Principles of Software Construction: **A Quick Tour of all 23 GoF Design Patterns**

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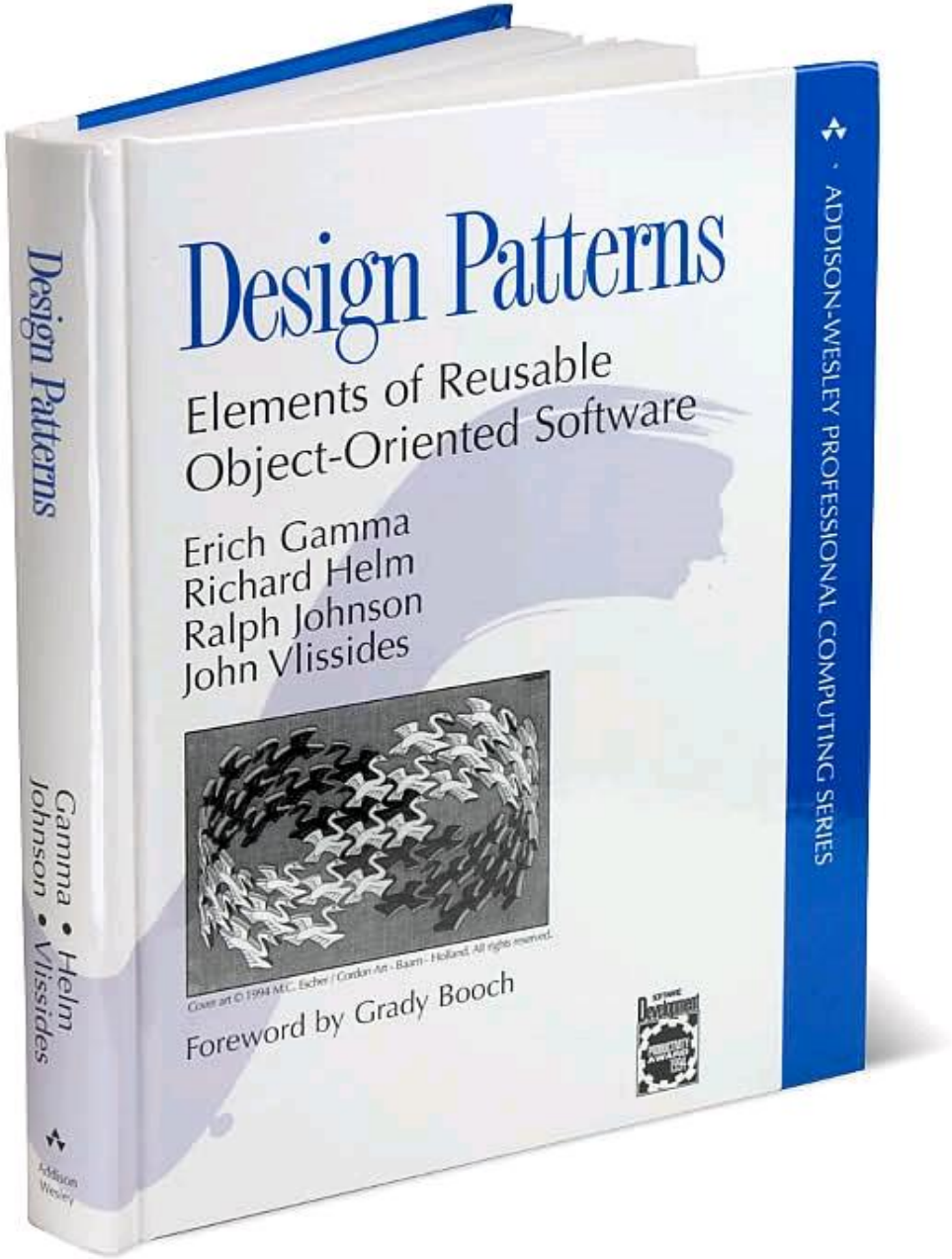
- Published 1994
- 23 Patterns
- Widely known



Our course so far

- Strategy
- Template Method
- Façade
- Iterator
- Proxy
- Adapter
- Composite
- Decorator
- Observer
- Marker interface
- Flyweight
- Different forms of factories
- Model view controller
- and concurrency patterns as producer-consumer, thread pool

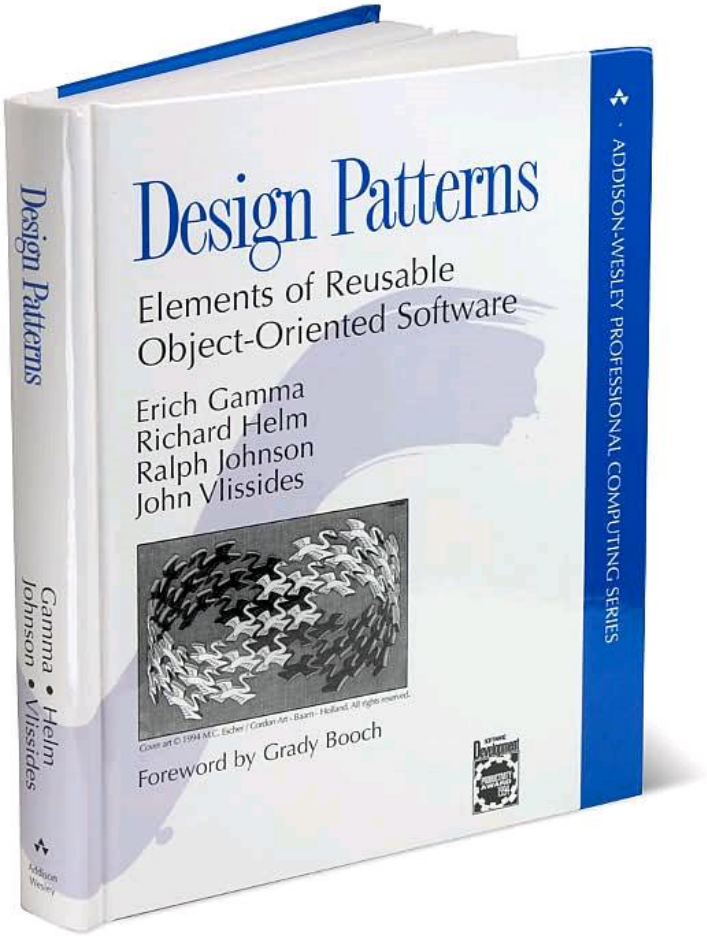
Why?

