Classes as Layers: Rewriting Design Patterns with COP

Alternative Implementations of Decorator, Observer, and Visitor

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Overview

Introduction

- **Related Work:** Instantiable layers in JCop [1] etc., previous work on COP-based class extensions [2]
- **Idea:** Unify classes and layers; partial methods are defined as part of classes (i.e., classes can acts as layers)
- **This presentation:** How to rewrite Decorator, Observer, Visitor [3] to take advantage of that
  - Pattern description
  - Traditional implementation example
  - COP implementation example
  - Benefits and disadvantages
- Not mere refactorings, but rewritings: changed semantics

Overview

Language Design

- Classes can have 4 different kinds of methods:
  - Member method (instance method)
  - Member partial method (partial method defined for instances)
  - Static method (class method)
  - Static partial method (partial method defined for class)
- Arbitrary objects can be (de)activated (no dedicated layer construct)
  - Global activation
  - Block scope activation
  - Per-object activation [4]
- Object providing partial methods: *layer object*
- Object(s) being adapted: *affected object(s)*

Language Design

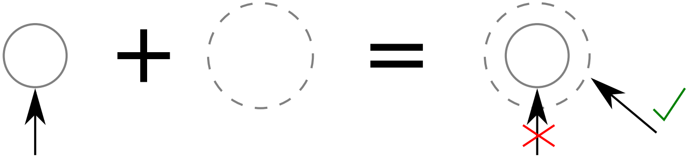
Example

```
class T {                                          /* target class */
  def foo() { /* ...  */ }
  def bar() { return "T"; }
}

class L {                                          /* layer class */
  def T.foo() {
    thisLayer.bar();                               /* -> "L" */
    this.bar();                                    /* -> "T" */
  }

  def bar() { return "L" }
}

new L().activate();                         /* global activation */
new L().activate(new T());               /* per-object activation */
with (new L()) { /* ...  */ }            /* block scope activation */
```

Overview

Decorator

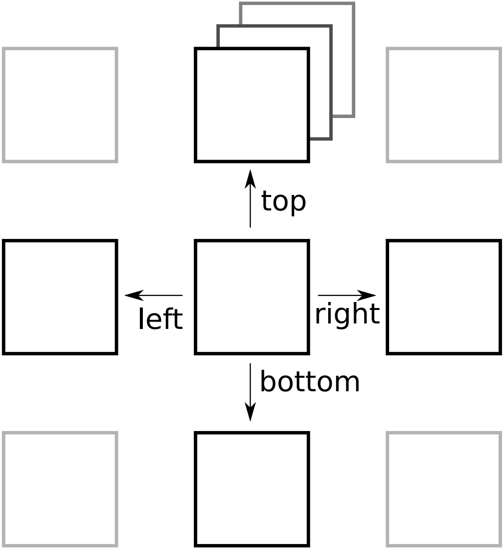
Pattern Description



- **Purpose:** Adding/removing responsibilities to an object at runtime
- **Mechanism:** Wrapping the object in a decorator, using the decorator instead of the object from now on
- **Problem:** References to the original object are not affected

Decorator

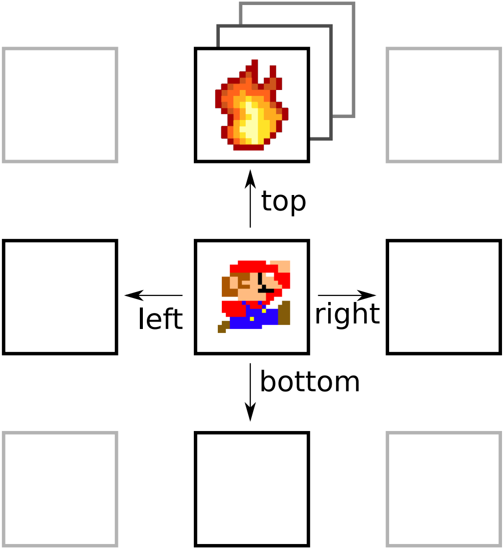
Example



- *Example:* Game with 2D grid (consisting of fields)
- Fields connected with adjacency lists
- Would like to ensure that references point to decorated fields

Decorator

Example



- *Example:* Game with 2D grid (consisting of fields)
- Fields connected with adjacency lists
- Would like to ensure that references point to decorated fields

