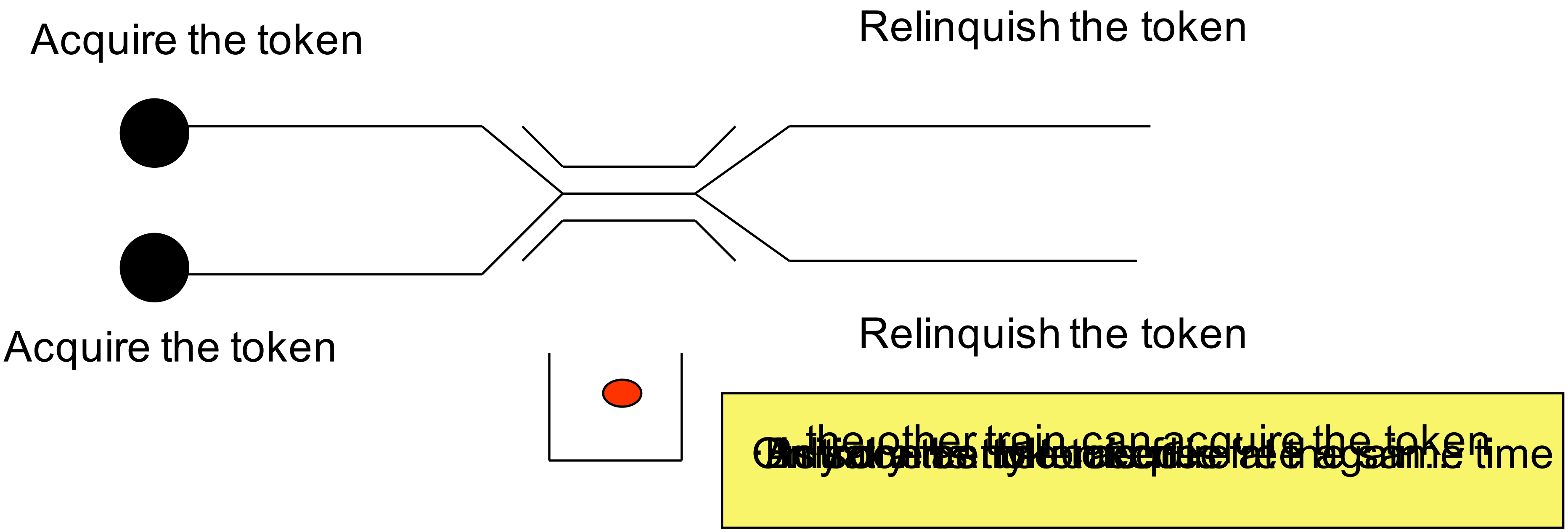
- Often race conditions occur because 2 agents have uncontrolled access to a shared resource
- Consider two train routes that share the same bridge



- Unless access to the shared resource is controlled, disaster may ensue.

Race Conditions

- A solution:
  - Before crossing the bridge, trains acquire a token
  - After crossing the bridge, trains relinquish the token



Race Conditions in Software

- Remember: objects are shared by threads
- In Java, access to an object's methods is uncontrolled, by default!!!!
- Suppose we have

```
public class Counter {
    private int count = 0;

    public void increment() {
        ++count;
        System.out.println(count);
    }
}
```

Race Conditions in Software

- Different threads can share the same Counter

```
public class CounterThread extends Thread {
    private Counter counter;

    CounterThread(Counter c) {
        this.counter = c;
    }

    @Override public void run() {
        for( int i=0 ; i<10 ; ++i ) {
            counter.increment();
        }
    }
}
```

Race Conditions in Software

- Execute the following:

```
public class CounterMain {
    public static void main(String[] args) {
        Counter c = new Counter();

        // Threads p and q share the same counter
        CounterThread p = new CounterThread(c);
        CounterThread q = new CounterThread(c);

        p.start();
        q.start();
    }
}
```

Race Conditions in Software

Possible Result:
1
2
3
4
5
6
7
8
9
10
12
13
14
15
16
17
18
19
20
11

WTF?

```
public class CounterMain {
    public static void main(String[] args) {
        Counter c = new Counter();
        CounterThread p = new CounterThread(c);
        CounterThread q = new CounterThread(c);

        p.start();
        q.start();
    }
}
```

Race Conditions in Software

- The reason is that the increment operation results in multiple bytecode (low-level JVM) instructions that can get interleaved
- Focus only on ++count

```
public class Counter {
    private int count = 0;

    public void increment() {
        ++count;
        System.out.println(count);
    }
}
```

Race Conditions in Software

- The statement ++count results in the following bytecode

```
load count to r0
r0 ← r0 + 1
store r0 to count
```

- r0 represents register 0

Race Conditions in Software

- Two threads invoke increment at about the same time
  - (Recall: Registers are local to the thread.)
- A “race condition” results.

p	q	count	r0 (in p)	r0 (in q)
load count to r0		41	41	
	load count to r0			41
	r0 $\leftarrow$ r0 + 1			42
	store r0 to count	42		
r0 $\leftarrow$ r0 + 1			42	
store r0 to count		42		

41+1+1 = 42? Of the two increments, one was lost.

Race Conditions: Another Example

- Consider transfers on an account

```
class AccountManager {
    private Account savings ;
    private Account chequing;

    public void transferToSavings( int amount ) {
            int s = savings.getBalance() ;
            int c = checking.getBalance() ;
            savings.setBal( s+amount ) ;
            chequing.setBal( c-amount ) ; } … }
```

- Two threads execute transfers.

