CSE 403
Design Patterns

Outline

Introduction to design patterns

Creational patterns (constructing objects)

Structural patterns (controlling heap layout)

Behavioral patterns (affecting object semantics)

What is a design pattern?

- **a standard solution to a common programming problem**
  - a design or implementation structure that achieves a particular purpose
  - a high-level programming idiom
- **a technique for making code more flexible**
  - reduce coupling among program components
- **shorthand for describing program design**
  - a description of connections among program components
  - the shape of a heap snapshot or object model

Example 1: Encapsulation (data hiding)

Problem: Exposed fields can be directly manipulated

Violations of the representation invariant

Dependences prevent changing the implementation

Solution: Hide some components

Permit only stylized access to the object

Disadvantages:

Interface may not (efficiently) provide all desired operations

Indirection may reduce performance

Example 2: Subclassing (inheritance)

Problem: Repetition in implementations

Similar abstractions have similar members (fields, methods)

Solution: Inherit default members from a superclass

Select an implementation via run-time dispatching

Disadvantages:

Code for a class is spread out, and thus less understandable

Run-time dispatching introduces overhead

Example 3: Iteration

Problem: To access all members of a collection, must perform a specialized traversal for each data structure

Introduces undesirable dependences

Does not generalize to other collections

The implementation has knowledge about the representation.

Solution:

The implementation performs traversals, does bookkeeping

Results are communicated to clients via a standard interface

Disadvantages:

Iteration order is fixed by the implementation and not under the control of the client

Example 4: Exceptions

Problem:

Errors in one part of the code should be handled elsewhere.
Code should not be cluttered with error-handling code.
Return values should not be preempted by error codes.

Solution: Language structures for throwing and catching exceptions

Disadvantages:

Code may still be cluttered.
It may be hard to know where an exception will be handled.
Use of exceptions for normal control flow may be confusing and inefficient.

Example 5: Generics

Problem:

Well-designed data structures hold one type of object

Solution:

Programming language checks for errors in contents

`List<Date>` instead of just `List`

Disadvantages:

Slightly more verbose types

Creating generic classes

Introduce a *type parameter* to a class

```
public class Graph<N> implements Iterable<N> {
  private final Map<N, Set<N>> node2neighbors;
  public Graph(Set<N> nodes, Set<Tuple<N,N>> edges) {
    ...
  }
}

public interface Path<N, P extends Path<N,P>>
  extends Iterable<N>, Comparable<Path<?, ?>> {
  public Iterator<N> iterator();
}
```

Code can perform any operation permitted by the bound

Tips for designing generic classes

First, write and test a concrete version

Consider creating a second concrete version

Then, generalize it by adding type parameters

The compiler will help you to find errors

A puzzle about generics

Integer is a subtype of Number

List<Integer> is not a subtype of List<Number>

Compare specs: add(Integer) is not stronger than add(Number)

What goes wrong if List<Integer> is a subtype of List<Number>?

```
List<Integer> li = new List<Integer>();
// legal if List<Integer> is subtype of List<Number>
List<Number> ln = li;
ln.add(new Float());
li.get(0); // we got a Float out of a List<Integer>!
```

Integer[] is a subtype of Number[]

Can we use similar code to break the Java type system?

When (not) to use design patterns

Rule 1: delay

Get something basic working first, then improve it once you understand it.

Design patterns can increase or decrease understandability

- Add indirection, increase code size
- Improve modularity, separate concerns, ease description

If your design or implementation has a problem, consider design patterns that address that problem

Canonical reference: the "Gang of Four" book

- *Design Patterns: Elements of Reusable Object-Oriented Software*, by Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides, Addison-Wesley, 1995.

Another good reference for Java

- *Effective Java: Programming Language Guide (2nd ed.)*, by Joshua Bloch, Addison-Wesley, 2008.

Why should you care?

You could come up with these solutions on your own

You shouldn't have to!

