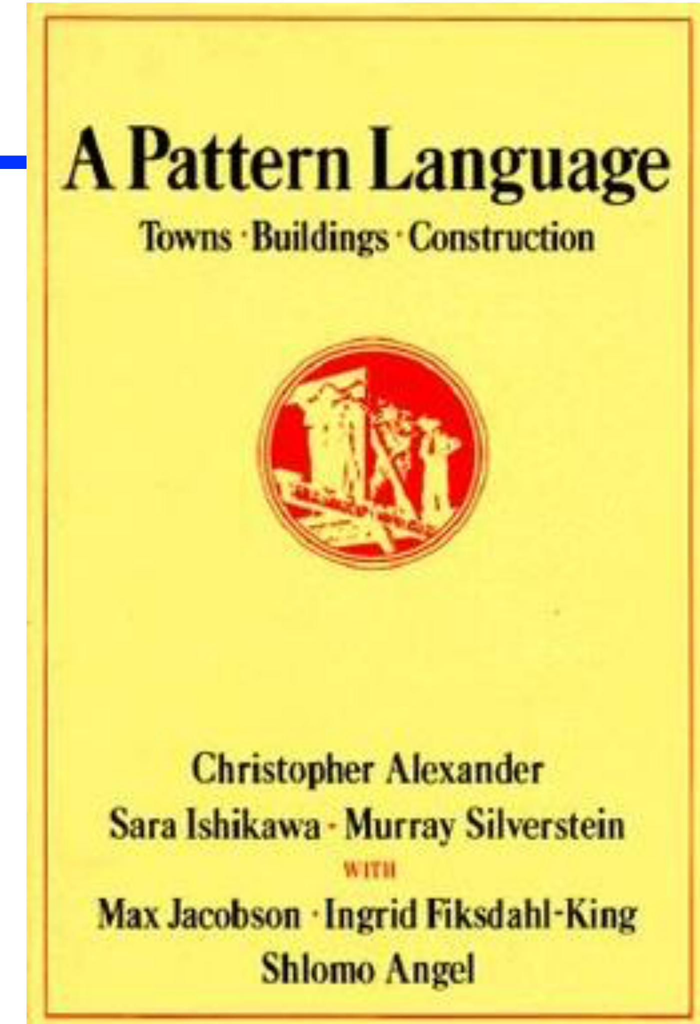
# COMP 150-SEN
# Software Engineering Foundations

## Design Patterns

Spring 2019

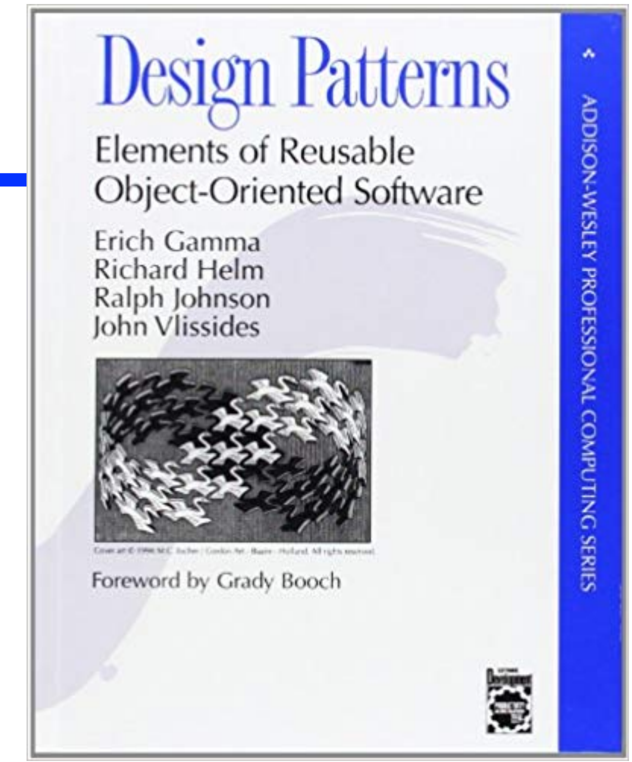
(Some slides from Ben Liblit, UWisc CS 506; Mike Ernst, UW CSE 331)

# A Pattern Language




- Book of 253 architectural patterns
  - #2: distribution of towns (city creation)
  - #232: roof cap (buliding problem)
- Each pattern describes
  - A problem that occurs over and over
  - The core of a solution
    - Not a full solution
    - Might lead to different solutions in different contexts
- Examples
  - “6-foot balcony” (the minimum depth that makes it useful)
  - “arcades” (a way to connect inside to outside gradually)

# Software Design Patterns




- Standard, reusable solutions to common programming problem
  - Gamma, Helm, Johnson, Vlissides (“Gang of Four”, “GoF”), *Design Patterns*, 1995
- Patterns provide
  - Vocabulary for common programming problems
  - Good design ideas for solving those problems
  - Tradeoffs between different design choices
- Patterns are not
  - Classes or libraries
  - Full designs
  - Very well defined (what is and what is not a pattern?)

# Iteration

- Problem: Loop through all objects in a collection

```
public class LinkedList { // from last lecture
  public int size() {
    int i = 0; Cell c = head;
    while (c != null) { i++; c = c.next; }
    return i;
  }
  public int get(int pos) {
    Cell c = head;
    for (int i = 0; i < pos; i++) {
      if (c == null) {
        throw new IndexOutOfBoundsException();
      }
      c = c.next;
    }
    return c.elt;
} }
```

# Iteration: Commonalities

- Problem: Loop through all objects in a collection

```
public class LinkedList { // from last lecture
  public int size() {
    int i = 0; Cell c = head;
    while (c != null) { i++; c = c.next; }
    return i;
  }
  public int get(int pos) {
    Cell c = head;
    for (int i = 0; i < pos; i++) {
      if (c == null) {
        throw new IndexOutOfBoundsException();
      }
      c = c.next;
    }
    return c.elt;
} }
```

# Iteration as Design Pattern?

- Examples are similar but not exactly the same
  - Seems fine for instance methods
  - Sensible to optimize those for implementation details

- But what if a client wants to iterate through a list?
  - Probably shouldn't expose `Cell` to them
  - Probably shouldn't expose other implementation details
  - Need to *abstract* the concept of iteration

- Tradeoffs of abstraction
  - Pros: ease-of-use, strong separation between client/library
  - Cons: increased overhead, limited iteration strategies

# Iteration in Java.Util

- Create an object to maintain state of iteration

```
public interface Iterator<E> {
  boolean hasNext();
  E next();
  // also, forEachRemaining and remove
}
```

- Example desired client usage

```
LinkedList l = …;
Iterator i = l.iterator();
while (i.hasNext()) {
  Integer x = i.next();
  // do something with x
}
```

# Iterators for LinkedList

```
public class LinkedList {
  public class LinkedListIterator
      implements Iterator<Integer> {
    Cell cur;
    LinkedListIterator(Cell head) { cur = head; }
    public boolean hasNext() { return cur != null; }
    public Integer next() {
      Integer temp = cur.elt;
      cut = cur.next;
  }
  public LinkedListIterator iterator() {
    return next LinkedListIterator(head);
  }
}
```

# Cool Java Syntactic Sugar

- If we add the following:

```
public class LinkedList implements Iterable<Integer>
```

  - `Iterable` interface just means we have an iterator method
  - *(The `Iterable` interface also includes a couple of default methods, which mean the interface provides code for them)*
- Then the following code is the same!

```
LinkedList l = …;
Iterator i = l.iterator();
while (i.hasNext()) {
  Integer x = i.next();
  // do something with x
}
```

```
LinkedList l = …;
for (Integer x : l) {
  // do something with x
}
```

# Some Tradeoffs

```
// suppose code in an
// instance method
LinkedList l = …;
Cell c = l.head;
while (c != null) {
  Integer x = c.elt;
  c = c.next;
  // do something with x
}
```

```
LinkedList l = …;
Iterator i = l.iterator();
while (i.hasNext()) {
  Integer x = i.next();
  // do something with x
}
```

| Direct code | Itertor code |
|---|---|
| Longer | Shorter |
| Stores iterator state on stack | (Heap) object for iterator state |
| Iteration code mixed in | Iteration code separate |

# Other Iteration Concerns

- Iterator should not modify collection
  - That's why `LinkedListIterator`s are separate objects
  - Design goal: allow multiple iterators at once
- Client should not modify list during iteration!
  - If client adds an element, should element be seen by iterator or not?
    - Might depend on implementation details
  - `java.util` classes will throw a `ConcurrentModificationException` if client tries this
- `Iterables` can choose whether to support removal only during iteration
  - See optional `remove` method in `Iterator` interface
  - Discussion: Is supporting `remove` a good idea?