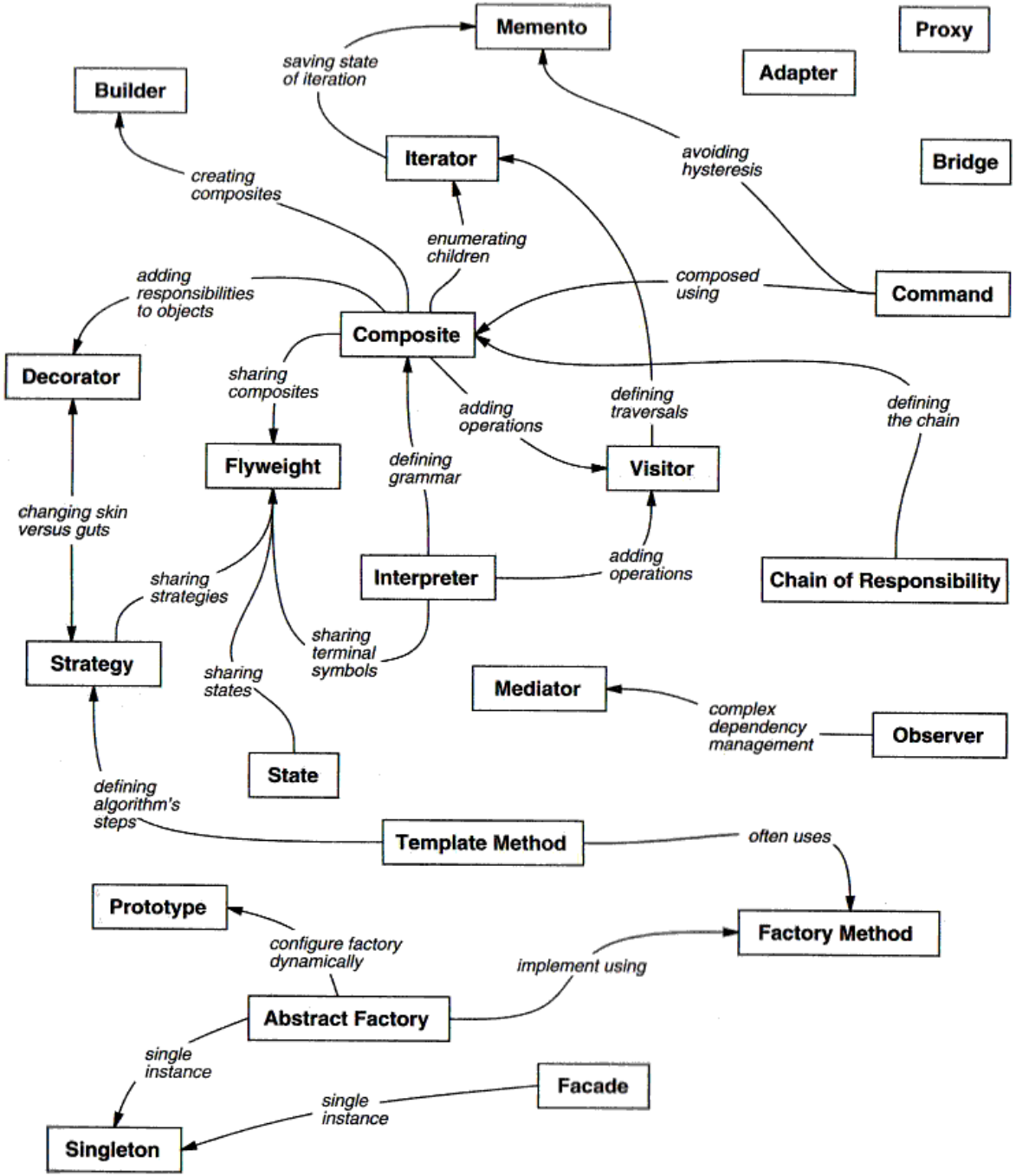
- Seminal and canonical list of well-known patterns
- Not all patterns are commonly used
- Does not cover all popular patterns

- At least know where to look up when somebody mentions the “Bridge pattern”

Grouping Patterns

I. Creational Patterns
II. Structural Patterns
III. Behavioral Patterns





Pattern Name

- **Intent** – the aim of this pattern
- **Use case** – a motivating example
- **Key types** – the types that define pattern
  - Italic type name indicates abstract class; typically this is an interface when the pattern is used in Java
- **JDK** – example(s) of this pattern in the JDK

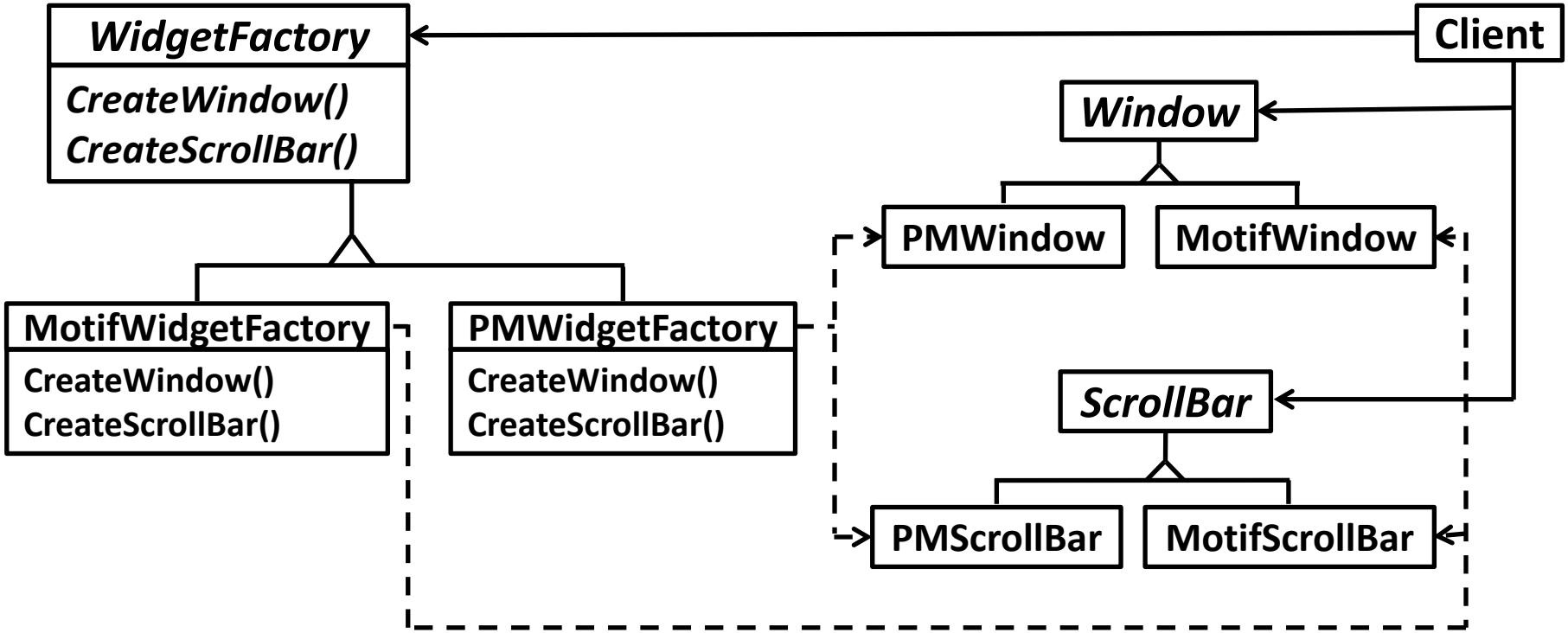
I. Creational Patterns

1. Abstract factory
2. Builder
3. Factory method
4. Prototype
5. Singleton

1. Abstract Factory

- Intent – allow creation of families of related objects independent of implementation
- Use case – look-and-feel in a GUI toolkit
  - Each L&F has its own windows, scrollbars, etc.
- Key types – *Factory* with methods to create each family member, *Products*
- JDK – not common