A design pattern is a known solution to a known problem

Creational patterns

Constructors in Java are inflexible

- Can't return a subtype of the class they belong to
- Always return a fresh new object, never re-use one

Factories

- Factory method
- Factory object
- Prototype

Sharing

- Singleton
- Interning
- Flyweight

Factories

Problem: client desires control over object creation

Factory method

Hides decisions about object creation

Implementation: put code in methods in client

Factory object

Bundles factory methods for a family of types

Implementation: put code in a separate object

Prototype

Every object is a factory, can create more objects like itself

Implementation: put code in clone methods

Motivation for factories: Changing implementations

Supertypes support multiple implementations

```
interface Matrix { ... }
class SparseMatrix implements Matrix { ... }
class DenseMatrix implements Matrix { ... }
```

Clients use the supertype (Matrix)

Still need to use a SparseMatrix or DenseMatrix constructor

Switching implementations requires code changes

Use of factories

Factory

```
class MatrixFactory {
  public static Matrix createMatrix() {
    return new SparseMatrix();
  }
}
```

Clients call createMatrix, not a particular constructor

Advantages

- To switch the implementation, only change one place
- Can decide what type of matrix to create

Example: bicycle race

```
class Race {

  // factory method
  Race createRace() {

    Bicycle bike1 = new Bicycle();
    Bicycle bike2 = new Bicycle();

    ...
  }

}
```

Example: Tour de France

```
class TourDeFrance extends Race {

  // factory method
  Race createRace() {
    Bicycle bike1 = new RoadBicycle();
    Bicycle bike2 = new RoadBicycle();
    ...
  }

}
```

Example: Cyclocross

```
class Cyclocross extends Race {

  // factory method
  Race createRace() {
    Bicycle bike1 = new MountainBicycle();
    Bicycle bike2 = new MountainBicycle();
    ...
  }

}
```

Factory method for Bicycle

```
class Race {
  Bicycle createBicycle() { ... }
  Race createRace() {
    Bicycle bike1 = createBicycle();
    Bicycle bike2 = createBicycle();
    ...
  }
}
```

Code using factory methods

```
class Race {
  Bicycle createBicycle() { ... }
  Race createRace() {
    Bicycle bike1 = createBicycle();
    Bicycle bike2 = createBicycle();
    ...
  }
}

class TourDeFrance extends Race {
  Bicycle createBicycle() {
    return new RoadBicycle();
  }
}

class Cyclocross extends Race {
  Bicycle createBicycle(Frame) {
    return new MountainBicycle();
  }
}
```

Factory objects/classes encapsulate factory methods

```
class BicycleFactory {
  Bicycle createBicycle() { ... }
  Frame createFrame() { ... }
  Wheel createWheel() { ... }
  ...
}

class RoadBicycleFactory extends BicycleFactory {
  Bicycle createBicycle() {
    return new RoadBicycle();
  }
}

class MountainBicycleFactory extends BicycleFactory {
  Bicycle createBicycle() {
    return new MountainBicycle();
  }
}
```

Using a factory object

```
class Race {
  BicycleFactory bfactory;
  // constructor
  Race() { bfactory = new BicycleFactory(); }
  Race createRace() {
    Bicycle bike1 = bfactory.createBicycle();
    Bicycle bike2 = bfactory.createBicycle();
    ...
  }
}

class TourDeFrance extends Race {
  // constructor
  TourDeFrance() { bfactory = new RoadBicycleFactory(); }
}

class Cyclocross extends Race {
  // constructor
  Cyclocross() { bfactory = new MountainBicycleFactory(); }
}
```

Separate control over bicycles and races

```
class Race {
  BicycleFactory bfactory;
  // constructor
  Race(BicycleFactory bfactory) { this.bfactory = bfactory; }
  Race createRace() {
    Bicycle bike1 = bfactory.completeBicycle();
    Bicycle bike2 = bfactory.completeBicycle();
    ...
  }
}
// No special constructor for TourDeFrance or for Cyclocross
```

Now we can specify the race and the bicycle separately:

```
  new TourDeFrance(new TricycleFactory())
```

DateFormat factory methods

DateFormat class encapsulates knowledge about how to format dates and times as text

Options: just date? just time? date+time? where in the world?
Instead of passing all options to constructor, use factories.
Tidy, and the subtype created doesn't need to be specified.

```
DateFormat df1 = DateFormat.getDateInstance();
DateFormat df2 = DateFormat.getTimeInstance();
DateFormat df3 = DateFormat.getDateInstance(DateFormat.FULL,
   Locale.FRANCE);
Date today = new Date();
System.out.println(df1.format(today)); // “Jul 4, 1776"
System.out.println(df2.format(today)); // "10:15:00 AM"
System.out.println(df3.format(today)); // “juedi 4 juillet 1776"
```

