Best Practices in Programming

Object Oriented Design Principles

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Software design

Finding solutions to complex problems

- Many sources of complexity
  - Functionality, cost constraints, performance, security, backwards compatibility, reliability, scalability, …

Software design is difficult!

- Design concerns structure and trade-offs.
  - Design is not code, but art and experience.
- Design has to fit the problem.
  - Often we need to solve the problem to understand it.
- Design has to fit the requirements.
  - Requirements tend to change.
  - We often ***don't know*** what they ***really*** are.

How hard can it be?

- Top Gear

What could possibly go wrong?

We could end up with poor design!

- Rigidity
  - System is difficult to change. Changes force further changes to other parts of the system.
- Fragility
  - Changes tend to break the system in places that have no conceptual relationship to the changed part.
- Immobility
  - Difficult to disentangle reusable components.
- Viscosity
  - Changes that preserve design are harder than hacks.

What could possibly go wrong?

We could end up with poor design!

- Needless complexity
  - System contains infrastructure that adds no direct benefit.
- Needless repetition
  - System contains repeated structures.
- Opacity
  - Code is difficult to read and understand.

How to arrive at good design?

What is good software design?

- Flexible, reusable, maintainable...
- Naturally fits the requirements.
- Robust in the face of changes.

How to arrive at good design?

- Start with a simple solutions.
- Stimulate changes to force design changes.
- Apply OO design principles when necessary.

What… principles?

SOLID object oriented design principles

- **S**ingle Responsibility Principle (SRP)
- **O**pen/Closed Principle (OCP)
- **L**iskov Substitution Principle (LSP)
- **I**nterface Segregation Principle (ISP)
- **D**ependency Inversion Principle (DIP)

… and a few more general principles

- Abstraction
- Encapsulation
- High cohesion
- Low coupling

Single Responsibility Principle

There should never be more than one reason for a class to change.

Single Responsibility Principle

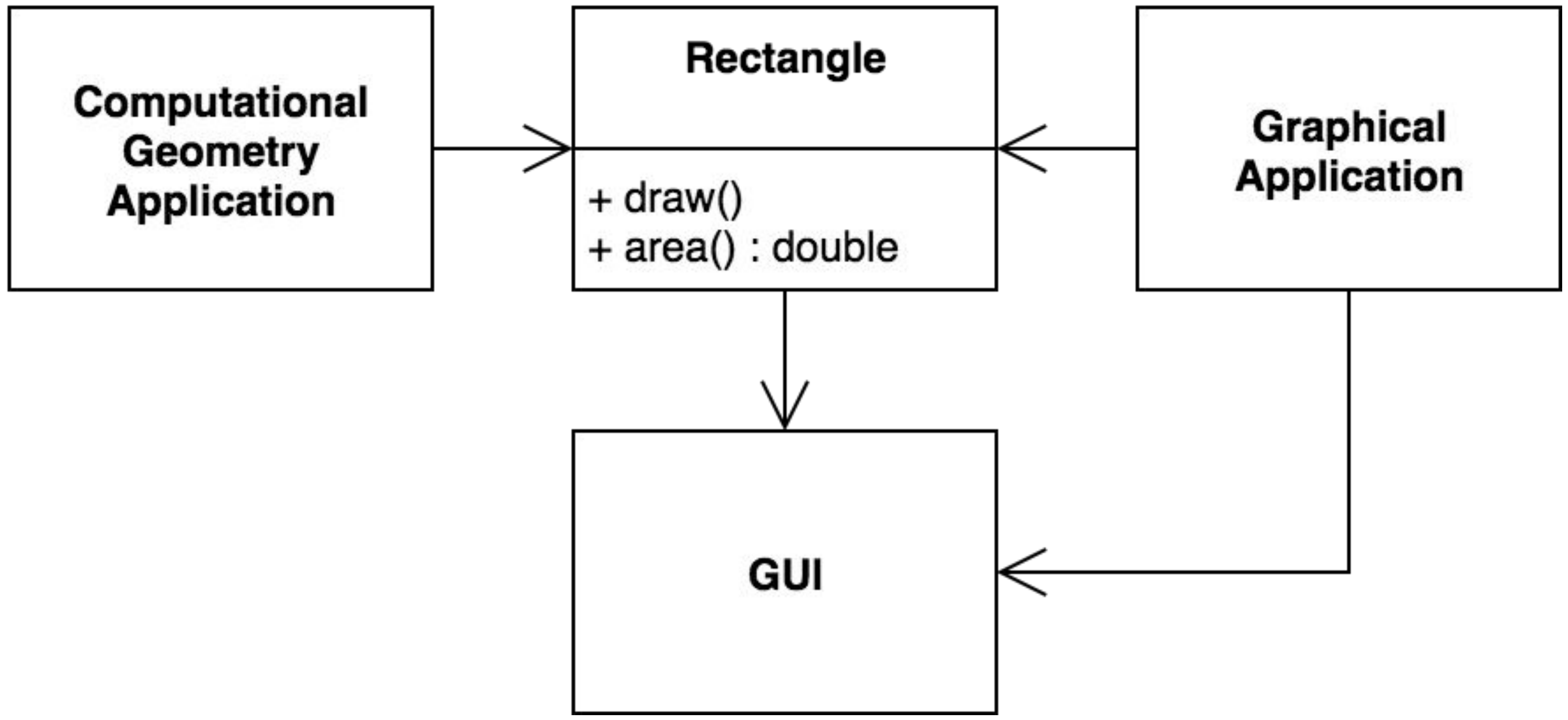
Each responsibility is an *axis of change*

- Changes in requirements manifest through changes in responsibility among classes
    - Class with more responsibilities will have more than one reason (i.e., along more axes) to change

Violation: more responsibilities in a single class

- Responsibilities become coupled
    - Changes to one responsibility may impair the ability of a class to meet other responsibilities
- Leads to fragile design that can break in unexpected ways when changed

