50.003: Elements of Software Construction

Week 5

Basics of Concurrency: Requirements

Example

NSA intercepted a RSA-encrypted secrete message which tells the location of a terrorist act, we believe that the act is going to happen one week from now, we need your help in decrypting the message.

Requirement/Analysis

"Given a semi-prime, your program outputs its prime factors within 6 days."

green: pre-condition

red: post-condition

purple: non-functional requirement

Total Correctness: If the precondition is satisfied, it is guaranteed that the method terminates and satisfies the postcondition.

Testing

Correctness Testing

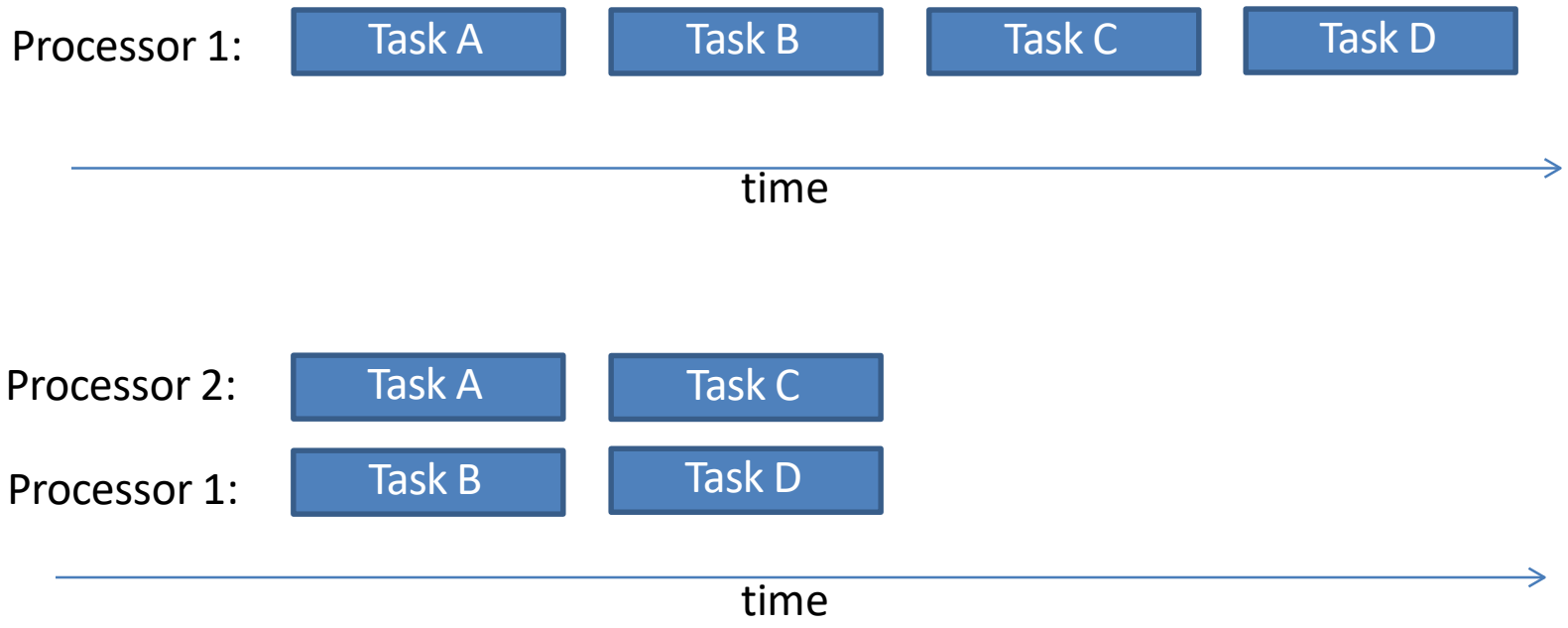
- 4294967297 (famous Fermat Number)
- 1127451830576035879
- 160731047637009729259688920385507056726966793490579598495689711866432421212774967029895340327197901
  756096014299132623454583177072050452755510701340673282385647899694083881316194642417451570483466327
  782135730575564856185546487053034404560063433614723836456790266457438831626375556854133866958349817
  172727462462516466898479574402841071703909138062456567624565784254101568378407242273207660892036869
  708190688033351601539401621576507964841597205952722487750670904522932328731530640706457382162644738
  538813247139315456213401586618820517823576427094125197001270350087878270889717445401145792231674098
  948416888868250143592026973853973785120217077951766546939577520897245392186547279572494177680291506
  578508962707934879124914880885500726439625033021936728949277390185399024276547035995915648938170415
  663757378637207011391538009596833354107737156273037494727858302028663366296943925008647348769272035
  532265048049709827275179381252898675965528510619258376779171030556482884535728812916216625430187039
  533668677528079544176897647303445153643525354817413650848544778690688201005274443717680593899