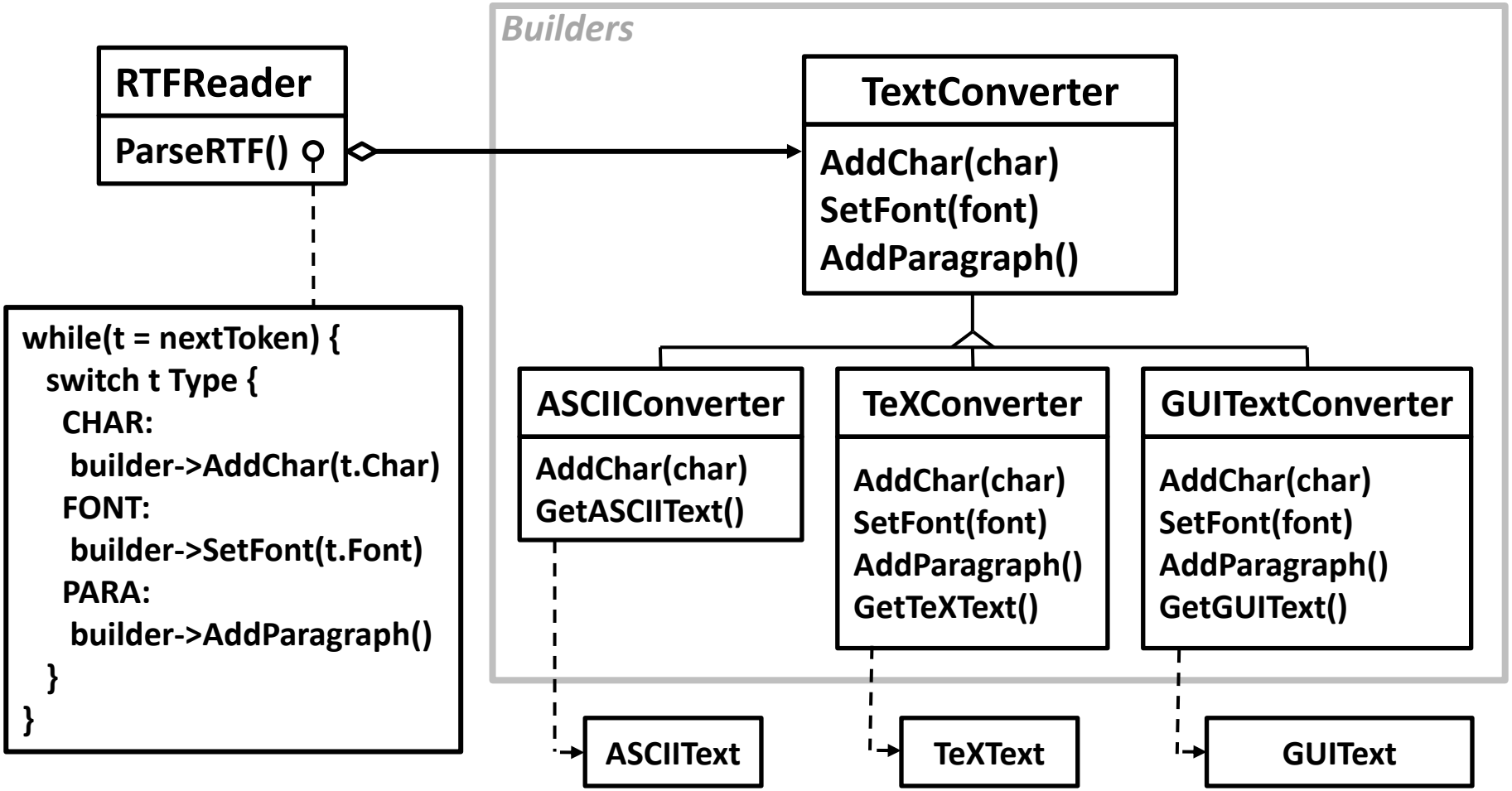
Abstract Factory Illustration



2. Builder

- Intent – separate construction of complex object from representation so same creation process can create different representations
- use case – converting rich text to various formats
- types – *Builder,* ConcreteBuilders, Director, Products
- JDK – `StringBuilder`, `StringBuffer`*
  - But there is no (visible) abstract supertype…
  - And both generate same product class (`String`)

Gof4 Builder Illustration



Effective Java Item 1

- Emulates named parameters in languages that don't support them
- Emulates 2^n constructors or factories with n builder methods, by allowing them to be combined freely
- Cost is an intermediate (Builder) object

EJ-style Builder Illustration

```
NutritionFacts twoLiterDietCoke = new NutritionFacts.Builder(
    "Diet Coke", 240, 8).sodium(1).build();

public class NutritionFacts {
    public static class Builder {
        public Builder(String name, int servingSize,
                int servingsPerContainer) { ... }
        public Builder totalFat(int val)     { totalFat = val; }
        public Builder saturatedFat(int val) { satFat = val; }
        public Builder transFat(int val)     { transFat = val; }
        public Builder cholesterol(int val)  { cholesterol = val; }
        ... // 15 more setters

        public NutritionFacts build() {
            return new NutritionFacts(this);
        }
    }
    private NutritionFacts(Builder builder) { ... }
}
```

3. Factory Method

- Intent – abstract creational method that lets subclasses decide which class to instantiate
- Use case – creating documents in a framework
- Key types – *Creator*, which contains abstract method to create an instance
- JDK – `Iterable.iterator()`
- Related *Static Factory pattern* is very common
  - Technically not a GoF pattern, but close enough

Factory Method Illustration

```
public interface Iterable<E> {
    public abstract Iterator<E> iterator();
}

public class ArrayList<E> implements List<E> {
    public Iterator<E> iterator() { ... }
    ...
}

public class HashSet<E> implements Set<E> {
    public Iterator<E> iterator() { ... }
    ...
}

Collection<String> c = ...;

for (String s : c)  // Creates an Iterator appropriate to c
    System.out.println(s);
```

Static Factory Method Example

```
public DatabaseConnection {
    private DatabaseConnection(String address) { … }
    public static DatabaseConnection create
                                        (String address) {
        //optional caching or checking…
        return new DatabaseConnection(address);
    }
}
```

~~c = new DatabaseConnection("localhost");~~

```
c = DatabaseConnection.create("localhost");
```

