CSE 331

Software Design & Implementation

Topic: Design Patterns I

Reminders

- No extensions on HW9 (one late day only)
    - Will not accept *any* work after Aug. 18 (Friday) at 11pm

Upcoming Deadlines

- Prep. Quiz: HW8 due Monday (8/07)
- HW8 due Thursday (8/10)

Last Time...

- Examples
  - Messaging App
- Debugging (part 1)

Today's Agenda

- Debugging
- History of Design Patterns
- Creational Design Patterns
  - Factories
  - Builder
  - Prototype
  - Singleton
  - Interning

A Bug's Life

defect – mistake committed by a human

error – incorrect computation

failure – visible error: program violates its specification

Debugging starts when a failure is observed

- Unit testing
- Integration testing
- In the field

Goal of debugging is to go *from failure back to defect*

How to Avoid Debugging

Levels of defense against painful debugging:

1. Make errors *impossible*
   - examples: Java prevents type errors, memory corruption
     Python prevents key mutation

2. Don't introduce defects
   - "get things right the first time" (by reasoning & unit testing)

3. Make errors *immediately visible* (often by defensive programming)
   - examples: assertions, **`checkRep`**
   - reduce *distance* from error to failure

(subtle bugs like key mutations are hard to find because of the distance between error and failure)

The bug removal process

step 1: *find (small) repeatable test case that produces the failure*

- smaller test case will make step 2 easier
- do *not* start step 2 until you have a repeatable test

step 2: *narrow down location and cause*

- *loop*: (a) study the data (b) hypothesize (c) experiment
- experiments often involve changing the code
- do *not* start step 3 until you understand the cause

step 3: *fix the defect*

- is it a simple typo or a design flaw?
- does it occur **elsewhere** in the code?

step 4: *run all the tests (including the new one)*

- is this failure fixed? are any other new failures introduced?

Localizing a defect

Sometimes you can take advantage of modularity

- start with everything, take away pieces until failure goes away
- start with nothing, add pieces back in until failure appears

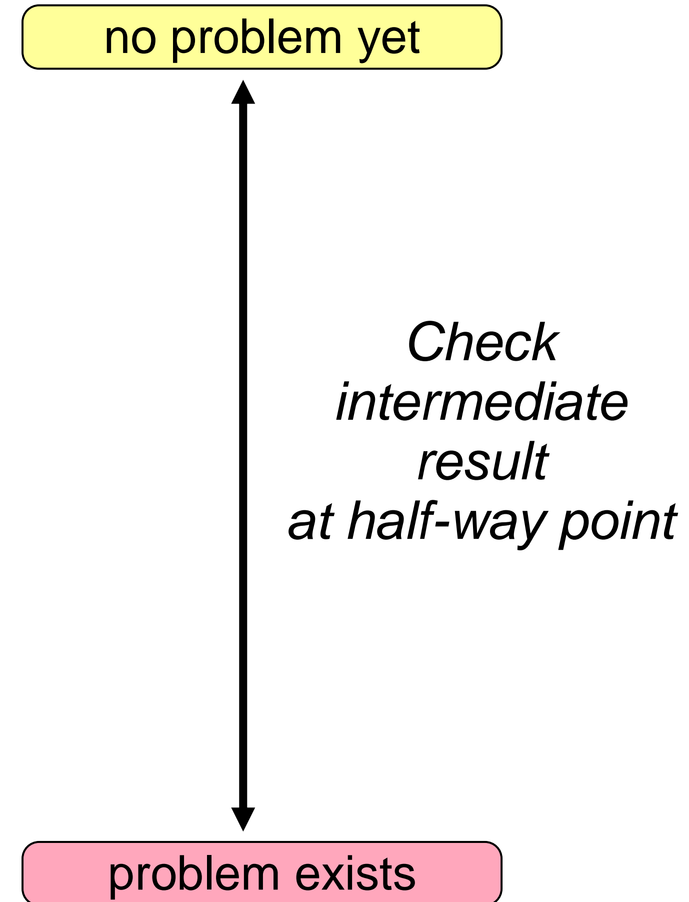
Binary search speeds up this process too

- error happens somewhere between first and last statement
- do binary search on that ordered set of statements
  - is the state correct after the middle statement?

Binary search on buggy code

```
public class MotionDetector {
    private boolean first = true;
    private Matrix prev = new Matrix();

    public Point apply(Matrix current) {
        if (first) {
            prev = current;
        }
        Matrix motion = new Matrix();
        getDifference(prev,current,motion);
        applyThreshold(motion,motion,10);
        labelImage(motion,motion);
        Hist hist = getHistogram(motion);
        int top = hist.getMostFrequent();
        applyThreshold(motion,motion,top,top);
        Point result = getCentroid(motion);
        prev.copy(current);
        return result;
    }
}
```



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        Point result = getCentroid(motion);
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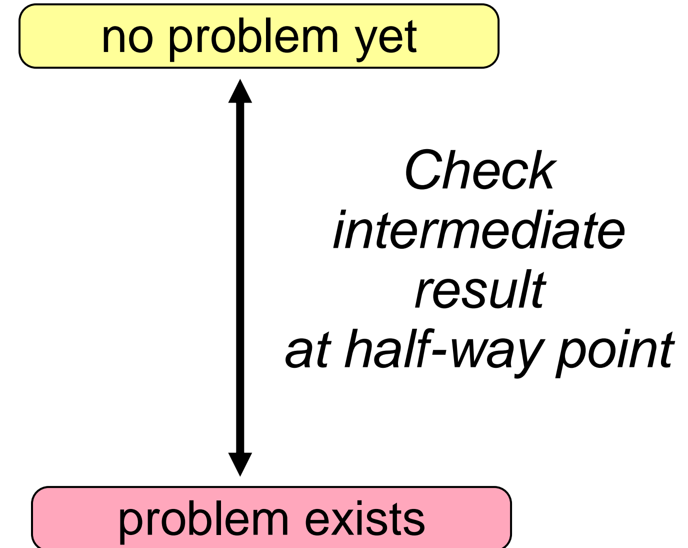


Detecting Bugs in the Real World

Real systems

- large and complex
- collection of modules, written by multiple people
- complex input
- many external interactions
- non-deterministic

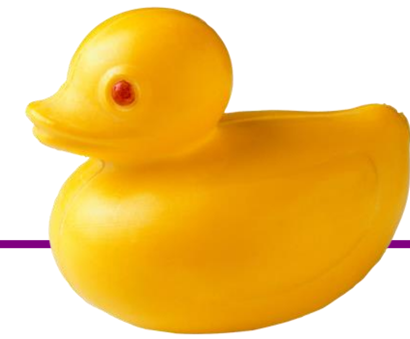
Replication can be an issue

- infrequent failure (the worst)
- instrumentation eliminates the failure (the worst of the worst)

Defects cross abstraction barriers

Large time lag from corruption (error) to detection (failure)

More Tricks for Hard Bugs



Rebuild system from scratch

- bug could be in your build system or persistent data structures

Make sure that you have correct source code

- check out fresh copy from repository; recompile everything

Explain the problem to a friend (or to a rubber duck)

- The Pragmatic Programmer calls this “rubber ducking”

Make sure it is a bug

- program may be working correctly!

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, *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`**, **`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

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

How: multiple approaches

```
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 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

```
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 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

```
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)

```
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`**

```
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

```
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

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