CSE 331
Software Design & Implementation

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Design Patterns
What is a design pattern?

A standard **solution** to a common programming problem
   – solution is usually language independent
   – sometimes a problem with some programming languages

Often a **technique** for making code more flexible [modularity]
   – reduces coupling among program components (at some cost)

Shorthand **description** of a software design [readability]
   – a high-level programming idiom
   – well-known terminology improves communication
   – makes it easier to think of using the technique

A couple **familiar** examples…. 
Example 1: Observer

Problem: other code needs to be called each time state changes but we would like the component to be reusable
  – can’t hard-code calls to everything that needs to be called

Solution:
  – object maintains a list of observers with a known interface
  – calls a method on each observer when state changes

Disadvantages:
  – code can be harder to understand
  – wastes memory by maintaining a list of objects that are known a priori (and are always the same)
Example 2: Iteration

Problem: accessing all members of a collection requires performing a specialized traversal for each data structure
– (makes clients strongly coupled to that data structure)

Solution:
– the implementation performs traversals, does bookkeeping
– results are communicated to clients via a standard interface (e.g., `hasNext()`, `next()`)

Disadvantages:
– less efficient: creates extra objects, runs extra code
– iteration order fixed by the implementation, not the client (you can have return different types of iterators though...)
Why (more) design patterns?

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

– language independent
– high-level designs, not specific “coding tricks”

They increase your vocabulary and your intellectual toolset

Often important to fix a problem in the underlying language:

– limitations of Java constructors
– lack of named parameters to methods
– lack of multiple dispatch
Why not (more) design patterns?

As with everything else, do not overuse them

- introducing new abstractions to your program has a cost
  - it can make the code more complicated
  - it takes time
- don’t fix what isn’t broken
  - wait until you have good evidence that you will run into the problem that pattern is designed to solve
Origin of term

The “Gang of Four” (GoF)
  – Gamma, Helm, Johnson, Vlissides
  – examples in C++ and SmallTalk

Found they shared several “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
  – for object-oriented programming
    • some patterns more general
    • others compensate for OOP shortcomings
Patterns vs patterns

The phrase *pattern* has been overused since GoF book

Often used as “[somebody says] X is a good way to write programs”
  – and “anti-pattern” as “Y is a bad way to write programs”

These are useful, but GoF-style patterns are more important
  – they have richness, history, language-independence, documentation and (most likely) more staying power
An example GoF pattern

For some class $C$, guarantee that at run-time there is exactly one (globally visible) instance of $C$

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...
• One `CampusPaths`?

• Have an object with fields / methods that are “like public, `static` fields / methods” but have a `constructor` decide their values
  – cannot be static because need run time info to create
  – e.g., have `main` decide which files to give `CampusPaths`
  – rest of the code can assume it exists

• Other benefits in certain situations
  – could delay expensive constructor until needed
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 ...
}

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 ...
}
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

Green = ones we’ve seen already
Creational patterns

Especially large number of **creational** patterns
Key reason is that Java constructors have limitations...
1. Can't return a subtype of the class
2. Can’t reuse an existing object
3. Don’t have useful names

Factories: patterns for how to create new objects
- Factory method, Factory object / Builder, Prototype

Sharing: patterns for reusing objects
- Singleton, Interning
Motivation for factories: Changing implementations

Super-types support multiple implementations

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

Clients use the supertype (`Matrix`)

BUT still call `SparseMatrix` or `DenseMatrix` constructor

- must decide concrete implementation `somewhere`
- might want to make the decision in one place
  - rather than all over in the code
- part that knows what to create could be far from uses
- factory methods put this decision behind an abstraction
Use of factories

class MatrixFactory {
    public static Matrix createMatrix(float density) {
        return (density <= 0.1) ?
            new SparseMatrix() : new DenseMatrix();
    }
}

Clients call createMatrix instead of a particular constructor

Advantages:
  – to switch the implementation, change only one place
**DateFormat** factory methods

**DateFormat** class encapsulates how to format dates & times
- options: just date, just time, date+time, w/ timezone, etc.
- instead of passing all options to constructor, use factories
- the subtype created by factory call need not be specified
- factory methods (unlike constructors) have useful **names**

```java
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); // "jeudi 4 juillet 1776"
```
Example: Bicycle race

class BikeRace {
    public BikeRace() {
        Bicycle bike1 = new Bicycle();
        Bicycle bike2 = new Bicycle();
        ... // assume lots of other code here
    }
    ...
}

Suppose there are different types of races
Each race needs its own type of bicycle…
Example: Tour de France

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

The Tour de France needs a road bike…
Example: Cyclocross

class Cyclocross extends BikeRace {
    public Cyclocross() {
        Bicycle bike1 = new MountainBicycle();
        Bicycle bike2 = new MountainBicycle();

        ...
    }
    ...
}

And the cyclocross needs a mountain bike.