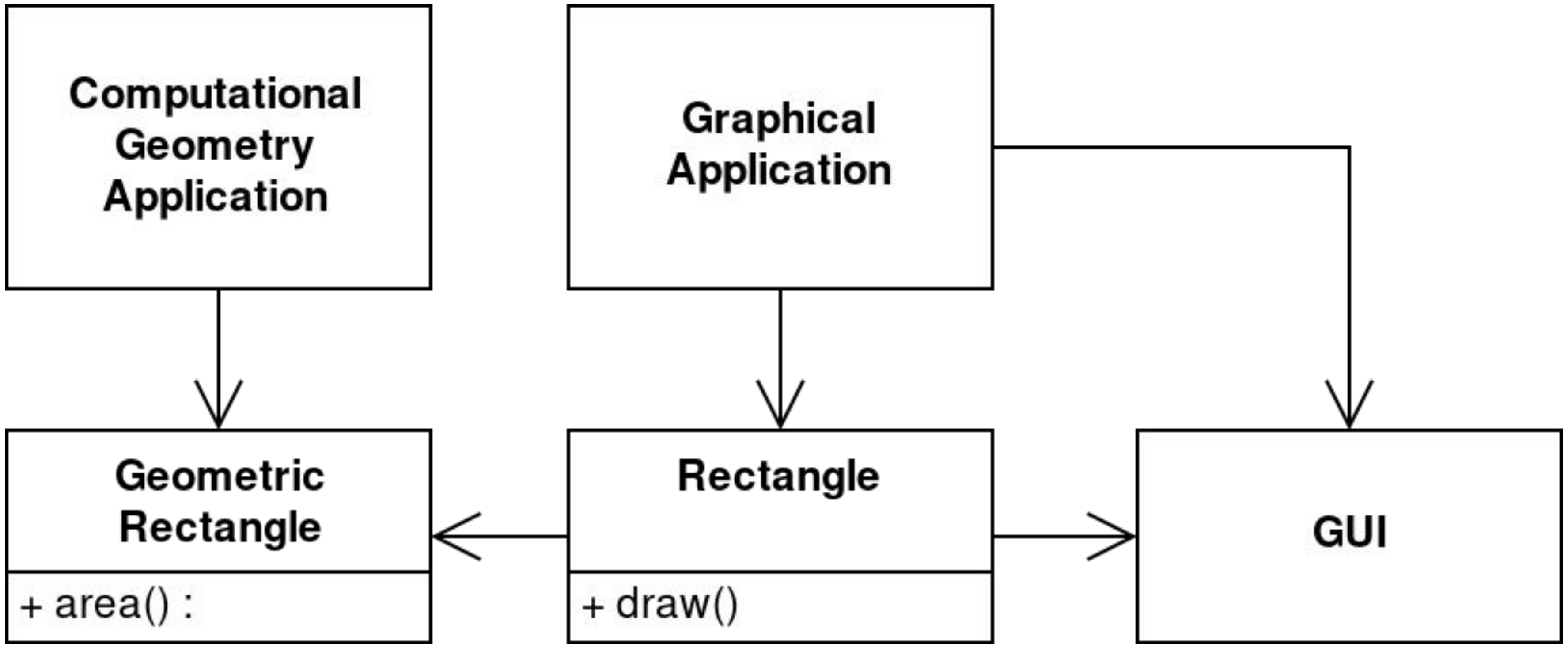
Example: SRP violation



Rectangle has 2 responsibilities

- Mathematical model
- Graphical rendering

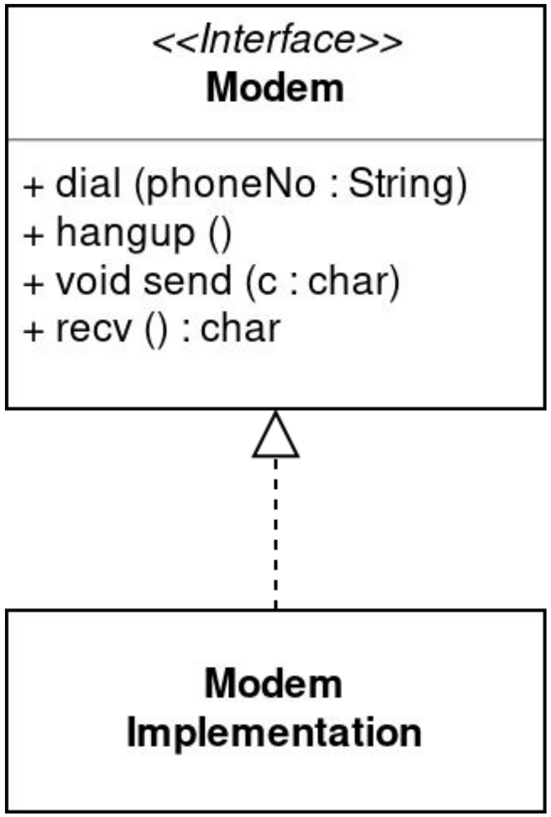
Solution: separated responsibilities



Responsibilities in two different classes

- Changes related to rendering of rectangles cannot affect the CG applications

Example: possible SRP violation



Interface looks reasonable, but...

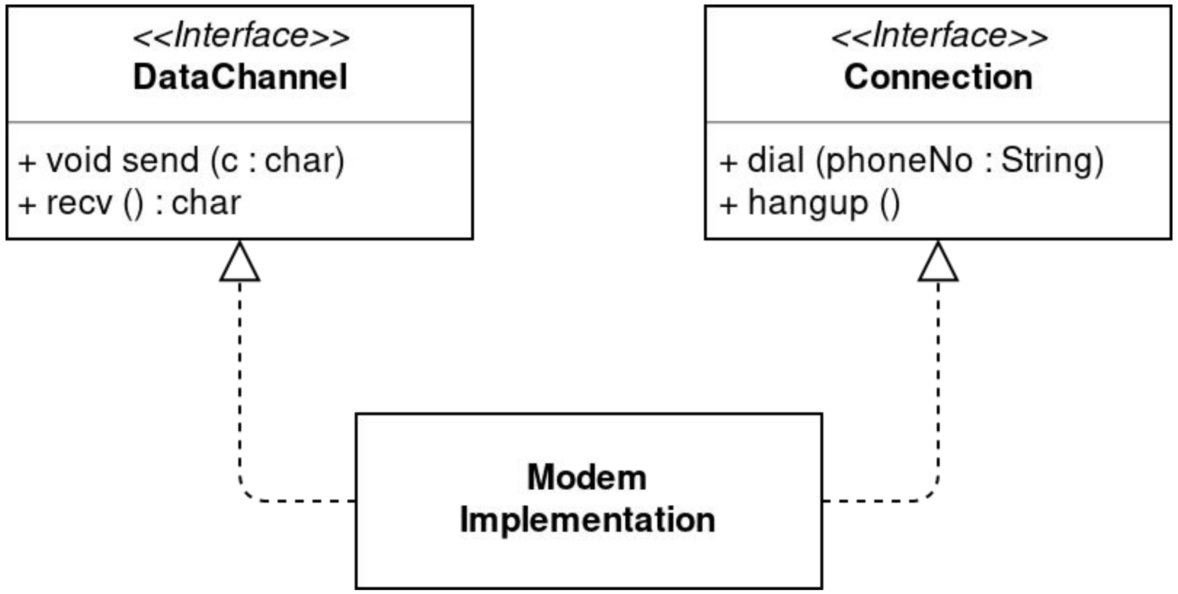
… Modem has *two* responsibilities!

- Connection management
- Data communication

Need separating? Almost certainly.

- *Two* sets of functions with nothing in common
- Used by different parts of an application
- Different reasons for change

Solution: separated responsibilities



Interface separation prevents SRP violation

- If there really are 2 different axes of change
- Needless complexity if responsibilities never change independently

Apply when there are symptoms of bad design!

Open Closed Principle

*Software entities should be open for extension,
but closed for modification.*

Open Closed Principle

Open for extension

- Write code so that entities can be extended with new behavior to satisfy changing requirements.
  - We rarely understand the system at first...

Closed for modification

- Extending an entity must not result in changes to the code of the entity.
  - Need to get (and keep) the system up and running...

Avoid modifying code that already works!

- Strive to implement changes by adding code

Satisfying the OCP

Reduces rigidity

- ○ Prevents cascading changes in dependent entities due to change.

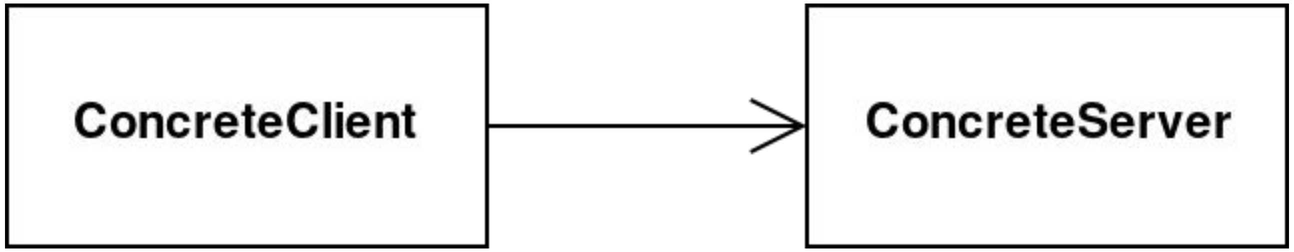
Seemingly contradictory

- How can we change entity behavior without changing its source code?

