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: 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 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:

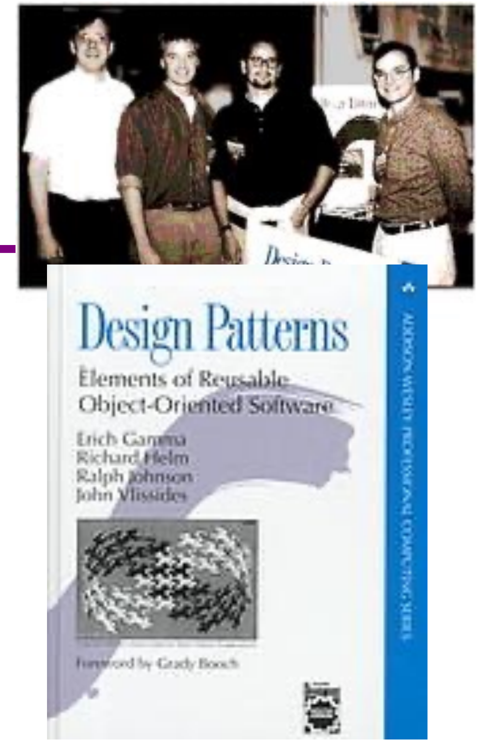
- limitations of Java constructors
- lack of named parameters to methods
- lack of multiple dispatch

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

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

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

```
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 <u>names</u>

```
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 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

```
class Race {
  Bicycle createBicycle() { return new Bicycle(); }
  public Race() {
    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 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

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

Example 1: **`StringBuilder`**

```
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:

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

so that you can use them like this:

```
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

```
myMethod(x, y, true, false, true);
```

into this

```
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