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 description of a software design
- Well-known terminology improves communication/documentation
- Makes it easier to “think to use” a known technique

A few simple examples….

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 the object

Disadvantages:
- Interface may not (efficiently) provide all desired operations to all clients
- Indirection may reduce performance

Example 2: Subclassing (inheritance)

Problem: Repetition in implementations
- Similar abstractions have similar components (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
- Hard to design and specify a superclass [as discussed]

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
- Results are communicated to clients via a standard interface (e.g., hasNext(), next())

Disadvantages:
- Iteration order 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
- Hard to remember and deal with code not running if an exception occurs in a callee
- It may be hard to know where an exception will be handled

Example 5: Generics

Problem:
- Well-designed (and used) 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

Why (more) design patterns?

Advanced programming languages like Java provide many powerful constructs – subtyping, interfaces, rich types and libraries, etc.
- But it’s not enough to “know everything in the language”
- Still many common problems not easy to solve

Design patterns are intended to capture common solutions / idioms, name them, make them easy to use to guide design
- For high-level design, not specific “coding tricks”

They increase your vocabulary and your intellectual toolset

Do not overuse them
- Not every program needs the complexity of advanced design patterns
- Instead, consider them to solve reuse/modularity problems that arise as your program evolves

Why should you care?

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
- A concise description of a successful “pro-tip”

Origin of term

The “Gang of Four” (GoF)
- Gamma, Helm, Johnson, Vlissides

Found they shared a number of “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
- Done for object-oriented programming
  - Some patterns more general; others compensate for OOP shortcomings
  - But any “paradigm” should have design patterns

Patterns vs. patterns

The phrase pattern has been wildly overused since the GoF patterns have been introduced

Misused as a synonym for “[somebody says] X is a good way to write programs.”
- And “anti-pattern” has become a synonym for “[somebody says] Y is a bad way to write programs.”

GoF-style patterns have richness, history, language-independence, documentation and thus (most likely) far more staying power
An example GoF pattern

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

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...
- Have an object with fields/properties that are “like public, static fields” but you can have a constructor decide their values – Maybe strings in a particular language for messages
- Make it easier to ensure some key invariants – There is only one instance, so never mutate the wrong one
- Make it easier to control when that single instance is created – If expensive, delay until needed and then don’t do it again