Performance Testing

FactorPrimeTest.java

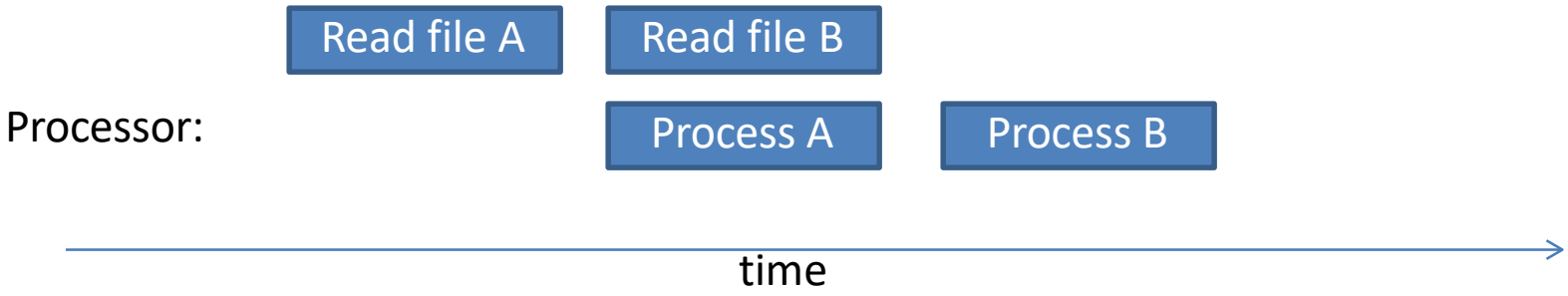
Concurrency: Benefit

Better resource utilization: with K processors, ideally we can be K times faster*



Concurrency: Benefit

Can we get better performance with 1 processor only?



Which thread moves first is non-deterministic

Runnable interface

- “implements Runnable” vs. “extends Thread”
  - Use Runnable that you can inherit other classes
  - Runnable allows better separation of the actual computation and thread control.

RunnableExample.java

How to Stop a Thread

Given FactorPrime.java, write a program so that multi-threads factor the number at the same time. Print the factor as soon as it is found.

How do we stop a thread as soon as a factor has been found?

How to Stop a Thread

- No
  - destroy()
  - or stop()
  - or stop(Throwable obj)
  - or suspend()
- Yes
  - Interrupt()

interrupt()

- Example 1: interrupt() results in Exception
- Example 2: handle interrupt() explicitly in run() by checking Thread.interrupted()

InterruptExample1.java and InterruptExample2.java

It’s Not That Simple

- Multi-threaded programs could have race conditions, visibility issues, deadlocks, etc.

Problem 1: Race Condition

Example

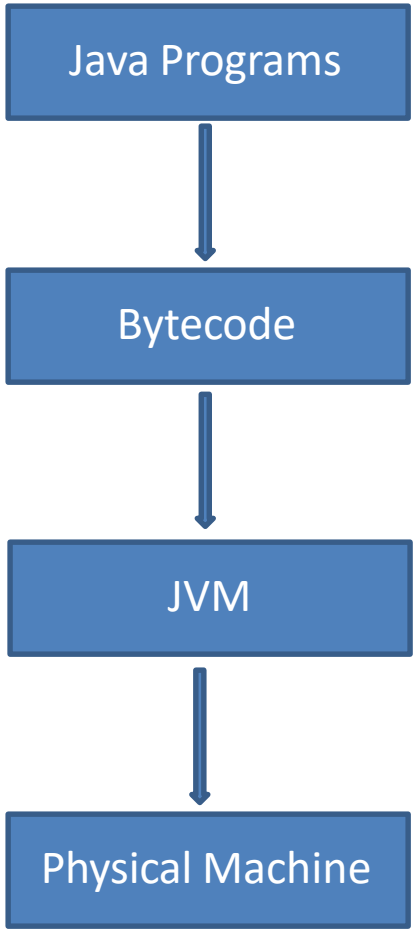
Program FirstError.java has 10000 threads which concurrently increment a static variable (initially 0) by 1.

What is the Problem?

- A sequential program consisted of a sequence of instructions (and a memory), where each instruction executed one after the other (to modify the memory, etc.).
- The sequential paradigm has the following two characteristics: the textual order of statements specifies their order of execution; successive statements must be executed without any overlap (in time) with one another.

Both are not true in concurrent programs.