Prototype pattern

Every object is itself a factory

Each class contains a `clone` method that creates a copy of the receiver object

```
class Bicyle {
  Bicycle clone() { ... }
}
```

You will often see `Object` as the return type of `clone`

- This is due to a design flaw in Java 1.4 and earlier
- **`clone`** is declared in **`Object`**
- Java 1.4 did not permit the return type to change in an overridden method

Using prototypes

```
class Race {
  Bicycle bproto;
  // constructor
  Race(Bicycle bproto) { this.bproto = bproto; }
  Race createRace() {
    Bicycle bike1 = (Bicycle) bproto.clone();
    Bicycle bike2 = (Bicycle) bproto.clone();
    ...
  }
}
```

Again, we can specify the race and the bicycle separately:

```
new TourDeFrance(new Tricycle())
```

Sharing

Recall the second weakness of Java constructors

Java constructors always return a new object, never a pre-existing object

Singleton: only one object exists at runtime

Factory method returns the same object every time

Interning: only one object with a particular (abstract) value exists at runtime

Factory method returns an existing object, not a new one

Flyweight: separate intrinsic and extrinsic state, represent them separately, and intern the intrinsic state

Implicit representation uses no space

Singleton

Only one object of the given type exists

```
class Bank {
  private static bank theBank;

  // private constructor
  private Bank() { ... }

  // factory method
  public static getBank() {
    if (theBank == null) {
      theBank = new Bank();
    }
    return theBank;
  }
  ...
}
```