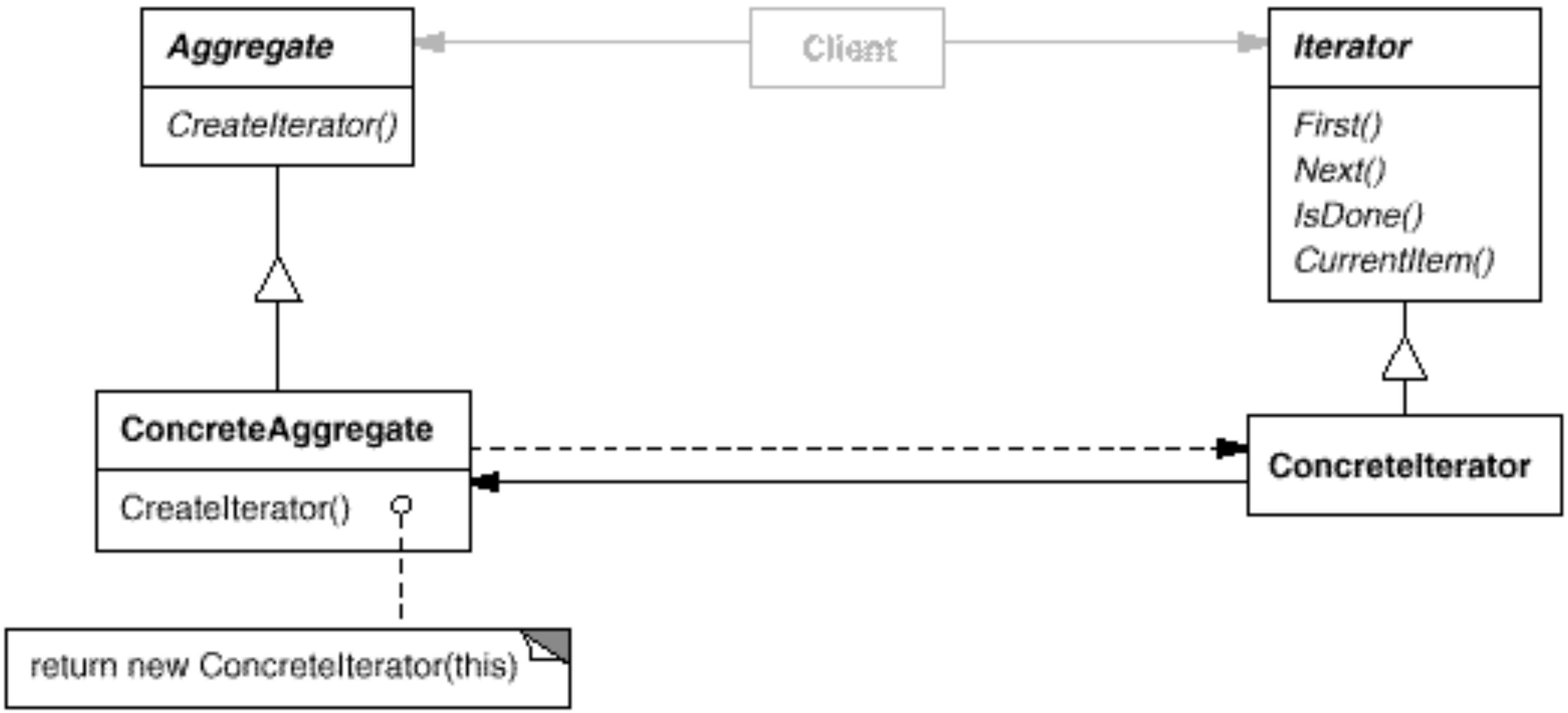
# Iterators are a Design Pattern

- Problem: Need specialized traversal for each different kind of data structure library
  - Introduces coupling between client and library
  - Does not generalize across collections
- Solution: library provides traversal functionality, tracks traversal state internally
  - The library knows its own internal representation
- Consequences
  - Support different and simultaneous traversal
  - Iteration order fixed by library, not under client control
  - Performance overhead (depending on compiler)

# Boxes and Arrows

- Imagine you were at the whiteboard, trying to explain iterators to another student
  - What would you draw?
  - Answer always seems to be: Boxes and arrows
- GoF book proposes *object modeling technique*
  - Class diagrams: static relationship between classes
  - Object diagrams: state of a program's objects
  - Interaction diagram: sequencing of method calls
- Became *Unified Modeling Language (UML)*
  - Standardized in 1997
  - Many people take UML very seriously
    - Please don't do so; UML is a means, not an end
    - And it's never sufficient in practice

# GoF Class Diagram for Iterators




- Notice design slightly different than Java
  - This is a difference between a *pattern* and directly reusing code
- For this course, don't worry about different arrows etc.

# Internal Iterators

- Alternative design: Client passes in *callback* to iterator method; library calls client once per element

```
interface Processor {
  void process(Integer x);
}
class LinkedList {
 void iterate(Processor p) {
    Cell cur = head;
    while (cur != null) {
      p.process(cur.elt);
      cur = cur.next;
} } }
```

```
class LengthProcessor {
  int size = 0;
  void process(Integer x) {
    size++;
  }
}
LinkedList l = …;
LengthProcessor p =
  new LengthProcessor();
l.iterate(p);
// p.size is list len
```