4. Prototype

- Intent – create an object by cloning another and tweaking as necessary
- Use case – writing a music score editor in a graphical editor framework
- Key types – *Prototype*
- JDK – Cloneable, but avoid (except on arrays)
  - Java and Prototype pattern are a poor fit

5. Singleton

- Intent – ensuring a class has only one instance
- Use case – GoF say print queue, file system, company in an accounting system
  - **Compelling uses are rare** but they do exist
- Key types – Singleton
- JDK – `java.lang.Runtime.getRuntime()`, `java.util.Collections.emptyList()`

Singleton Illustration

```
public class Elvis {
    public static final Elvis ELVIS = new Elvis();
    private Elvis() { }
    ...
}


// Alternative implementation
public enum Elvis {
    ELVIS;

    sing(Song song) { ... }

    playGuitar(Riff riff) { ... }

    eat(Food food) { ... }

    take(Drug drug) { ... }
}
```

Singleton Discussion

- It's an ***instance-controlled class***; others include
  - **Static utility class** – non-instantiable
  - **Enum** – one instance per value, all values known at compile time
  - **Interned class** – one canonical instance per value, new values created at runtime
- There is a duality between singleton and static utility class

II. Structural Patterns

1. Adapter
2. Bridge
3. Composite
4. Decorator
5. Façade
6. Flyweight
7. Proxy

1. Adapter

- Intent – convert interface of a class into one that another class requires, allowing interoperability
- Use case – numerous, e.g., arrays vs. collections
- Key types – Target, Adaptee, Adapter
- JDK – `Arrays.asList(T[])`

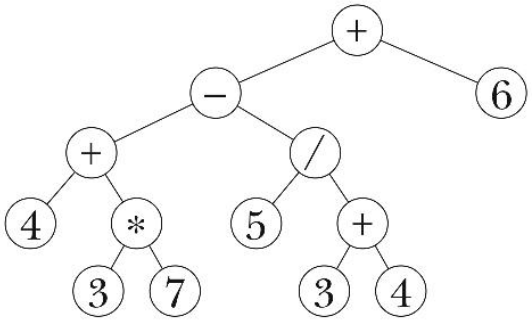
2. Bridge

- Intent – decouple an abstraction from its implementation so they can vary independently
- Use case – portable windowing toolkit
- Key types – Abstraction, *Implementor*
- JDK – JDBC, Java Cryptography Extension (JCE), Java Naming & Directory Interface (JNDI)
- Bridge pattern *very* similar to Service Provider
  - Abstraction ~ API, *Implementer* ~ SPI

3. Composite

- Intent – compose objects into tree structures. **Let clients treat primitives & compositions uniformly.**
- Use case – GUI toolkit (widgets and containers)
- Key type – *Component* that represents both primitives and their containers
- JDK – `javax.swing.JComponent`

Composite Illustration

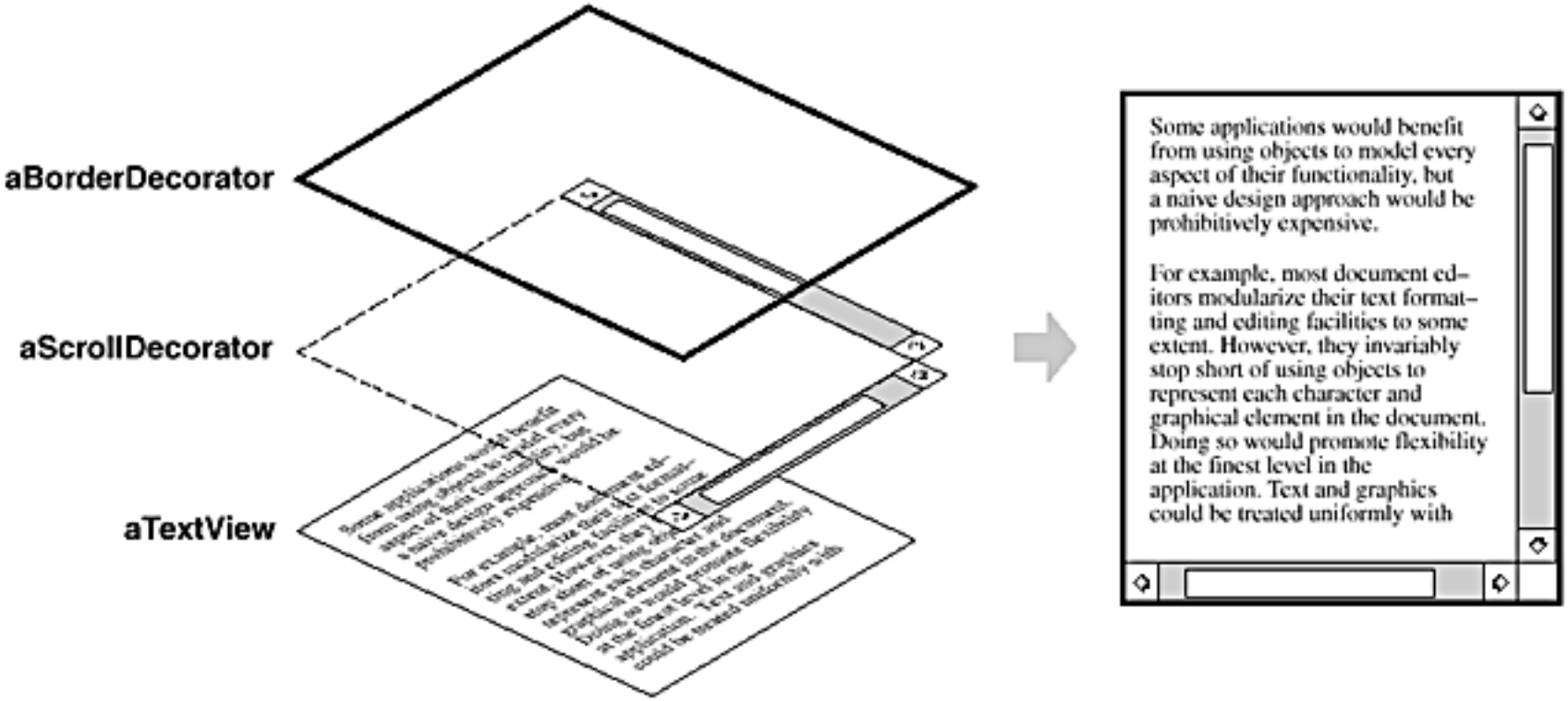



```
public interface Expression {
    double eval();     // Returns value
    String toString(); // Returns infix expression string
}

public class UnaryOperationExpression implements Expression {
    public UnaryOperationExpression(
            UnaryOperator operator, Expression operand);
}
public class BinaryOperationExpression implements Expression {
    public BinaryOperationExpression(BinaryOperator operator,
            Expression operand1, Expression operand2);
}
public class NumberExpression implements Expression {
    public NumberExpression(double number);
}
```

