Module 13

Threads

Objectives

- Define a thread
- Create separate threads in a Java technology program, controlling the code and data that are used by that thread
- Control the execution of a thread and write platform-independent code with threads
- Describe the difficulties that might arise when multiple threads share data
- Use `wait` and `notify` to communicate between threads
- Use `synchronized` to protect data from corruption

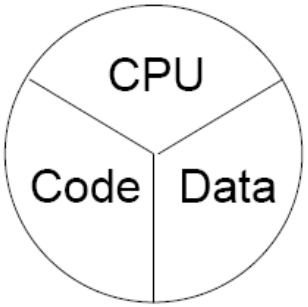
Relevance

How do you get programs to perform multiple tasks concurrently?

Threads

- What are threads?

  Threads are a virtual CPU.
- The three parts of at thread are:
  - CPU
  - Code
  - Data



A thread or
execution context

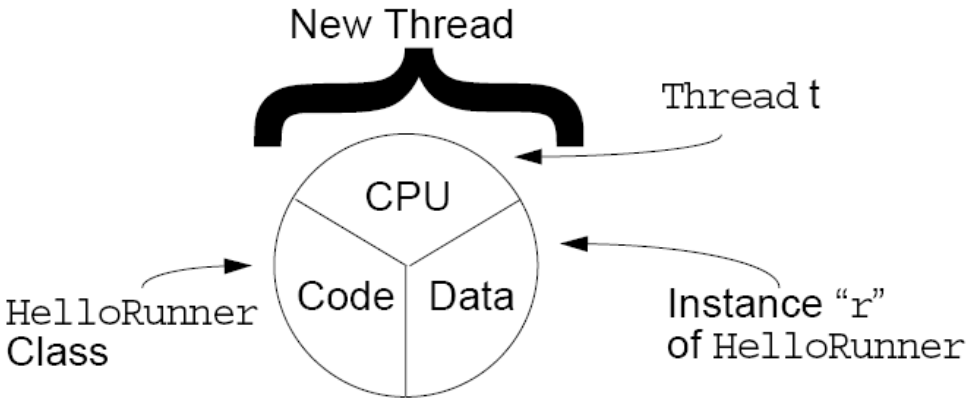
Creating the Thread

```
1   public class ThreadTester {
2     public static void main(String args[]) {
3       HelloRunner r = new HelloRunner();
4       Thread t = new Thread(r);
5       t.start();
6     }
7   }
8   class HelloRunner implements Runnable {
9     int i;
10    public void run() {
11      i = 0;
12      while (true) {
13        System.out.println("Hello " + i++);
14        if ( i == 50 ) {
15          break;
16        }
17      }
18    }
19  }
```

Creating the Thread

- Multithreaded programming has these characteristics:
  - Multiple threads are from one `Runnable` instance.
  - Threads share the same data and code.
- For example:

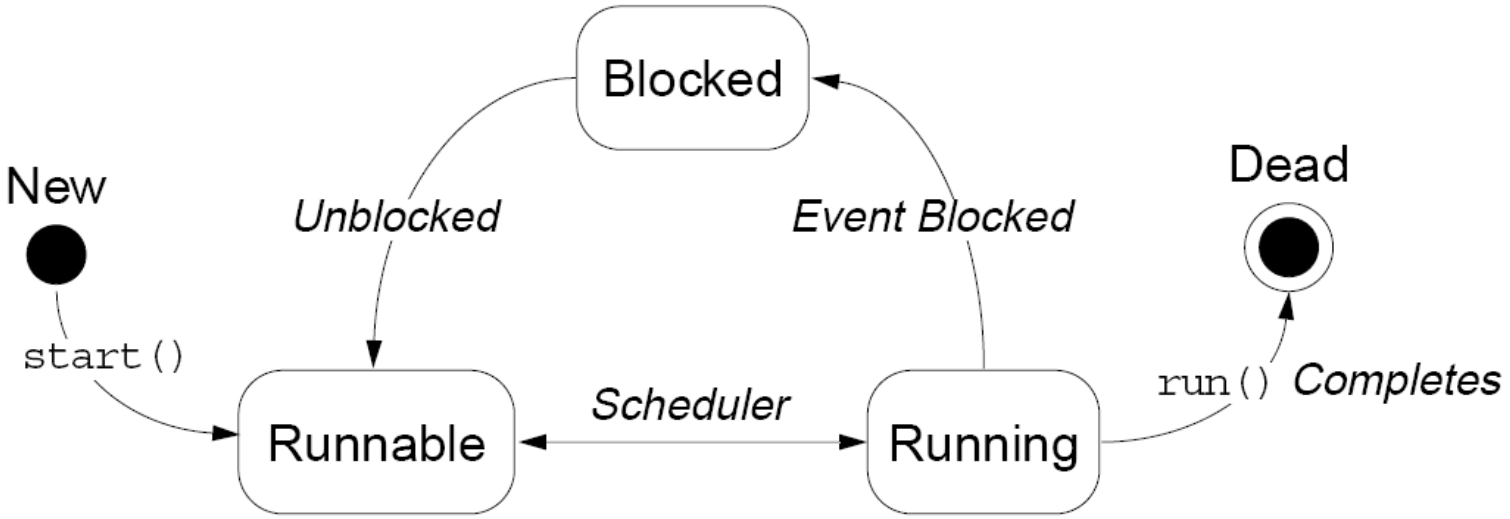
```
Thread t1 = new Thread(r);
Thread t2 = new Thread(r);
```



Starting the Thread

- Use the `start` method.
- Place the thread in a runnable state.

Thread Scheduling



Thread Scheduling Example

```
1   public class Runner implements Runnable {
2     public void run() {
3       while (true) {
4         // do lots of interesting stuff
5         // ...
6         // Give other threads a chance
7         try {
8           Thread.sleep(10);
9         } catch (InterruptedException e) {
10          // This thread's sleep was interrupted
11          // by another thread
12        }
13      }
14    }
15  }
```

Terminating a Thread

```
1   public class Runner implements Runnable {
2     private boolean timeToQuit=false;
3
4     public void run() {
5       while ( ! timeToQuit ) {
6         // continue doing work
7       }
8       // clean up before run() ends
9     }
10
11    public void stopRunning() {
12      timeToQuit=true;
13    }
14  }
```

Terminating a Thread

```
1   public class ThreadController {
2     private Runner r = new Runner();
3     private Thread t = new Thread(r);
4
5     public void startThread() {
6       t.start();
7     }
8
9     public void stopThread() {
10      // use specific instance of Runner
11      r.stopRunning();
12    }
13  }
```

Basic Control of Threads

- Test threads:

```
isAlive()
```

- Access thread priority:

```
getPriority()
setPriority()
```

- Put threads on hold:

```
Thread.sleep()  // static method
join()
Thread.yield()  // static method
```

The `join` Method

```
1   public static void main(String[] args) {
2     Thread t = new Thread(new Runner());
3     t.start();
4     ...
5     // Do stuff in parallel with the other thread for a while
6     ...
7     // Wait here for the other thread to finish
8     try {
9       t.join();
10    } catch (InterruptedException e) {
11      // the other thread came back early
12    }
13    ...
14    // Now continue in this thread
15    ...
16  }
```

Other Ways to Create Threads

```
1   public class MyThread extends Thread {
2     public void run() {
3       while ( true ) {
4         // do lots of interesting stuff
5         try {
6           Thread.sleep(100);
7         } catch (InterruptedException e) {
8           // sleep interrupted
9         }
10      }
11    }
12
13    public static void main(String args[]) {
14      Thread t = new MyThread();
15      t.start();
16    }
17  }
```

Selecting a Way to Create Threads

- Implement `Runnable`:
  - Better object-oriented design
  - Single inheritance
  - Consistency
- Extend `Thread`:

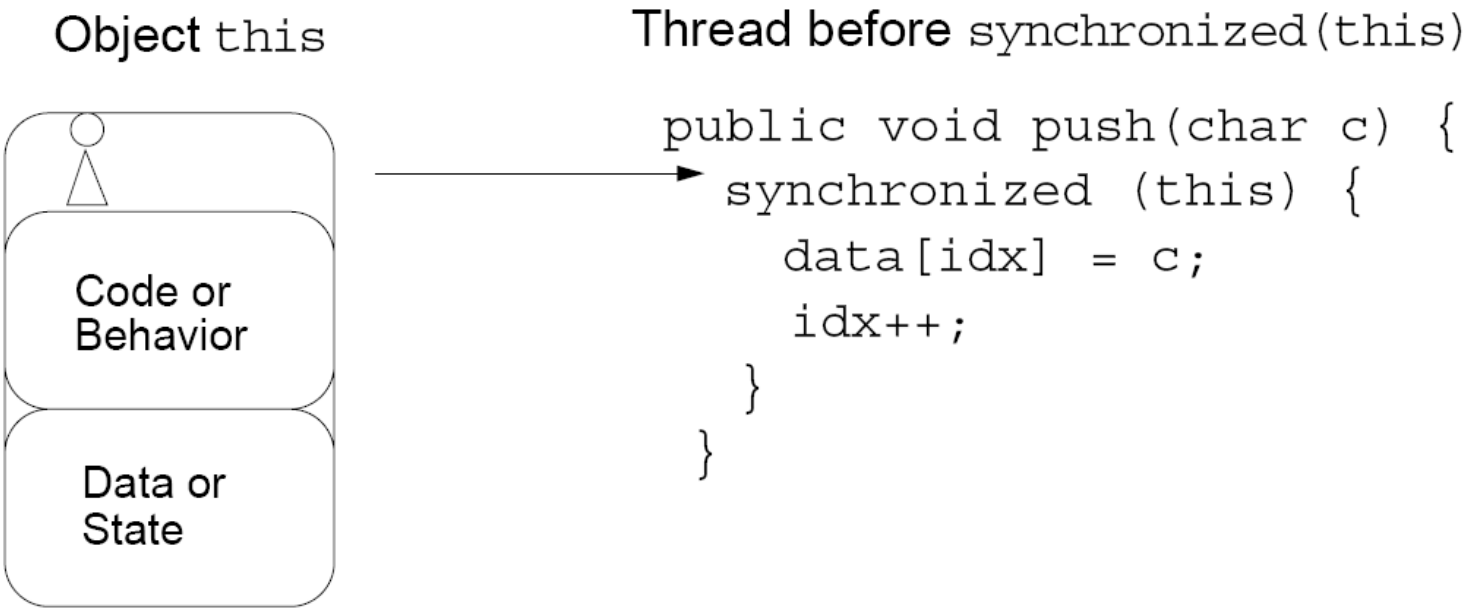
  Simpler code

Using the `synchronized` Keyword

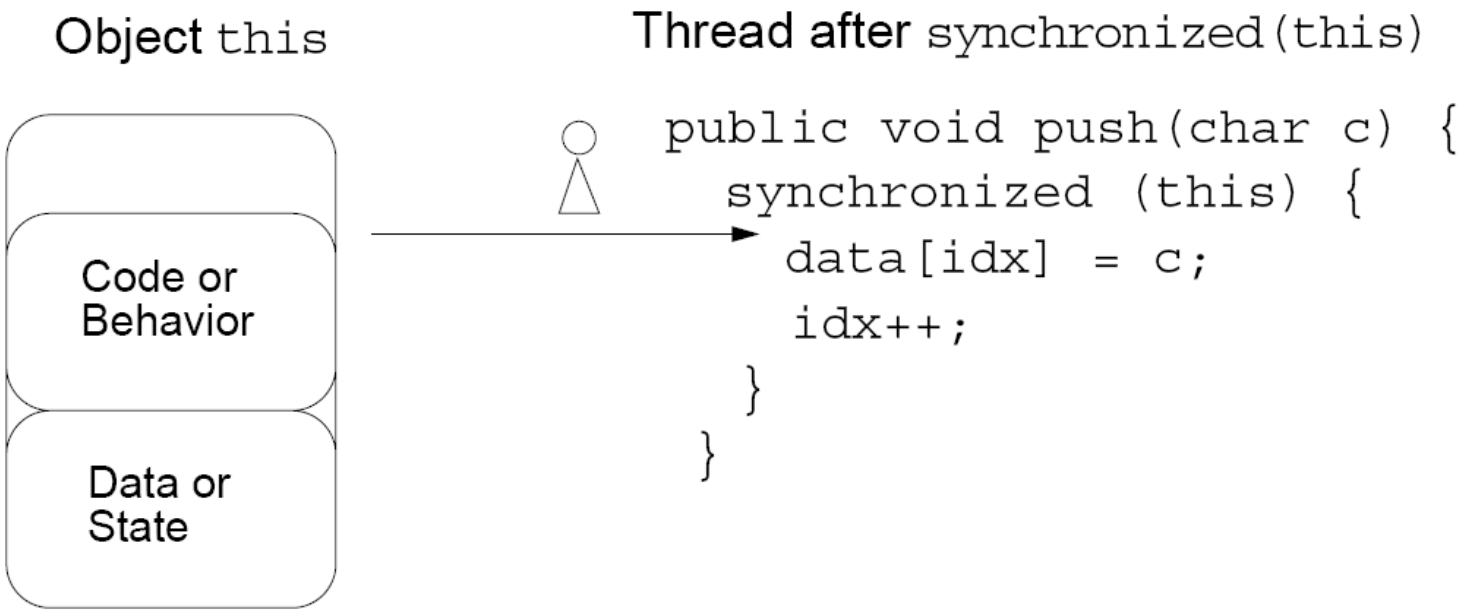
```
1   public class MyStack {
2
3     int idx = 0;
4     char [] data = new char[6];
5
6     public void push(char c) {
7       data[idx] = c;
8       idx++;
9     }
10
11    public char pop() {
12      idx--;
13      return data[idx];
14    }
15  }
```

The Object Lock Flag

- Every object has a flag that is a type of *lock flag*.
- The `synchronized` enables interaction with the lock flag.

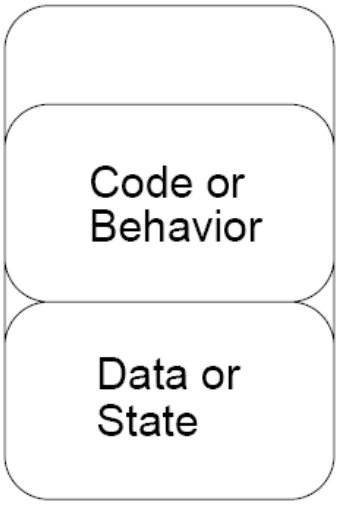


The Object Lock Flag



The Object Lock Flag

Object `this`
lock flag missing



Another thread, trying to
execute `synchronized(this)`

Waiting for
object lock

```
public char pop() {
  synchronized (this) {
    idx--;
    return data[idx];
  }
}
```

Releasing the Lock Flag

The lock flag is released in the following events:

- Released when the thread passes the end of the `synchronized` code block
- Released automatically when a break, return, or exception is thrown by the `synchronized` code block

Using `synchronized` – Putting It Together

- *All* access to delicate data should be `synchronized`.
- Delicate data protected by `synchronized` should be `private`.