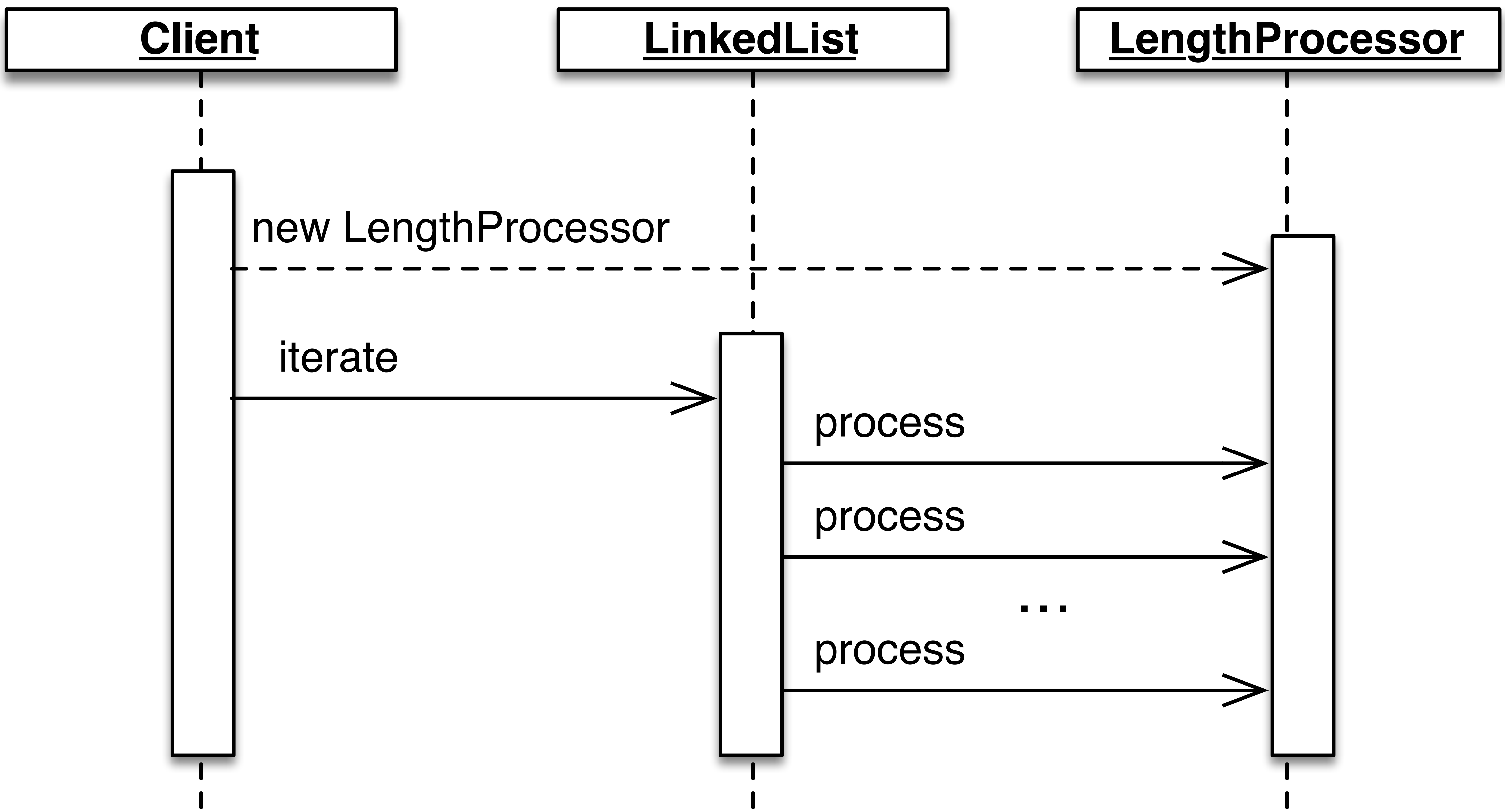
# Anonymous Inner Classes

- Could also use an *anonymous inner class*
  - `new C() {` *fields and methods* `}` creates a subclass of C with the given fields and methods, and creates one instance of it
  - Works with class or interface

```
LinkedList l = …;
LengthProcessor p = new Processor() {
  int size = 0;
  void process(Integer x) {
    size++;
} }
l.iterate(p);
// p.size is list len
```

# Sequence Chart Example

- Shows calling pattern



# Coupling

- Design patterns often reduce *coupling*
  - Coupling is the amount of interdependence among modules
  - Low coupling helps make software easier to understand and change
- Iterator pattern reduces coupling
  - Hides implementation details from client
  - Helps separate iteration code from other concerns
- But it's not perfect
  - Performance details are *not* hidden
  - Whether elts can be removed during iteration *not* hidden
- ADTs also reduce coupling!

# Cohesion

- *Cohesion* is the degree to which a module's internal elements are related
  - `LinkedList`, `ArrayList` have high cohesion because all the methods are concerned with the data structures
  - But, `java.lang.Math` has only moderate cohesion, because the methods are not that related
    - E.g., `sin` and `cos` (sine and cosine) should be in same class, but does `sqrt` need to be in the same class?
- High cohesion is good because
  - Code that may need to be modified together is grouped together
  - Code that has dependencies on each other is grouped inside a module
- Design patterns say little to nothing about cohesion!

# When Not to Use Design Patterns

- Key rule: Avoid premature complication!
  - Don’t add a design pattern just because
  - First get something working, then generalize it
- Design patterns can cause bloat
  - Adds indirection, increases code size, adds complexity
  - Could wind up making code *harder* to understand!
- Important: Design patterns are not fixed and rigid
  - They *must* be modified to suit the circumstances
  - Focus on solving your problem well, not on using a particular pattern

# Design Patterns Across Languages

- Most design patterns don't generalize that well across different programming paradigms
  - And most design patterns are for OO languages
  - Functional programming has design pattern-like stuff, but it's not usually design patterns
- Design patterns often compensate for language weaknesses
  - E.g., internal iterators are really common in functional programming, like `map` and `fold` (see COMP 105)

# Creational Patterns

# Singleton Objects

- Some classes should have one instance
  - `FileSystem`, `ThreadPool`, `Runtime`, `PrinterSpooler`, `WindowManager`, `Logger`, …
- Problem: No way to intercept `new`
  - Each call to new allocates a fresh object and initializes it
  - But we want to somehow return the same object
- Solution: don't expose `new`
  - Make constructor `private`
  - Create a single instance and manage it through a method
- Benefits
  - Reuse can increase performance
  - Client code doesn't need to worry about details
  - Code can use physical instead of structural equality (maybe)

# Singleton Example

```
class Logger {
  private static theLogger;

  private Logger() { … }

  public static getLogger() {
    if (theLogger == null) {
      theLogger = new Logger();
    }
    return theLogger;
} }
```

- `theLogger` only created once
  - Notice: we can guarantee that without looking at other code!
  - Lazy allocation, on first use

# Singleton Example (Alternative)

```
class Logger {
  private Logger() { … }

  final private static theLogger =
    new Logger();

  public static getLogger() {
   return theLogger;
} }
```

- A `final` field cannot be overwritten
- `theLogger` guaranteed created before use
  - Eager allocation, when `Logger` class loaded

# Generalizing Singletons: Enums

- What if we need several, related unique objects rather than one?
  - Common scenario: an enumeration, i.e., a finite set of objects representing a finite set of abstract things
  - E.g., days of week: `MONDAY`, `TUESDAY`, `WEDNESDAY`, …
  - E.g., card suits: `CLUBS`, `DIAMONDS`, `HEARTS`, `SPADES`
- C solution: enumeration
  - `enum suit { clubs, diamonds, hearts spades }`
  - Problem: not type safe!
  - Freely interchangeable with `int`s
- Java solution: multiple instances of a class

# Typesafe Enum Example

```
private class Suit {
  private final String name;
  private Suit(String name) { this.name = name; }
  public String toString() { return name; }

  public static final Suit CLUBS = new Suit("clubs");
  public static final Suit DIAMONDS = new Suit("diamonds");
  public static final Suit HEARTS = new Suit("hearts");
  public static final Suit SPADES = new Suit("spades");
}
```

- Why is `toString()` safe? It exposes internal state!
  - Because `String`s are immutable, so it's okay to get one
  - Did you make `succ` in Project 1 safe from clients?!

# Java Enumerations

- This design pattern is actually built in to Java!

```
public enum Suit {CLUBS, DIAMONDS, HEARTS, SPADES}
```

  - (Exercise: Use `javap -c` to figure out implementation!)
- Type checked at compile time, unlike in C
  - A `Suit` is not an `int`
- Enums have some other useful methods
  - `values()` — enumerator elements
  - `valueOf(String name)` — get corresponding element

# java.lang.Boolean

```
public class Boolean {
  private final boolean value;
  public Boolean(boolean value) { this.value = value; }
  public static Boolean TRUE = new Boolean(true);
  public static Boolean FALSE = new Boolean(false);
  public static Boolean valueOf(boolean b) {
    return (b ? TRUE : FALSE);
} }
```

https://hg.openjdk.java.net/jdk/jdk11/file/1ddf9a99e4ad/src/java.base/share/classes/java/lang/Boolean.java

- Why is the constructor public?!
  - "The Boolean type should not have had public constructors…I've seen programs that produce millions of trues and millions of falses, creating needless work for the garbage collector." *—Josh Bloch, JavaWorld, Jan 4, 2004*

# Factories

- Making constructor `private` is generally useful
  - Gives us a “hook” so classes can control object creation
- Three additional design patterns that use this idea
  - *Factory methods* — A method called to create objects
    - Key: Might not return a fresh object each time
  - *Factory object* — An object with a creator method
    - The object can be passed around, i.e., object creation becomes “higher order”
  - *Dependency injection* — External reference to object creation

