CSE 331
Software Design & Implementation

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Design Patterns, Part 2
(Based on slides by Mike Ernst, Dan Grossman, David Notkin, Hal Perkins, Zach Tatlock)
Announcements

• Course evaluation: https://uw.iasystem.org/survey/179905

• Email cse331-staff (or me directly) if you want to demo on Wed

• Web site has details on final
  – important concepts
  – prior exams
    • 16su will be most informative
Review: Factories

Goal: want more flexible abstractions for what class to instantiate

Factory method
  – call a method to create the object
  – method can do computation, return subtype, reuse objects

Factory object (also Builder)
  – Factory has factory methods for some type(s)
  – Builder has methods to describe object and then create it

Prototype
  – every object is a factory, can create more objects like itself
  – call clone to get a new object of same subtype as receiver

Dependency Injection
  – put choice of subclass in a file to avoid source-code changes when decision changes (meh)
Review: Factory Method

Factory method: call a method to create the object

- can return any subtype or an existing object
- can give it a better name

```java
new Matrix(double[] vals) { ... }
new Matrix(double[] vals, int rowSize) { ... }
```

**versus** Matrix.fromX

```java
Matrix fromVector(double[] vals)
Matrix fromRowMajorEntries(double[] vals, int rowSize)
Matrix fromColMajorEntries(double[] vals, int colSize)
```

- Has two methods with same signature — impossible w/ constructors
- This approach can be used for *any* Java class.
Review: Builder

**Builder**: object with methods to describe object and then create it
- fits especially well with immutable classes when clients want to add data one bit at a time

**Example: StringBuilder**
```java
StringBuilder buf = new StringBuilder();
buf.append("Total distance: ");
buf.append(dist);
buf.append(" meters");
return buf.toString();
```

**Example: Graph.Builder**
- `addNode`, `addEdge`, and `createGraph` methods
- *(static inner class `Builder` can use private constructors)*
Sharing

Second weakness of constructors: they always return a new object

**Singleton:** only one object exists at runtime
  - factory method returns the same object every time
  - (we’ve seen this already)

**Interner:** only one object with a particular value exists at runtime
  - (with a particular *abstract* value)
  - factory method can return an existing object (not a new one)
  - interning can be used without factory methods
    • see `String.intern`
Interning pattern

Reuse existing objects instead of creating new ones:

StreetSegment without string interning

StreetSegment with string interning
Interning mechanism

- Maintain a collection of all objects in use
- If an object already appears, return that instead
  - (be careful in multi-threaded contexts)

```java
HashMap<String, String> segNames;
String canonicalName(String n) {
    if (segNames.containsKey(n)) {
        return segNames.get(n);
    } else {
        segNames.put(n, n);
        return n;
    }
}
```

- Java builds this in for strings: `String.intern()`
Interning pattern

• Benefits of interning:

1. May compare with \texttt{==} instead of \texttt{equals()}
   • eliminates a source of common bugs!!

2. May save space by creating fewer objects
   • (space is less and less likely to be a problem nowadays)
   • also, interning can actually waste space if objects are not cleaned up when \textit{no longer needed}
     – there are additional techniques to fix that (“weak references”)

• Sensible only for immutable objects
java.lang.Boolean does not use the Interning pattern

```java
public class Boolean {
    private final boolean value;

    // construct a new Boolean value
    public Boolean(boolean value) {
        this.value = value;
    }

    public static Boolean FALSE = new Boolean(false);
    public static Boolean TRUE = new Boolean(true);

    // factory method that uses interning
    public static Boolean valueOf(boolean value) {
        if (value) {
            return TRUE;
        } else {
            return FALSE;
        }
    }
}
```
Recognition of the problem

Javadoc for `Boolean` constructor:

Allocates a `Boolean` object representing the value argument.

**Note:** It is rarely appropriate to use this constructor. Unless a new instance is required, the static factory `valueOf(boolean)` is generally a better choice. It is likely to yield significantly better space and time performance.