Avoid depending on concrete classes

- Abstraction
- Polymorphism (both static and dynamic)

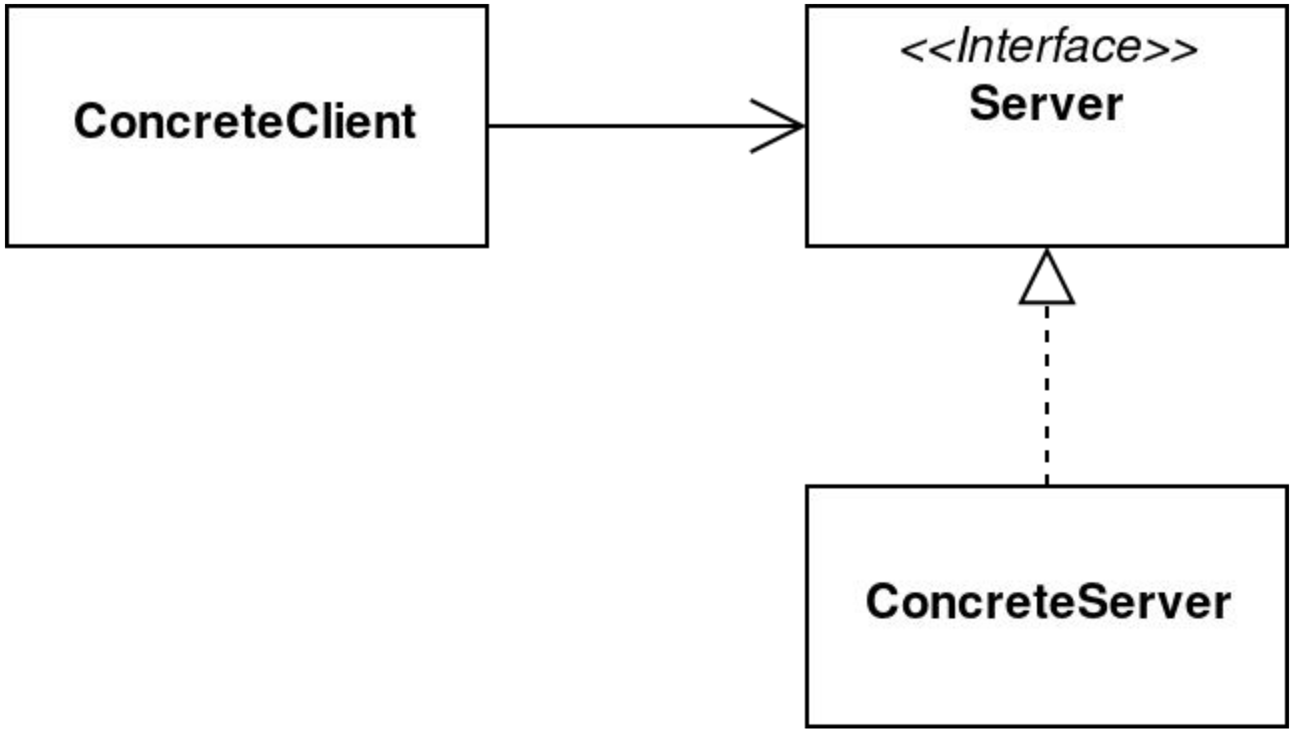
Example: OCP violation



The client uses the server directly

- Client must be modified to use a different server
- Changes in server force changes in client

Solution: encapsulate what changes



Strategy pattern (more on that later)

- Server can be changed without affecting the client

Strategic closure in OCP

Strict adherence to OCP is costly

- Abstraction can incur needless complexity!

No program can be 100% closed

- All changes cannot be anticipated.
- Closure needs to be strategic!
  - Choose the kind of changes to close against.

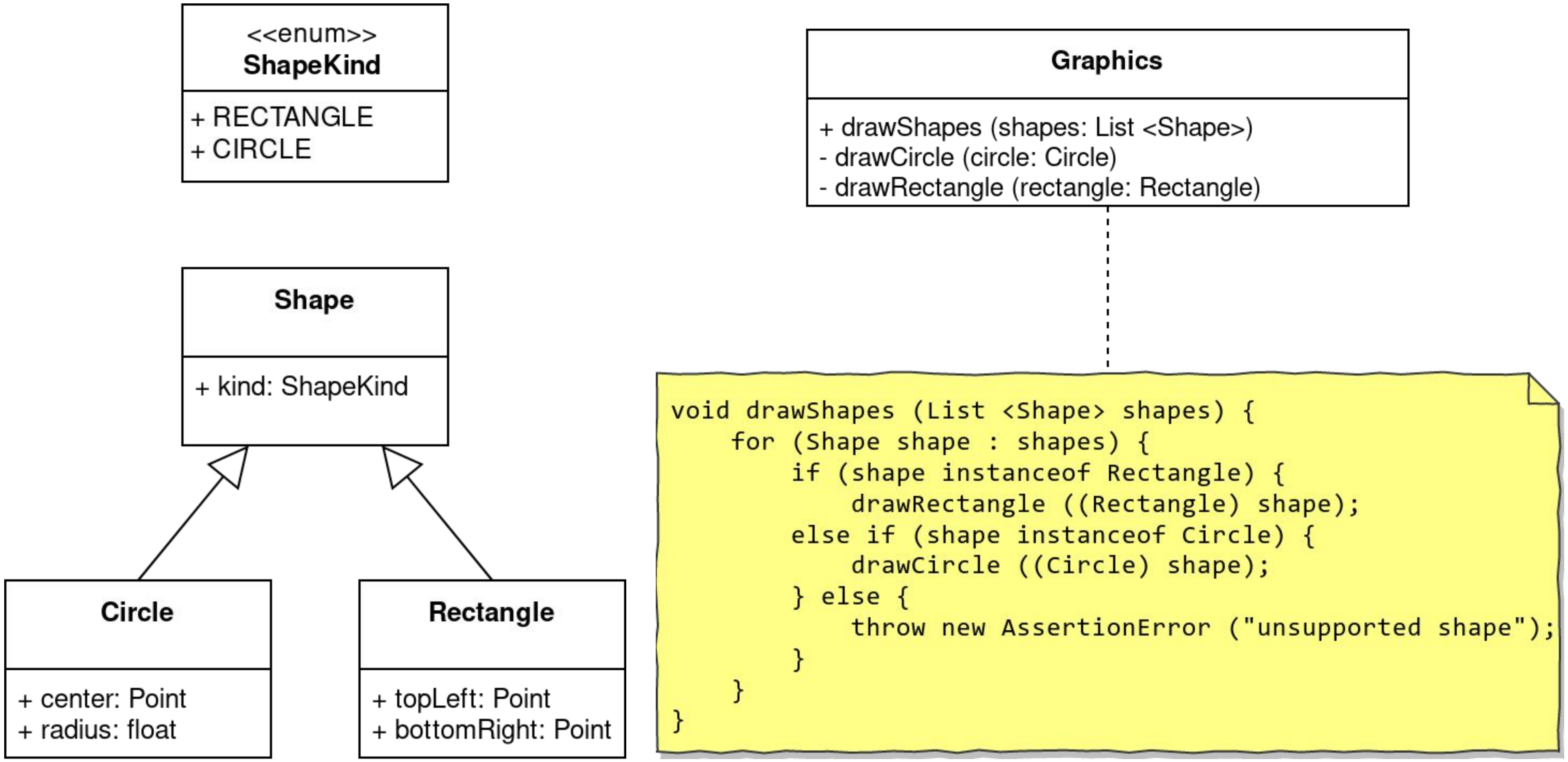
Which changes to close against?

- Focus on the most obvious/likely changes.
- Apply OCP when needed for the first time.