# Integer.valueOf Factory Method

```
public class Integer {
  public static Integer valueOf(int i) {
    if (i >= IntegerCache.low && i <= IntegerCache.high)
      return IntegerCache.cache[i + (-IntegerCache.low)];
    return new Integer(i);
} }
```

https://hg.openjdk.java.net/jdk/jdk11/file/1ddf9a99e4ad/src/java.base/share/classes/java/lang/Integer.java

- Complex logic to reduce number of allocations
  - "Small" integers are preallocated in cache and reused
  - Other integers are allocated on the fly and *not* reused
- Notice we need to know to use this

# Calendar.getInstance Factory Meth

```
public static Calendar getInstance() {
  Locale aLocale = Locale.getDefault(Locale.Category.FORMAT);
  return createCalendar(defaultTimeZone(aLocale), aLocale);
}
```

https://hg.openjdk.java.net/jdk/jdk11/file/1ddf9a99e4ad/src/java.base/share/classes/java/util/Calendar.java

- Uses default time zone and locale to create and return an appropriate `Calendar` object

# Factory Objects for Themes

```
interface GUITheme {
  …Button newButton(int x, int y);…
}
class OSXTheme implements GUITheme {
  …Button newButton(…) { … }…
}
class OSXDarkTheme implements GUITheme {
  …Button newButton(…) { … }…
}
GUITheme t;
if (…) t = new OSXTheme();
else if (…) t = new OSXDarkTheme();
createWindow(t);
```

- `createWindow` uses argument object to construct GUI widgets

# External Dependency Injection

```
GUITheme t;
t = DependencyManager.get(“config.theme”);
createWindow(t);
```

```
<service-point id=“GUITheme”>
  <invoke-factory>
    <service>OSXDark</service>
 </invoke-factory>
</service-point>
```

- Change factory by changing external file
  - Typos in file caught at run-time, not compile time
  - Program can’t run without external file
  - (Note: This is a made up example, it doesn’t correspond to any actual XML format)

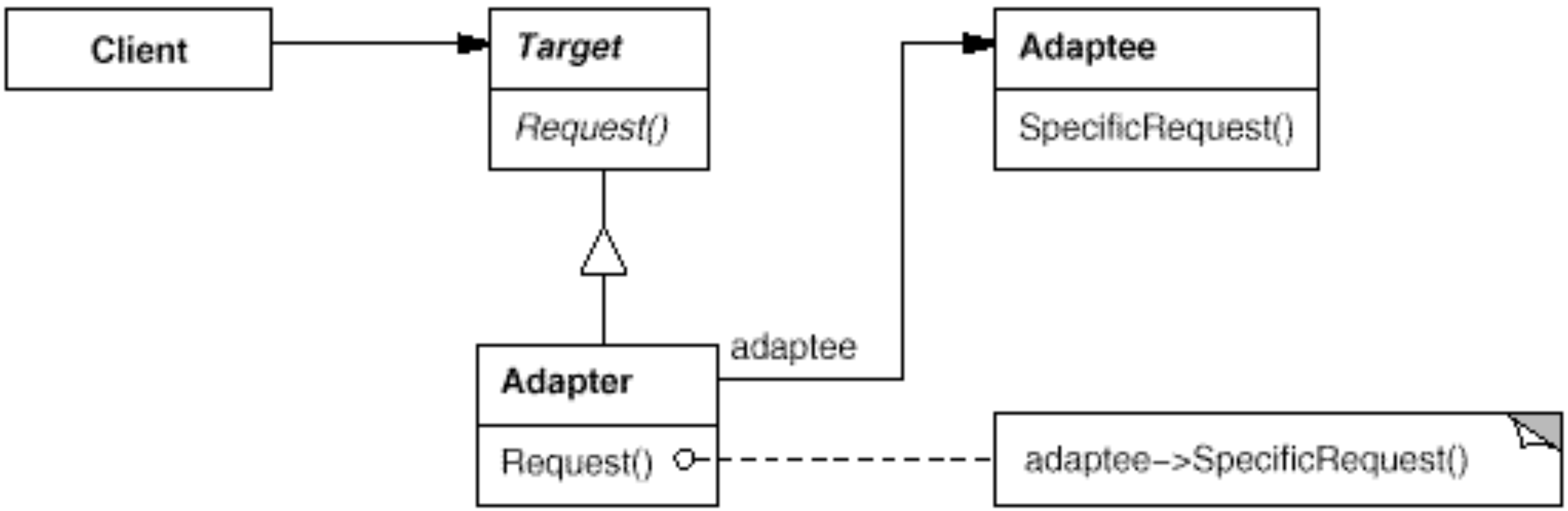
# Structural Patterns

# Wrappers

- Wrappers are a thin layer around an existing class
  - Adapter — same functionality, different interface
  - Proxy — same interface, additional logic
    - Usually, access control or condition checking
  - Decorator — same interface, change functionality

# Adapter Pattern

- Problem: Client needs functionality of another class (*adaptee*) but is written to a different interface
- Solution: Introduce an *adapter*



# Example

```
interface Graph {
    boolean addNode(String n);
    boolean addEdge(String n1, String n2);
    boolean hasNode(String n);
    boolean hasEdge(String n1, String n2);
}
```

```
public interface EdgeGraph {
    boolean addEdge(Edge e);
    boolean hasNode(String n);
    boolean hasEdge(Edge e);
    boolean hasPath(List l);
}
```

```
public class EdgeGraphAdapter implements EdgeGraph {
    private Graph g;
    EdgeGraphAdapter(Graph g) { this.g = g; }
    // methods of EdgeGraph
}
```

# Another Example

```
interface Rect {
  void scale(float factor);
  float getWidth();
  float area();
}
```

```
class RectShape {
  // no scale method
  float getWidth() { … }
  float area() { … }
  …
}
```

```
class RectAdapter implements Rect {
  RectShape rs;
  RectAdapter(RectShape rs) { this.rs = rs; }
  float getWidth() { return rs.getWidth(); }
  float area() { return rs.area(); }
  void scale(float factor) {
    rs.setWidth(rs.getWidth() * factor);
    rs.setHeight(rs.getHeight() * factor);
} }
```

# Adapting by Subclassing

- Notice to write `RectAdapter`, need `RectShape` to have certain functionality
  - Otherwise it would not be possible to scale
- Another approach: subclass `RectShape`
  - Easy to add `scale` method
  - Easy to add any others methods we like
  - But then there will be high coupling between subclass and `RectShape`
    - Not recommended

# Discussion

- Why not just change the adaptee to have the new interface?
  - There might be other code that relies on the current adaptee interface
  - The adaptee might be code someone else "owns"
    - Either externally, e.g., some open source code from GitHub
    - Or internally, e.g., another group in your company
- Why not duplicate the adaptee and change its interface?
  - Okay temporary, but what happens as the adaptee evolves
  - Need to continually maintain your "shadow" copy of the adaptee and apply your changes to it
  - LIkely more painful than maintaining adapter because adapter is written to the public interface

