Design Patterns (1)

CSE 331
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What is a design pattern?

• A standard solution to a common programming problem
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 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

• 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
Other examples

• Reuse implementation without subtyping
• Reuse implementation, but change interface
• Permit a class to be instantiated only once
• Constructor that might return an existing object
• Constructor that might return a subclass object
• Combine behaviors without compile-time extends clauses
Why should you care about design patterns?

• 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
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
  – connections among program components
  – the shape of a heap snapshot or object model
• Vocabulary for communication & documentation
Why do we need design patterns?

• The programming language does not build in solutions to every problem (why not?)
  – Best solution depends on context
  – Every language has shortcomings
    • So does every paradigm: OO, functional, declarative, ...
  – Language features start out as design patterns
When (not) to use design patterns

• Rule 1: delay
  – Get something basic and concrete working first
  – Improve or generalize it once you understand it

• Design patterns can increase or decrease understandability
  – Usually adds indirection, increases code size
  – Improves modularity and flexibility, separates concerns, eases 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 Gamma, Helm, Johnson, and Vlissides

• Another good reference for Java
  – Effective Java: Programming Language Guide, by Bloch
Outline

• Introduction to design patterns
• **Creational** patterns
  – constructing objects
• **Structural** patterns
  – combining objects, controlling heap layout
• **Behavioral** patterns
  – communicating among objects, affecting object semantics
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 – ADT creators that are not Java constructors
  - Factory method
  - Factory object
  - Prototype
  - Dependency injection

- Sharing – reuse objects (save space)
  - Singleton – only one object ever exists
  - Interning – only one object with a given abstract value exists
  - Flyweight – share part of an object’s representation
Factories

- Problem: client desires control over object creation
- **Factory method** = creator method
  - Hides decisions about object creation
  - Implementation: put code in methods in client
- **Factory object** = has a creator op, can be *passed around*
  - Bundles factory methods for a family of types
  - Implementation: put code in a separate object
- **Prototype** = knows how to clone itself
  - Every object is a factory, can create more objects like itself
  - Implementation: put code in `clone` methods
- **Dependency injection** = external reference to a creator op
  - Client controls construction, without changing code
  - Implementation: read method name from a file, call reflectively
Motivation for factories: Changing implementations

• A supertype may have multiple implementations

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

• Clients declare variables using the supertype (**Matrix**)
  – Clients must use a **SparseMatrix** or **DenseMatrix** constructor
    • Code: `new SparseMatrix(...)` or `new DenseMatrix(...)`
  – Switching implementations requires **code changes 😞**
Use of factories

Factory

class MatrixFactory {
    public static Matrix createMatrix(...) {
        if (...) {
            return new SparseMatrix(...);
        } else {
            return new DenseMatrix(...);
        }
    }
}

Clients call `createMatrix`, not a particular constructor

Advantages

To switch the implementation, only change one place

Factory method can decide at run time what to create
Factory method in the JDK

class Calendar {
    static Calendar getInstance(Locale);
}

might return a BuddhistCalendar, JapaneseImperialCalendar, GregorianCalendar, ...
class Race {
    public Race() {
        Bicycle bike1 = new Bicycle();
        Bicycle bike2 = new Bicycle();
        ...
    }
}
Specializations of bicycle race

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

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

Reimplemented the constructor just to use a different subclass of Bicycle
class Race {

    Race() {
        Bicycle bike1 = new Bicycle();
        Bicycle bike2 = new Bicycle();
        ...
    }
}

Bicycle race without factories
class Race {
    Bicycle createBicycle() { return new Bicycle(); }
    Race() {
        Bicycle bike1 = createBicycle();
        Bicycle bike2 = createBicycle();
        ...
    }
}

Defining and using a factory method requires foresight.
class Race {
    Bicycle createBicycle() { return new Bicycle(); }
    Race() {
        Bicycle bike1 = createBicycle();
        Bicycle bike2 = createBicycle();
        ...
    }
}

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

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

Could make this a factory method, too

No need to override constructor!
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 {
    public Race(BicycleFactory bfactory) {
        Bicycle bike1 = bfactory.createBicycle();
        Bicycle bike2 = bfactory.createBicycle();
        ...
    }
}

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

class Cyclocross extends Race {
    public Cyclocross() {
        this(new MountainBicycleFactory());
    }
}
Separate control over bicycles and races

class Race {
    public Race(BicycleFactory bfactory) {
        Bicycle bike1 = bfactory.createBicycle();
        Bicycle bike2 = bfactory.createBicycle();
        ...
    }
}

No need for a constructor for TourDeFrance or Cyclocross

Delegate bicycle creation to a factory object ⇒ flexibility

  – Specify the race and the bicycle separately
    
    new TourDeFrance(new TricycleFactory())

  – Change the factory at run time by setting the field.

