

### Today:

- A Brief Side Trip: Enumeration types.
- *DSIJ*, Chapter 10, *HFJ*, pp. 489-516.
  - Threads
  - Communication between threads
  - Synchronization
  - Mailboxes

## Side Trip into Java: Enumeration Types

- Problem: Need a type to represent something that has a few, named, discrete values.
- In the purest form, the only necessary operations are == and !=; the only property of a value of the type is that it differs from all others.
- In older versions of Java, used named integer constants:

```
interface Pieces {
    int BLACK_PIECE = 0,    // Fields in interfaces are static final.
        BLACK_KING = 1,
        WHITE_PIECE = 2,
        WHITE_KING = 3,
        EMPTY = 4;
}
```

- C and C++ provide *enumeration types* as a shorthand, with syntax like this:
 

```
enum Piece { BLACK_PIECE, BLACK_KING, WHITE_PIECE, WHITE_KING, EMPTY };
```
- But since all these values are basically **ints**, accidents can happen.

## Enum Types in Java

- New version of Java allows syntax like that of C or C++, but with more guarantees:

```
public enum Piece {
    BLACK_PIECE, BLACK_KING, WHITE_PIECE, WHITE_KING, EMPTY
}
```

- Defines *Piece* as a new *reference type*, a special kind of class type.
- The names *BLACK\_PIECE*, etc., are static, final *enumeration constants* (or *enumerals*) of type *PIECE*.
- They are automatically initialized, and are the only values of the enumeration type that exist (illegal to use **new** to create an enum value.)
- Can safely use ==, and also switch statements:

```
boolean isKing (Piece p) {
    switch (p) {
        case BLACK_KING: case WHITE_KING: return true;
        default: return false;
    }
}
```

## Making Enumerals Available Elsewhere

- Enumerals like *BLACK\_PIECE* are static members of a class, not classes.
- Therefore, unlike C or C++, their declarations are not automatically visible outside the enumeration class definition.
- So, in other classes, must write *Piece.BLACK\_PIECE*, which can get annoying.
- However, with version 1.5, Java has *static imports*: to import all static definitions of class *checkers.Piece* (including enumerals), you write
 

```
import static checkers.Piece.*;
```

 among the import clauses.
- Alas, *cannot* use this for enum classes in the anonymous package.

## Operations on Enum Types

- Order of declaration of enumeration constants significant: `.ordinal()` gives the position (numbering from 0) of an enumeration value. Thus, `Piece.BLACK_KING.ordinal ()` is 1.
- The array `Piece.values()` gives all the possible values of the type. Thus, you can write:

```
for (Piece p : Piece.values ())
    System.out.printf ("Piece value %d is %s\n", p.ordinal (), p);
```
- The static function `Piece.valueOf` converts a String into a value of type Piece. So `Piece.valueOf ("EMPTY") == EMPTY`.

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## Fancy Enum Types

- Enums are classes. You can define all the extra fields, methods, and constructors you want.
- Constructors are used only in creating enumeration constants. The constructor arguments follow the constant name:

```
enum Piece {
    BLACK_PIECE (BLACK, false, "b"), BLACK_KING (BLACK, true, "B"),
    WHITE_PIECE (WHITE, false, "w"), WHITE_KING (WHITE, true, "W"),
    EMPTY (null, false, " ");

    private final Side color;
    private final boolean isKing;
    private final String textName;

    Piece (Side color, boolean isKing, String textName) {
        this.color = color; this.isKing = isKing; this.textName = textName;
    }

    Side color () { return color; }
    boolean isKing () { return isKing; }
    String textName () { return textName; }
}
```

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## 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.

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## 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.

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## 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 ();
```

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## 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
    }

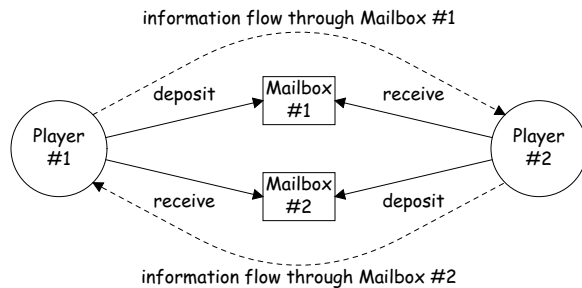
    public synchronized Object receive () throws InterruptedException {
        while (queue.isEmpty ()) wait ();
        return queue.remove (0);
    }
}
```

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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` (written `receive(0)` in our actual package) 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;
    }
    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;
    }
}
```

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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 (); }
```

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## 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

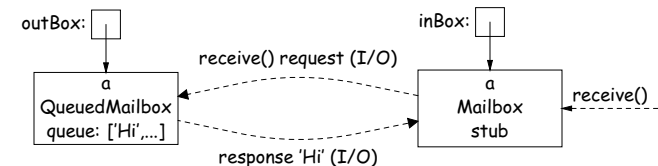
```
class QueuedMailbox ... implements Mailbox {
    Same implementation as before, roughly
}
```

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## 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`).

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