# Proxy Pattern

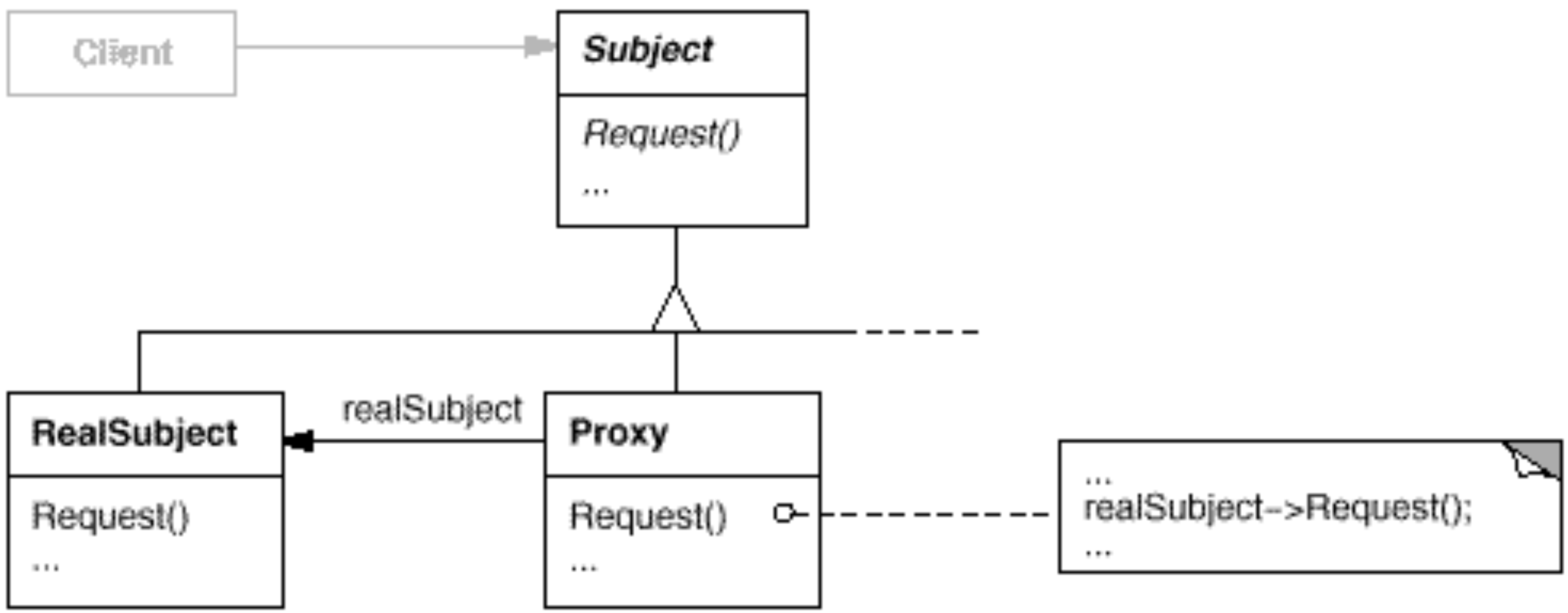
- Prevent object from being accessed directly
  - Introduce proxy object to mediate requests
  - Most likely, proxy object should *own* proxied object
    - No way to get to proxied object except through proxy
  - Guarantees *complete mediation*, i.e., all accesses go through proxy
- Use cases
  - Access control: check client has permission to call methods
  - Virtual proxy: don't create proxied object until used
    - Useful if object creation is expensive
  - Communication proxy: object conceptually lives on a remote system, hide that fact from client
    - It's a bad idea to hide it completely, since clients must worry about network failure

# Proxy Pattern Example

```
class Employee {
   int getSalary() { … }
}
```

```
class ProtectedEmployee {
  private Employee e;
  int getSalary() {
    if User.currentUser().supervises(e)
      return e.getSalary();
    else
      throw UnauthorizedAccessException();
} }
```

# Proxy Pattern Class Diagram




- Like adapter, but interface doesn't change

# Discussion

- Security checks should really be in `Employee`
  - It's hard to envision a real code base where they wouldn't be
- Both proxy and adapter are a bit of a hack
  - Might be hard to sustain long-term
  - If the adaptee/proxied class is not intended for the adapted/proxied use, it might change in ways incompatible with it
- Ideal: these are temporary solutions that will eventually be eliminated through long-term changes
  - Convince the adaptee/proxied class to change
  - If functionality diverges significantly, implement your own version of adaptee/proxied class with features you want
- Line between adapter/proxy unclear
  - What if we both adapt and add proxy features? Then maybe it's just a "wrapper"

# Decorator Pattern

- Problem:
  - Want to add several different pieces of functionality to object
  - Want to combine these pieces *without* making classes for all possible combinations
  - Want to decide *at run time* what the combinations are
- Solution: The decorator pattern
  - Act like a proxy/adapter, but also *implement the same interface as the original component*
  - That way, multiple decorators can be combined

# Example: LineNumberReader

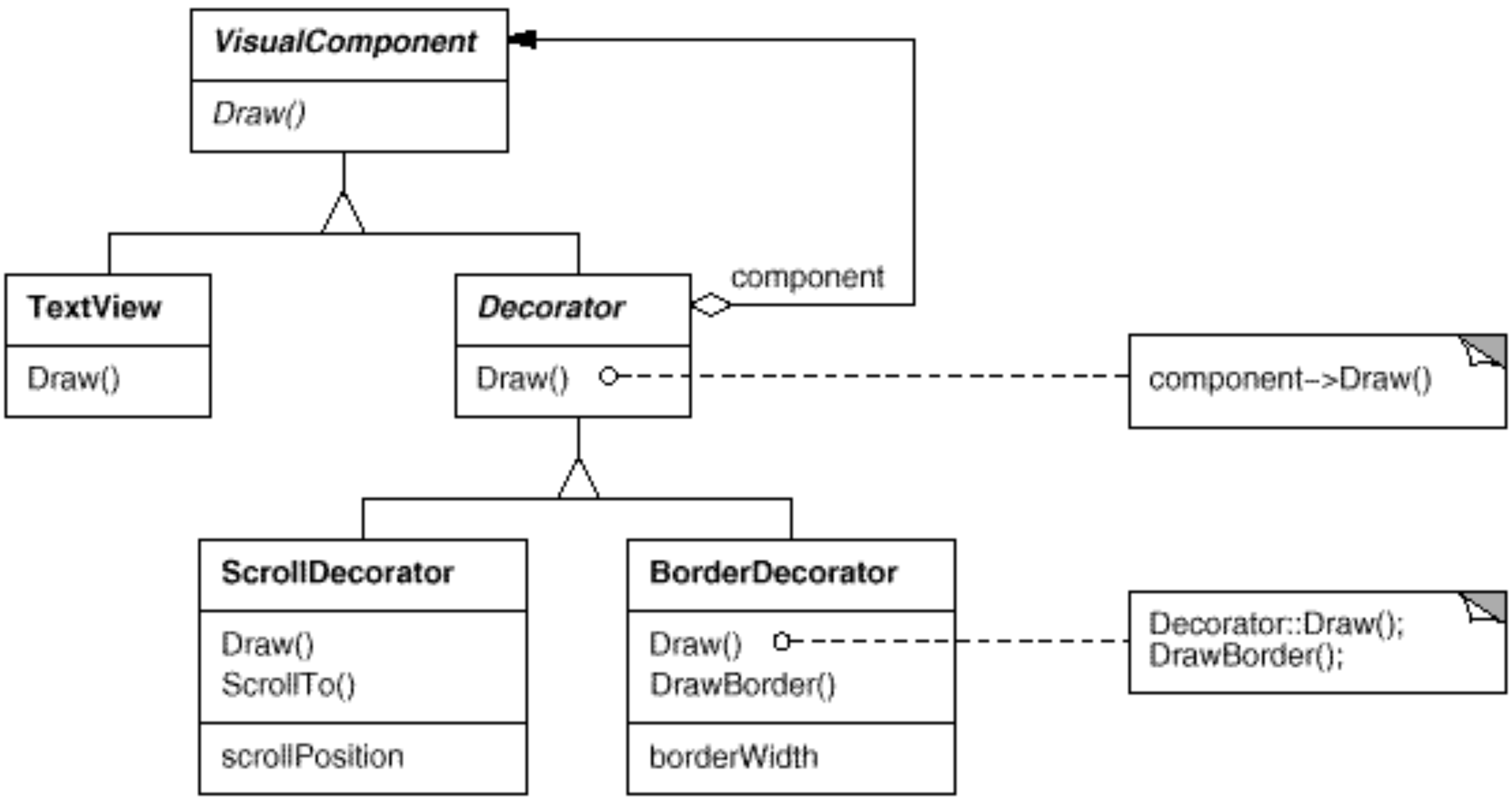
```
package java.io;
class Reader { … }
class BuffferedReader { … }
class LinkeNumber reader extends BufferedReader {
  private int lineNumber;
  public LineNumberReader(Reader in) { super(in); }
  public int getLineNumber() { return lineNumber; }

  public int read() { // Simplified
    int c = super.read();
    if (c == ‘\n’) { lineNumber++; return ‘\n’; }
    return c;
} }
```

https://hg.openjdk.java.net/jdk/jdk11/file/1ddf9a99e4ad/src/java.base/share/classes/java/io/LineNumberReader.java

