Today: DSIJ, Chapter 10.
  • Threads
  • Communication between threads
  • Synchronization
  • Mailboxes

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

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":
    ```java
    class Chewer1 implements Runnable {
      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):
    ```java
    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 ();
    ```

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.
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
  
  \[
  \text{p.next = new ListCell(x, p.next)};
  \]

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

  ```java
  class DataExchanger {
      Object value = null;
      void 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

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

  ```java
  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:

  ```text
  information flow through Mailbox #1
  deposit
  Player #1
  receive
  Mailbox #1
  
  information flow through Mailbox #2
  receive
  Player #2
  deposit
  ```

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

  ```java
  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:
  
  ```java
  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:
  
  ```java
  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:
  
  ```java
  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);
      Object x = m.receive ();
      if (x is end marker)
        break;
      do something with x;
    }
    void traverse (Tree t) {
      if (t == null) return;
      traverse (t.left);
      traverse (t.right);
    }
  }
  ```

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.

Highlights of a GUI Component

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