Josh Bloch (JavaWorld, January 4, 2004):

The `Boolean` type should not have had public constructors. There's really no great advantage to allow multiple `true`s or multiple `false`s, and I've seen programs that produce millions of `true`s and millions of `false`s, creating needless work for the garbage collector.

So, in the case of immutables, I think factory methods are great.
GoF patterns: three categories

*Creational Patterns* are about the object-creation process
  - Factory Method, Abstract Factory, Singleton, Builder, Prototype, ...

*Structural Patterns* are about how objects/classes can be combined
  - Adapter, Bridge, Composite, Decorator, Façade, Proxy, ...

*Behavioral Patterns* are about communication among objects
  - Command, Interpreter, Iterator, Mediator, Observer, State, Strategy, Chain of Responsibility, Visitor, Template Method, ...

Green = ones we’ve seen already
Structural patterns: Wrappers

Wrappers are a thin veneer over an encapsulated class
- modify the interface
- extend behavior
- restrict access
The encapsulated class does most of the work

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Functionality</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adapter</td>
<td>same</td>
<td>different</td>
</tr>
<tr>
<td>Decorator</td>
<td>different</td>
<td>same</td>
</tr>
<tr>
<td>Proxy</td>
<td>same</td>
<td>same</td>
</tr>
</tbody>
</table>

Some wrappers have qualities of more than one of adapter, decorator, and proxy
Adapter

Real life example: adapter to go from US to UK power plugs
  – both do the same thing
  – but they have slightly interface expectations

Change an interface without changing functionality
  – rename a method
  – convert units
  – implement a method in terms of another

Example: angles passed in radians vs. degrees
Example: use “old” method names for legacy code
Adapter example: rectangles

Our code is using this Rectangle interface:

```java
interface Rectangle {
    // grow or shrink this by the given factor
    void scale(float factor);
    // move to the left or right
    void translate(float x, float y);
}
```

But we want to use a library that has this class:

```java
class JRectangle {
    void scaleWidth(float factor) { ... }
    void scaleHeight(float factor) { ... }
    void shift(float x, float y) { ... }
}
```
Adapter example: rectangles

Create an adapter that delegates to `Rectangle`:

```java
class RectangleAdapter implements Rectangle {
    JRectangle rect;
    RectangleAdapter(JRectangle rect) {
        this.rect = rect;
    }
    void scale(float factor) {
        rect.scaleWidth(factor);
        rect.scaleHeight(factor);
    }
    void translate(float x, float y) {
        rect.shift(x, y);
    }
    ...
}
```
Adapters

• This sort of thing happens a lot
  – unless two libraries were designed to work together, they probably won’t fit together without an adapter

• The example code uses delegation:
  – special case of composition where the outer object just forwards calls on to one other object

• Adapters can also remove methods

• Adapters can also be written by subclassing
  – but then all the usual warnings about subclassing apply
    if you override any methods of the superclass
  – your subclass could easily break when superclass changes
Decorator

- Add functionality without breaking the interface:
  1. Add to existing methods to do something extra
     - satisfying a stronger specification
  2. Provide extra methods

- Subclasses are often decorators
  - but not always: Java subtypes are not always true subtypes
Decorator example: Bordered windows

interface Window {
    // rectangle bounding the window
    Rectangle bounds();
    // draw this on the specified screen
    void draw(Screen s);
    ...
}

class WindowImpl implements Window {
    ...
}
Bordered window implementations

Via subclassing:

```java
class BorderedWindow1 extends WindowImpl {
    void draw(Screen s) {
        super.draw(s);
        bounds().draw(s);
    }
}
```

Via delegation:

```java
class BorderedWindow2 implements Window {
    Window innerWindow;
    BorderedWindow2(Window innerWindow) {
        this.innerWindow = innerWindow;
    }
    void draw(Screen s) {
        innerWindow.draw(s);
        innerWindow.bounds().draw(s);
    }
}
```

Delegation permits multiple borders on a window, or a window that is both bordered and shaded.
A decorator can remove functionality

Remove functionality without changing the Java interface
  – no longer a true subtype, but sometimes that is necessary

Example: UnmodifiableList
  – What does it do about methods like add and put?
    • throws an exception
    • moves error checking from the compiler to runtime
      – like Java array subtypes are another example of this

Problem: UnmodifiableList is not a true subtype of List

Decoration via delegation can create a class with no Java subtyping relationship, which is often desirable
  • Java subtypes that are not true subtypes are confusing
  • maybe necessary for UnmodifiableList though
Proxy

• Same interface *and* functionality as the wrapped class
  – so... uh... wait, what?