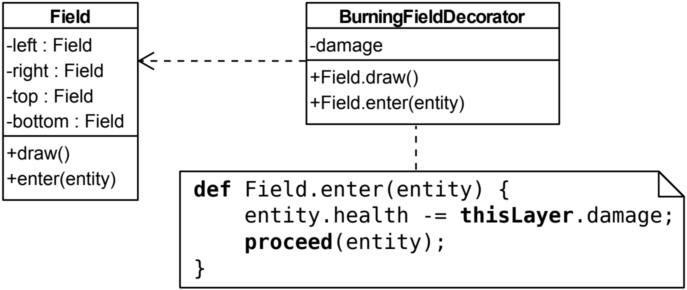
Decorator

Traditional Implementation: Example

```
class Field {
  def left, right, top, bottom;
  def draw() { /* ...  */ }
  def enter(entity) { /* ...  */}
  def neighbors() { /* ...  */ }
}

class BurningFieldDecorator {
  def decoratee;
  def damage = 15;

  def draw() { /* ...  */ }

  def enter(entity) {
    entity.health -= damage;
    decoratee.enter(entity);
  }

  def neighbors() { return decoratee.neighbors(); }
}
```

Decorator

COP Implementation: Example



- A decorator is an object that provides partial methods for additional/modified behavior
- Partial methods can call `proceed` to invoke next/original method

Decorator

COP Implementation: Example

```
def field = /* ... */
def decorator = new BurningFieldDecorator();

// Active decorator on object field
decorator.activate(field.left);

// Call decorated method
def moveLeft() {
  def player = /* ... */
  field.left.enter(player);
}
```

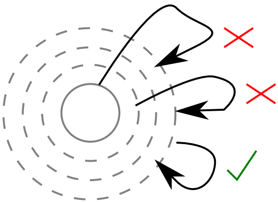
Decorator

COP Implementation: Example

```
def field = /* ...  */
def decorator = new BurningFieldDecorator();
def anotherDecorator = new MineFieldDecorator();

// Active decorator on object field
decorator.activate(field.left);
anotherDecorator.activate(field.left);

// Call decorated method
def moveLeft() {
  def player = /* ...  */
  field.left.enter(player);
}
```

Decorator

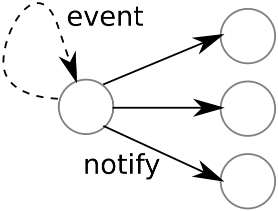
COP Implementation: Consequences



- ⊖ Method calls within an object (`this` calls) are affected
  Is that a bad thing if we layer only `public` methods?
- ⊖ Partial methods rely on static types for target class (i.e., `BurningFieldDecorator` can only layer `Field` objects)
  → Do we need wildcard class names? (`*.enter(entity)`)
- ⊕ No "object schizophrenia"

Observer

Pattern Description



- **Purpose:** Reacting to state changes/events of a dependent object
- **Mechanism:** Maintaining a list of observers, notifying all observers about state changes/events
- **Problem:** All observers are notified about all state changes/events
- **Problem:** Difficult to pass information about different events
- **Problem:** Troublesome to observe all instances of a class

Observer

Example

- Application with login, register functionality: class `UserManager`
- `LoginMonitor`: listens to login attempts
- `SecurityMonitor`: listens to failed login attempts and new user registrations

Observer

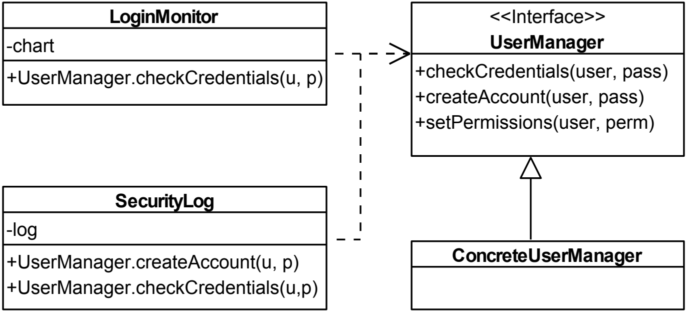
Traditional Implementation: Example

```
class UserManager {
  def observers = new List();
  def notify(type, data) {
    for (def o in observers) {
      o.update(type, data);
    }
  }

  def checkCredentials(user, pass) {
    notify("login", user)
    if (wrongPass) {
      notify("failed_login", user);
    }
  }

  def createAccount() {
    notify("create_acc", null);
  }
}
```

```
class SecurityLog {
  def update(type, data) {
    if (
      type == "failed_login" ||
      type == "create_acc") {
      /* ... */
    }
  }
}

class LoginMonitor {
  def update(type, data) {
    if (type == "login") {
      /* ... */
    }
  }
}
```

Observer

COP Implementation: Example



- An observer is an object that provides partial methods for methods indicating state changes/events
- Partial methods immediately call `proceed` and handle event