4. Decorator

- Intent – attach features to an object dynamically
- Use case – attaching borders in a GUI toolkit
- Key types – *Component*, implement by decorator *and* decorated
- JDK – Collections (e.g., `Synchronized` wrappers), `java.io` streams, Swing components

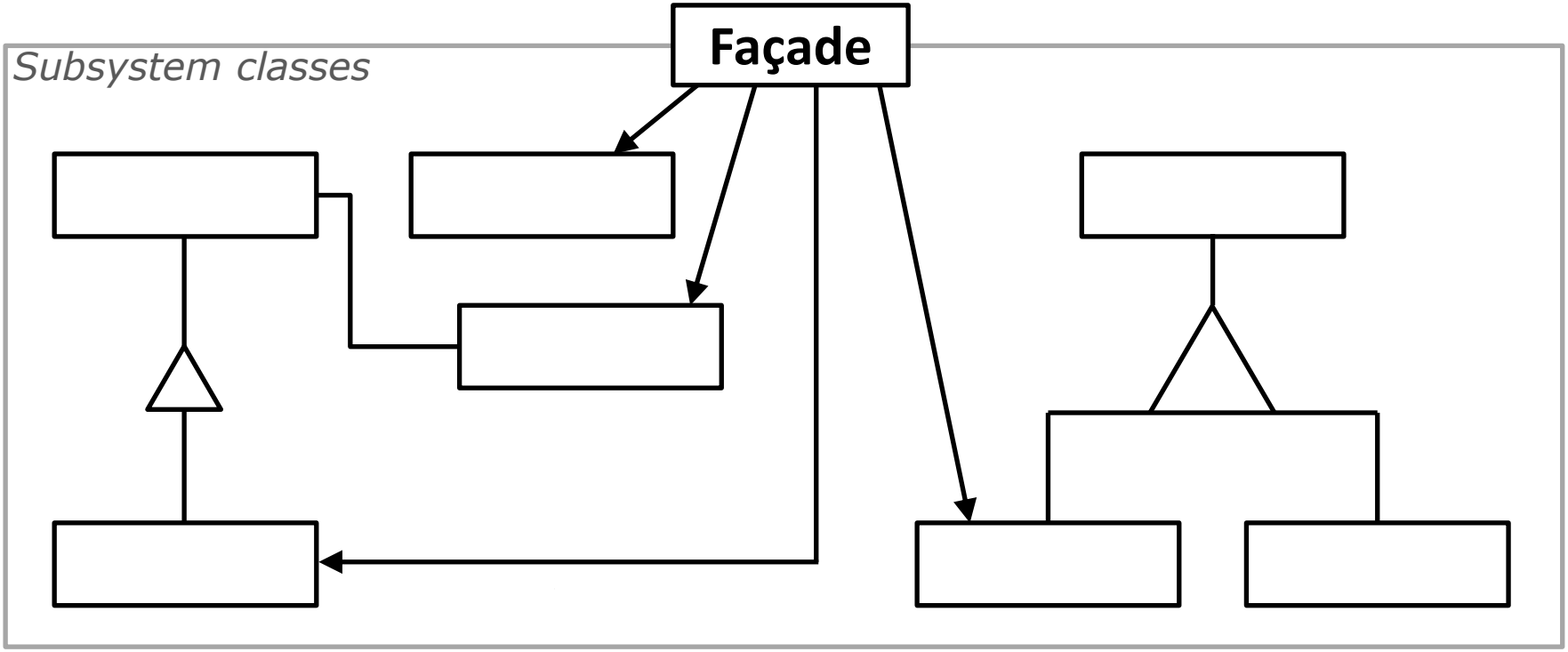
Decorator Illustration



5. Façade

- Intent – provide a simple unified interface to a set of interfaces in a subsystem
  - GoF allow for variants where the complex underpinnings are exposed and hidden
- Use case – any complex system; GoF use compiler
- Key types – Façade (the simple unified interface)
- JDK – `java.util.concurrent.Executors`

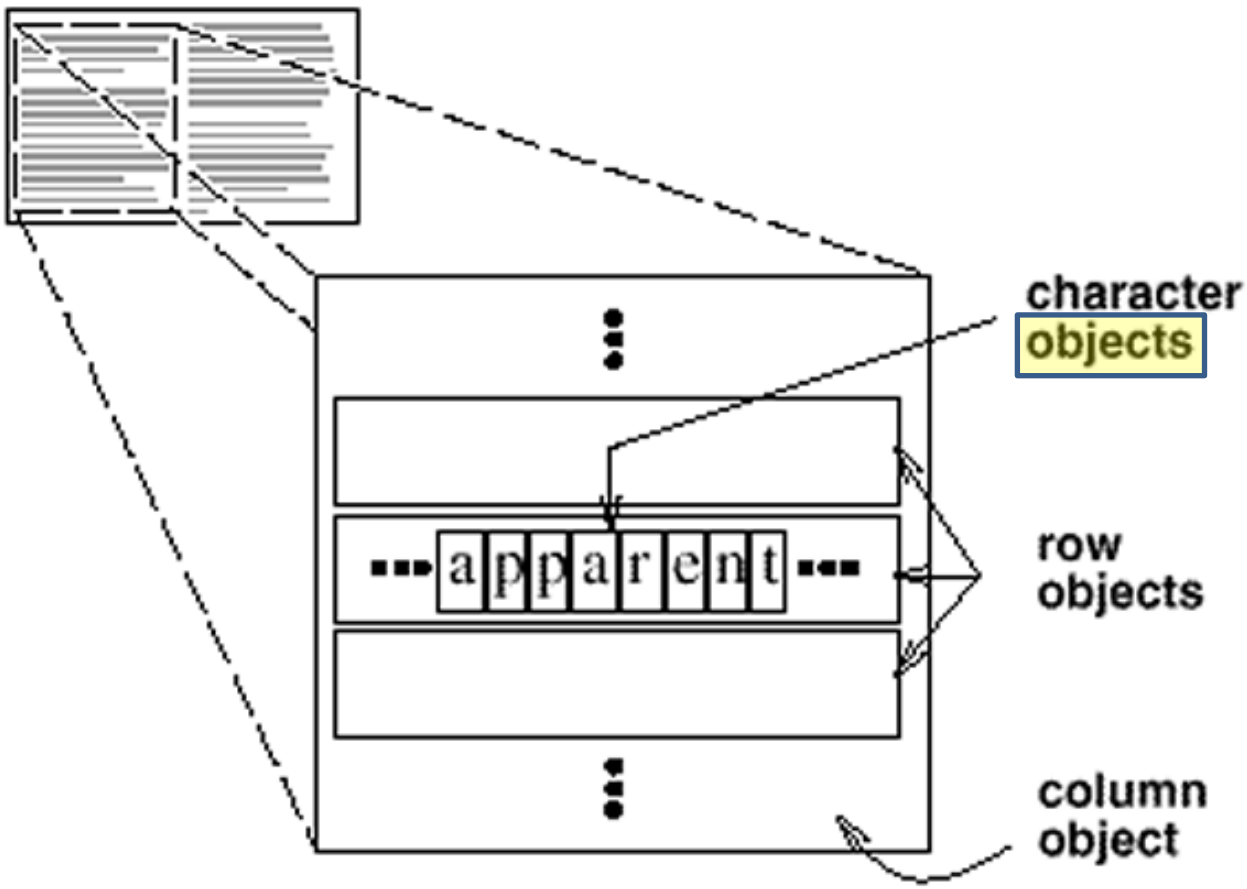
Façade Illustration



6. Flyweight

- Intent – use sharing to support large numbers of fine-grained objects efficiently
- Use case – characters in a document
- Key types – Flyweight (instance-controlled!)
  - Some state can be *extrinsic* to reduce number of instances
- JDK – String literals (JVM feature)