Reality is Messy

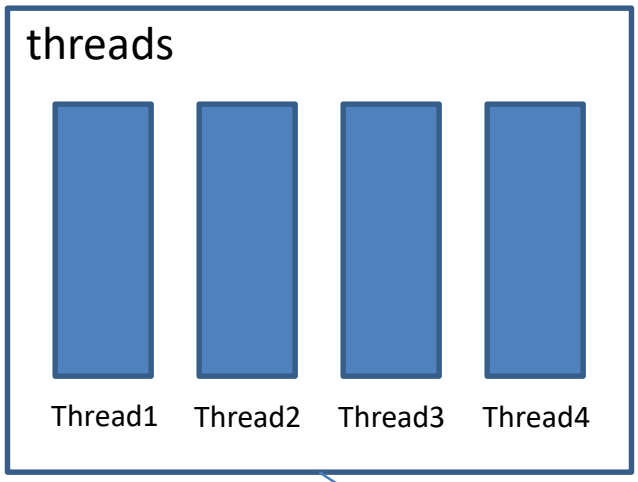


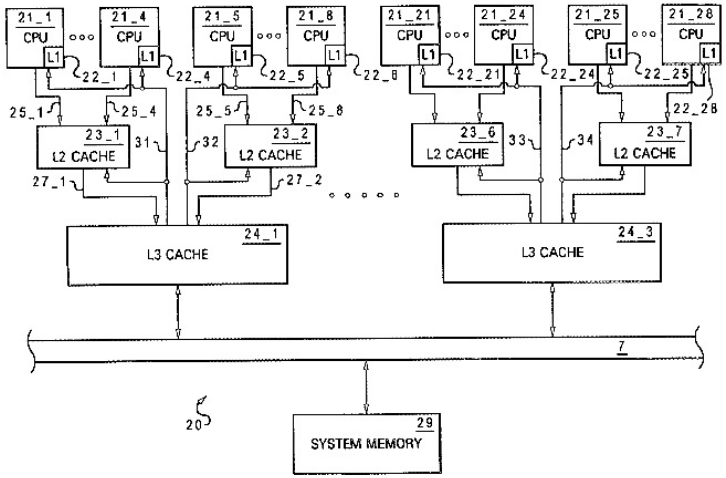
What are the atomic steps?

What are the order of execution?

What and where are the variable values?