Strategy: stimulate early changes

- Fast iterations, constant feedback on design

Example: OCP violation

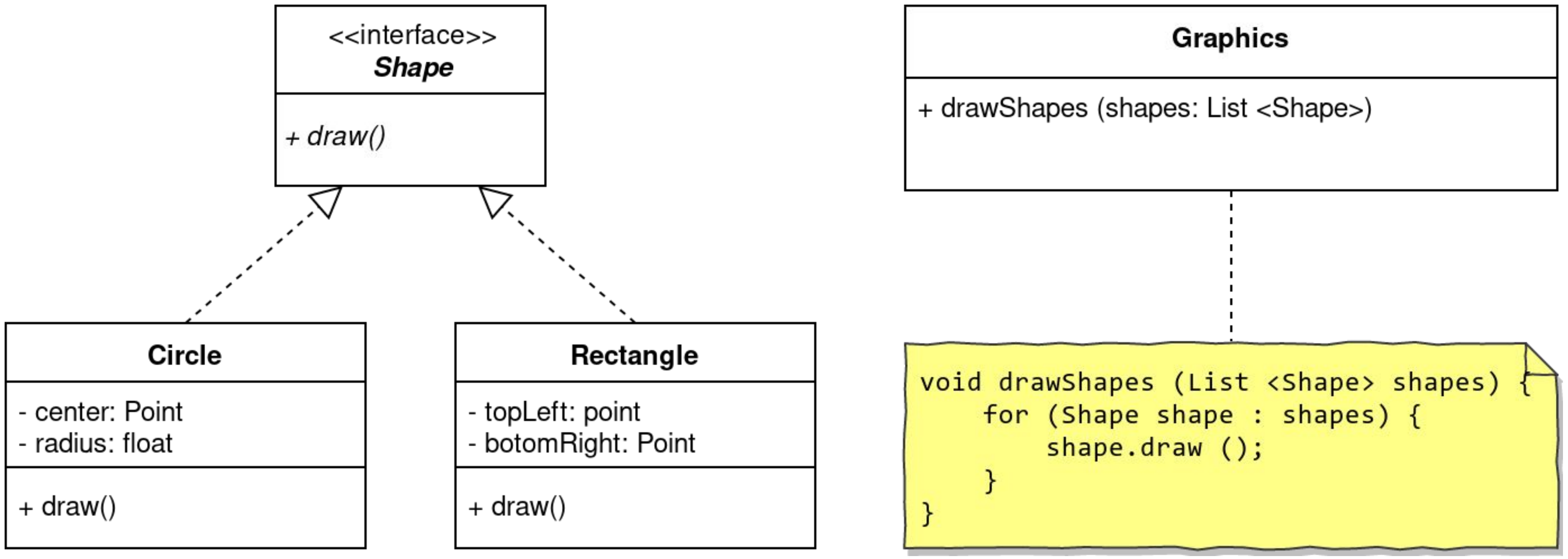


```
void drawShapes (List <Shape> shapes) {
    for (Shape shape : shapes) {
        if (shape instanceof Rectangle) {
            drawRectangle ((Rectangle) shape);
        else if (shape instanceof Circle) {
            drawCircle ((Circle) shape);
        } else {
            throw new AssertionError ("unsupported shape");
        }
    }
}
```

The `drawShapes()` method violates OCP

- Not closed against new shape types

Solution: abstraction & polymorphism



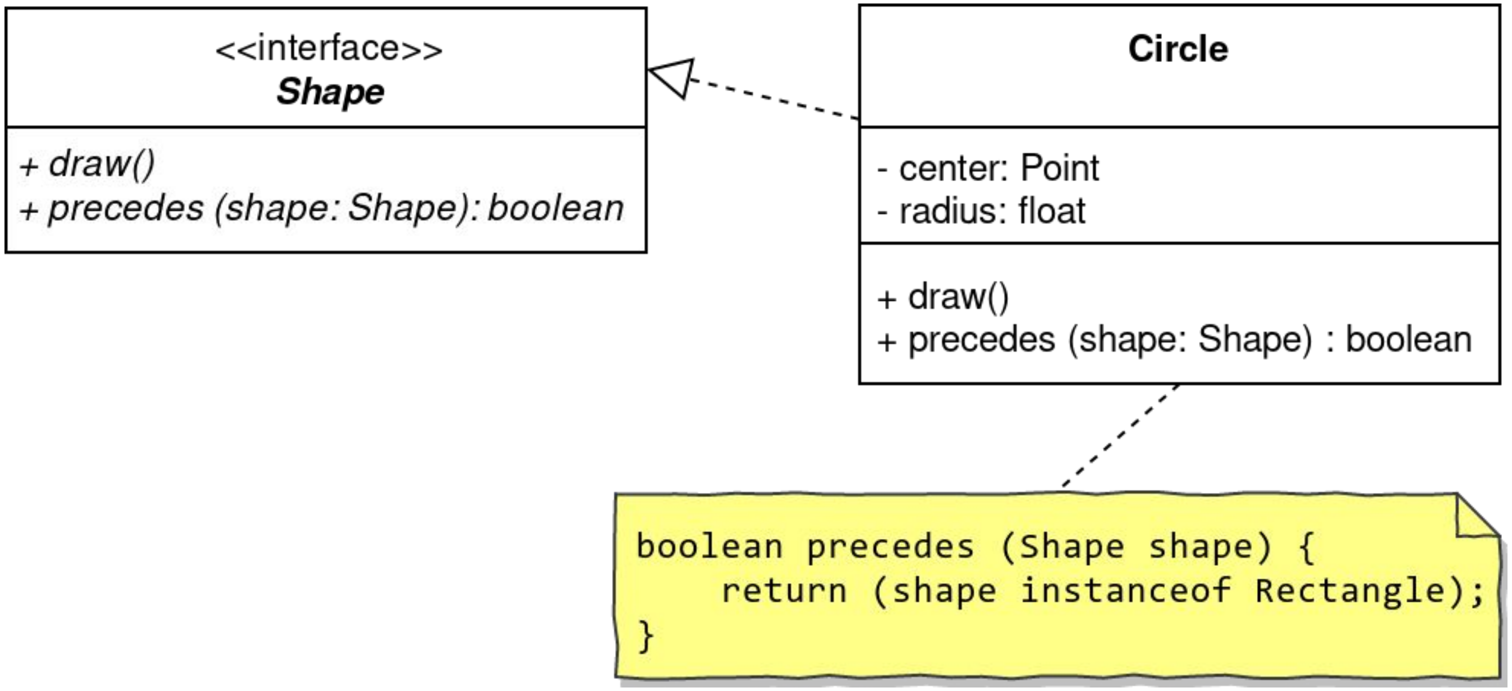
```
void drawShapes (List <Shape> shapes) {
    for (Shape shape : shapes) {
        shape.draw ();
    }
}
```

Closed against adding new shapes...

- No need to modify the `drawShapes()` method

What if circles need to be drawn before rectangles?

Solution: abstraction

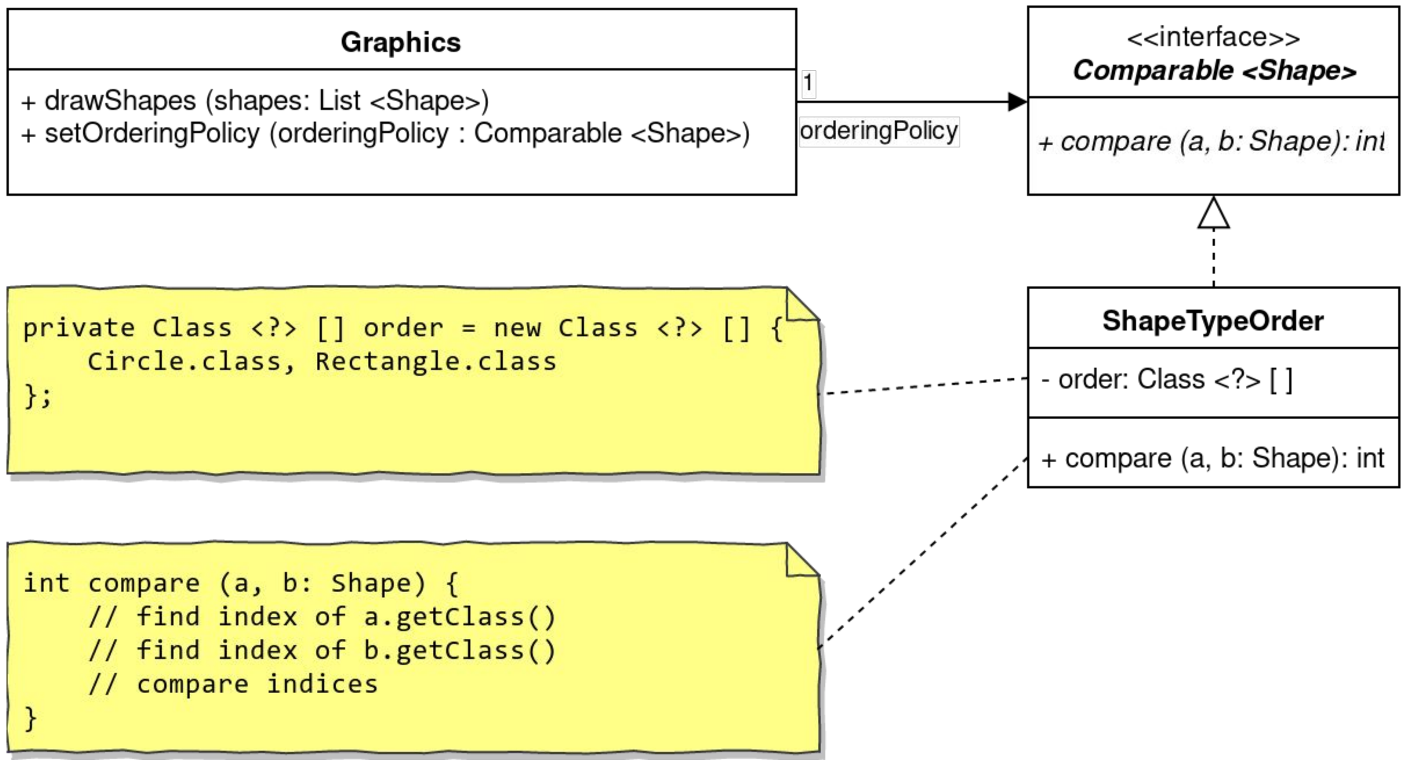


```
boolean precedes (Shape shape) {
    return (shape instanceof Rectangle);
}
```