Race Conditions : Another Example

One Thread (amount = 500)	Another Thread (amount = 1000)	sav	chq
	s = savings.getBalance()	3000	3000
	c = chequing.getBalance()		
s = savings.getBalance()			
	4000 savings.setBal(s+1000)		
	2000 chequing.setBal(c-1000)		2000
c = chequing.getBalance()			
3500 savings.setBal(s+500)			
1500 chequing.setBal(c-500)			

I started with $6000 and ended with $5000. This is not good.

synchronized to the rescue

- **Methods may be declared synchronized**

```
public class Counter {
    private int count = 0;

    public synchronized void increment() {
        ++count;
        System.out.println(count);
    }
}
```

synchronized to the rescue

- Each object has an associated *token* called its lock.
- At each point in time, each lock either is owned by no thread or is owned by one thread.
- A thread that attempts to acquire a lock must wait until no thread owns the lock.
- After acquiring a lock, a thread owns it until it relinquishes it.

synchronized to the rescue

- When a thread invokes a **synchronized** method x.m():
  - If it does not already <u>own</u> the recipient’s (x’s) lock,
    - It waits until it can <u>acquire</u> the lock
  - Once the lock has been acquired the thread begins to execute the method
- When a thread leaves an invocation of a **synchronized** method:
  - If it is leaving the last synchonronized invocation for that object
    - It relinquishes the lock as it leaves

synchronized to the rescue

- Hence, for any object x, at most one thread may be executing any of x's synchronized methods.

synchronized to the rescue

Example: Two threads invoke c.increment() at about the same time.

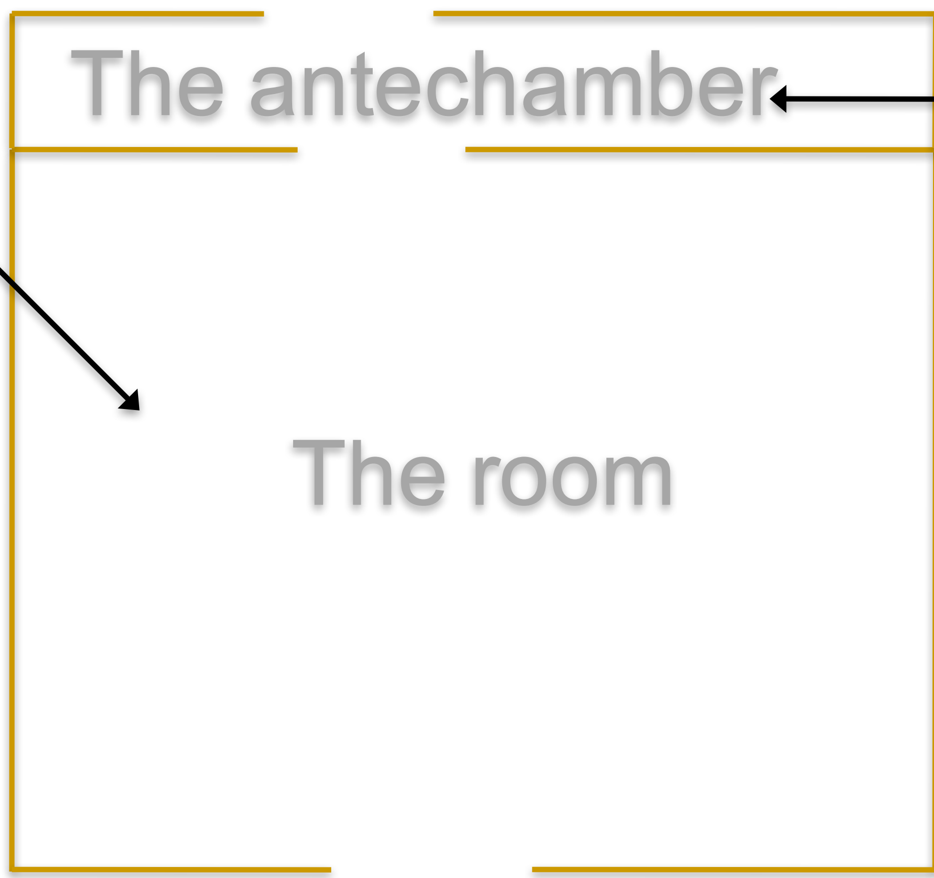
synchronized to the rescue

Thread p	**Thread q**
request lock on object c	
acquire lock on object c	
load count to r0	
	request lock on object o
	waits
r0 ← r0 + 1	*waits*
store r0 to count	*waits*
relinquish lock on object o	*waits*
	acquire lock on object o
	load count to r0
	r0 ← r0 + 1
	store r0 to count
	relinquish lock on object o

The “Room metaphor”

When a thread has left all **synchronized** methods of the object, it leaves the room …

… allowing another thread to enter.



When a thread not in the room calls a **synchronized** method, it enters an antechamber.

There it waits until the room is empty.

When the room is empty, at most one thread is allowed to enter the room

Design rule: Shared Objects

- For any object that might be used by more than one thread at the same time
  - Declare all methods that access or mutate the data **synchronized**
    - (Note: private methods are exempted from this rule, as they can only be called once a nonprivate method has been called.)

Constructors need not (and can not) be **synchronized**

Accounts

- In AccountManager add synchronized to all methods

```
class AccountManager {
    private Account savings ;
    private Account chequing;

    public synchronized void transferToSavings(
                                                  int amount ) {
        int s = savings.getBalance() ;
        int c = checking.getBalance() ;
        savings.setBal( s+amount ) ;
        chequing.setBal( c-amount ) ; } … }
```