Scheduling

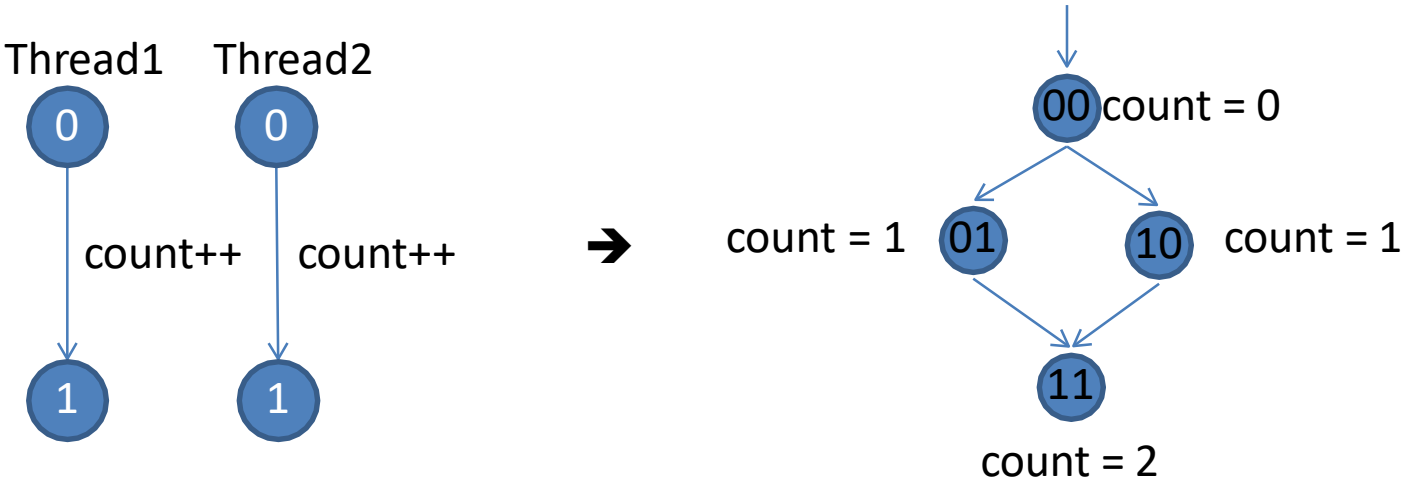




Scheduler

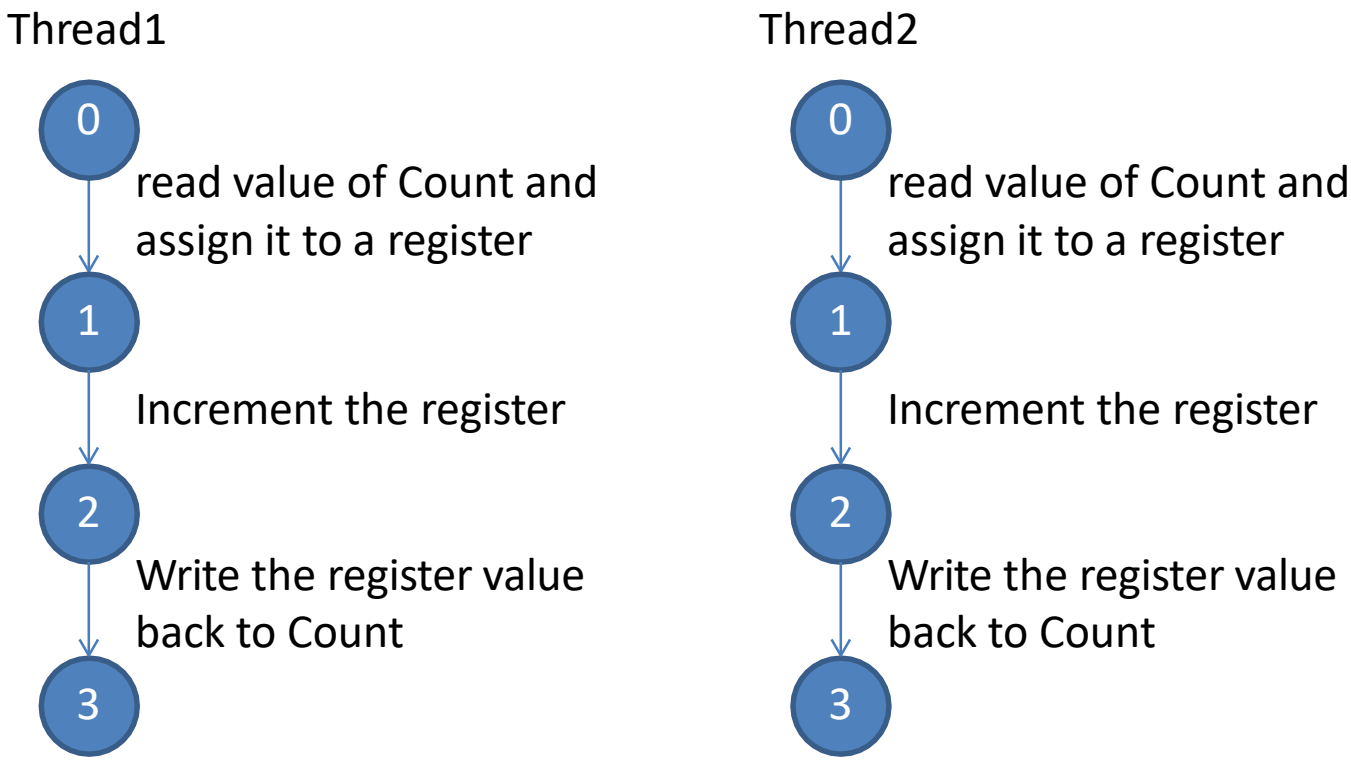
The scheduler is ‘un-predictable’

Is This Real?



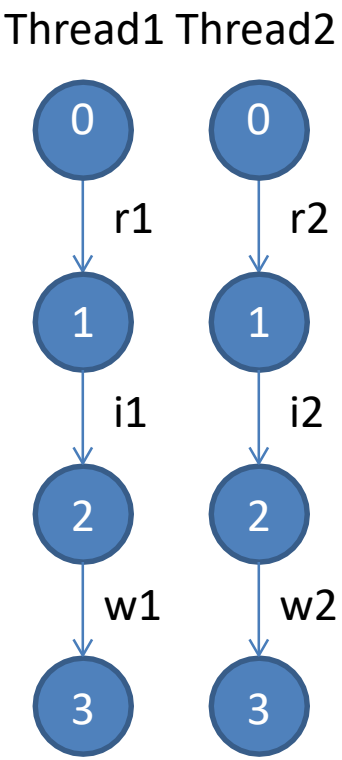
This is assuming that count++ is one step. Or is it?

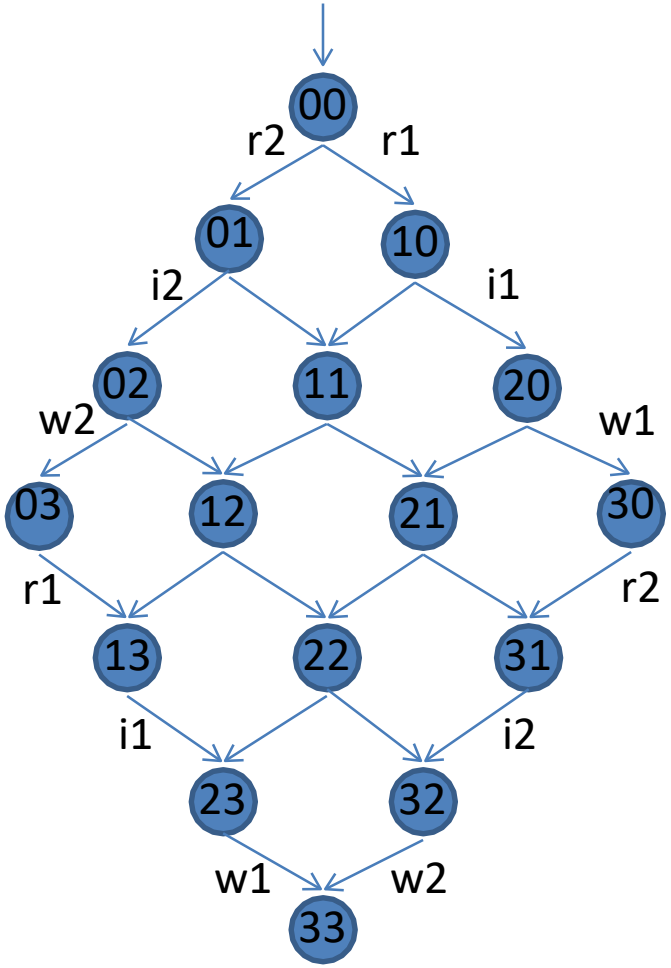
What Really Happened?



