CSE 331
Software Design & Implementation

Topic: Design Patterns I

💬 Discussion: What do you do to prevent being burned out?
Reminders

• No extensions on HW9 (one late day only)
  • Will not accept any work after Aug. 19 (Friday) at 11pm

Upcoming Deadlines

• Prep. Quiz: HW8 due Monday (8/08)
• HW8 due Thursday (8/11)
Last Time...

- Examples
  - Messaging App
- Debugging

Today’s Agenda

- History of Design Patterns
- Creational Design Patterns
  - Factories
  - Builder
  - Prototype
  - Singleton
  - Interning
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: Iterator

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 sent to clients via a standard interface (e.g., `hasNext()`, `next()`)

What are the disadvantages of this?
Example 2: Iterator

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 sent 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 are used to solve many otherwise difficult problems
  - are language independent
  - well-documented
  - (most likely) will be around for a long time
An example GoF pattern

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

First, \textit{why} might you want this?
- what design goals are achieved?

Second, \textit{how} might you achieve this?
- how to leverage language constructs to enforce the design

A pattern has a recognized \textit{name}
- this is the \textit{Singleton} pattern
Possible reasons for Singleton

- One `RandomNumber` generator
- One `KeyboardReader, Logger, 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
}
How: multiple approaches

```java
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

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 static factory methods

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

```
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

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

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

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

And the cyclocross needs a mountain bike.

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

```java
class Race {
    Bicycle bike1, bike2;

    Bicycle createBicycle() { return new Bicycle(); }

    public Race() {
        bike1 = createBicycle();
        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

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

class Cyclocross extends Race {
    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
- 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** encapsulate factory method(s)

```java
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();
    }
}

Note: Ok to return subtypes of Bicycle!
```
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
Builder

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

- fits 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 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: return this

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

You can use this type of Builder like so:

    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
Before next class...

1. Finish Prep. Quiz: HW8
   - Practice some React questions

2. Begin implementing HW8 early!
   - React is new, you will likely have many questions
   - See examples from lecture + section for ideas