CSE 331
Software Design & Implementation

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Design Patterns, Part 1

(Based on slides by Mike Ernst, Dan Grossman, David Notkin, Hal Perkins)

Outline

- Introduction to design patterns
- Creational patterns (constructing objects)

Next lecture:

- 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 description of a software design

- Well-known terminology improves communication/documentation
- Makes it easier to "think to use" a known technique

A few simple examples….

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

- Constrain ways to access the object

Disadvantages:

- Interface may not (efficiently) provide all desired operations to all clients
- Indirection may reduce performance

Example 2: Subclassing (inheritance)

Problem: Repetition in implementations

- Similar abstractions have similar components (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
- Hard to design and specify a superclass [as discussed]

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

Solution:

- The *implementation* performs traversals, does bookkeeping
- Results are communicated to clients via a standard interface (e.g., **`hasNext()`**, **`next()`**)

Disadvantages:

- Iteration order 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
- Hard to remember and deal with code not running if an exception occurs in a callee
- It may be hard to know where an exception will be handled

Example 5: Generics

Problem:

- Well-designed (and used) data structures hold one type of object

Solution:

- Programming language checks for errors in contents
- **`List<Date>`** instead of just **`List`**

Disadvantages:

- More verbose types

Why (more) design patterns?

Advanced programming languages like Java provide many powerful constructs – subtyping, interfaces, rich types and libraries, etc.

- But it's not enough to "know everything in the language"
- Still many common problems not easy to solve

Design patterns are intended to capture common solutions / idioms, name them, make them easy to use to guide design

- For high-level design, not specific "coding tricks"

They increase your vocabulary and your intellectual toolset

Do not overuse them

- Not every program needs the complexity of advanced design patterns
- Instead, consider them to solve reuse/modularity problems that arise as your program evolves

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

- A concise description of a successful “pro-tip”

Origin of term

The “Gang of Four” (GoF)

- Gamma, Helm, Johnson, Vlissides

Found they shared a number of “tricks” and decided to codify them

- A key rule was that nothing could become a pattern unless they could identify at least three real [different] examples
- Done for object-oriented programming
  - Some patterns more general; others compensate for OOP shortcomings
  - But any “paradigm” should have design patterns

Patterns vs. patterns

The phrase *pattern* has been wildly overused since the GoF patterns have been introduced

Misused as a synonym for “[somebody says] **X** is a good way to write programs.”

- And “anti-pattern” has become a synonym for “[somebody says] **Y** is a bad way to write programs.”

GoF-style patterns have richness, history, language-independence, documentation and thus (most likely) far more staying power

An example GoF pattern

For some class **C**, guarantee that at run-time there is exactly one instance of **C**

- And that the instance is globally visible

First, *why* might you want this?

- What design goals are achieved?

Second, *how* might you achieve this?

- How to leverage language constructs to enforce the design

A pattern has a recognized *name*

- This is the *Singleton Pattern*

Possible reasons for Singleton

- One **`RandomNumber`** generator
- One **`KeyboardReader`**, **`PrinterController`**, etc…
- Have an object with fields/properties that are “like public, static fields” but you can have a constructor decide their values
  - Maybe strings in a particular language for messages

- Make it easier to ensure some key invariants
  - There is only one instance, so never mutate the wrong one

- Make it easier to control when that single instance is created
  - If expensive, delay until needed and then don’t do it again

How: multiple approaches

```
public class Foo {
  private static final Foo instance = new Foo();
  // private constructor prevents instantiation outside class
  private Foo() { … }
  public static Foo getInstance() {
    return instance;
  }
  … instance methods as usual …
}
```

Eager allocation of instance

```
public class Foo {
  private static Foo instance;
  // private constructor prevents instantiation outside class
  private Foo() { … }
  public static synchronized Foo getInstance() {
    if (instance == null) {
      instance = new Foo();
    }
    return instance;
  }
  … instance methods as usual …
}
```

Lazy allocation of instance

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, Flyweight, 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

Creational patterns

Constructors in Java are inflexible

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

Factories: Patterns for code that you call to get new objects other than constructors

- Factory method, Factory object, Prototype, Dependency injection

Sharing: Patterns for reusing objects (to save space *and* other reasons)

- Singleton, Interning, Flyweight

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

- Must decide concrete implementation *somewhere*
- Don’t want to change code to use a different constructor
- Factory methods put this decision behind an abstraction