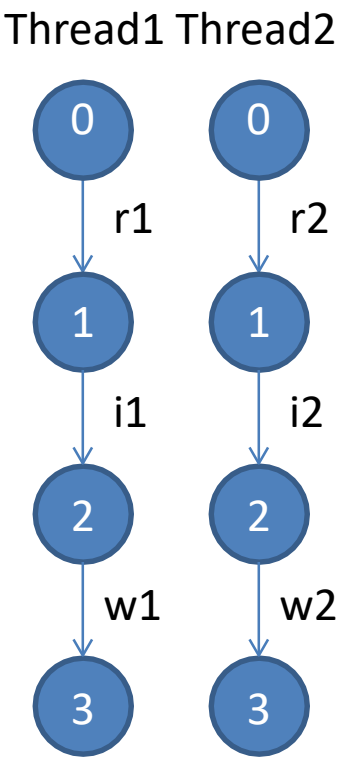
For double type, even read/write is not atomic!

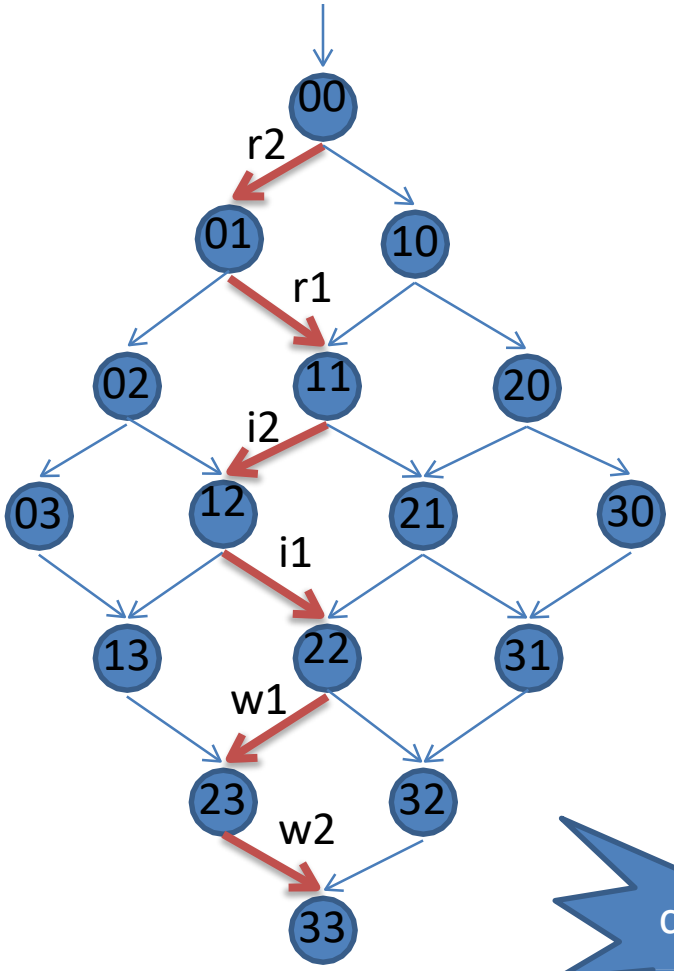
What Really Happened?





What Really Happened?





count=1

Is this correct?

AtomicXXX

If the shared variable is of a type Boolean, int, int array, and etc., use classes in package java.util.concurrent.atomic

Example:

AtomicInteger x = new AtomicInteger(0)

x.incrementAndGet() //increments x by 1 atomically

Example: FirstErrorFixed.java

Compound Actions

Sometime it is not sufficient to simply use an AtomicXXX object.

```
//withdraw from a bank account
//check and update
if (amount >= 1000) {
        amount = amount - 1000;
}
```

Refer to example: SecondError.java

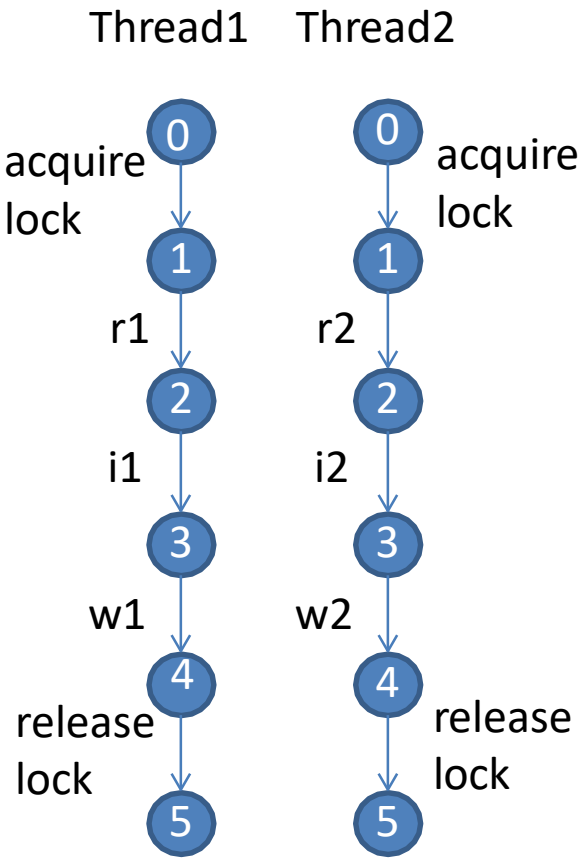
Intrinsic Locks

- Every Java object can implicitly act as a lock for purposes of synchronization.

```
synchronized (lock) {
        //Access shared state guarded by lock
}
```

- Intrinsic locks acts as mutexes (mutual exclusion locks), i.e., at most one thread may own the lock.
- Since only one thread at a time can execute a block of code guarded by a given lock, the synchronized blocks guarded by the same lock execute atomically with respect to one another.