Shapes can be ordered before drawing

- But **all** `precedes()` methods violate OCP
  - Not closed against new Shape implementations

Solution: data driven approach


Graphics
+ drawShapes (shapes: List <Shape>)
+ setOrderingPolicy (orderingPolicy : Comparable <Shape>)
1
orderingPolicy
<<interface>>
Comparable <Shape>
+ compare (a, b: Shape): int
ShapeTypeOrder
- order: Class <?> [ ]
+ compare (a, b: Shape): int

```
private Class <?> [] order = new Class <?> [] {
    Circle.class, Rectangle.class
};
```

```
int compare (a, b: Shape) {
    // find index of a.getClass()
    // find index of b.getClass()
    // compare indices
}
```

Shape derivatives closed against new derivatives

- The table in the ShapeTypeOrder comparator is not closed against new Shape implementations
    - But provides closure against different ordering policies

Liskov Substitution Principle

Subtypes must be substitutable for their base types.

Liskov Substitution Principle

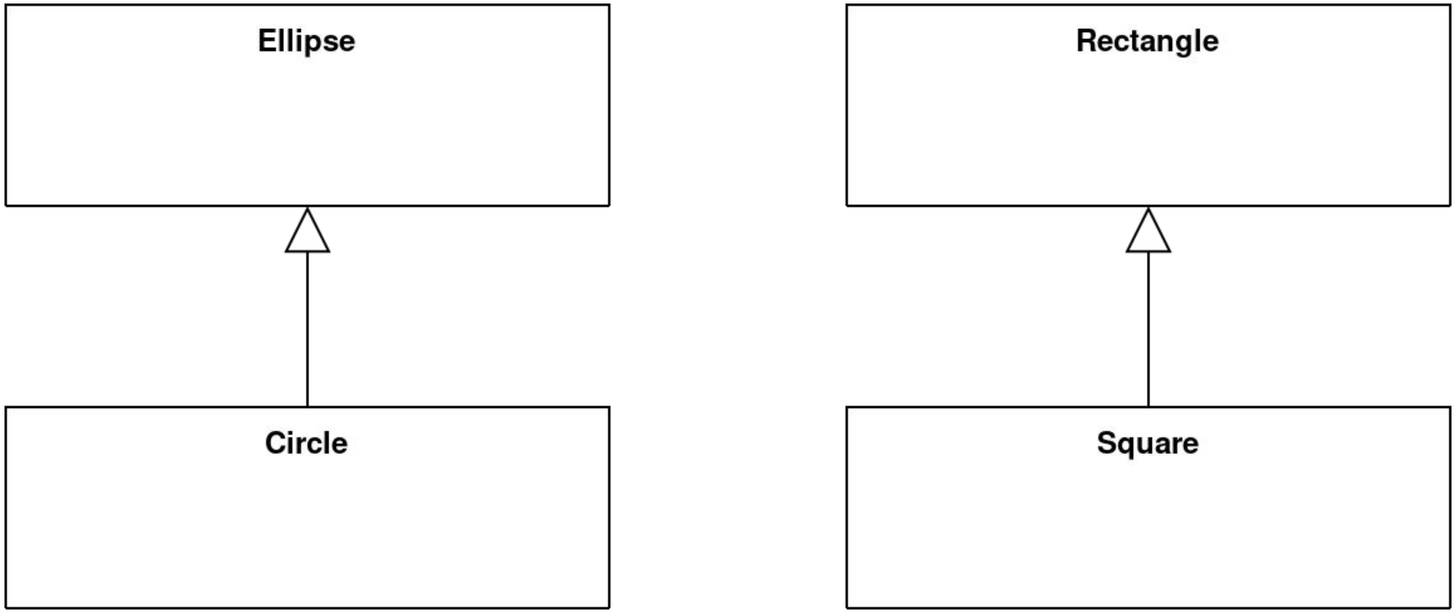
Functions should not know about derived classes

- User of a base class should continue to function properly if a derived class is passed to it.
    - Both existing and future derived classes.

Related to Design by Contract

- The (implied) contract of the base class must be honored by all derived classes.
- Expect no more and provide no less
    - Derived method pre-conditions are no stronger than the base class method.
    - Derived method post-conditions are no weaker.

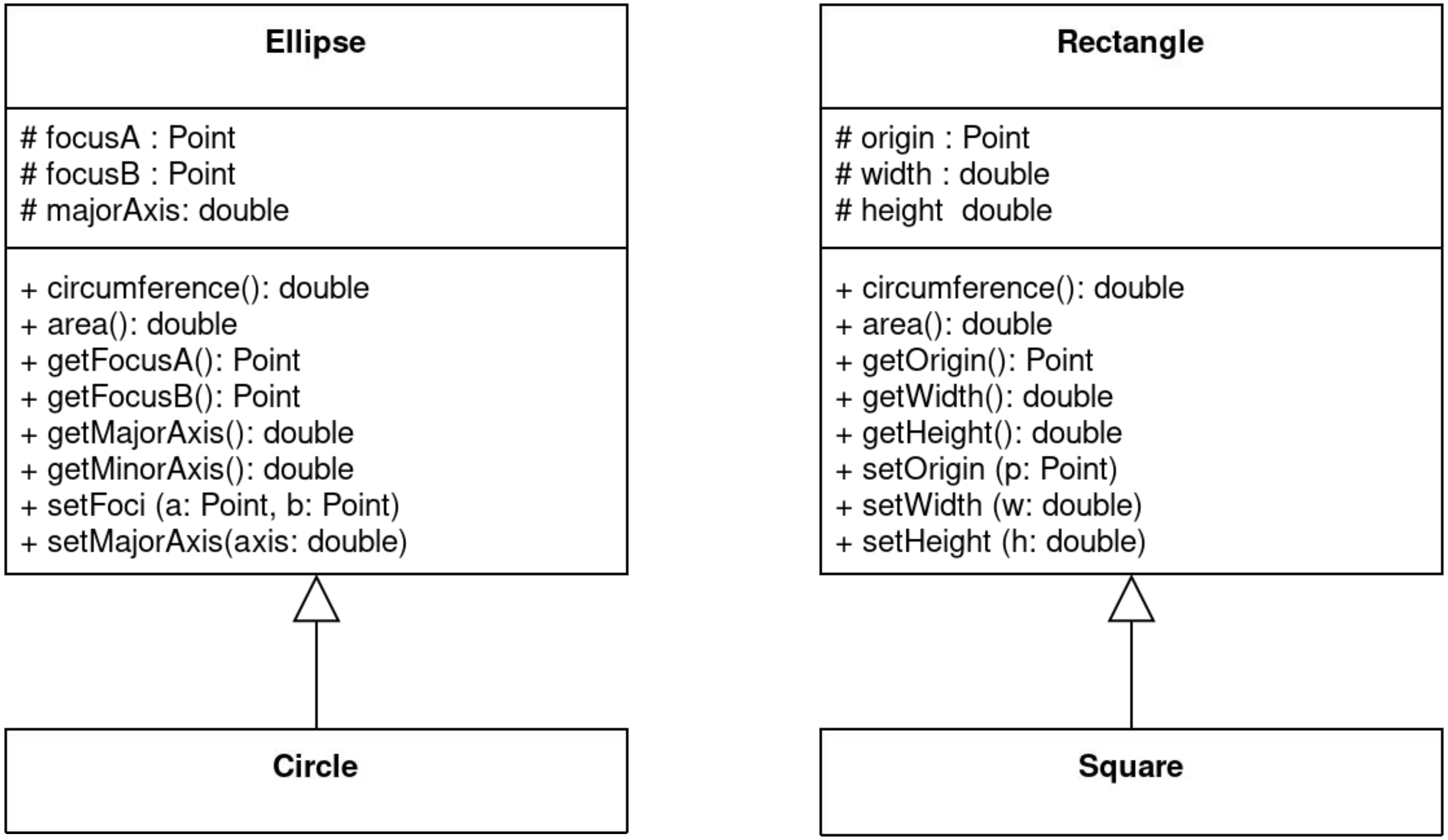
Example: LSP violation



Classic Circle/Ellipse (Square/Rectangle) dilemma

- Math: circle is a degenerate form of ellipse
- Math: square is degenerate form of rectangle

