Object Oriented Programming and Design in Java

Session 17

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Announcements

- Homework 3 due now.
- Homework 4 released today.
  Due Mon. Apr. 19
- Final Exam Monday May 10 at 9 AM

Review

- Horstmann's graph editor framework
- Prototype pattern
- Simple Graph Editor:
  - extended Graph, AbstractEdge
  - implemented Node

Today's Plan

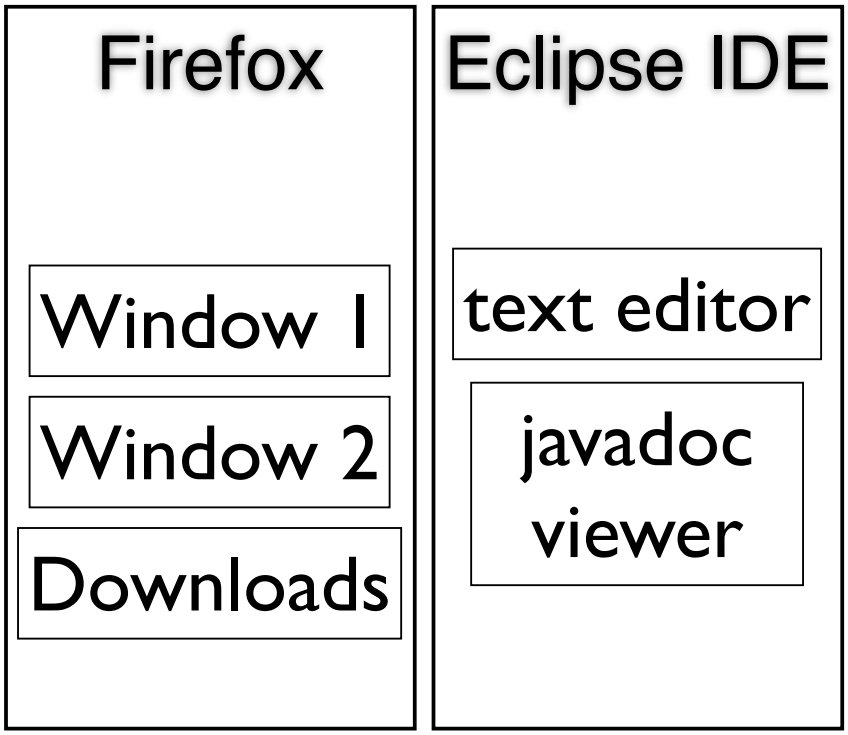
- Multithreading and Concurrency
  - Multithreading in Java
- Handling race conditions
  - Handling race conditions in Java

Multithreading

- Modern computer programs perform various calculations simultaneously
- Each parallel program unit is called a *thread*
- In most cases, threads are not actually run in parallel, but by taking turns
- But the OS is responsible for the turn-taking; we don’t know its policy

Processes vs. Threads

- Modern OS distinguish processes from threads
- Threads share memory
- Processes don't share memory



Threads in Java

- `java.lang.Thread`
- Construct with `Thread(Runnable target)`
  - interface `Runnable` has a single method: `void run()`
- Thread: `start()`, `sleep(long millis)`, `interrupt()`, `yield()`, `join()`

GreetingProducer

```
public class GreetingProducer implements Runnable
{
   public GreetingProducer(String aGreeting) {
      greeting = aGreeting;
   }

   public void run() {
      try  {
         for (int i = 1; i <= REPETITIONS; i++) {
            System.out.println(i + ": " + greeting);
            Thread.sleep(DELAY);
         }
      } catch (InterruptedException exception) { }
   }

   private String greeting;
   private static final int REPETITIONS = 10;
   private static final int DELAY = 100;
}
```