# Discussion

- `LineNumberReader` is a decorator for `Reader`
  - It wraps an instance of `Reader`
  - Implements the same interface
    - Can use it wherever a `Reader` is expected
  - It adds functionality (`getLineNumber()`)
    - Can access the functionality either through `LineNumberReader` type or by downcasting to that type
  - Wrapping happens at runtime
    - When  we create a `Reader`, we don't need to allocate it as a `LineNumberReader`
    - We can wrap it some time later

# Decorator Class Diagram



# A More Interesting Decorator

```
interface Window { void draw(); }
class WindowImpl implements Window { … }

class BorderedWindow implements Window {
  Window inner;
  BorderdWindow(Window inner) { this.inner = inner; }
  void draw() { inner.draw(); /* and draw border */ }
}
class ScrollingWindow implements Window {
  Window inner;
  ScrollingWindow(Window inner) { this.inner = inner; }
  void draw() { inner.draw(); /* and draw scrollbar */ }
}

/* Now can make a plain window, a bordered window, a
scrolling window, or a bordered scrolling window, with
only three classes defined */
```

# Removing Functionality

```
interface List {                                        (slightly simplified)
  static List<E> copyOf(Collection<E> coll);
  // returns unmodifiable List containing elts of coll
}
```

- Can't add, remove, or replace list elements
  - Removing functionality via decoration
  - (But can mutate list elements themselves if they have mutable fields)
- It's slightly awkward that we now have a `List` that's behaviorally not a list in that some methods can't actually be called

# Decorator Pattern Discussion

- Advantages
  - Fewer classes than with static interhitence
    - Don’t need to define classes for combinations of decorators
  - Dynamic addition/removal of decorators
  - Keeps root classes simple
- Disadvantages
  - Proliferation of run-time instances
    - Adds overhead through extra method calls, extra object allocations
  - Still need to have a common interface for all decorators
- Overall, unclear if decorator pattern is best choice
  - Might be better in practice to make a single class with all functionality, and use a field to keep track of which functionality is enabled

# Behavioral Patterns

# Observer Pattern

- Problem: One object must be consistent with another's state

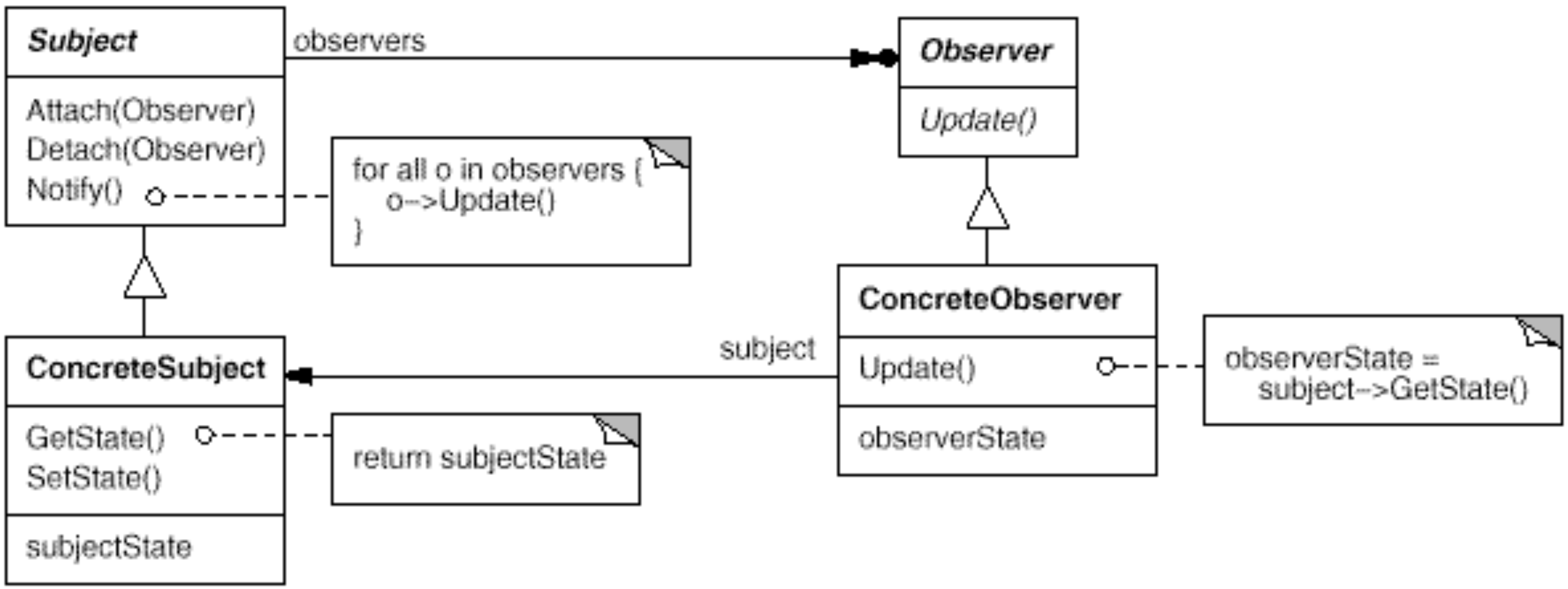
- Solution:
  - One object is the *subject*, it holds the state
  - Another object is the *observer*, it wants to know when the subject's state changes
  - Whenever the subject changes, *notify* the observer

# Observer Pattern Example: GUIs

```
// From Java Swing
class AbstractButton {
  void addActionListener(ActionListener l) { … }
}
class JButton extends AbstractButton { … }
interface ActionListener {
  void actionPerformed(ActionEvent e);
}
class MyListener {
  void actionPerformed(ActionEvent e) {
    System.out.println(“Button clicked!”);
} }
JButton b = new JButton(“Click me!”);
b.addActionListener(new MyListener())
```

- When the button’s state changes (via a click), the `Button` will call the registered handler
- This pattern is very common in GUIs

# Observer Class Diagram



# Example Observers in Android

- Android LifeCycle: three methods called at various points of app startup
  - Depending on whether launched (`onCreate`), on screen (`onStart`), or in the foreground (`onResume`)

```
class MyActivity extends Activity { // an app screen
  void onCreate(Bundle b) { … }
  void onStart() { … }
  void onResume() { … }
}
```

- Receive notifications of location changes

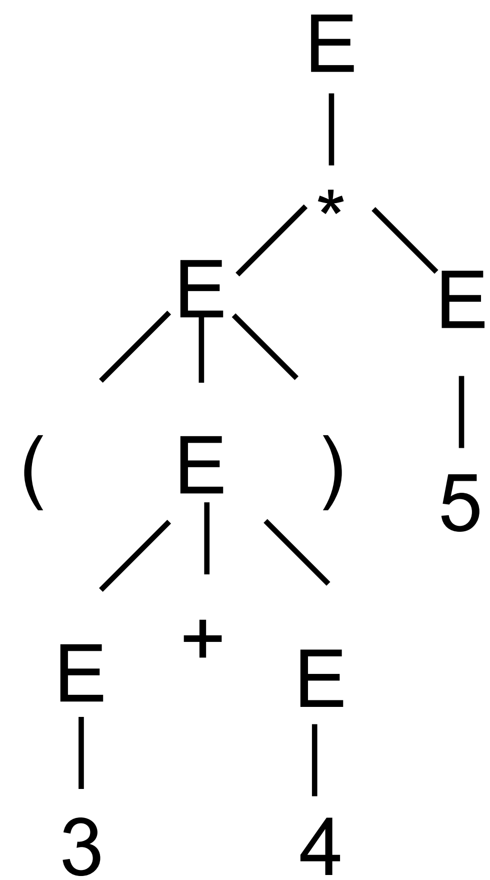
```
interface LocationListener {
  void onLocationChanged(Location loc); …
}
```

