CS61B Lecture #32

Today: *DSIJ*, Chapter 10.

- Threads
- Communication between threads
- Synchronization
- Mailboxes

Coming Up: Backtracking; Graph Structures: *DSIJ*, Chapter 12

Threads

- So far, all our programs consist of single sequence of instructions.
- Each such sequence is called a *thread* (for "thread of control") in Java.
- Java supports programs containing *multiple* threads, which (conceptually) run concurrently.
- Actually, on a uniprocessor, only one thread at a time actually runs, while others wait, but this is largely invisible.
- To allow program access to threads, Java provides the type `Thread` in `java.lang`. Each `Thread` contains information about, and controls, one thread.
- Simultaneous access to data from two threads can cause chaos, so are also constructs for controlled communication, allowing threads to *lock* objects, to *wait* to be notified of events, and to *interrupt* other threads.

But Why?

- Typical Java programs always have > 1 thread: besides the main program, others clean up garbage objects, receive signals, update the display, other stuff.
- When programs deal with asynchronous events, is sometimes convenient to organize into subprograms, one for each independent, related sequence of events.
- Threads allow us to insulate one such subprogram from another.
- GUIs often organized like this: application is doing some computation or I/O, another thread waits for mouse clicks (like 'Stop'), another pays attention to updating the screen as needed.
- Large servers like search engines may be organized this way, with one thread per request.
- And, of course, sometimes we *do* have a real multiprocessor.

Java Mechanics

- To specify the actions "walking" and "chewing gum":

```
class Chewer1 implements Runnable {
   public void run ()
     { while (true) ChewGum(); }
}
class Walker1 implements Runnable {
   public void run ()
     { while (true) Walk(); }
}
```

```
// Walk and chew gum
Thread chomp
  = new Thread (new Chewer1 ());
Thread clomp
  = new Thread (new Walker1 ());
chomp.start (); clomp.start ();
```

- Concise Alternative (uses fact that Thread implements Runnable):

```
class Chewer2 extends Thread {
  public void run ()
    { while (true) ChewGum(); }
}
class Walker2 extends Thread {
  public void run ()
    { while (true) Walk(); }
}
```

```
Thread chomp = new Chewer2 (),
       clomp = new Walker2 ();
chomp.start ();
clomp.start ();
```

Avoiding Interference

- When one thread has data for another, one must wait for the other to be ready.
- Likewise, if two threads use the same data structure, generally only one should modify it at a time; other must wait.
- E.g., what would happen if two threads simultaneously inserted an item into a linked list at the same point in the list?
- *A*: Both could conceivably execute

  ```
  p.next = new ListCell(x, p.next);
  ```

  with the *same* values of `p` and `p.next`; one insertion is lost.
- Can arrange for only one thread at a time to execute a method on a particular object with either of the following equivalent definitions:

```
void f (...) {
  synchronized (this) {
    body of f
  }
}
```

```
synchronized void f (...) {
  body of f
}
```

Communicating the Hard Way

- Communicating data is tricky: the faster party must wait for the slower.
- Obvious approaches for sending data from thread to thread don't work:

```
class DataExchanger {
   Object value = null;
   Object receive () {
      Object r; r = null;
      while (r == null)
        { r = value; }
      value = null;
      return r;
   }
   void deposit (Object data) {
      while (value != null) { }
      value = data;
   }
}
```

```
DataExchanger exchanger
  = new DataExchanger ();

--------------------------------

// thread1 sends to thread2 with
exchanger.deposit ("Hello!");

--------------------------------

// thread2 receives from thread1 with
msg = (String) exchanger.receive ();
```

- BAD: One thread can monopolize machine while waiting; two threads executing `deposit` or `receive` simultaneously cause chaos.