ThreadTester

```
/**
   This program runs two threads in parallel.
*/
public class ThreadTester {
   public static void main(String[] args) {
      Runnable r1 = new
        GreetingProducer("Hello, World!");
      Runnable r2 = new
        GreetingProducer("Goodbye, World!");

      Thread t1 = new Thread(r1);
      Thread t2 = new Thread(r2);

      t1.start();
      t2.start();
   }
}
```

```
1: Hello, World!
1: Goodbye, World!
2: Hello, World!
2: Goodbye, World!
3: Hello, World!
3: Goodbye, World!
4: Hello, World!
4: Goodbye, World!
5: Hello, World!
5: Goodbye, World!
6: Hello, World!
6: Goodbye, World!
7: Hello, World!
7: Goodbye, World!
8: Hello, World!
8: Goodbye, World!
9: Hello, World!
9: Goodbye, World!
10: Hello, World!
10: Goodbye, World
```

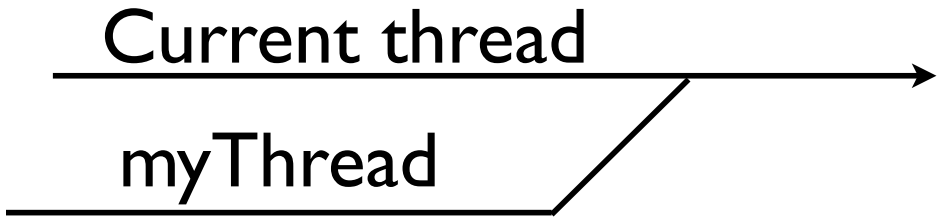
Interrupting Threads

- If you need to terminate a thread, call Thread.interrupt()
- Causes Thread.sleep() to throw InterruptedException
- Your run method should be structured to handle interrupts cleanly

```
public void run() {
   try {
      while(more_work_to_do) {
         // do work
         Thread.sleep(DELAY);
      }
   }
   catch(InterruptedException e)
   {
   }
   // clean up
}
```

Joining Threads

- myThread.join() joins Thread myThread with the current thread
  - i.e., waits for myThread to finish its run() method

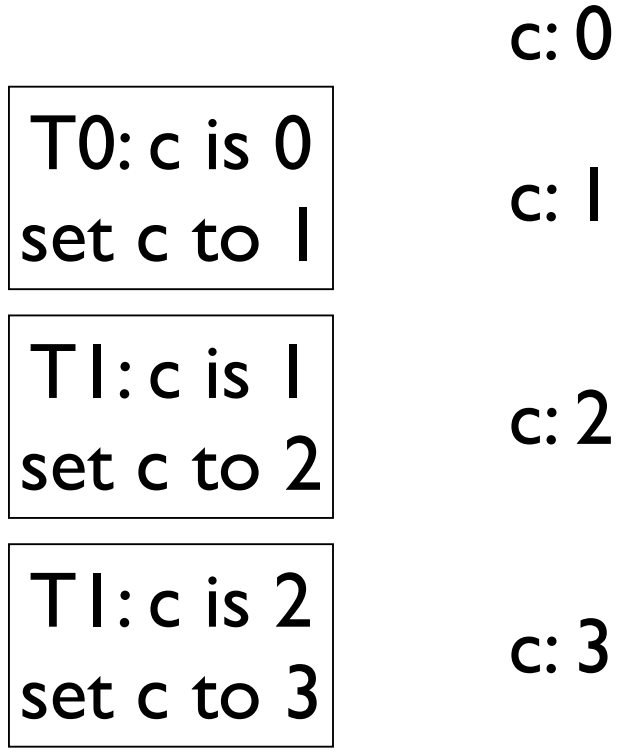


Race Conditions

- Multiple threads can modify the same memory
- Race condition: when poor timing causes threads to modify memory with unexpected results
  - Usually involving multiple threads “racing” to modify the memory first

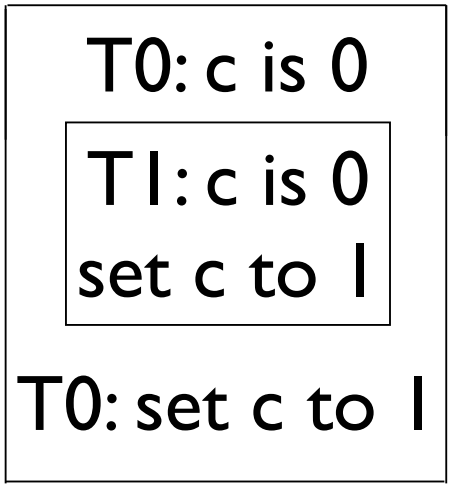
Incrementing a Counter

- Thread 0: c = c + 1;
- Thread 1: c = c + 1;
  - The operation reads current value of c
  - Sets c to that value + 1