How Lock Works



SecondErrorFixed.java

Cohort Exercise 3

Assuming that we would like to maintain that "saving + cash = 5000" always, fix the following class: LockStaticVariables.java.

Hint: Think about what is the lock?

if synchronise (this)
it will not work for the amount thing
cause there will be different locks, you are only
sync-ing your thread with ur thread.

wait() and notify()

- Busy waiting is not efficient
  - Consider a voting system with two threads. One collects votes and the other is waiting to count the votes when the voting is completed.

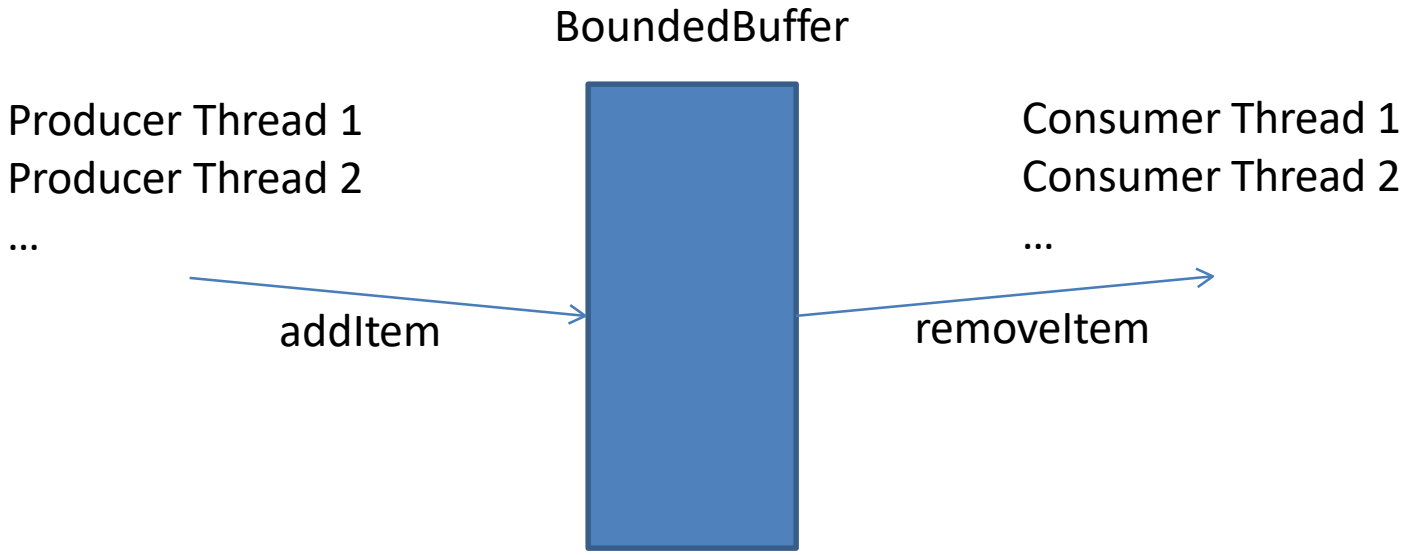
```
while (true) {
        synchronized(this) {
                if (votingComplete) {
                        break;
                }
        }
}
```