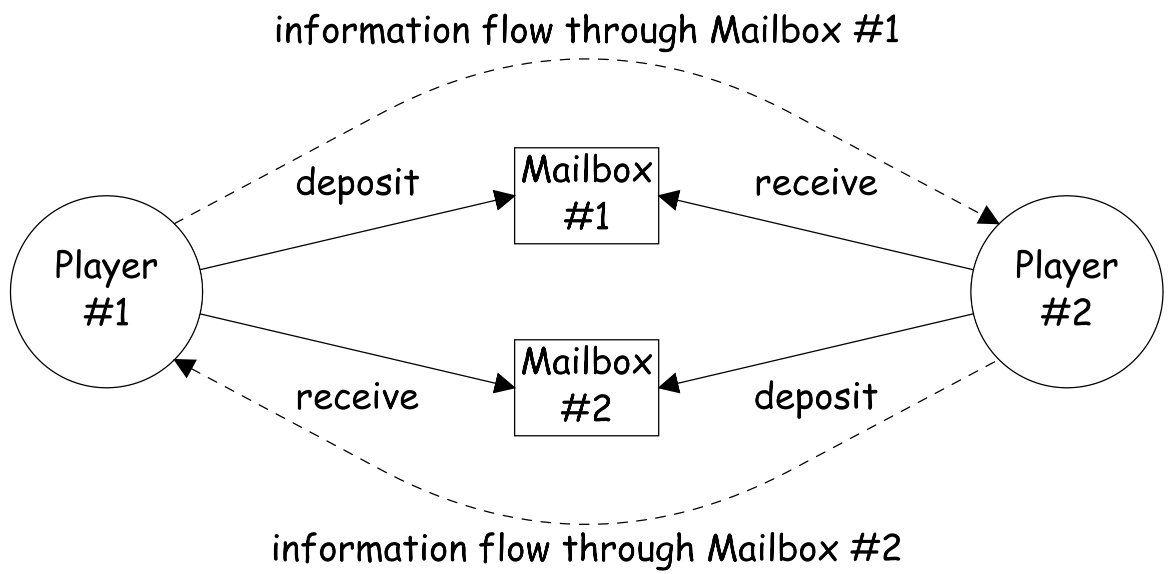
Primitive Java Facilities

- `wait` method on Object makes thread wait (not using processor) until notified by `notifyAll`, unlocking the Object while it waits.
- Example, `ucb.util.mailbox` has something like this (simplified):

```
interface Mailbox {
  void deposit (Object msg) throws InterruptedException;
  Object receive () throws InterruptedException;
}

class QueuedMailbox implements Mailbox {
  private List<Object> queue = new LinkedList<Object> ();

  public synchronized void deposit (Object msg) {
    queue.add (msg);
    this.notifyAll (); // Wake any waiting receivers
  }

  public synchronized Object receive () throws InterruptedException {
    while (queue.isEmpty ()) wait ();
    return queue.remove (0);
  }
}
```

Message-Passing Style

- Use of Java primitives very error-prone. Wait until CS162.
- We will just use mailboxes and be happy.
- They allow the following sort of program structure:



- Where each Player is a thread that looks like this:

```
while (! gameOver ()) {
  if (myMove ())
    outBox.deposit (computeMyMove (lastMove));
  else
    lastMove = inBox.receive ();
}
```

More Concurrency

- Previous example can be done other ways, but mechanism is very flexible.
- E.g., suppose you want to think during opponent's move:

```
while (! gameOver ()) {
  if (myMove ())
    outBox.deposit (computeMyMove (lastMove));
  else {
    do {
      thinkAheadALittle ();
      lastMove = inBox.receiveIfPossible ();
    } while (lastMove == null);
}
```

- `receiveIfPossible` doesn't wait; returns `null` if no message yet, perhaps like this:

```
public synchronized Object receiveIfPossible ()
   throws InterruptedException {
  if (queue.isEmpty ())
    return null;
  return queue.remove (0);
}
```

Coroutines

- A *coroutine* is a kind of synchronous thread that explicitly hands off control to other coroutines so that only one executes at a time. Can get similar effect with threads and mailboxes.
- Example: recursive inorder tree iterator:

```
class TreeIterator extends Thread {
  Tree root; Mailbox r;
  TreeIterator (Tree T, Mailbox r) {
    this.root = T; this.dest = r;
  }
  public void run () {
    traverse (root);
    r.deposit (End marker);
  }
  void traverse (Tree t) {
    if (t == null) return;
    traverse (t.left);
    r.deposit (t.label);
    traverse (t.right);
  }
}
```

```
void treeProcessor (Tree T) {
  Mailbox m = new QueuedMailbox ();
  new TreeIterator (T, m).start ();
  while (true) {
     Object x = m.receive ();
     if (x is end marker)
        break;
     do something with x;
  }
}
```

Use In GUIs

- Jave runtime library uses a special thread that does nothing but wait for *events* like mouse clicks, pressed keys, mouse movement, etc.
- You can designate an object of your choice as a *listener;* which means that Java's event thread calls a method of that object whenever an event occurs.
- As a result, your program can do work while the GUI continues to respond to buttons, menus, etc.
- Another special thread does all the drawing. You don't have to be aware when this takes place; just ask that the thread wake up whenever you change something.