**Problem**: must override the constructor in every BikeRace subclass just to use a different subclass of Bicycle
Factory method for Bicycle

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

Solution: use a factory method to avoid choosing which type to create
    – let the subclass decide by overriding createBicycle
Subclasses override factory method

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

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

• Requires foresight to use factory method in superclass constructor
• Subtyping in the overriding methods!
• Supports other types of reuse (e.g. addBicycle could use it too)
A Brief Aside

Did you see what that code just did?

- it called a subclass method from a constructor!
- factory methods should usually be static methods
Super/Subclass Coupling

Examples of tight coupling between subclass and superclass:

• presence of self-calls
  – subclass can see which methods call which others

• order of calls self-calls
  – subclass can see which method is called first
  – (distinct from the previous case)

• subclass calls where rep invariant does not hold
  – sometimes necessary in the superclass (e.g., when mutating)
  – subclass can see that the state is invalid

EJ: Either design for inheritance or prohibit it (make class final)
Factory objects

- Let’s move the method into a separate class
  - so that it is part of a factory object

- Advantages:
  - no longer risks horrifying bugs
  - can pass factories around at runtime
    - e.g., let main decide which one to use

- Disadvantages:
  - uses bit of extra memory
  - debugging can be more complex when decision of which object to create is far from where it is used
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();
    }
}

These are returning subtypes
Using a factory object

class BikeRace {
    BicycleFactory bfactory;
    public BikeRace(BicycleFactory f) {
        bfactory = f;
        Bicycle bike1 = bfactory.createBicycle();
        Bicycle bike2 = bfactory.createBicycle();
        ...
    }
    public BikeRace() { 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 BikeRace {
    public TourDeFrance() {
        super(new RoadBicycleFactory());
    }
}

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

Voila!

- Just call the superclass constructor with a different factory
- BikeRace 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 BikeRace {
    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
Builder

**Builder**: object with methods to describe object and then create it

- fits especially well with immutable classes when clients want to add data a bit at a time
  - (mutable Builder creates immutable object)

**Example 1: StringBuilder**

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

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

Example 2: `Graph.Builder`
- `addNode`, `addEdge`, and `createGraph` methods
- (static inner class `Builder` can use `private` constructors)
- `containsNode` etc. may not need to be especially fast
Enforcing Constraints with Types

• These examples use the type system to enforce constraints

• Constraint is that some methods should not be called until after the “finish” method has been called
  – solve by splitting type into two parts
  – Builder part has everything that can be called before “finish”
  – normal object has everything that can be called after “finish”

• This approach can be used with other types of constraints
• Instead of asking clients to remember not to violate them, see if you can use type system to enforce them
  – use tools rather than just reasoning

• (This can be done in a general manner, but it’s way out of scope for this class.)
Builder Idioms

Builder classes are often written like this:

```java
class FooBuilder {
    public FooBuilder setX(int x) {
        this.x = x;
        return this;
    }
    public Foo build() { ... }
}
```

so that you can use them like this:

```java
Foo f = new FooBuilder().setX(1).setY(2).build();
```
Methods with Many Arguments

• Builders useful for cleaning up methods with too many arguments
  – recall the problem that clients can easily mix up argument order

  E.g., turn this
  
  ```java
  myMethod(x, y, true, false, true);
  ```

  into this
  
  ```java
  myMethod(x, y, Options.create()
      .setA(true)
      .setB(false)
      .setC(true).build());
  ```

  This simulates named (rather than positional) argument passing.
Prototype pattern

• Each object is itself a factory:
  – objects contain a **clone** method that creates a copy

• Useful for objects that are created via a process
  – Example: java.awt.geom.AffineTransform
    • create by a sequence of calls to translate, scale, etc.
    • easiest to make a similar one by copying and changing
  – Example: android.graphics.Paint
  – Example: JavaScript classes
    • use prototypes so every instance doesn’t have all methods stored as fields
Factories: summary

Goal: 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 (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