Use of factories

Factory

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

Clients call **`createMatrix`** instead of a particular constructor

Advantages:

- To switch the implementation, change only *one* place
- **`createMatrix`** can do arbitrary computations to decide what kind of matrix to make (unlike what's shown above)

`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
- The subtype created by factory call need not be specified

```
DateFormat df1 = DateFormat.getDateInstance();
DateFormat df2 = DateFormat.getTimeInstance();
DateFormat df3 = DateFormat.getDateInstance
                   (DateFormat.FULL, Locale.FRANCE);

Date today = new Date();

df1.format(today)  // "Jul 4, 1776"
df2.format(today)) // "10:15:00 AM"
df3.format(today));// "juedi 4 juillet 1776"
```

Example: Bicycle race

```
class Race {
  public Race() {
    Bicycle bike1 = new Bicycle();
    Bicycle bike2 = new Bicycle();
    …
  }
  …
}
```

New example:

- No factories yet
- Coming: factories for the *bicycles* to get flexibility and code reuse
- Could also use factories for the *races*, but that complicates the example, so will stick with constructors

Example: Tour de France

```
class TourDeFrance extends Race {
  public TourDeFrance() {
    Bicycle bike1 = new RoadBicycle();
    Bicycle bike2 = new RoadBicycle();
    …
  }
  …
}
```

The problem: We are reimplementing the constructor in every **`Race`** subclass just to use a different subclass of **`Bicycle`**

Example: Cyclocross

```
class Cyclocross extends Race {
  public Cyclocross() {
    Bicycle bike1 = new MountainBicycle();
    Bicycle bike2 = new MountainBicycle();
    …
  }
  …
}
```

The problem: We are reimplementing the constructor in every **`Race`** subclass just to use a different subclass of **`Bicycle`**

Factory *method* for Bicycle

```
class Race {
  Bicycle createBicycle() { return new Bicycle(); }
  public Race() {
    Bicycle bike1 = createBicycle();
    Bicycle bike2 = createBicycle();
    ...
  }
}
```

Use a factory method to avoid dependence on specific new kind of bicycle in the constructor

- Call the factory method instead

Subclasses override factory method

```
class TourDeFrance extends Race {
  Bicycle createBicycle() {
    return new RoadBicycle();
  }
  public TourDeFrance() { super(); }
}
class Cyclocross extends Race {
  Bicycle createBicycle() {
    return new MountainBicycle();
  }
  public Cyclocross() { super(); }
}
```

- “Foresight” to use factory method in superclass constructor
- Then dynamic dispatch to call overridden method
- Subtyping in the overriding methods (covariant returns type also ok)
- Would look like even more code reuse outside of constructors
  - Example: Can inherit an **`addBicycle`** that calls **`createBicycle`**

Next step

- **`createBicycle`** was just a factory method
- Now let's move the method into a separate class
  - So it's part of a *factory object*
- Advantages:
  1. Can group related factory methods together
     - Not shown: **`repairBicycle`**, **`createSpareWheel`**, …
  2. Can pass factories around as objects for flexibility
     - Choose a factory at runtime
     - Use different factories in different objects (e.g., races)
     - Example…

Factory ***objects***/**classes** encapsulate factory method(s)

```
class BicycleFactory {
  Bicycle createBicycle() {
   return new Bicycle();
  }
}
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;
  public Race(BicycleFactory f) {
    bfactory = f;
    Bicycle bike1 = bfactory.createBicycle();
    Bicycle bike2 = bfactory.createBicycle();
    …
  }
  public Race() { this(new BicycleFactory()); }
  …
}
```

Setting up the flexibility here:

- Factory object stored in a field, set by constructor
- Can take the factory as a constructor-argument
- But an implementation detail (?), so 0-argument constructor too
  - Java detail: call another constructor in same class with **`this`**

The subclasses

```
class TourDeFrance extends Race {
  public TourDeFrance() {
    super(new RoadBicycleFactory());
  }
}

class Cyclocross extends Race {
  public Cyclocross() {
    super(new MountainBicycleFactory());
  }
}
```

Voila!

