

Today: *DSIJ*, Chapter 10.

- Threads
- Communication between threads
- Synchronization
- Mailboxes

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

- 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 { // Walk and chew gum
    public void run ()
        { while (true) ChewGum(); }
}
class Walker1 implements Runnable {
    public void run ()
        { while (true) Walk(); }
}
```

```
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  
}
```

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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.

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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):

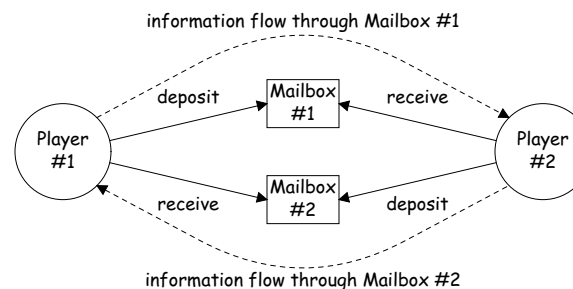
```
interface Mailbox {  
    void deposit (Object msg) throws InterruptedException;  
    Object receive () throws InterruptedException;  
}  
  
class QueuedMailbox implements Mailbox {  
    private List<Object> queue = new LinkedList<Object> ();  
  
    public synchronized void deposit (Object msg) {  
        queue.add (msg);  
        this.notifyAll (); // Wake any waiting receivers  
    }  
  
    public synchronized Object receive () throws InterruptedException {  
        while (queue.isEmpty ()) wait ();  
        return queue.remove (0);  
    }  
}
```

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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 ();  
}
```

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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);
}
```

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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;
    }
    void treeProcessor (Tree T) {
        Mailbox m = new QueuedMailbox ();
        new TreeIterator (T, m).start ();
    }
    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);
    }
}
```

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Use In GUIs

- Java 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.

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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 (); }
    ...
}
```

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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:

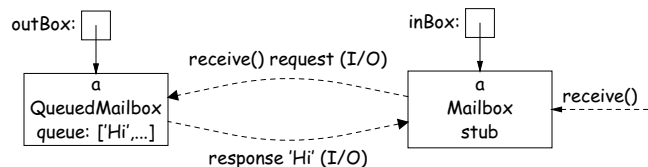
```
import java.rmi.*;
interface Mailbox extends Remote {
 void deposit (Object msg)
 throws InterruptedException, RemoteException;
 Object receive ()
 throws InterruptedException, RemoteException;
 ...
}
```

- 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`).