# Observer Design Choices

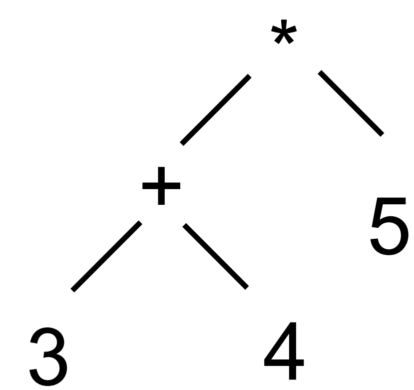
- Where is list of observers stored?
  - Typically in subject
- How much is communicated to observer?
  - Easiest: an observer only observes a single kind of event
  - For multiple events, pass an object (e.g., `ActionEvent`)
    - Or use multiple observer methods, e.g., `onCreate`, `onStart`, `onResume`
  - Or, observer inspects subject to figure out what changed
- Who triggers the update?
  - State-setting operations of the subject
  - Does every state change trigger an event?
    - E.g., `onLocationChange` is not called instantly on a location change
- Granularity of events that can be observed
  - Notified on any state change? Only certain state changes?

# Abstract Syntax Trees (ASTs)

- An *abstract syntax tree* is a data structure representing some program code
  - Example: (3+4)*5




Parse Tree




Abstract Syntax Tree

# Implementing ASTs in OO

```
interface Expr { }
class IntExpr implements Expr {
  int val;
  IntExpr(int val) { this.val = val; }
}
class AddExpr  implements Expr{
  Expr left, right;
  AddExpr(Expr left, Expr right) { this.left=left;
                                    this.right=right; }
}
class MultExpr implements Expr {
 /* Similar to AddExpr */
}

Expr e = new MultExpr(new AddExpr(new IntExpr(3),
                                  new IntExpr(4)),
                      new IntExpr(5));
// e = (3+4)*5
```

# Traversal Patterns

- In general, we could have many more expressions
  - More operators, e.g., subtraction, division, etc
  - Conditionals
  - Variables
  - Assignments
  - Method calls
  - etc.
- We also might want to implement several computations over ASTs
  - Evaluate
  - toString()
  - Typecheck
  - …

# Functional-Style Traversal

```
int eval(Expr e) {
  if (e instanceof IntExpr) {
    IntExpr ie = (IntExpr e);
    return ie.val;
  } else if (e instanceof AddExpr) {
    AddExpr ae = (AddExpr e);
    return eval(ae.left) + eval(ae.right);
  } else if (e instanceof MultExpr) {
    MultExpr me = (MultExpr e);
    return eval(me.left) * eval(me.right);
} }
```

- Variation: put each case in a method
  - …if (e instanceof IntExpr) { return eval((IntExpr) e); }…
  - int eval(IntExpr e) { return e.val; }

# Functional-Style Traversal Variation

```
// could also use overloading
int eval(IntExpr e) { return e.val; }
int eval(AddExpr e) {
  return eval(e.left) + eval(e.right);
}
int eval(MultExpr e) {
  return eval(e.left)*eval(e.right);
}
int eval(Expr e) {
  if (e instanceof IntExpr) {
    return eval((IntExpr) e);
  } else if (e instanceof AddExpr) {
    return eval((AddExpr) e);
  } else if (e instanceof MultExpr) {
    return eval((MultExpr) e);
} }
```

# OO-Style Traversal

```
interface Expr { … int eval(); }
class IntExpr implements Expr {
  … int eval() { return val; }
}
class AddExpr implements Expr { …
  int eval() { return left.eval() + right.eval(); }
}
class MultExpr implements Expr { …
  int eval() { return left.eval() + right.eval(); }
}
```

# Tradeoffs

- Functional-style traversal
  - Code for single operation grouped together
  - Code for different operations separated
  - Easy to add operations
  - Hard to add classes, need to modify every operation
  - Need to duplicate conditional tests for every operation
    - And cascaded `if-then-else`s might not be that efficient
- OO-style traversal
  - Code for single operation spread across classes
  - All operations for single class grouped together
  - Hard to add operations, need to modify every class
  - Easy to add classes, just go through and implement all ops

# Implementing OO Traversal Once

- What if we want to
  - Use the OO-style traversal
  - Implement multiple operations (`eval`, `toString`, etc)
  - **Only write the traversal code once**

```
interface Expr { }
class IntExpr implements Expr { … }
class AddExpr implements Expr { … }
class MultExpr implements Expr { … }
```

```
interface Visitor { … }
class Eval implements Visitor { … }
class ToString implements Visitor { … }
```

# The Problem: Single Dispatch

- Here's what we want to do:

```
Expr ex = new MultExpr(…);
Eval ev = new Eval();
// Use ev to evaluate ex
```

- Which method should we start running?
  - Clearly, `Eval`'s method for `MultExpr`
- So, the method we want to call depends on both
  - The run-time type of `ex`
  - The run-time type of `ev`
- Standard use of dynamic dispatch can't handle this
  - Calling `ev.m(ex)` can only choose which `m` based on `ev`, not based on `ex`

# Double Dispatch Problem

```
interface I
class A implements I { }
class B implements I { }

interface Z
class X implements Z { }
class Y implements Z { }
```

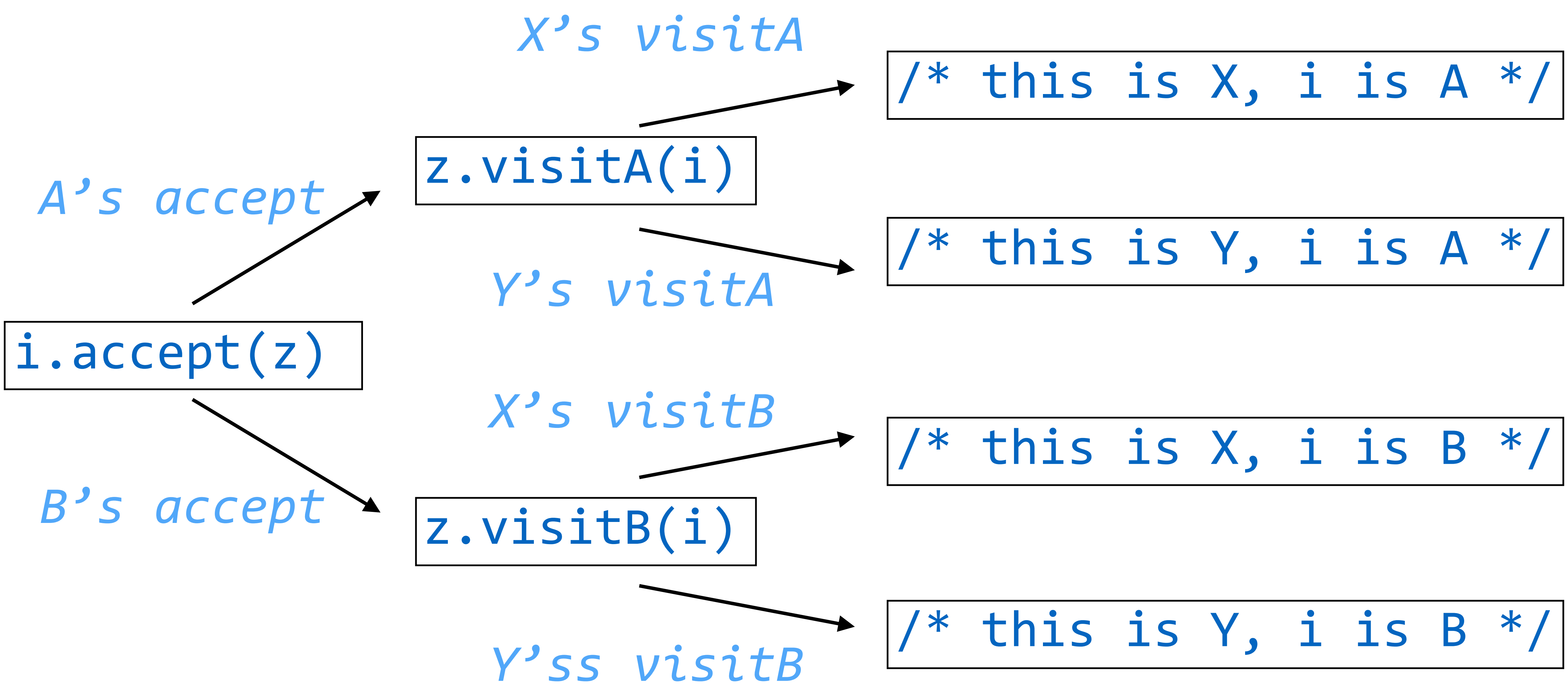
- Suppose
  - We have an `I` and a `Z`
  - We want to invoke method depending on those objects' run-time types (classes)
  - So we are choosing among four methods
    - (A, X), (A, Y), (B, X), (B, Y)