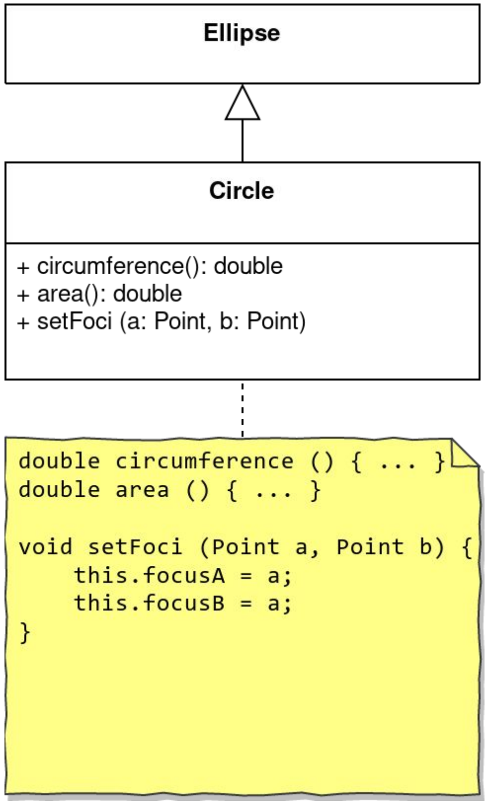
Example: LSP violation



Minor issue: inheriting unnecessary attributes

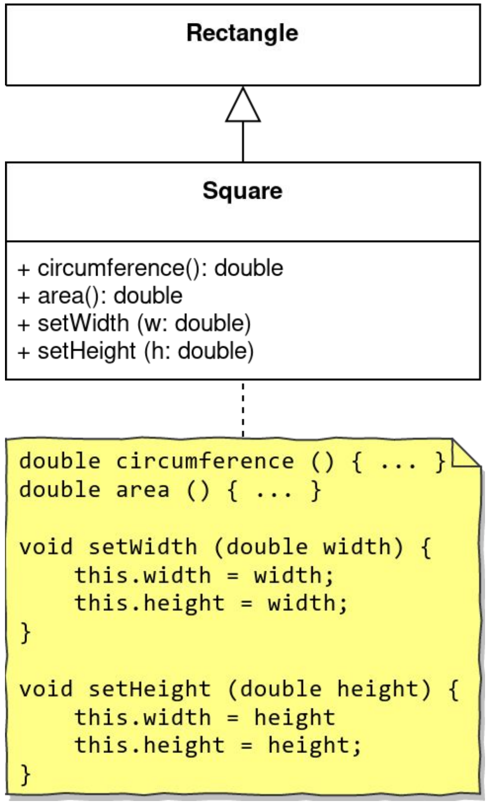
- Nothing we could fix with a bit of creative overriding...

Example: LSP violation



```
double circumference () { ... }
double area () { ... }

void setFoci (Point a, Point b) {
    this.focusA = a;
    this.focusB = a;
}
```



```
double circumference () { ... }
double area () { ... }

void setWidth (double width) {
    this.width = width;
    this.height = width;
}

void setHeight (double height) {
    this.width = height
    this.height = height;
}
```

Major issue: mutation methods

- Opportunity for clients to break things...

Example: LSP violation

Clients indeed do "ruin" everything...

```
void useEllipse (Ellipse e) {
    Point a = new Point (-1, 0);
    Point b = new Point (1, 0);

    e.setFoci (a, b);
    e.setMajorAxis (3.0);

    assert a.equals (e.getFocusA ());
    assert b.equals (e.getFocusB ());
    assert e.getMajorAxis == 3.0;
}
```

Clients expect to be able to set foci and major axis...

… and verify that they have been set.

But the function fails if we pass Circle to it...

The Circle subclass violates the Ellipse contract!

- Weakens (implicit) postcondition in `setFoci()` ensuring that arguments get copied to member variables.

LSP and OCP are related

OCP enabled by abstraction and polymorphism

- Key mechanisms: subtyping and inheritance

LSP restricts the use of inheritance

- Provide designs that conform to OCP

LSP violations are latent violations of OCP!

- Syntactically correct violations of semantics.
- Difficult to detect until it is too late.
    - Redesign can be difficult/impossible.
    - May be "fixed" by using type checks to ensure that a method operates on a compatible subtype.
    - But: the use of type checks violates OCP!

Interface Segregation Principle

Clients should not be forced to depend on interfaces they do not use.

Interface Segregation Principle

Many client-specific interfaces are better than one general purpose interface.

- Avoid “fat” and non-cohesive interfaces.
- Create client-specific interfaces.

Related to Single Responsibility Principle

- Decoupling responsibilities.

Interface Segregation Principle

Avoid fat (general purpose) interfaces

- Contains methods needed by all clients.
- Can introduce coupling between clients.
  - Recall: clients own interfaces!
  - When one client forces interface change, others will be affected as well.

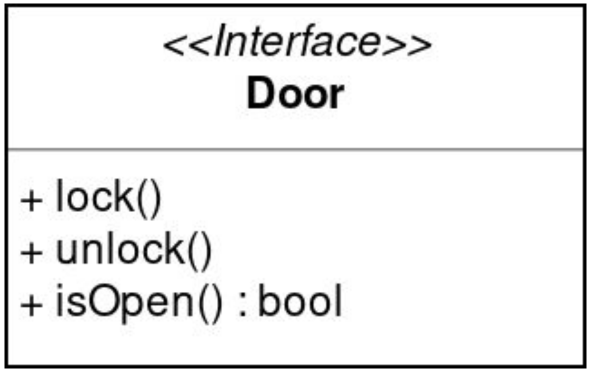
Create client-specific interfaces

- Targeted to a particular type of clients.
- Clients depend only on methods they need/use.
- Probability of change is reduced.
- Impact of changes to one interface is smaller.
- No interface pollution.

Example: interface pollution

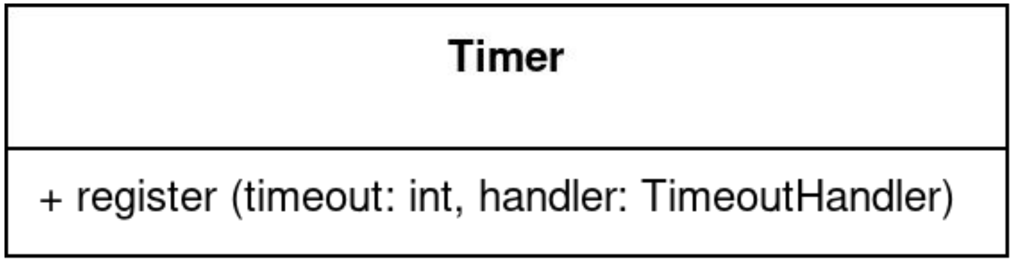
Security door

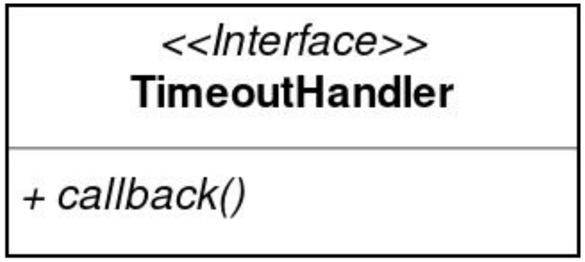
- Can be locked and unlocked, and knows whether it is open or closed.