Incrementing a Counter

- Both threads can read at the same time, and set c to c + 1
- Result should be c + 2, but instead is c + 1



c: 0

c: 1

c: 1

Locks

- We can use *locks* to fix race conditions
- Threads temporarily acquire ownership of locks
- Only one thread can own a lock at a time
- If a thread tries to acquire a lock but it is owned by another, it waits
- When a lock owner releases the lock, all waiting threads are notified

Lock Interface

- `java.util.concurrent.locks` package includes the `Lock` interface
- Objects that implement `Lock` have
  - `lock() // prevent other threads from`
    `// locking this object`
  - `unlock() // allow other threads to lock this`

```java
import java.util.ArrayList;

/**
 * Running multiple threads of this on the same list will cause
 * race conditions
 */
public class UnsafeAdder implements Runnable {
   public UnsafeAdder(ArrayList<Integer> a) {
      list = a;
   }

   public void run() {
      try {
         for (int i = 0; i < 10; i++) {
            list.add(i);
            Thread.sleep(10);
         }
      } catch (InterruptedException e) {}
   }

   private ArrayList<Integer> list;
}
```

```
public class SafeAdder implements Runnable {
   public SafeAdder(ArrayList<Integer> a, Lock myLock) {
      list = a;
      lock = myLock;
   }

   public void run() {
      try {
         for (int i = 0; i < 10; i++) {
            lock.lock();
            try {
               list.add(i);
            } finally {
               lock.unlock();  // Guaranteed to unlock even if
            }                  // list.add(i) throws an exception
            Thread.sleep(10);
         }
      } catch (InterruptedException e) {}
   }

   private Lock lock;
   private ArrayList<Integer> list;
}
```

```
public class LockTest {
   public static void main(String [] args) {
      ArrayList<Integer> a = new ArrayList<Integer>();
      Thread t1 = new Thread(new UnsafeAdder(a));
      Thread t2 = new Thread(new UnsafeAdder(a));
      t1.start(); t2.start();
      try {
         t1.join(); t2.join();
      } catch (InterruptedException e) {}
      System.out.println("No lock: " + a);

      Lock lock = new ReentrantLock();
      ArrayList<Integer> b = new ArrayList<Integer>();
      Thread t3 = new Thread(new SafeAdder(b, lock));
      Thread t4 = new Thread(new SafeAdder(b, lock));
      t3.start(); t4.start();
      try {
         t3.join(); t4.join();
      } catch (InterruptedException e) {}
      System.out.println("With lock: " + b);
   }
```

```
No lock: [0, 0, 1, 2, 3, 4, 5, 6, 7, 8, null, 9]
With lock: [0, 0, 1, 1, 2, 2, 3, 3, 4, 4, 5, 5, 6, 6, 7, 7, 8, 8, 9, 9]
```

Producer/Consumer

- Common pattern in threaded programs
- Some threads produce resources, other consume resources
  - e.g., producers add elements to a set while consumers remove elements
- Consumers must wait until set is nonempty
  - Locks are not enough to make this work

Consumer Attempt 1

- while set is empty
    Thread.sleep(DELAY)
  setLock.lock()
  consume(set.remove())
  setLock.unlock()

- JVM could switch to another thread after passing through while check
- Then when this thread resumes, set could be empty

Consumer Attempt 2

- setLock.lock()
  while (set is empty)
  Thread.sleep(DELAY)
  consume(set.remove())
  setLock.unlock()
- While this thread is waiting for the set to be non-empty, no one else can lock()