• Control access to other objects
  – communication: manage network details when using a remote object
  – locking: serialize access by multiple clients
  – security: permit access only if proper credentials
  – creation: object might not yet exist (creation is expensive)
    • hide latency when creating object
    • avoid work if object is never used
Composite pattern

- Composite permits a client to manipulate either an *atomic* unit or a *collection* of units in the same way
  - no need to “always know” if an object is a collection of smaller objects or not

- Good for dealing with “part-whole” relationships

- Used by jQuery in JavaScript

- An extended example…
Composite example: Bicycle

- Bicycle
  - Wheel
    - Skewer
      - Lever
      - Body
      - Cam
      - Rod
  - Hub
  - Spokes
  - Nipples
  - Rim
  - Tape
  - Tube
  - Tire
  - Frame
  - Drivetrain
  - ...
Methods on components

```java
abstract class BicycleComponent {
    int weight();
    float cost();
}

class Skewer extends BicycleComponent {
    float price;
    float cost() { return price; }
}
class Wheel extends BicycleComponent {
    float assemblyCost;
    Skewer skewer;
    Hub hub;
    ...
    float cost() {
        return assemblyCost + skewer.cost() + hub.cost() + ...;
    }
}
```
Composite example: Libraries

Library
  Section (for a given genre)
    Shelf
      Volume
        Page
          Column
            Word
              Letter

interface Text {
  String getText();
}
class Page implements Text {
  String getText() {
    ... return concatenation of column texts ...
  }
}

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Composite example: jQuery

- jQuery provides a function \$ that returns one or many objects
  - \$("#foo") would return the object with ID "foo"
    - (or returns an empty collection if none exists)
  - \$("p") would return a collection of all P nodes

- Calling a method on a jQuery object calls that method on all objects in the collection:
  - if foo is a node with id "foo", then
    - foo.hide() has the same effect as $("foo").hide()
  - $("p").hide() would hide all the P nodes
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Traversing composites

- Goal: perform operations on all parts of a composite

- Idea is to generalize the notion of an iterator: process the components in an order appropriate for the application

- This is really important when writing a compilers
  - (doesn’t come up nearly as much elsewhere though)

- Example: arithmetic expressions in Java
  - how do we represent, say, \( x = \text{foo}*b + c/d; \)
  - how do we traverse/process these expressions?
Representing Java code

\[ x = \text{foo} \times b + c / d; \]
Abstract syntax tree (AST) for Java code

class PlusOp extends Expression { // + operation
    Expression leftExp;
    Expression rightExp;
}
class VarRef extends Expression { // variable use
    String varname;
}
class EqualOp extends Expression { // test a==b;
    Expression leftExp; // left-hand side: a in a==b
    Expression rightExp; // right-hand side: b in a==b
}
class CondExpr extends Expression { // a?b:c
    Expression testExp;
    Expression thenExp;
    Expression elseExp;
}
Object model vs. type hierarchy

- AST for $a + b$:

- Class hierarchy for $Expression$:
Operations on abstract syntax trees

Need to write code for each entry in this table

<table>
<thead>
<tr>
<th>Operations</th>
<th>Types of Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CondExpr</td>
</tr>
<tr>
<td>typecheck</td>
<td></td>
</tr>
<tr>
<td>print</td>
<td></td>
</tr>
</tbody>
</table>

- Question: Should we group together the code for a particular operation or the code for a particular expression?
  - That is, do we group the code into rows or columns?
- Given an operation and an expression, how do we “find” the proper piece of code?
Interpreter and procedural patterns