- Use wait()/nofityAll() to avoid busy waiting

Voting.java

Cohort Exercise 4

- Producer/Consumer Pattern

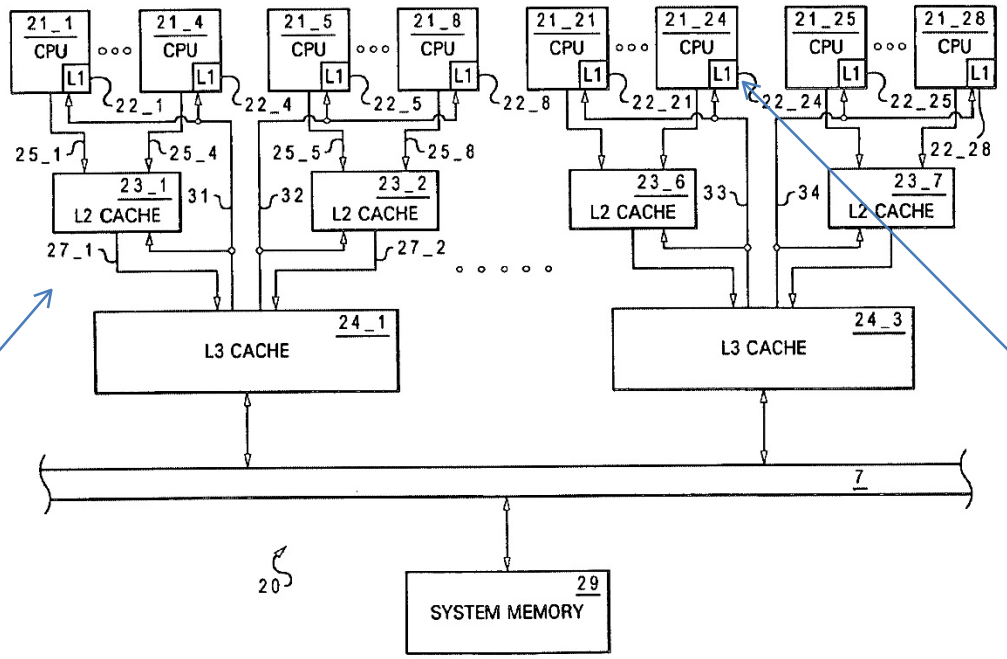


- Exercise: fixed the Buffer class in BufferExample.java so that it is thread-safe and efficient

```
public class BufferFixed {
        public int SIZE;
        private Object[] objects;
        private int count = 0;

        public BufferFixed (int size) {
                SIZE = size;
                objects = new Object[SIZE];
        }

        public synchronized void addItem
(Object object) throws Exception {
                while (count == SIZE-1) {
                        wait();
                }

                objects[count] = object;
                count++;
                notifyAll();
        }
```

```
public synchronized Object removeItem() throws
Exception {
        while (count == 0) {
                wait();
        }

        count--;
        Object object = objects[count];
        notifyAll();
        return object;
        }
```

Problem 2: Visibility



new found

old found

How could we know where?

Example: FactorThread.java

Problem 3: Execution Ordering

Thread 1	Thread 2
1: r2 = A;	3: r1 = B;
2: B = 1;	4: A = 2;

- Initially A, B, r1 and r2 are all 0.
- What are the values of the variables after both threads complete?
- Is it possible to have B = 1 and r2 = 2 and A = 2 and r1 = 1?

What are the order of execution?

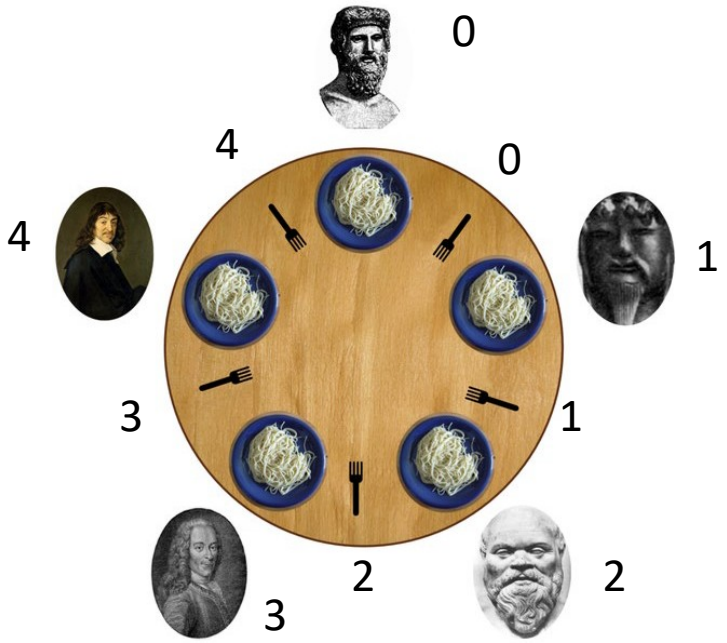
- Java compiler might switch the order of sequential statements (e.g., for efficiency)
- Example: line 2 and line 3 might be switched

```
1.  x++;
2.  y++;
3.  x++;
```

// if x++ x++ together, then save number of executions.

How could we know the order of execution?
Self-read: Java Memory Model

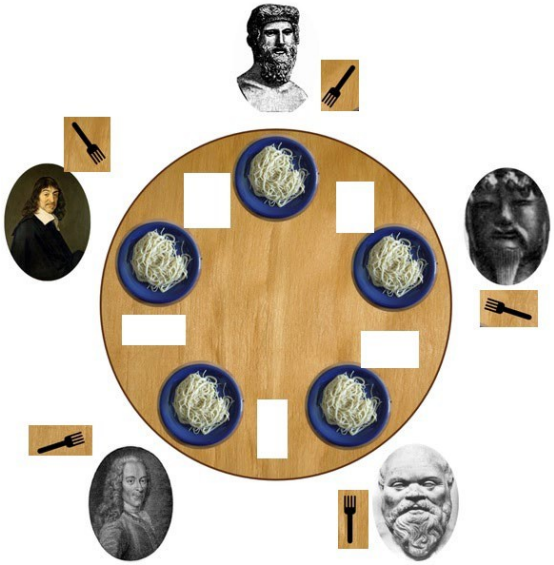
Problem 4: Deadlock



- Each philosopher needs two forks to eat.
- Each philosopher picks the one on the left first.