# Double Dispatch Solution

```
interface I { }
class A implements I {
  void accept(Z z) { z.visitA(this); }
}
class B implements I {
  void accept(Z z) { z.visitB(this); }
}

interface Z
class X implements Z {
  void visitA(I i) { /* this is X, i is A */ }
  void visitB(I i) { /* this is X, i is B */ }
}
class Y implements Z {
  void visitA(I i) { /* this is Y, i is A */ }
  void visitB(I i) { /* this is Y, i is B */ }
}
```

# Double Dispatch, Pictorally

*i∈{A,B}  z∈{X,Y}*




- Use dynamic dispatch on one value, then flip args and use dynamic dispatch on the other value

# Visitor Pattern

- Combine two things
  - External iteration, usually over a tree structure
    - We have two objects: the tree and the visitor
  - Double dispatch
    - So that we can call a method depending on the run-time type of a tree node and which visitor object is doing the visiting

```
class SomeExpr implements Expr {
  void accept(Visitor v) {
    // postorder traversal
    for each child of this node { child.accept(v); }
    v.visitSomeExpr(this);
} }
class SomeVisitor implements Visitor {
  void visitSomeExpr(SomeExpr e) { … }
  void visitOtherExpr(OtherExpr e) { … }
}
```

# AST Visitor

```
interface Expr {
 void accept(Visitor v);
}
class IntExpr implements Expr{
 void accept(Visitor v) {
  v.visitIntExpr(this);
}}
class AddExpr implements Expr{
 void accept(Visitor v) {
  left.accept(v);
  right.accept(v);
  v.visitAddExpr(this);
}}
class MultExpr implements Expr{
 void accept(Visitor v) {
  left.accept(v);
  right.accept(v);
  v.visitMultExpr(this);
}}
```

```
// assume every Expr also has a
evald field to store what it
evaluates to

interface Visitor { … }
class Eval implements Visitor {
 void visitIntExpr(IntExpr e) {
  e.evald = e.val;
}
 void visitAddExpr(AddExpr e) {
  e.evald = e.left.evald +
          e.right.evald;
 }
 void visitMultExpr(AddExpr e) {
  e.evald = e.left.evald *
          e.right.evald;
 }
```

# AST Visitor Example Run

```
Expr e = new MultExpr(new AddExpr(new IntExpr(3),
                                  new IntExpr(4)),
                      new IntExpr(5));
Visitor v = new Eval();
e.accept(v); // calls MultExpr’s accept
e.left.accept(e); // calls AddExpr’s accept
  e.left.left.accept(e); // call IntExpr(3)’s accept
    e.left.left.evald = 3;
  e.left.right.accept(e);
    e.left.right.evald = 4;
  e.visitAddExpr(e);
    e.left.evald = 7; // 3+4
e.right.accept(e); // call IntExpr(5)’s accept
  e.right.evald = 5;
v.vistMultExpr(e);
  e.evald = 12 // 7+5
```

# AST Visitor with Overloading

```
interface Expr {
 void accept(Visitor v);
}
class IntExpr implements Expr{
 void accept(Visitor v) {
  v.visit(this);
}}
class AddExpr implements Expr{
 void accept(Visitor v) {
  left.accept(v);
  right.accept(v);
  v.visit(this);
}}
class MultExpr implements Expr{
 void accept(Visitor v) {
  left.accept(v);
  right.accept(v);
  v.visit(this);
}}
```

```
// Just have a single method
name, visit, and rely on
overloading to resolve which
visit method is called

interface Visitor { … }
class Eval implements Visitor {
 void visit(IntExpr e) {
  e.evald = e.val;
}
 void visit(AddExpr e) {
  e.evald = e.left.evald +
          e.right.evald;
 }
 void visit(AddExpr e) {
  e.evald = e.left.evald *
          e.right.evald;
 }
```

# Challenges with Visitors

- Visit order is fixed by `accept` method
  - What if we want to visit in preorder? inorder?
  - Could do the following, but then visitors are big

```
void accept(Visitor v) {
 v.visitPre(this)
 left.accept(v);
 v.visitIn(this);
 right.accept(v);
 v.visitPost(this);
}
```

- `visit` methods needs to store results elsewhere
  - In `this`, in custom data structure or in the data structure
- Visitors are popular but are pretty clunky
  - Pattern matching is a much better solution

# More Patterns?

The following aren’t usually called “design patterns,” but they kind of are…

# OO Programming in C

- C is not object-oriented
  - Should that stop us from using objects in C? No!

```
enum clazz {A, B};
typedef struct PrintI { // an interface
  enum clazz id;
  void (*print)(void);
} *PrintI;

void printA(void) { printf("I'm an A!\n"); }
PrintI newA(void) {
  PrintI o = malloc(sizeof(struct PrintI));
  o->id = A; o->print = printA;
  return o;
}

PrintI a = newA();
a->print(); // dynamic dispatch!
```

# Imperative Programming in Haskell

- Haskell is a *pure* functional programming language
  - Does not allow changing value of a variable or of heap cell
- *Monads:* program imperatively in pure func. setting
  - Idea: pass state around to all functions

```
class State {
 public final int x, y;
 State(int x, String y) { this.x = x; this.y = y; }
}
State theWorld;
theWorld = new State(0, “”);
theWorld = newState(theWorld.x + 1, theWorld.y);
theWorld = m(42, theWorld);

State m(int z, State theWorld) {
 return new State(theWorld.x + z, theWorld.y);
}
```



  - Monads include syntactic sugar to avoid the boilerplate

# Convention over Configuration

- A *framework* is a code base that supports the development of a certain class of applications
  - E.g., Ruby on Rails is a framework for building web apps
  - Unlike a library, which is called by an app, the framework runs on the "outside" and executes the app code
- Frameworks tend to be broad and shallow
  - Supports many different bits and pieces of functionality
    - E.g., Rails includes support for: accessing database, rendering web pages, running different web servers, sending email, storing persistent objects, testing apps, securing apps, supporting JavaScript, etc, etc
- How can anyone program something that complex?
  - *Convention over configuration* = developer only needs to specify non-standard parts of the app

# Conv. over Config. w/Rails Routing

```
# config/routes.rb
Talks::Application.routes.draw do
  resources :talks
end

# app/controllers/talks_controller.rb
class TalksController < ApplicationController
  def index … end
end

# app/views/talks/index.html.erb
```

- Above specifies standard behavior:
  - Requesting URL / will invoke `TalksController#index`
  - When `TalksController#index` finished, it will send `views/talks/index.html.erb` back to the user
  - (Same for `show`, `edit`, etc)