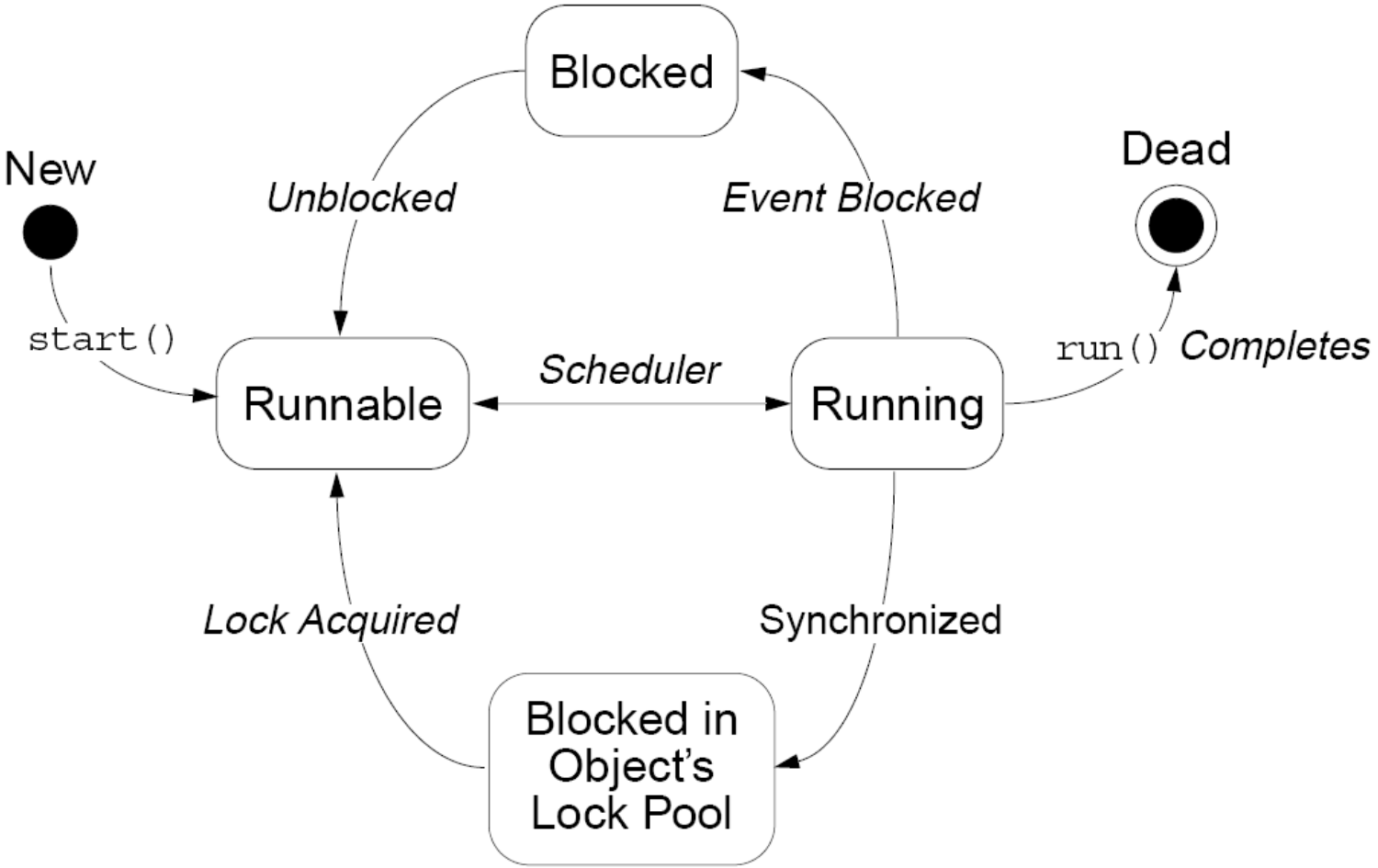
Using `synchronized` – Putting It Together

The following two code segments are equivalent:

```
public void push(char c) {
  synchronized(this) {
    // The push method code
  }
}

public synchronized void push(char c) {
  // The push method code
}
```

Thread State Diagram With Synchronization



Deadlock

A deadlock has the following characteristics:

- It is two threads, each waiting for a lock from the other.
- It is not detected or avoided.
- Deadlock can be avoided by:
  - Deciding on the order to obtain locks
  - Adhering to this order throughout
  - Releasing locks in reverse order

Thread Interaction – `wait` and `notify`

- Scenario:

  Consider yourself and a cab driver as two threads.
- The problem:

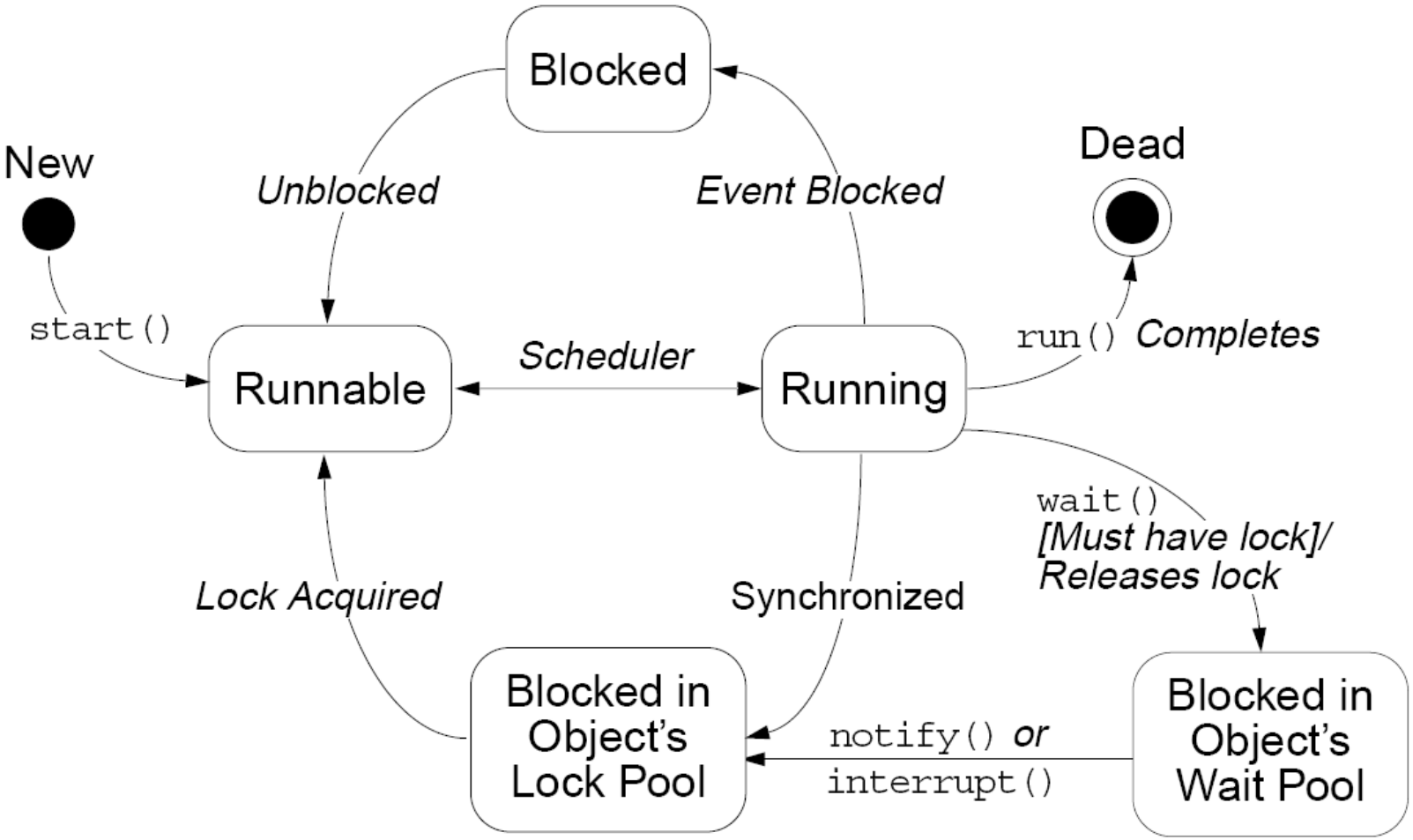
  How do you determine when you are at your destination?
- The solution:
  - You notify the cab driver of your destination and relax.
  - The driver drives and notifies you upon arrival at your destination.

