CSE 331
Software Design & Implementation

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Design Patterns I

(Slides by Mike Ernst and David Notkin)

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 (static structure)
  - the shape of a heap snapshot or object model (dynamic structure)

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
  - 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 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

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
    - The implementation has knowledge about the representation
  - Results are communicated to clients via a standard interface (e.g., **`hasNext(), next()`**)
- 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:
  - More verbose types

Why design patterns?

- Advanced programming languages like Java provide lots of powerful constructs – subtyping, interfaces, rich types and libraries, etc.
- By the nature of programming languages, they can't make everything easy to solve
- To the first order, design patterns are intended to overcome common problems that arise in even advanced object-oriented programming languages
- They increase your vocabulary and your intellectual toolset

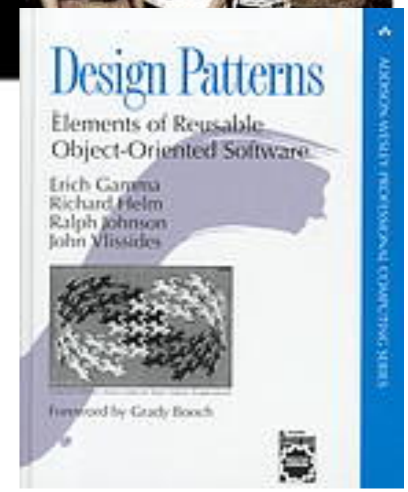
When (not) to use design patterns

- Rule 1: delay
  - Get something basic working first
  - 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

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

Whence design patterns?



- The Gang of Four (GoF) – Gamma, Helm, Johnson, Vlissides
- Each an aggressive and thoughtful programmer
- Empiricists, not theoreticians
- 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 examples

Patterns vs. patterns

- The phrase “pattern” has been wildly overused since the GoF patterns have been introduced
- “pattern” has become 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.”
- A graduate student recently studied so-called “security patterns” and found that very few of them were really GoF-style patterns
- GoF-style patterns have richness, history, language-independence, documentation and thus (most likely) far more staying power

An example of a GoF pattern

- Given a class C, what if you want to guarantee that there is precisely one instance of C in your program? And you want that instance globally available?
- First, why might you want this?
- Second, how might you achieve this?

Possible reasons for Singleton

- One `RandomNumber` generator
- One graph model object
- One `KeyboardReader`, etc…
- Make it easier to ensure some key invariants
- Make it easier to control when that single instance is created – can be important for large objects
- …

Several solutions

```
public class Singleton {
  private static final Singleton instance
      = new Singleton(); // Private constructor prevents
                         // instantiation from other classes
  private Singleton() { }
  public static Singleton getInstance() {
    return instance;
  }
}
```

Eager allocation of instance

```
public class Singleton {
  private static Singleton instance;
  private Singleton() { }
  public static synchronized Singleton getInstance() {
    if (instance == null) {
      instance = new Singleton();
    }
    return instance;
  }
}
```

Lazy allocation of instance

GoF patterns: three categories

- Creational Patterns – these abstract the object-instantiation process
  - Factory Method, Abstract Factory, Singleton, Builder, Prototype, …
- Structural Patterns – these abstract how objects/classes can be combined
  - Adapter, Bridge, Composite, Decorator, Façade, Flyweight, Proxy, …
- Behavioral Patterns – these abstract communication between objects
  - Command, Interpreter, Iterator, Mediator, Observer, State, Strategy, Chain of Responsibility, Visitor, Template Method, …

- Blue = ones we've seen already

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
- 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 for bicycle race
  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();
    ...
  }
}
```

- Use a factory method to avoid dependence on specific new kind of bicycle in **`createRace`**()

Code using Bicycle 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.
- 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() { ... }
}
```

- 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
    - This is a problem for achieving true subtyping

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())
```

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
- Harder to understand
- Easier to make mistakes

Sharing

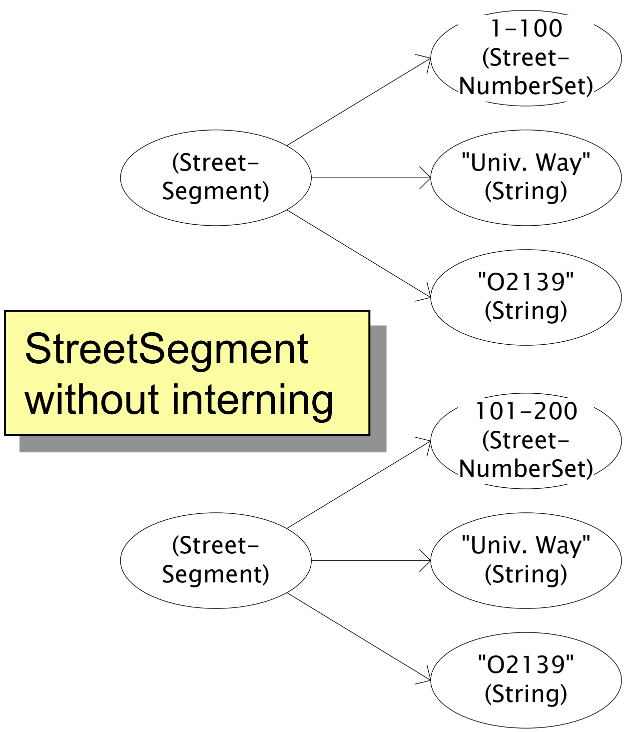
Recall the second weakness of Java constructors

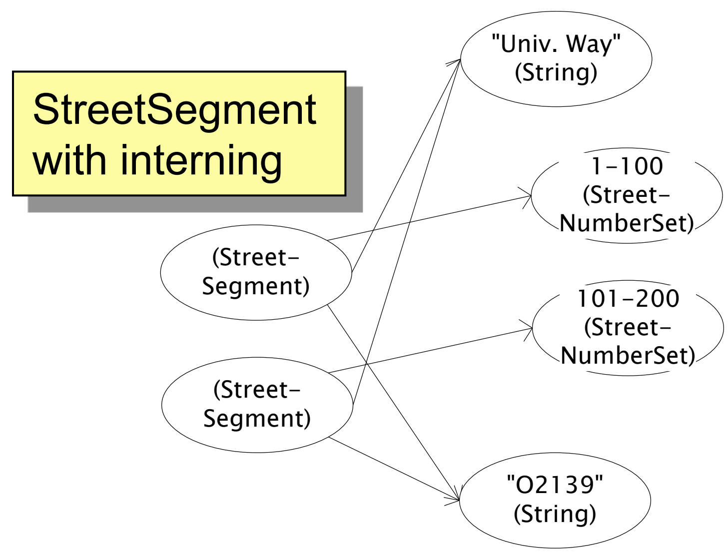
Java constructors always return a new object, never a pre-existing object

- Singleton: only one object exists at runtime
  - Factory method returns the same object every time (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
  - Implicit representation uses no space

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

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 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: same across all objects
  - Technique: intern it (interning requires immutability)
- Extrinsic state: different for different objects
  - Represent it explicitly
  - Advanced technique: make it implicit (don't even represent it!)
    - Making it implicit requires immutability (or other properties)

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 save space: it's the same as FullSpoke

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

This saves space

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

… but flyweight version 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, which affects the wheel
      ... spokes[i].tighten(numturns, i) ...
    }
  }
}
```

Flyweight discussion

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

- What if **`FullSpoke`** contains a **`wheel`** field pointing at the **`Wheel`** containing it?
- What if **`FullSpoke`** contains a **`boolean`** broken field?

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