Flyweight Illustration

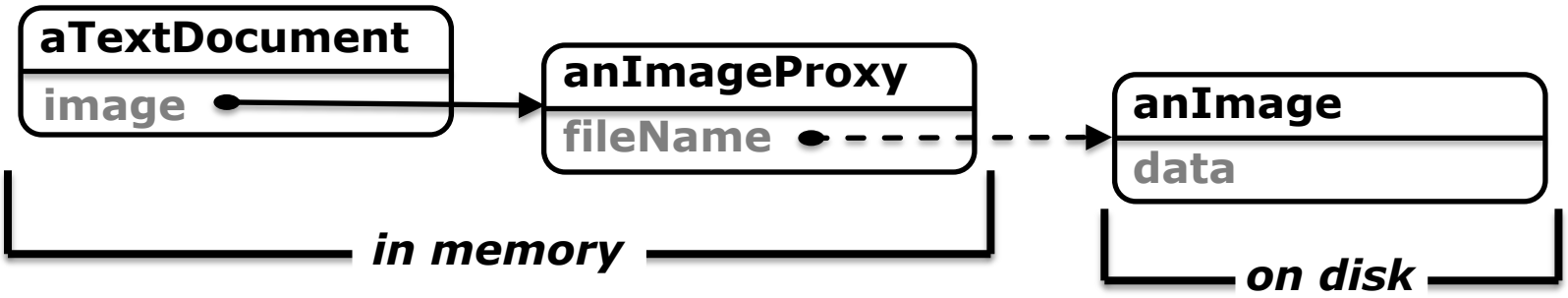


7. Proxy

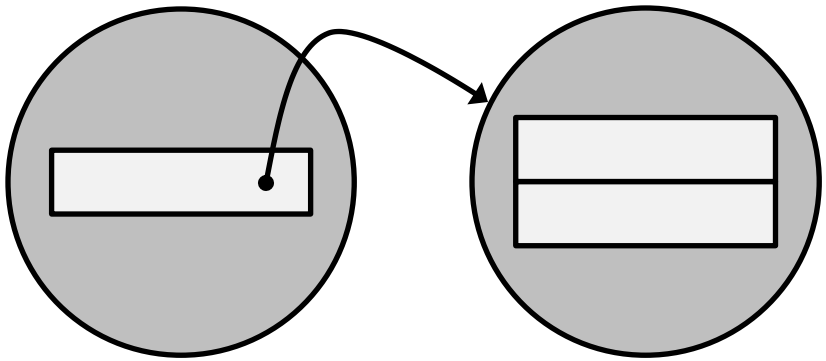
- Intent – surrogate for another object
- Use case – delay loading of images till needed
- Key types – *Subject*, Proxy, RealSubject
- Gof mention several flavors
  - virtual proxy – stand-in that instantiates lazily
  - remote proxy – local representative for remote obj
  - protection proxy – denies some ops to some users
  - smart reference – does locking or ref. counting, e.g.
- JDK – RMI, collections wrappers

Proxy Illustrations

Virtual Proxy

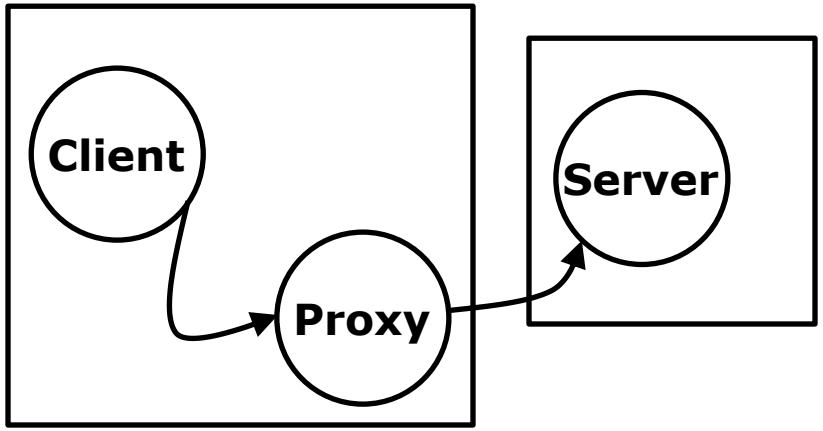


Smart Reference



SynchronizedList ArrayList

Remote Proxy



III. Behavioral Patterns

1. Chain of Responsibility
2. Command
3. Interpreter
4. Iterator
5. Mediator
6. Memento
7. Observer
8. State
9. Strategy
10. Template method
11. Visitor

1. Chain of Responsibility

- Intent – avoid coupling sender to receiver by passing request along until someone handles it
- Use case – context-sensitive help facility
- Key types – *RequestHandler*
- JDK – `ClassLoader`, `Properties`
- Exception handling could be considered a form of Chain of Responsibility pattern

Chain of Responsibility Example

```
interface PluginLoader {
  Plugin loadPlugin(String s);
}
class BasicPluginLoader {
  Plugin loadPlugin(String s) { ServiceLoader… }
}
class JarPluginLoader {
  private final PluginLoader o;
  JarPluginLoader(PluginLoader other) { o=other;}
  Plugin loadPlugin(String s) {
    Plugin l = …//try to load from Jar
    if (l==null) l = o.loadPlugin(s);
    return l;
  }
}
```

2. Command

- Intent – encapsulate a request as as an object, letting you parameterize one action with another, queue or log requests, etc.
- Use case – menu tree
- Key type – *Command* (`Runnable`)
- JDK – Common! Executor framework, etc.
- Is it Command pattern if you run it repeatedly? If it takes an argument? Returns a val?