- Just call the superclass constructor with a different factory
- **`Race`** class had foresight to delegate "what to do to create a bicycle" to the factory object, making it more reusable

Separate control over bicycles and races

```
class TourDeFrance extends Race {
  public TourDeFrance() {
    super(new RoadBicycleFactory()); // or this(…)
  }
  public TourDeFrance(BicycleFactory f) {
    super(f);
  }
  …
}
```

By having factory-as-argument option, we can allow arbitrary mixing by client: **`new TourDeFrance(new TricycleFactory())`**

Less useful in this example (?): Swapping in different factory object whenever you want

Reminder: Not shown here is also using factories for creating *races*

Prototype pattern

- Every object is itself a factory
- Each class contains a **`clone`** method that creates a copy of the receiver object

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

Often, **`Object`** is the return type of **`clone`**

- **`clone`** is declared in **`Object`**
- Design flaw in Java 1.4 and earlier: the return type may not change covariantly in an overridden method

  i.e., return type could not be made more restrictive

Using prototypes

```
class Race {
  Bicycle bproto;

  public Race(Bicycle bproto) {
    this.bproto = bproto;
    Bicycle bike1 = (Bicycle) bproto.clone();
    Bicycle bike2 = (Bicycle) bproto.clone();
    ...
  }
}
```

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

```
    new Race(new Tricycle())
```

Dependency injection

- Change the factory without changing the code
- With a regular in-code factory:

```
BicycleFactory f = new TricycleFactory();
Race r = new TourDeFrance(f)
```

- With external dependency injection:

```
BicycleFactory f = ((BicycleFactory)
        DependencyManager.get("BicycleFactory"));
Race r = new TourDeFrance(f);
```

- *Plus* an external file:

```
<service-point id="BicycleFactory">
  <invoke-factory>
    <construct class="Bicycle">
      <service>Tricycle</service>
    </construct>
  </invoke-factory>
</service-point>
```

+ Change the factory without recompiling
- External file is essential part of program

Factories: summary

Problem: want more flexible abstractions for what class to instantiate

Factory method

- Call a method to create the object
- Method can do any computation and return any subtype

Factory object

- Bundles factory methods for a family of types
- Can store object in fields, pass to constructors, etc.

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 or even recompiling when decision changes

Sharing

Recall the second weakness of Java constructors

Java constructors 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)

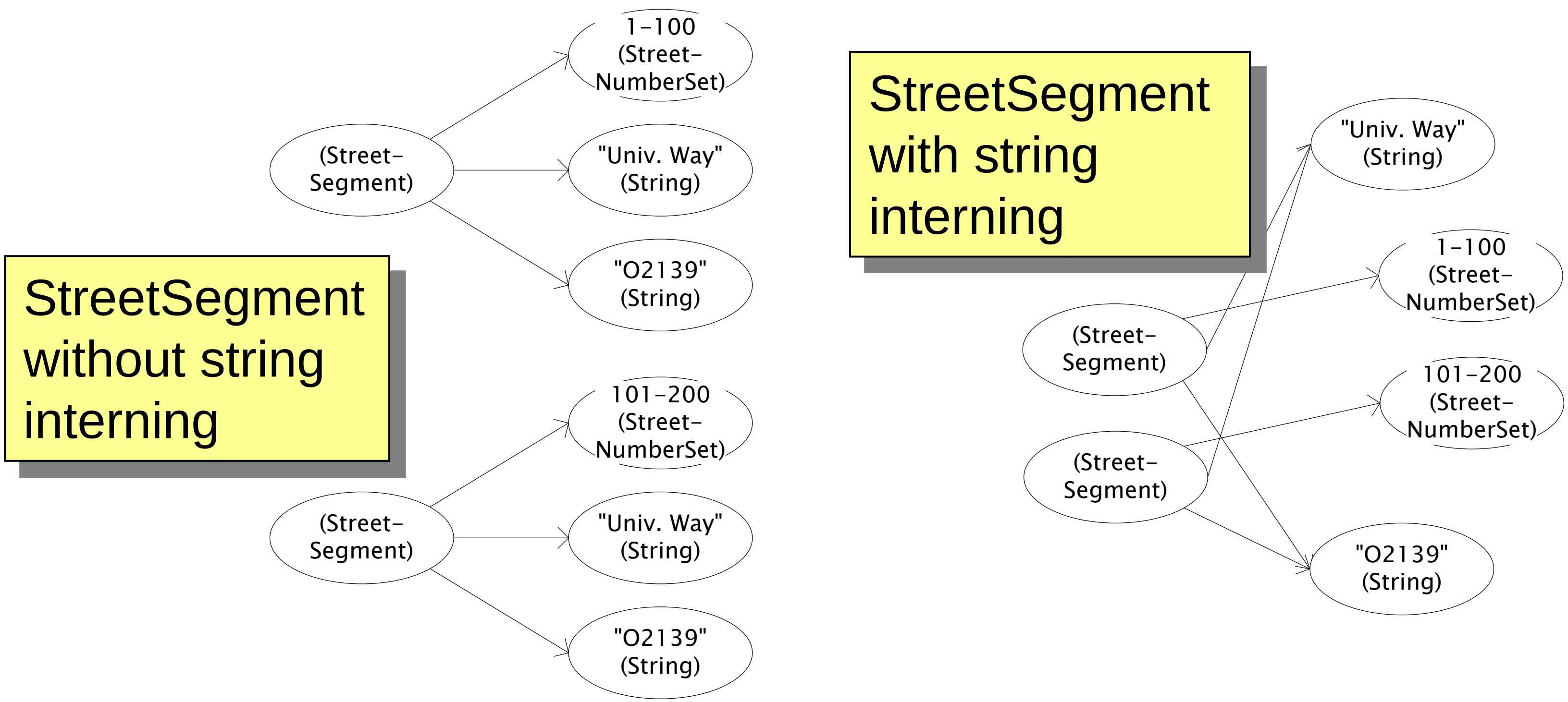
Interning: only one object with a particular (abstract) value exists at runtime