We need a `TimedDoor`

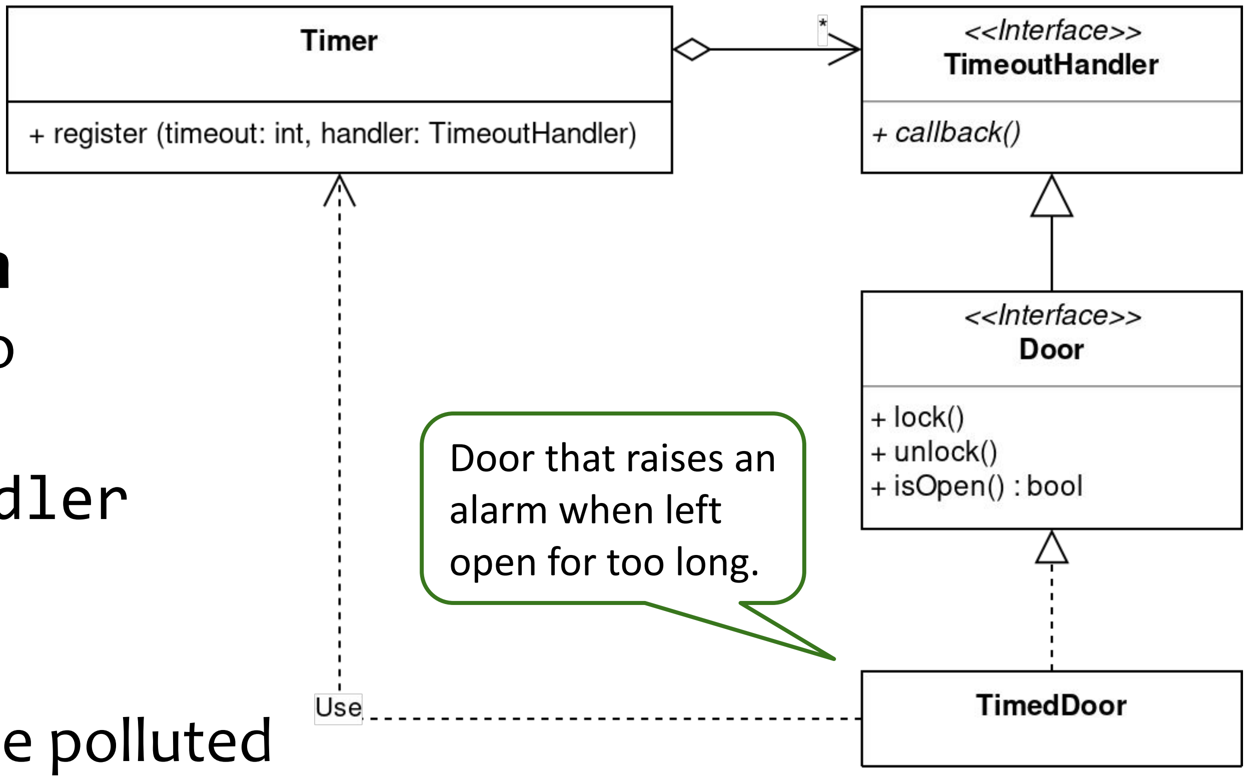
- Raises an alarm if it remains open for too long.
- Uses a `Timer` object to implement timeout.





How can `TimeoutHandler` notify `TimedDoor`?

Example: interface pollution



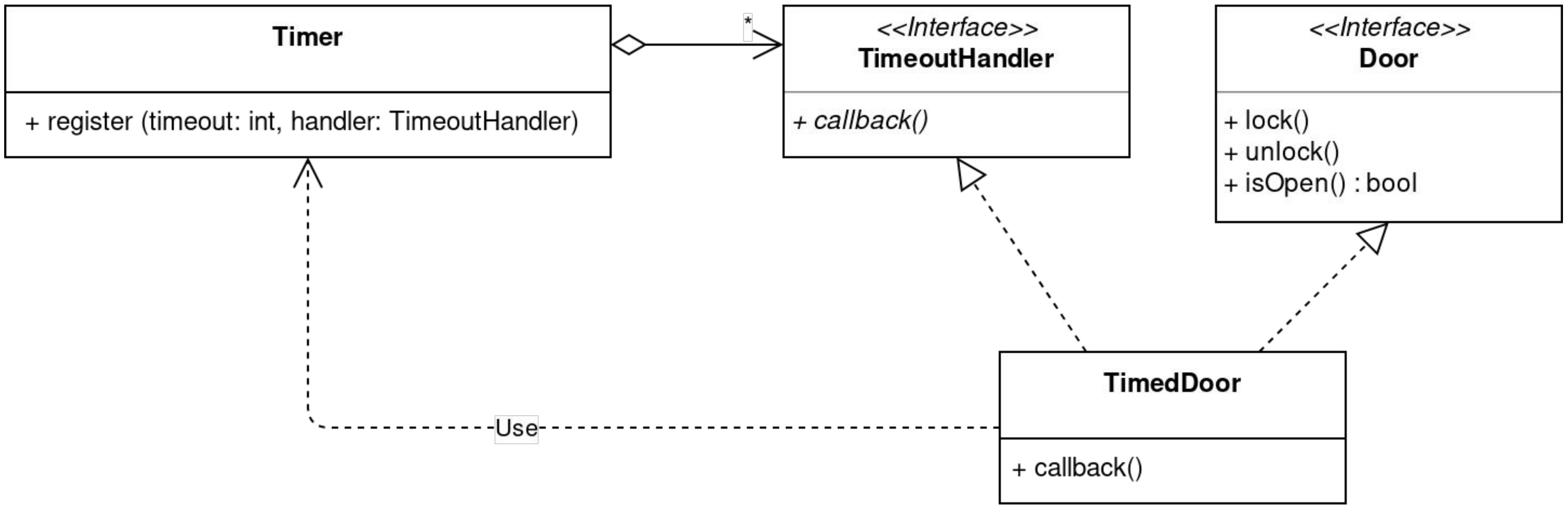
Common solution

- Force Door to inherit from `TimeoutHandler`

Consequences

- Door interface polluted with method from `TimeoutHandler`
- Most Door implementations will provide a degenerated `callback()` method: violates LSP
- Changes in `TimeoutHandler` affect all Door implementations

Example: avoiding interface pollution



`TimedDoor` used through two separate interfaces

- Correspond to two roles assumed by its clients.
- Changes in `TimeoutHandler` only affect clients that actually use it.

Role-based interface design

Interfaces designed from the service user's perspective

- Not from the service provider's perspective
- Recall: clients own interfaces

Interfaces should represent client roles

- Clients assume roles when using a service.
- Classes implement many interfaces, interfaces implemented by many classes.

Client/role version control

- New interfaces for clients requiring new services
- Easier to preserve design (less viscosity)
- Old clients keep working

Dependency Inversion Principle

Depend upon abstractions.

Dependency Inversion Principle

High-level modules should not depend on low-level ones

- Both should depend on abstractions.

Abstractions should not depend on details

- Details should depend on abstractions.

Rationale

- Concrete (low-level) things change a lot.
- Abstract (high-level) things change less frequently.
- Abstractions are “hinge” points.
    - Places where design can bend or be extended without being modified (OCP).