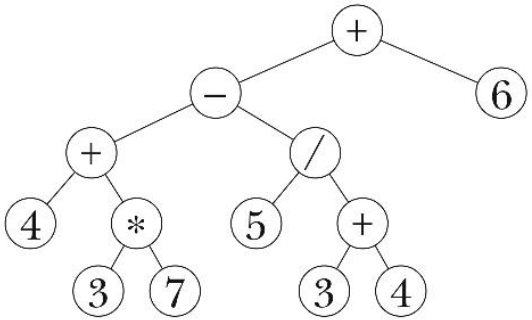
Command Illustration

```
public static void main(String[] args) {
   SwingUtilities.invokeLater(() -> new Demo().setVisible(true));
}
```

3. Interpreter

- Intent – given a language, define class hierarchy for parse tree, recursive method to interpret it
- Use case – regular expression matching
- Key types – *Expression*, *NonterminalExpression*, *TerminalExpression*
- JDK – no uses I'm aware of
  - Our expression evaluator (HW2) is a classic example
- Necessarily uses Composite pattern!

Interpreter Illustration




```
public interface Expression {
    double eval();     // Returns value
    String toString(); // Returns infix expression string
}

public class UnaryOperationExpression implements Expression {
    public UnaryOperationExpression(
            UnaryOperator operator, Expression operand);
}
public class BinaryOperationExpression implements Expression {
    public BinaryOperationExpression(BinaryOperator operator,
            Expression operand1, Expression operand2);
}
public class NumberExpression implements Expression {
    public NumberExpression(double number);
}
```

4. Iterator

- Intent – provide a way to access elements of a collection without exposing representation
- Use case – collections
- Key types – *Iterable*, *Iterator*
  - But GoF discuss internal iteration, too
- JDK – collections, for-each statement, etc.

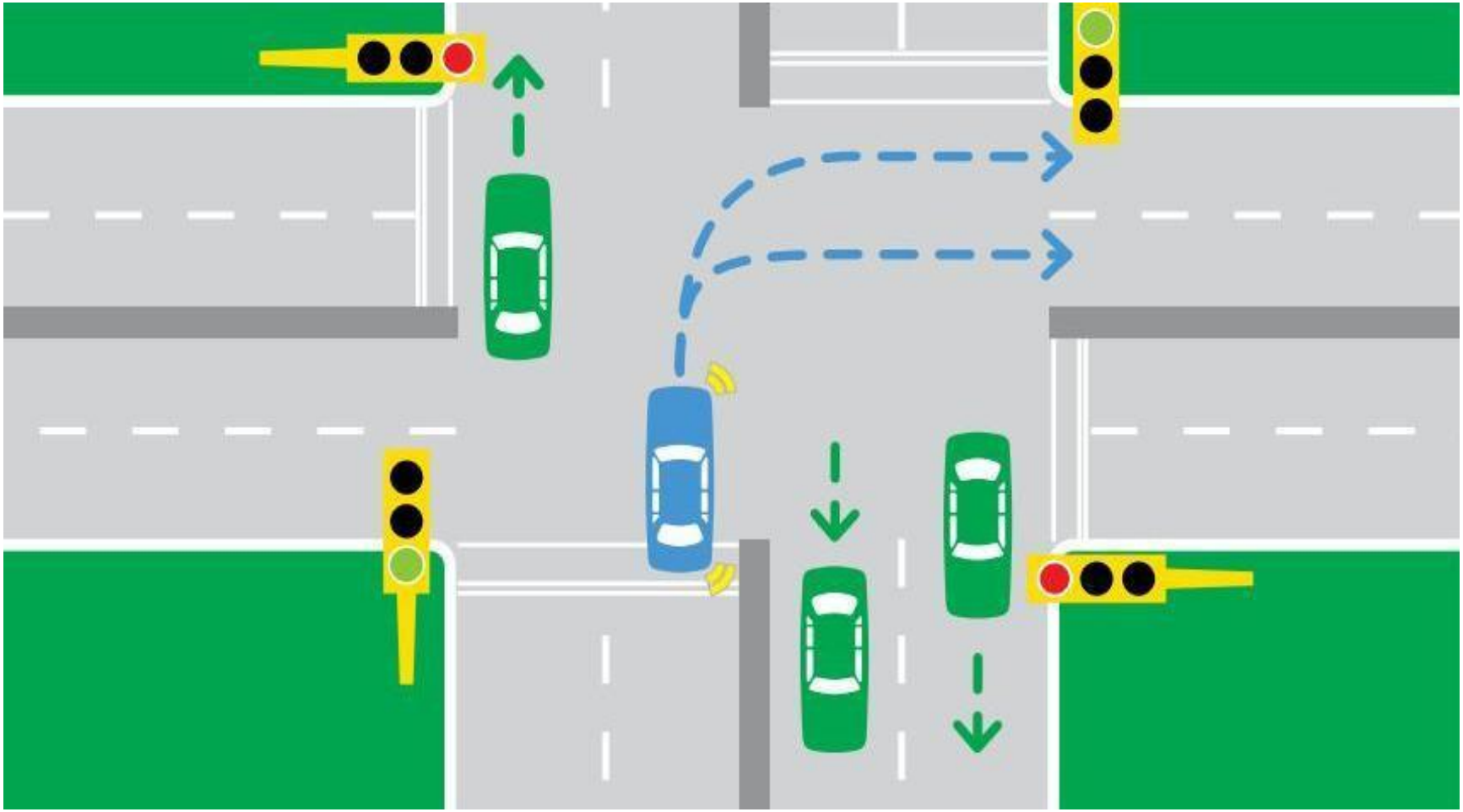
Iterator Illustration

```
public interface Iterable<E> {
    public abstract Iterator<E> iterator();
}

public class ArrayList<E> implements List<E> {
    public Iterator<E> iterator() { ... }
    ...
}

public class HashSet<E> implements Set<E> {
    public Iterator<E> iterator() { ... }
    ...
}

Collection<String> c = ...;

for (String s : c)  // Creates an Iterator appropriate to c
    System.out.println(s);
```

5. Mediator

- Intent – define an object that encapsulates how a set of objects interact, to reduce coupling.
  - $\mathcal{O}(n)$ couplings instead of $\mathcal{O}(n^2)$
- Use case – dialog box where change in one component affects behavior of others
- Key types – Mediator, Components
- JDK – Unclear

Mediator Illustration



6. Memento

- Intent – without violating encapsulation, allow client to capture an object's state, and restore
- Use case – undo stack for operations that aren't easily undone, e.g., line-art editor
- Key type – Memento (opaque state object)
- JDK – none that I'm aware of (*not* serialization)

7. Observer

- Intent – let objects observe the behavior of other objects so they can stay in sync
- Use case – multiple views of a data object in a GUI
- Key types – *Subject* (“Observable”), *Observer*
  - GoF are agnostic on many details!
- JDK – Swing, left and right

Observer Illustration

```
// Implement roll button and dice type field
JTextField diceSpecField = new JTextField(diceSpec, 5); // Field width
JButton rollButton = new JButton("Roll");
rollButton.addActionListener(event -> {
if (!diceSpecField.getText().equals(diceSpec)) {
      diceSpec = diceSpecField.getText();
      dice = Die.dice(diceSpec);
      jDice.resetDice(dice);
  }
  for (Die d : dice) d.roll();
  jDice.repaint();
});
```