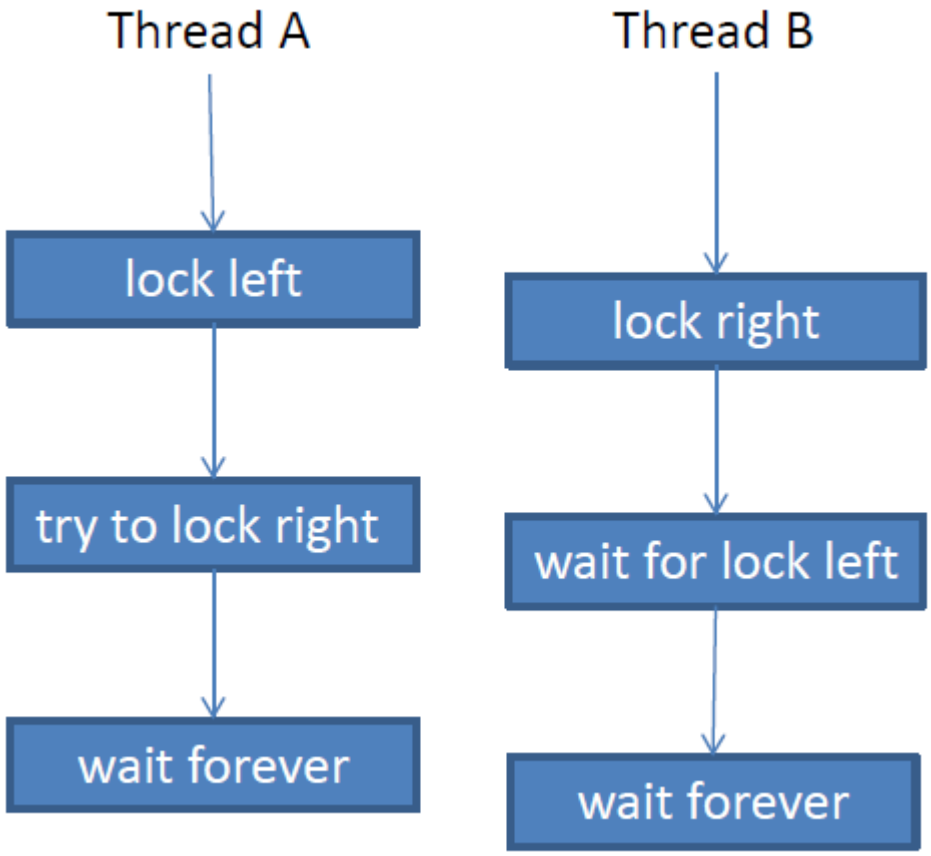
Deadlock

- Deadlock is the situation when two or more threads are both waiting for the others to complete, forever.



Lock-Ordering Deadlock

```
public class LeftRightDeadlock {
        private final Object left = new Object ();
        private final Object right = new Object ();

        public void leftRight () {
                synchronized (left) {
                        synchronized (right) {
                                doSomething();
                        }
                }
        }

        public void rightLeft () {
                synchronized (right) {
                        synchronized (left) {
                                doSomethingElse();
                        }
                }
        }
}
```



Example

```
public void transferMoney (Account from, Account to, int amount) {
    synchronized (from) {
        synchronized (to) {
            if (from.getBalance() < amount) {
                //raiseException
            }
            else {
                from.debit(amount);
                to.credit(amount)
            }
        }
    }
}
```

deadlock when you try to transfer from A to B and B to A.

A->B
lock A
wait for B

B->A
lock B
wait for A

Is it deadlocking?

Example

```
public void transferMoney (Account from, Account to, int amount) {
    synchronized (from) {
        synchronized (to) {
            if (from.getBalance() < amount) {
                //raiseException
            }
            else {
                from.debit(amount);
                to.credit(amount)
            }
        }
    }
}
```

How can transferMoney deadlock?

Thread A: transferMoney(myAccount, yourAccount, 1)

Thread B: transferMoney(yourAccount, myAccount, 1)

Check out: DemonstrateDeadlock.java

Cohort Exercise 6

- Given DLExample.java, explain whether it is possibly deadlocking.
- Write a test case which potentially demos the deadlock.

to explain deadlock, need 2 threads and 2 locks
each thread, which is calling which methods, lock they hold

if only 1 lock, worst case is you having to wait till the other thread is done.

Other Liveness Hazards

- Deadlock is the most widely encountered liveness hazard.
- Starvation occurs when a thread is denied access to resources it needs in order to make progress.
  - Often caused by use of thread priority or executing infinite loops with a lock held.

Avoid using thread priority, since they increase platform dependence and can cause liveness problems.

Other Liveness Hazards (cont'd)

- Poor responsiveness
  - may be caused by poor lock management.
- Livelock: a thread, while not blocked, still cannot make progress because it keeps retrying an operation that will always fail.
  - e.g., when two overly polite people are walking in the opposite direction in a hallway.

Requirements

Multi-threaded programs have at least the following additional requirements.

- No race condition
- No visibility issue
- No execution ordering problem
- No deadlocks
- Efficiency!

How do we make sure our multi-threaded program satisfies these requirements?