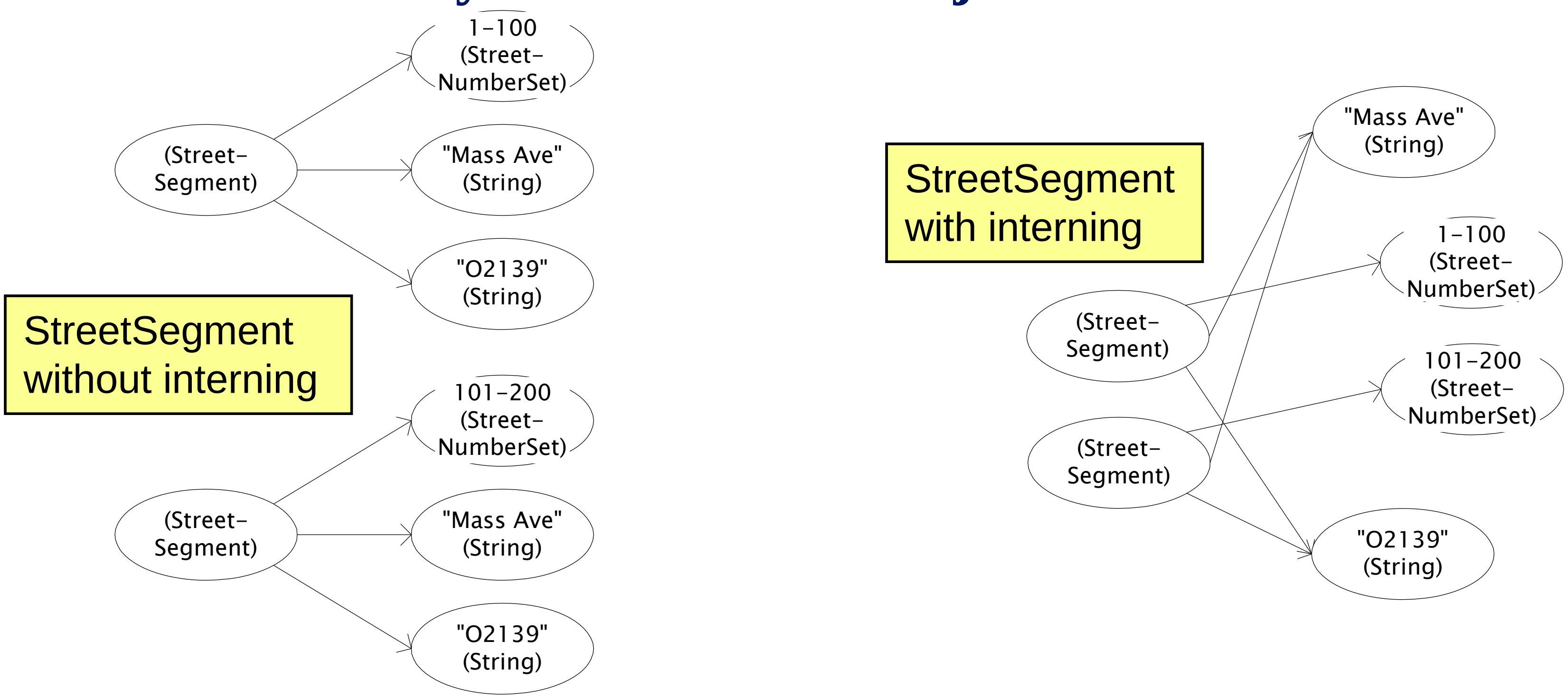
Interning pattern

Reuse existing objects instead of creating new ones

Less space

May compare with **==** instead of **equals()**

Permitted only for immutable objects



Interning mechanism

Maintain a collection of all objects

If an object already appears, return that instead

```
HashMap<String, String> segnames; // why not Set<String>?
String canonicalName(String n) {
  if (segnames.containsKey(n)) {
    return segnames.get(n);
  } else {
    segnames.put(n, n);
    return n;
  }
}
```

`Set` supports **`contains`** but not **`get`**

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

Two approaches:

- create the object, but perhaps discard it and return another
- check against the arguments before creating the new object

Failure to use the Interning pattern: java.lang.Boolean

```
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 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 trues or multiple falses, and I've seen programs that produce millions of trues and millions of falses, creating needless work for the garbage collector.

So, in the case of immutables, I think factory methods are great.

Flyweight pattern

Good when many objects are mostly the same

- Interning works only if objects are entirely the same (and immutable!)

Intrinsic state: same across all objects

- Technique: intern it
- Remember that interning requires immutability

Extrinsic state: different for different objects

- Technique: make it implicit (don’t even represent it!)
- Making it implicit also requires immutability
- Mutable parts of object must still be represented explicitly

Example without flyweight: bicycle spoke

```
class Wheel {
  FullSpoke[] spokes;
  ...
}
class FullSpoke {
  int length;
  int diameter;
  bool tapered;
  Metal material;
  float weight;
  float threading;
  bool crimped;
  int location;   // rim and hub holes this is installed in
}
```

Typically 32 or 36 spokes per wheel, but only 3 varieties per bicycle.

In a bike race, hundreds of spoke varieties, millions of instances

Alternatives to FullSpoke

```
class IntrinsicSpoke {
  int length;
  int diameter;
  boolean tapered;
  Metal material;
  float weight;
  float threading;
  boolean crimped;
}
```

This doesn't work: it's the same as FullSpoke

```
class InstalledSpokeFull extends IntrinsicSpoke {
  int location;
}
```

This works, but flyweight version uses even less space

```
class InstalledSpokeWrapper {
  IntrinsicSpoke s;     // refer to interned object
  int location;
}
```

Original code to true (align) a wheel

```
class FullSpoke {
  // Tension the spoke by turning the nipple the
  // specified number of turns.
  void tighten(int turns) {
    ... location ...    // location is a field
  }
}

class Wheel {
  FullSpoke[] spokes;
  void align() {
    while (wheel is misaligned) {
      // tension the ith spoke
      ... spokes[i].tighten(numturns) ...
    }
  }
}
```

Flyweight code to true (align) a wheel

```
class IntrinsicSpoke {
  void tighten(int turns, int location) {
    ... location ...    // location is a parameter
  }
}

class Wheel {
  IntrinsicSpoke[] spokes;

  void align() {
    while (wheel is misaligned) {
      // tension the ith spoke
      ... spokes[i].tighten(numturns, i) ...
    }
  }
}
```

Flyweight discussion

What if `FullSpoke` contains a `wheel` field pointing at the `Wheel` containing it?

> **`Wheel`** methods pass this to the methods that use the **`wheel`** field.

What if `FullSpoke` contains a `boolean` broken field?

> Add an array of **`boolean`**s in **`Wheel`**, parallel to the array of **`Spokes`**s.

Flyweight is manageable only if there are very few mutable (extrinsic) fields.

Flyweight complicates the code.

Use flyweight only when profiling has determined that space is a *serious* problem.