- Factory method returns an existing object, not a new one

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

Interning pattern

- Reuse existing objects instead of creating new ones
  - Less space
  - May compare with **==** instead of **`equals()`**
- Sensible only for immutable objects



Interning mechanism

- Maintain a collection of all objects
- If an object already appears, return that instead

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

Why not `Set<String>` ?

`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

Space leaks

- Interning can waste space if your collection:
  - Grows too big
  - With objects that will never be used again
- Not discussed here: The solution is to use *weak references*
  - This is their canonical purpose
- Do not reinvent your own way of keeping track of whether an object in the collection is being used
  - Too error-prone
  - Gives up key benefits of garbage-collection

`java.lang.Boolean` does not use the Interning pattern

```
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.

Flyweight pattern

Good when many objects are *mostly* the same

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

Intrinsic state: Independent of object's "context"

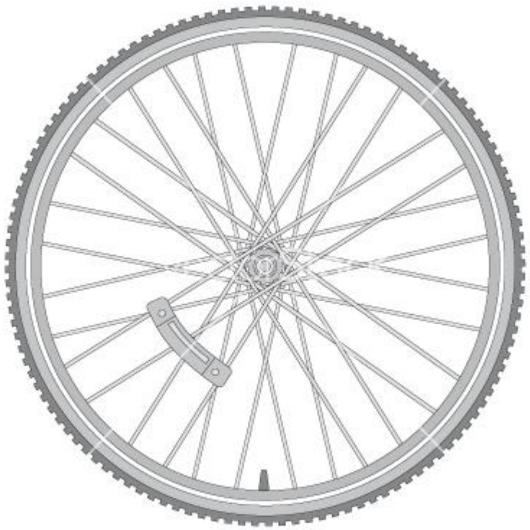
- Often same across many objects and immutable
- Technique: intern it

Extrinsic state: different for different objects; depends on "context"

- Have clients store it separately, or better:
- Advanced technique:
  - Make it implicit (clients *compute* it instead of represent it)
  - Saves space

Example without flyweight: bicycle spoke

```
class Wheel {
  FullSpoke[] spokes;
  ...
}
class FullSpoke {
  int length;
  int diameter;
  boolean tapered;
  Metal material;
  float weight;
  float threading;
  boolean crimped;
  int location;  // position on the rim
}
```



- 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 does *not* save space compared to **`FullSpoke`**

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

This *does* saves space

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

But flyweight version [still coming up] uses even less space…

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) ...
    }
  }
}
```

What is the value of the **location** field in **spokes[i]**?

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) ...
    }
  }
}
```

What happened

- *Logically*, each spoke is a different object
  - A spoke “has” all the intrinsic state and a location
- But if that would be a lot of objects, i.e., space usage, we can instead…
- Create *one actual* flyweight object that is used “in place of” all logical objects that have that intrinsic state
  - Use interning to get the sharing
  - Clients store or compute the extrinsic state and pass it to methods to get the right behavior
  - Only do this when logical approach is cost-prohibitive and it’s not too complicated to manage the extrinsic state
    - Here spoke location was particularly easy and cheap because it was implicit in array location of reference

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`** field **`broken`**?

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

Flyweight: resist it

- 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