8. State

- Intent – allow an object to alter its behavior when internal state changes. “Object will appear to change class.”
- Use case – TCP Connection (which is stateful)
- Key type – *State* (Object delegates to state!)
- JDK – none that I’m aware of, but…
  - Works *great* in Java
  - Use enums as states
  - Use `AtomicReference<State>` to store it

State Example

Without the pattern:

```
class Connection {
  boolean isOpen = false;
  void open() {
    if (isOpen) throw new Inval…
    …//open connection
    isOpen=true;
  }
  void close() {
    if (!isOpen) throw new Inval…
    …//close connection
    isOpen=false;
  }
}
```

With the pattern:

```
class Connection {
  private State state = new Closed();
  public void setState(State s) { … }
  void open() { state.open(this); }
  …
}
interface State {
   void open(Connection c);
   void close(Connection c);
}
class Open implements State {
   void open(Connection c) { throw …}
   void close(Connection c) {
     //…close connection
     c.setState(new Closed());
   }
}
class Closed impl. State { … }
```

9. Strategy

- Intent – represent a behavior that parameterizes an algorithm for behavior or performance
- Use case – line-breaking for text compositing
- Key types – *Strategy*
- JDK – `Comparator`

Strategy Illustration

Comparator is a strategy for ordering

```
public static synchronized void main(String[] args) {
    Arrays.sort(args, Comparator.reverseOrder());
    System.out.println(Arrays.toString(args));

    Arrays.sort(args, Comparator.comparingInt(String::length));
    System.out.println(Arrays.toString(args));
}
```

```
java Foo i eat wondrous spam
[wondrous, spam, i, eat]
[i, eat, spam, wondrous]
```

10. Template Method

- Intent – define skeleton of an algorithm or data structure, deferring some decisions to subclasses
- Use case – application framework that lets plugins implement all operations on documents
- Key types – *AbstractClass*, ConcreteClass
- JDK – skeletal collection impls (e.g., `AbstractList`)

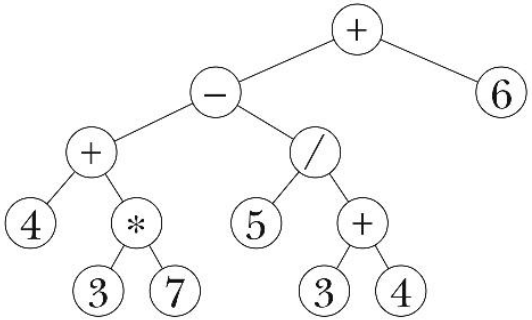
Template Method Illustration

```
// List adapter for primitive int arrays
public static List<Integer> intArrayList(final int[] a) {
    return new AbstractList<Integer>() {
        public Integer get(int i) {
            return a[i];
        }

        public Integer set(int i, Integer val) {
            Integer oldVal = a[i];
            a[i] = val;
            return oldVal;
        }

        public int size() {
            return a.length;
        }
    };
}
```

11. Visitor

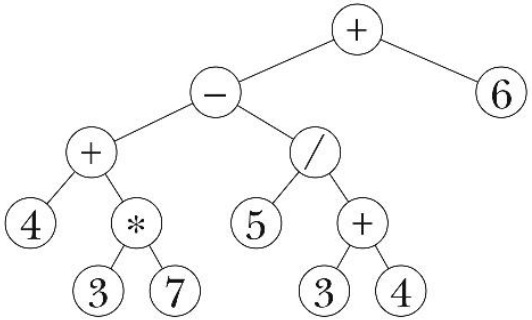
- Intent – represent an operation to be performed on elements of an object structure (e.g., a parse tree). Visitor lets you define a new operation without modifying the type hierarchy.
- Use case – type-checking, pretty-printing, etc.
- Key types – *Visitor*, ConcreteVisitors, all the element types that get visited
- JDK – none that I'm aware of; very common in compilers

Visitor Illustration (1/3)



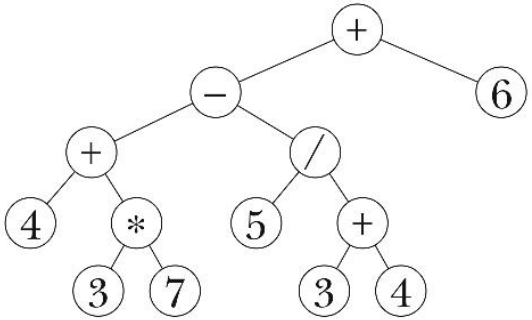

```
public interface Expression {
    public <T> T accept(Visitor<T> v);  // No eval or toString!
}

public class UnaryOperationExpression implements Expression {
    public UnaryOperationExpression(
            UnaryOperator operator, Expression operand);
    public <T> T accept(Visitor<T> v) { return v.visitUnaryExpr(this); }
}
public class BinaryOperationExpression implements Expression {
    public BinaryOperationExpression(BinaryOperator operator,
            Expression operand1, Expression operand2);
    public <T> T accept(Visitor<T> v) {  return v.visitBinaryExpr(this) ; }
}
public class NumberExpression implements Expression {
    public NumberExpression(double number);
    public <T> T accept(Visitor<T> v) { return v.visitNumberExpr(this); }
}
```

Visitor Illustration (2/3)




```
public interface Visitor<T>  { // T is result type
    public T visitUnaryExpr(UnaryExpression ue);
    public T visitBinaryExpr(BinaryExpression be);
    public T visitNumberExpr(NumberExpression ne);
}

public class EvalVisitor implements Visitor<Double> {
    public Double visitUnaryExpr(UnaryExpression ue) {
        return ue.operator.apply(ue.operand.accept(this));
    }
    public Double visitBinaryExpr(BinaryExpression be) {
        return be.operator.apply(be.operand1.accept(this),
                                 be.operand2.accept(this));
    }
    public Double visitNumberExpr(NumberExpression ne) { return ne.number; }
}
```

Visitor Illustration (3/3)




```
public class ToStringVisitor implements Visitor<String> {
    public String visitUnaryExpr(UnaryExpression ue) {
        return ue.operator + ue.operand.accept(this);
    }
    public String visitBinaryExpr(BinaryExpression be) {
        return String.format("(%s %s %s)", be.operand1.accept(this),
                             be.operator, be.operand2.accept(this));
    }
    public String visitNumberExpr(NumberExpression ne) {
        return Double.toString(ne.number);
    }
}

// Sample use of visitors
System.out.println(e.accept(new ToStringVisitor()) + " = " +
                   e.accept(new EvalVisitor()));
```

More on Visitor

- Visitor is NOT merely traversing a graph structure and applying a method
  - That's Iterator!
- The essence of visitor is *double-dispatch*
  - First dynamically dispatch on the Visitor
  - Then on the element being visited

Summary

- Now you know *all* the Gang of Four patterns
- Definitions can be vague
- Coverage is incomplete
- But they're extremely valuable
  - They gave us a vocabulary
  - And a way of thinking about software
- Look for patterns as you read and write software
  - GoF, non-GoF, and undiscovered