Observer

COP Implementation: Example

```
class SecurityLog
  def UserManager.checkCredentials(user, pass) {
    if (!proceed(user, pass)) {
      /* ...  */
    }
  }
}

def userManager = /* ...  */
def loginMonitor = new LoginMonitor();
def securityLog = new SecurityLog();

// Activate observer on object userManager
loginMonitor.activate(userManager);

// Activate observer on all UserManager implementation objects
securityLog.activate();
```

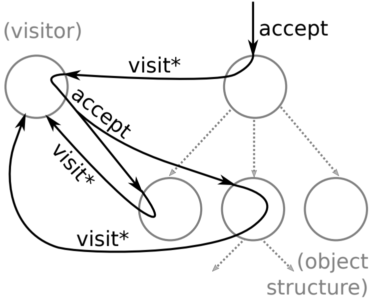
Observer

COP Implementation: Consequences

- ⊖ **Less Flexibility:** Notifications only before or after method calls, but not inside (less flexibility)
- ⊖ **Modularity:** Potentially tighter coupling between subject and observer (binding observer to method names of subjects)
- ⊕ **Argument Passing:** Every partial method can have its own signature
- ⊕ **Notification Levels:** Observers can listen to different events
- ⊕ **Group Observation:** Observers can listen to all objects of a class
- ⊕ **Dynamic Adaptation:** Subject does not have to implement an interface

Visitor

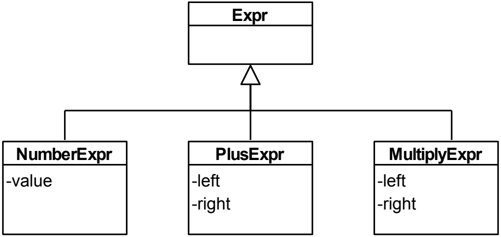
Pattern Description



- **Purpose:** Adding new operations to a family of classes
- **Mechanism:** Separate *visitor* class, back-and-forth interaction (*double dispatch*) between objects and visitor
- **Problem:** Complex object interaction (double dispatch)

Visitor

Example



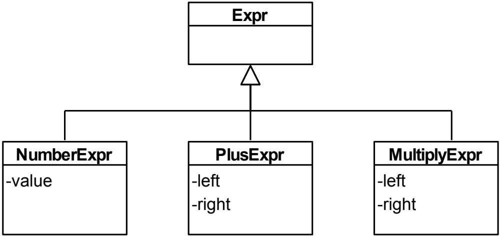
Visitor

Traditional Implementation: Example

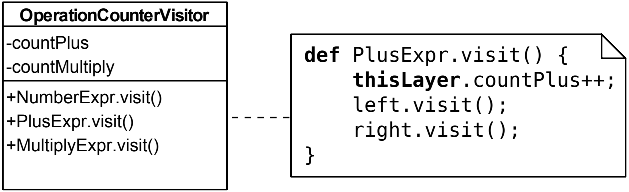
```
class PlusExpression extends Expression {
  def left, right;
  def accept(visitor) { visitor.visitPlusExpr(this); }
}

class NumberExpression extends Expression {
  def value;
  def accept(visitor) { visitor.visitNumberExpr(this); }
}

class OperationCounterVisitor {
  def countPlus, countNumber;

  def visitPlusExpr(node) {
    this.countPlus++;
    node.left.accept(this); node.right.accept(this);
  }

  def visitNumberExpr(node) { this.countNumber++; }
}
```

Visitor

COP Implementation: Example



- A visitor is an object that provides partial methods for new operations
- Partial methods can call visitor methods on other objects directly



Visitor

COP Implementation: Example

```
def treeRoot = /* ...  */
def visitor = new OperationCounterVisitor();

// Activate visitor in a block scope
with (visitor) {
  def result = treeRoot.visit();
}
```

Visitor

COP Implementation: Consequences

- ⊖ **Composability:** Potential name clashes between simulataneouly activated visitors (but visitors can use different method names)
- ⊕ **Simple Object Interaction:** No double dispatch necessary
- ⊕ **Dynamic Adaptation:** Classes do not have to provide accept methods

Overview

Summary

- **Classes as Layers:** Partial methods are members of classes and classes are instantiable
- COP Implementation of **Design Patterns**
  - *Decorator:* layer instance with partial methods for decorated methods
  - *Observer:* layer instance with partial methods for methods triggering state changes
  - *Visitor:* layer instance with partial methods for new operations
- Design patterns are not mere refactorings and have different semantics
- **Future work:** Implementation, analysis of other GoF design patterns, language features (e.g., partial method visibility), performance optimizations

References

[1] M. Appeltauer, R. Hirschfeld, J. Lincke. Declarative Layer Composition with the JCop Programming Language. Journal of Object Technology, Vol. 12, 2013

[2] M. Springer, H. Masuhara, R. Hirschfeld. Hierarchical Layer-based Class Extensions in Squeak/Smalltalk. Modularity Companion 2016.