Condition Objects

- Each `Lock` can have any number of `Condition` objects
- `Condition setNonEmpty = setLock.newCondition()`
- ```
  setLock.lock()
  while(set.isEmpty())
      setNonEmpty.await() // releases the lock
  ```
- Whenever the condition could have changed, call `setNonEmpty.signalAll()`
  - Unblock all waiting threads, but a thread must reacquire the lock before returning from `await`
  ```

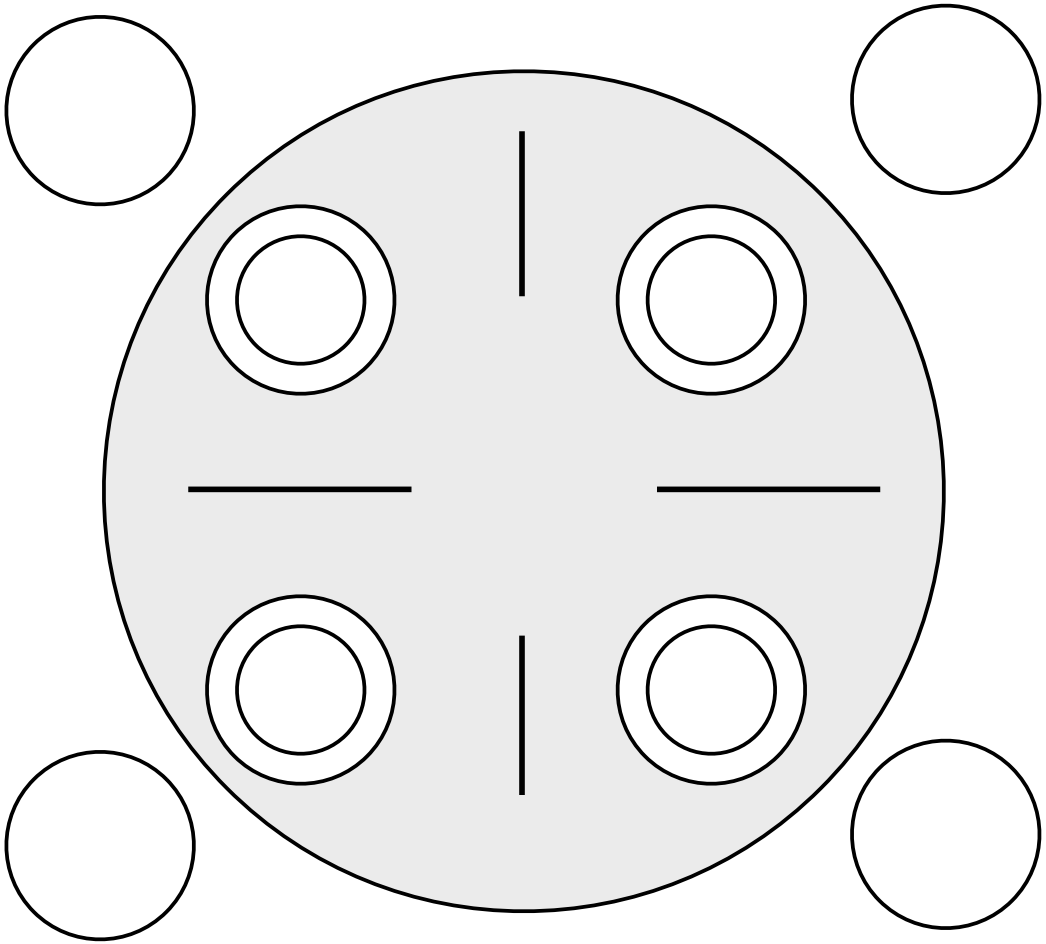
Object Locks

- Java Objects have built-in locks
- Any method tagged with keyword `synchronized` requires a lock
- When the method finishes, the lock is automatically released
- Object locks also allow the command `wait()`, used to wait for a condition
- After a condition changes, call `notifyAll()`

Object Locked ArrayList<E>

- ```
  public synchronized E remove()
  {
      while (size == 0) wait();
      ...
  }
  ```
- ```
  public synchronized void add(E obj)
  {
      ...
      notifyAll();
  }
  ```

Dining Philosophers



Threads

- Multithreading allows our programs to perform tasks in parallel
- But requires coordination of the threads' memory operations
- Coordinate threads using locks and conditions
  - `Lock` interface
  - Object locks (`synchronized` methods)

Reading

- Horstmann 9.1-9.2