Highlights of a GUI Component

```
/** A widget that draws multi-colored lines indicated by mouse. */
class Lines extends JComponent implements MouseListener {
  private List<Point> lines = new ArrayList<Point> ();

  Lines () {  // Main thread calls this to create one
    setPreferredSize (new Dimension (400, 400));
    addMouseListener (this);
  }
  public synchronized void paintComponent (Graphics g) { // Paint thread
    g.setColor (Color.white);   g.fillRect (0, 0, 400, 400);
    int x, y;   x = y = 200;
    Color c = Color.black;
    for (Point p : lines)
      g.setColor (c); c = chooseNextColor (c);
      g.drawLine (x, y, p.x, p.y); x = p.x; y = p.y;
    }
  }
  public synchronized void mouseClicked (MouseEvent e) // Event thread
    { lines.add (new Point (e.getX (), e.getY ())); repaint (); }
  ...
}
```

Interrupts

- An *interrupt* is an event that disrupts the normal flow of control of a program.
- In many systems, interrupts can be totally *asynchronous*, occurring at arbitrary points in a program, the Java developers considered this unwise; arranged that interrupts would occur only at controlled points.
- In Java programs, one thread can interrupt another to inform it that something unusual needs attention:

```
otherThread.interrupt ();
```

- But `otherThread` does not receive the interrupt until it waits: methods `wait`, `sleep` (wait for a period of time), `join` (wait for thread to terminate), and mailbox deposit and receive.
- Interrupt causes these methods to throw `InterruptedException`, so typical use is like this:

```
try {
  msg = inBox.receive ();
} catch (InterruptedException e) { HandleEmergency (); }
```

Remote Mailboxes (A Side Excursion)

- RMI: Remote Method Interface allows one program to refer to objects in another program.
- We use it to allow mailboxes in one program be received from or deposited into in another.
- To use this, you define an *interface* to the remote object:

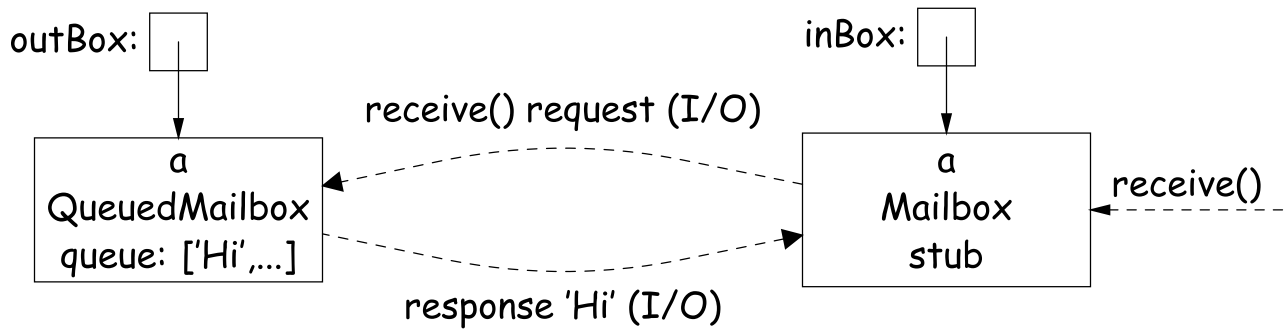
```
import java.rmi.*;
interface Mailbox extends Remote {
  void deposit (Object msg)
    throws InterruptedException, RemoteException;
  Object receive ()
    throws InterruptedException, RemoteException;
  ...
}
```

- On machine that actually will contain the object, you define

```
class QueuedMailbox ... implements Mailbox {
    Same implementation as before, roughly
}
```

Remote Objects Under the Hood

```
// On machine #1:              // On Machine #2:
Mailbox outBox                  Mailbox inBox
  = new QueuedMailbox ();        = get outBox from machine #1
```



- Because `Mailbox` is an interface, hides fact that on Machine #2 doesn't actually have direct access to it.
- Requests for method calls are relayed by I/O to machine that has real object.
- Any argument or return type OK if it also implements `Remote` or can be *serialized*—turned into stream of bytes and back, as can primitive types and String.
- Because I/O involved, expect failures, hence every method can throw RemoteException (subtype of IOException).