[3] E. Gamma, R. Johnson, R. Helm, J. Vlissides. Design Patterns: Elements of Reusable Object-Oriented Software, 1994.

[4] J. Lincke, M. Appeltauer, B. Steinert, R. Hirschfeld. An open implementation for context-oriented layer composition in ContextJS. Science of Computer Programming, 2011.

Appendix

Method Lookup

- **Design Patterns:** How can we write an abstract visitor?
- **Language Semantics:** What happens if we override a partial method?
- **3 Dimensions:** Receiver class inheritance, layer inheritance, layer composition

Visitor

Overwriting Partial Methods: Layer Subclassing

```
class Evaluator
  def PlusNode.visit() {
    return left.visit() + right.visit();
  }
}

class ModEvaluator extends Evaluator {
  def modulo;

  ModEvaluator(def modulo) {
    this.modulo = modulo;
  }

  @override
  def PlusNode.visit() {
    return super.visit() % thisLayer.modulo;
  }
}
```

Visitor

Overwriting Partial Methods: Polymorphic Overriding

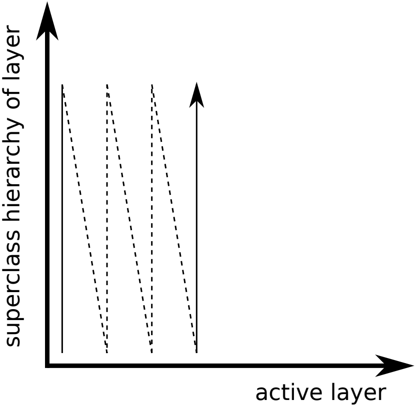
```
class SomeVisitor
  def Node.visit() {
    return /* ...  */
  }

  @override
  def PlusNode.visit() {
    return super.visit() + /* ...  */;
  }
}
```

Visitor

Overwriting Partial Methods: Layer Composition

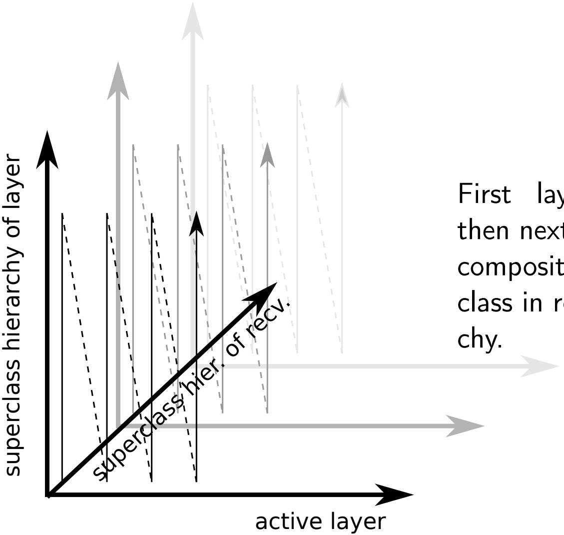
```
class SomeVisitor
  def Node.visit() {
    return /* ...  */
  }
}

class AnotherVisitor
  def Node.visit() {
    return super.visit() + /* ...  */;
  }
}

with (new Visitor()) {
  with (new AnotherVisitor()) {
    node.visit();
  }
}
```

Method Lookup



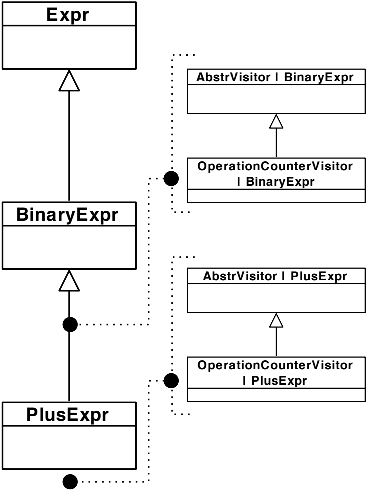
First layer hierarchy, then next class in layer composition.

Method Lookup



First layer hierarchy, then next class in layer composition, then next class in receiver hierarchy.

Method Lookup



$$LayerHierarchy(L, C) = \sum_{i=0}^{\#L} \langle super^i(L)[C] \rangle$$

$$ClassLayers(C) = \left(\sum_{i=1}^{|S|} LayerHierarchy(S[i], C) \right) + \langle C \rangle$$

$$Effective(C) = \sum_{i=0}^{\#C} ClassLayers(super^i(C))$$