How: multiple approaches

```java
public class Foo {
    private static final Foo instance = new Foo();
    // private constructor prevents instantiation outside class
    private Foo() { ... } // use with Eager allocation
    public static Foo getInstance() {
        return instance;
    }
    ... instance methods as usual ...
}
```

```java
public class Foo {
    private static Foo instance;
    // private constructor prevents instantiation outside class
    private Foo() { ... } // use with Lazy allocation
    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
- Command, Interpreter, Iterator, Mediator, Observer, State, Strategy, Chain of Responsibility, Visitor, Template Method, ...

Green = ones we’ve seen already

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: Patterns for code that you call to get new objects other than constructors
- Factory method, Factory object, Prototype, Dependency injection

Sharing: Patterns for reusing objects (to save space and other reasons)
- Singleton, Interning, Flyweight

Motivation for factories: Changing implementations

Supertypes support multiple implementations
```java
interface Matrix { ... }
class SparseMatrix implements Matrix { ... }
class DenseMatrix implements Matrix { ... }
```

Clients use the supertype (\( \text{Matrix} \))

Still need to use a \( \text{SparseMatrix} \) or \( \text{DenseMatrix} \) constructor
- Must decide concrete implementation somewhere
- Don’t want to change code to use a different constructor
- Factory methods put this decision behind an abstraction
Use of factories

Factory
class MatrixFactory {
    public static Matrix createMatrix() {
        return new SparseMatrix();
    }
}

Clients call createMatrix instead of a particular constructor

Advantages:
- To switch the implementation, change only one place
- createMatrix can do arbitrary computations to decide what kind of matrix to make

Example: Bicycle race
class Race {
    // factory method for bicycle race
    Race createRace() {
        Bicycle bike1 = new Bicycle();
        Bicycle bike2 = new Bicycle();
        ...
    }
}
The problem: We are reimplementing createRace in every Race subclass just to use a different subclass of Bicycle

Example: Tour de France
class TourDeFrance extends Race {
    // factory method
    Race createRace() {
        Bicycle bike1 = new RoadBicycle();
        Bicycle bike2 = new RoadBicycle();
        ...
    }
}
The problem: We are reimplementing createRace in every Race subclass just to use a different subclass of Bicycle

Example: Cyclocross
class Cyclocross extends Race {
    // factory method
    Race createRace() {
        Bicycle bike1 = new MountainBicycle();
        Bicycle bike2 = new MountainBicycle();
        ...
    }
}
The problem: We are reimplementing createRace in every Race subclass just to use a different subclass of Bicycle

Factory method for Bicycle
class Race {
    Bicycle createBicycle() { ... }
    Race createRace() {
        Bicycle bike1 = createBicycle();
        Bicycle bike2 = createBicycle();
        ...
    }
}

Use a factory method to avoid dependence on specific new kind of bicycle in createRace
- Now the Race factory calls the Bicycle factory

Code using Bicycle factory methods
class Race {
    Bicycle createBicycle() {
        return new Bicycle();
    }
    Race createRace() {
        Bicycle bike1 = createBicycle();
        Bicycle bike2 = createBicycle();
        ...
    }
}
class TourDeFrance extends Race {
    Bicycle createBicycle() {
        return new RoadBicycle();
    }
}
class Cyclocross extends Race {
    Bicycle createBicycle() {
        return new MountainBicycle();
    }
}
Factory objects/classes encapsulate factory methods

```java
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

```java
class Race {
    BicycleFactory bfactory;
    Race() { bfactory = new BicycleFactory(); }
    Race createRace() {
        Bicycle bike1 = bfactory.createBicycle();
        Bicycle bike2 = bfactory.createBicycle();
        ...
    }
}
class TourDeFrance extends Race {
    TourDeFrance() {
        bfactory = new RoadBicycleFactory();
    }
}
class Cyclocross extends Race {
    Cyclocross() {
        bfactory = new MountainBicycleFactory();
    }
}
```

Separate control over bicycles and races

```java
class Race {
    BicycleFactory bfactory;
    // constructor
    Race(BicycleFactory bfactory) { this.bfactory = bfactory; }
    Race createRace() {
        Bicycle bike1 = bfactory.completeBicycle();
        Bicycle bike2 = bfactory.completeBicycle();
        ...
    }
    // No difference in constructors for
    // TourDeFrance or Cyclocross (just give
    // BicycleFactory to super constructor)
    
    Now we can specify the race and the bicycle separately:
    new TourDeFrance(new TricycleFactory())
}
```

DateFormat factory methods

```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"
```

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
  - i.e., return type could not be made more restrictive

Using prototypes

```java
class Race {
    Bicycle bproto;
    // constructor
    Race(Bicycle bproto) { this.bproto = bproto; }
    Race createRace() {
        Bicycle bike1 = (Bicycle) bproto.clone();
        Bicycle bike2 = (Bicycle) bproto.clone();
        ...
    }
    
    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 in-code factory:
  ```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>
  ```

Factories: summary

Problem: 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
- Bundles factory methods for a family of types
- Can store object in fields, pass to constructors, etc.

Prototype
- Every object is a factory, can create more objects like itself
- Call clone to get a new object of same subtype as receiver

Dependency Injection
- Put choice of subclass in a file to avoid source-code changes or even recompiling when decision changes

Sharing

Recall the second weakness of Java constructors

Java constructors always return a new object

Singleton: only one object exists at runtime
- Factory method returns the same object every time (we've seen this already)

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

Interning pattern

- Reuse existing objects instead of creating new ones
  - Less space
  - May compare with == instead of equals()
- Sensible only for immutable objects

Interning mechanism

- Maintain a collection of all objects
- If an object already appears, return that instead
  ```java
  String canonicalName(String n) {
    if (segnames.containsKey(n)) {
      return segnames.get(n);
    } else {
      segnames.put(n, n);
      return n;
    }
  }
  ```
- Java builds this in for strings: String.intern()
- Two approaches:
  - Create the object, but perhaps discard it and return another
  - Check against the arguments before creating the new object

Space leaks

- Interning can waste space if your collection:
  - Grows too big
  - With objects that will never be used again
- Not discussed here: The solution is to use weak references
  - This is their canonical purpose
- Do not reinvent your own way of keeping track of whether an object in the collection is being used
  - Too error-prone
  - Gives up key benefits of garbage-collection
Java.lang.Boolean does not use the Interning pattern