Thread Interaction

Thread interactions include:

- The `wait` and `notify` methods
- The pools:
  - Wait pool
  - Lock pool

Thread State Diagram With `wait` and `notify`



Monitor Model for Synchronization

- Leave shared data in a consistent state.
- Ensure programs cannot deadlock.
- Do not put threads expecting different notifications in the same wait pool.

The `Producer` Class

```
1   package mod13;
2
3   public class Producer implements Runnable {
4     private SyncStack theStack;
5     private int num;
6     private static int counter = 1;
7
8     public Producer (SyncStack s) {
9       theStack = s;
10      num = counter++;
11    }
12
```

The `Producer` Class

```
13    public void run() {
14      char c;
15
16      for (int i = 0; i < 200; i++) {
17        c = (char)(Math.random() * 26 +'A');
18        theStack.push(c);
19        System.out.println("Producer" + num + ": " + c);
20        try {
21          Thread.sleep((int)(Math.random() * 300));
22        } catch (InterruptedException e) {
23          // ignore it
24        }
25      }
26    } // END run method
27
28  } // END Producer class
```

The Consumer Class

```
1   package mod13;
2
3   public class Consumer implements Runnable {
4     private SyncStack theStack;
5     private int num;
6     private static int counter = 1;
7
8     public Consumer (SyncStack s) {
9       theStack = s;
10      num = counter++;
11    }
12
```

The Consumer Class

```
13    public void run() {
14      char c;
15      for (int i = 0; i < 200; i++) {
16        c = theStack.pop();
17        System.out.println("Consumer" + num + ": " + c);
18
19        try {
20          Thread.sleep((int)(Math.random() * 300));
21        } catch (InterruptedException e) {
22          // ignore it
23        }
24      }
25    } // END run method
26
```

The `SyncStack` Class

This is a sketch of the `SyncStack` class:

```
public class SyncStack {

  private List<Character> buffer = new ArrayList<Character>(400);

  public synchronized char pop() {
    // pop code here
  }

  public synchronized void push(char c) {
    // push code here
  }
}
```

The pop Method

```
9     public synchronized char pop() {
10      char c;
11      while (buffer.size() == 0) {
12        try {
13          this.wait();
14        } catch (InterruptedException e) {
15          // ignore it...
16        }
17      }
18      c = buffer.remove(buffer.size()-1);
19      return c;
20    }
```

The `push` Method

```
22    public synchronized void push(char c) {
23      this.notify();
24      buffer.add(c);
25    }
```

The SyncTest Class

```
1   package mod13;
2   public class SyncTest {
3     public static void main(String[] args) {
4       SyncStack stack = new SyncStack();
5       Producer p1 = new Producer(stack);
6       Thread prodT1 = new Thread (p1);
7       prodT1.start();
8       Producer p2 = new Producer(stack);
9       Thread prodT2 = new Thread (p2);
10      prodT2.start();
11
12      Consumer c1 = new Consumer(stack);
13      Thread consT1 = new Thread (c1);
14      consT1.start();
15      Consumer c2 = new Consumer(stack);
16      Thread consT2 = new Thread (c2);
17      consT2.start();
18    }
19  }
```

The `SyncTest` Class

```
Producer2: F
Consumer1: F
Producer2: K
Consumer2: K
Producer2: T
Producer1: N
Producer1: V
Consumer2: V
Consumer1: N
Producer2: V
Producer2: U
Consumer2: U
Consumer2: V
Producer1: F
Consumer1: F
Producer2: M
Consumer2: M
Consumer2: T
```