Might want a default constructor: new TourDeFrance()
Prototype pattern

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

```java
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
Using prototypes

class Race {

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

    Compare to using a factory object:
    public Race(BicycleFactory bfactory) {
        Bicycle bike1 = bfactory.createBicycle();
    }
}

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 factory object:
  ```java
  BicycleFactory f = new TricycleFactory();
  Race r = new TourDeFrance(f)
  ```
- With external dependency injection:
  ```java
  BicycleFactory f = (BicycleFactory) DependencyManager.get("BicycleFactory");
  Race r = new TourDeFrance(f);
  ```
- **Plus** an external file:
  ```xml
  <service-point id="BicycleFactory">
    <invoke-factory>
      <construct class="Bicycle">
        <service>Tricycle</service>
      </construct>
    </invoke-factory>
  </service-point>
  ```

  + Change the factory without recompiling
  - Program requires external file to run
  - Mistakes in the file are caught at run time
Aside: Reflection (= meta-programming)

• Call a method named by a string

Ordinary code:  `Date y = MyClass.foo();`
Reflective code:

```java
String className = "MyClass";
String methodName = "foo";
Class[] paramTypes = {};
Object[] args = {};
Class clazz = Class.forName(className);
// above line has same effect as:  clazz = MyClass.class
Method method = clazz.getMethod(methodName, paramTypes);
Date y = (Date) method.invoke(null, args);
```

• Ask an object all its methods and fields
• Etc.

Powerful
Error-prone, confusing,
no compile-time checking
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
• Shared resource
• Examples:
  – Cache
  – FileSystem, ThreadPool, Runtime
  – I/O: KeyboardReader, PrinterController, Desktop
  – Logger for diagnostic messages
  – Configuration file
• An object has fields like “static fields” but a constructor decides their values
  – Logically group the values (don’t pollute namespace)
  – Example: Internationalization: messages in a particular language
Singleton

Only one object of the given type exists

class Bank {
    private static Bank theBank;

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

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

...
Singleton

Only one object of the given type exists

class Bank {
    private static Bank theBank;

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

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

What are the tradeoffs between the two approaches?
Interning pattern

• Reuse existing objects instead of creating new ones
  – Less space
  – May compare with == instead of equals()

• Sensible only for immutable objects

• Java builds this in for strings: `String.intern()`
How to implement interning

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

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

• Two approaches:
  – Create the object, but perhaps discard it and return another
  – Check against the arguments before creating the new object

This ought to use *weak references.*

Why not Set<String>?

Set supports contains (which uses equals) but not get; no good way to get the canonical value.

Why not return n?

It is not the canonical value.
The constructor of the `Boolean` class does not use interning.

```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 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.
Save space by not storing data twice (one aspect of “Flyweight” pattern)

class Edge {
    Node start;
    Node end;
    String label;
}

class Graph {
    Map<Node, Set<Edge>> edges;
}

// client code
Edge e = g.getFirstEdge(n);
... e.start ... e.end ... e.label ...

class OutgoingEdge {
    Node start;
    Node end;
    String label;
}

class Graph {
    Map<Node, Set<OutgoingEdge>> edges;
}

// client code
Edge e = g.getFirstEdge(n);
... n ... e.end ... e.label ...
Flyweight pattern

• Good when many objects are mostly the same
  – Interning works only if objects are entirely the same and do not change (e.g., 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!)
    • Clients store or compute it
    • Implicit data must not change (or can be recomputed)
Example without flyweight: bicycle spoke

```java
class Wheel {
    FullSpoke[] spokes;
    ...
}

class FullSpoke {
    int length;
    int diameter;
    bool tapered;
    Metal material;
    float weight;
    float threading;
    bool crimped;
    int location;  // position on the rim and hub
}
```

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

// Represents a spoke but not its location
class IntrinsicSpoke {
    int length;
    int diameter;
    boolean tapered;
    Metal material;
    float weight;
    float threading;
    boolean crimped;
    // no location field (FullSpoke has a location field)
}

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 the flyweight version will use even less space
What is the value of the location field in spokes[i]?
Flyweight code to true (align) a wheel

// This class is interned
class IntrinsicSpoke {
    // Tension the spoke by turning the nipple the
    // specified number of turns.
    // modifies: the wheel but not the spoke
    void tighten(int turns, int location) {
        ... location ...    // location is a parameter
    }
}

class Wheel {
    IntrinsicSpoke[] spokes;

    void align() {
        while (wheel is misaligned) {
            // tension the i\textsuperscript{th} spoke, which affects the wheel
            ... spokes[i].tighten(numturns, i) ...
        }
    }
}

Clients store or compute extrinsic state (location).

Represent only the intrinsic state. Use interning to save space.

Logically, each spoke has intrinsic state and a location.

Is this a reasonable abstraction?
Flyweight discussion

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

Flyweight is rarely used

• 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.