```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 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 `true`s or multiple `false`s, and I've seen programs that produce millions of `true`s and millions of `false`s, creating needless work for the garbage collector.

So, in the case of immutables, I think factory methods are great.

Flyweight pattern

Good when many objects are mostly the same
– Interning works only if objects are entirely the same (and immutable)

Intrinsic state: Independent of object’s "context"
– Often same across many objects and immutable
– Technique: intern it

Extrinsic state: different for different objects; depends on "context"
– Have clients store it separately, or better:
– Advanced technique:
  • Make it implicit (clients compute it instead of represent it)
  • Saves space

Example without flyweight: bicycle spoke

```java
class Wheel {
    FullSpoke[] spokes;
    ...
}
class FullSpoke {
    int length;
    int diameter;
    boolean tapered;
    Metal material;
    float weight;
    float threading;
    boolean crimped;
    int location;  // position on the rim
}
```

• 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

```java
class IntrinsicSpoke {
    int length;
    int diameter;
    boolean tapered;
    Metal material;
    float weight;
    float threading;
    boolean crimped;
}
```

This does not save space compared to `FullSpoke`
```java
class InstalledSpokeFull extends IntrinsicSpoke {
    int location;
}
```

This does saves space
```java
class InstalledSpokeWrapper {
    IntrinsicSpoke s; // refer to interned object
    int location;
}
```

But flyweight version [still coming up] uses even less space...

Original code to true (align) a wheel

```java
class FullSpoke {
    // Tension the spoke by turning the nipple the
    // specified number of turns.
    void tighten(int turns) {
        ... location ...  // location is a field
    }
}
class Wheel {
    FullSpoke[] spokes;
    void align() {
        while (wheel is misaligned) {
            // tension the i\textsuperscript{th} spoke
            ... location ...  // location is a field
        }
    }
}
```

What is the value of the location field in `spokes[i]`?
Flyweight code to true (align) a wheel

```java
class IntrinsicSpoke {
    void tighten(int turns, int location) {
        ... location ... // location is a parameter
    }
}
class Wheel {
    IntrinsicSpoke[] spokes;
    void align() {
        while (wheel is misaligned) {
            // tension the i-th spoke
            ... spokes[i].tighten(numturns, i) ...
        }
    }
}
```

What happened

- Logically, each spoke is a different object
  - A spoke “has” all the intrinsic state and a location
- But if that would be a lot of objects, i.e., space usage, we can instead...
- Create one actual flyweight object that is used “in place of” all logical objects that have that intrinsic state
  - Use interning to get the sharing
  - Clients store or compute the extrinsic state and pass it to methods to get the right behavior
  - Only do this when logical approach is cost-prohibitive and it’s not too complicated to manage the extrinsic state
    - Here spoke location was particularly easy and cheap because it was implicit in array location of reference

Flyweight discussion

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

```
Wheel methods pass this to the methods that use the wheel field.
```

What if `FullSpoke` contains a `boolean` field `broken`?

```
Add an array of `booleans` in `Wheel`, parallel to the array of `Spokes`.
```

Flyweight: resist it

- 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