**Interpreter:** collects code for similar **objects**, spreads apart code for similar operations
- easy to add new types
- hard to add operations
- **Composite** pattern

**Procedural:** collects code for similar **operations**, spreads apart code for similar objects
- easy to add operations
- hard to add new types
- **Visitor** pattern

(See CSE341 for an extended take on this question:
- statically typed functional languages help with procedural whereas statically typed OO languages help with interpreter)
Interpreter pattern

Add a method to each class for each supported operation

abstract class Expression {
  ...
  Type typecheck();
  String print();
}

class EqualOp extends Expression {
  ...
  Type typecheck() { ... }
  String print() { ... }
}

class CondExpr extends Expression {
  ...
  Type typecheck() { ... }
  String print() { ... }
}
Procedural pattern

Create a class per operation, with a method per operand type

```java
class Typecheck {
    Type typeCheckCondExpr(CondExpr e) {
        Type condType = typeCheckExpr(e.condition);
        Type thenType = typeCheckExpr(e.thenExpr);
        Type elseType = typeCheckExpr(e.elseExpr);
        if (condType.equals(BoolType) && thenType.equals(elseType))
            return thenType;
        else
            return ErrorType;
    }

    Type typeCheckEqualOp(EqualOp e) {
        ...
    }
}
```

How to invoke the right method for an expression e?
Definition of `typeCheckExpr` (using procedural pattern)

class Typecheck {

    ...

    Type typeCheckExpr(Expression e) {
        if (e instanceof PlusOp) {
            return typeCheckPlusOp((PlusOp)e);
        } else if (e instanceof VarRef) {
            return typeCheckVarRef((VarRef)e);
        } else if (e instanceof EqualOp) {
            return typeCheckEqualOp((EqualOp)e);
        } else if (e instanceof CondExpr) {
            return typeCheckCondExpr((CondExpr)e);
        } else ...
        ...
    }

    ...

    return ...
}

... Maintaining this code is tedious and error-prone

- No help from type-checker to get all the cases
  (unlike in functional languages)

Cascaded if tests are likely to run slowly (in Java)

Need similar code for each operation
Visitor pattern:
A variant of the procedural pattern

- Nodes (objects in the hierarchy) accept visitors for traversal
- Visitors visit nodes (objects)

```java
class SomeExpression extends Expression {
    void accept(Visitor v) {
        for each child of this node {
            child.accept(v);
        }
        v.visit(this);
    }
}
class SomeVisitor extends Visitor {
    void visit(SomeExpression n) {
        perform work on n
    }
}
```

`n.accept(v)` traverses the structure rooted at `n`, performing `v`'s operation on each element of the structure
Example: accepting visitors

class VarOp extends Expression {
    ...
    void accept(Visitor v) {
        v.visit(this);
    }
}
class EqualsOp extends Expression {
    ...
    void accept(Visitor v) {
        leftExp.accept(v);
        rightExp.accept(v);
        v.visit(this);
    }
}
class CondOp extends Expression {
    ...
    void accept(Visitor v) {
        testExp.accept(v);
        thenExp.accept(v);
        elseExp.accept(v);
        v.visit(this);
    }
}
Sequence of calls to accept and visit

a.accept(v)
b.accept(v)
d.accept(v)
v.visit(d)
e.accept(v)
v.visit(e)
v.visit(b)
c.accept(v)
f.accept(v)
v.visit(f)
v.visit(c)
v.visit(a)

Sequence of calls to visit: d, e, b, f, c, a
Example: Implementing visitors

class TypeCheckVisitor
    implements Visitor {
    void visit(VarOp e) { ... }
    void visit(EqualsOp e) { ... }
    void visit(CondOp e) { ... } 
}

class PrintVisitor implements Visitor {
    void visit(VarOp e) { ... }
    void visit(EqualsOp e) { ... }
    void visit(CondOp e) { ... }
}

Now each operation has its cases back together
And type-checker should tell us if we fail to implement an abstract method in Visitor
Again: overloading just a nicety
Again: An OOP workaround for procedural pattern
• Because language/type-checker is not instance-of-test friendly