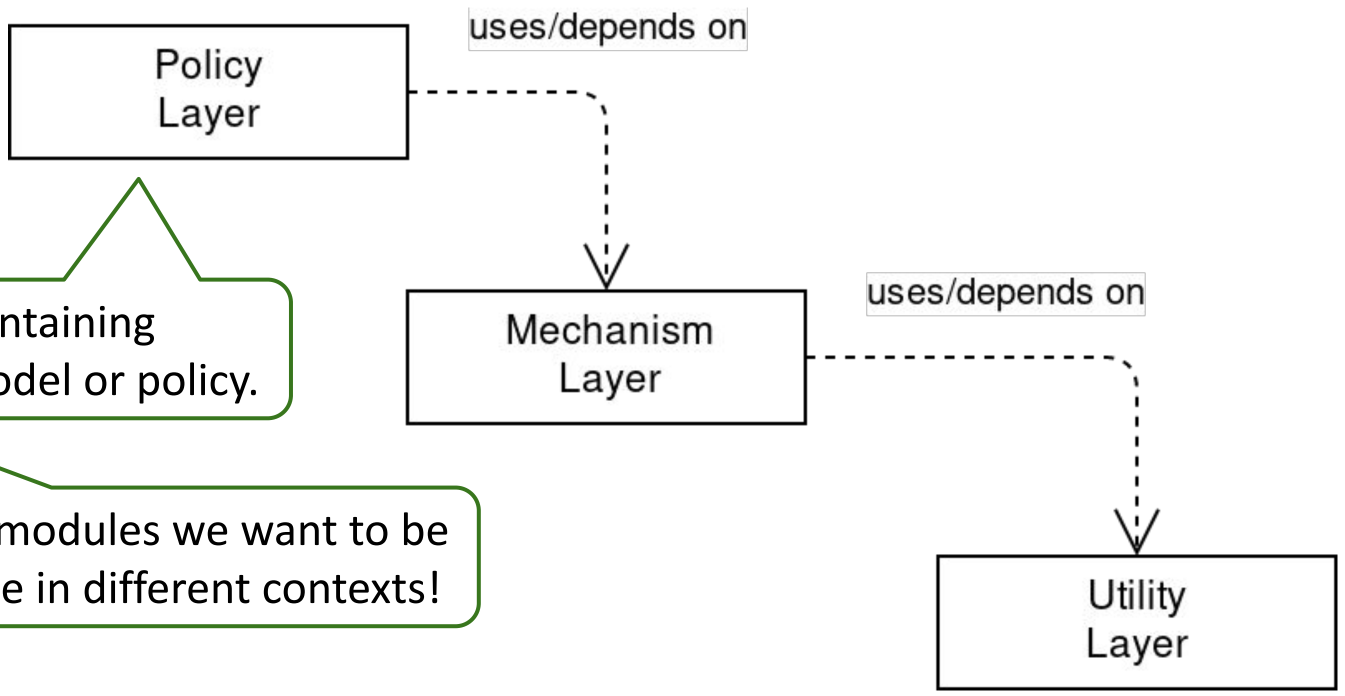
Overall purpose

- Prevent dependency on volatile modules.

Why dependency *inversion*?

Traditional (structural, procedural) design

- High-level modules depend upon low-level modules.
- Abstractions depend upon details.



Modules containing business model or policy.

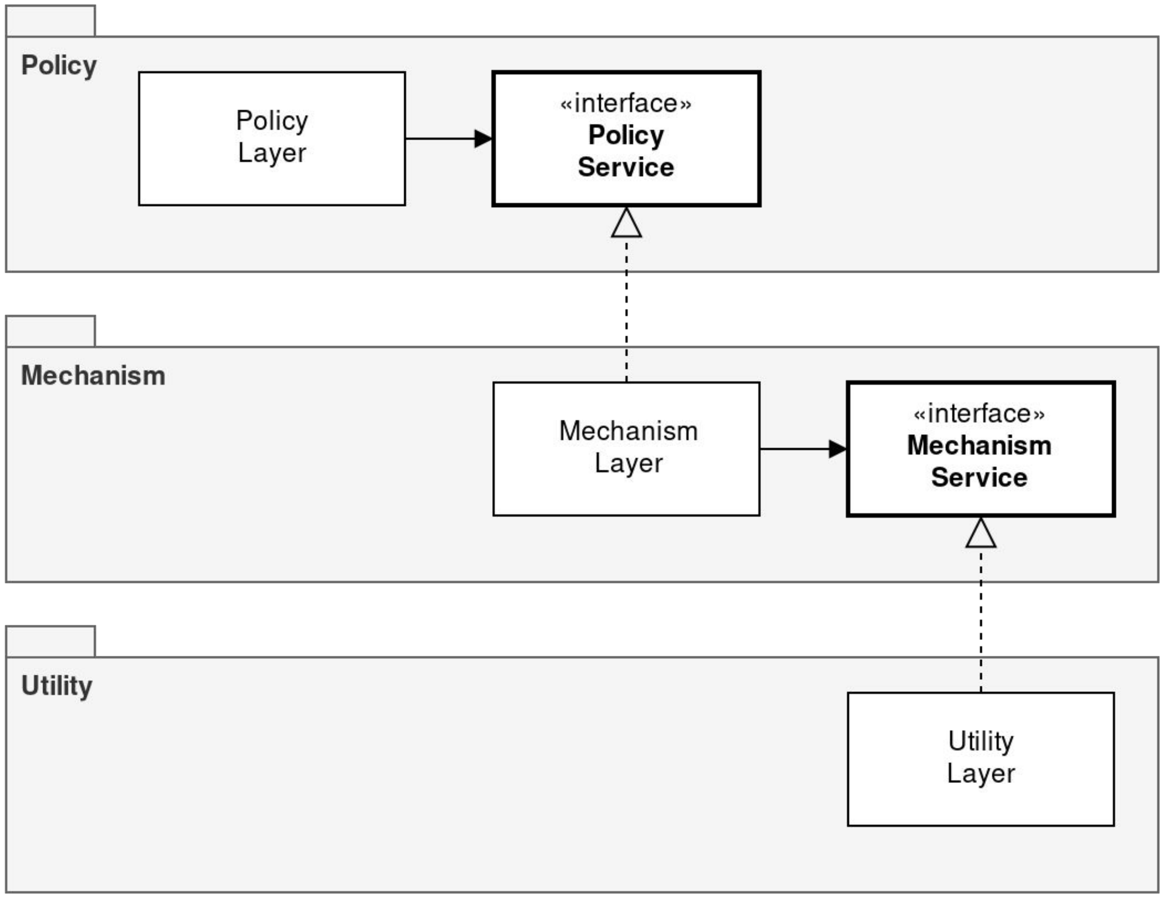
Exactly the modules we want to be able to reuse in different contexts!

Changes in low-level modules can ***force*** high-level modules to change.... Preposterous!

Why dependency inversion?

Good object-oriented architecture design

- ***Inverted*** dependency structure and interface ownership.
- Dependencies (mostly) point to abstractions.



Clients own abstract interfaces, **servers derive** from them.

Policy layer not affected by changes to Mechanism and Utility layers.

Policy can be reused in contexts where lower-level modules **conform** to PolicyService interface.

Depending upon abstractions

Guiding principle

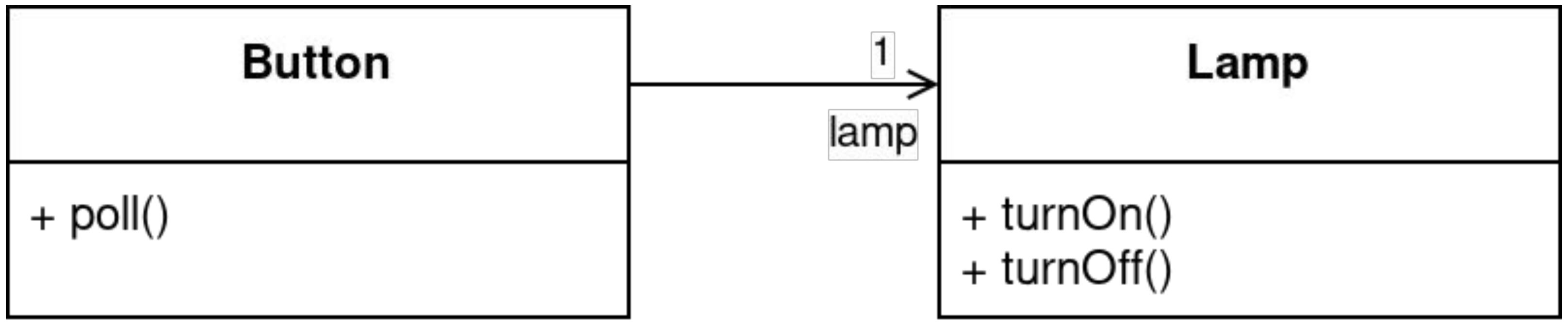
- Every dependency in a design should target an interface or an abstract class.
  - No variable should refer to concrete class.
  - No class should derive from concrete class.
  - No method should override an implemented method in any of its base classes.

Mitigating forces

- Concrete class that is very unlikely to change.
  - Avoids needless complexity, especially if a concrete class is non-volatile (e.g., java.lang.String).
- Modules creating class instances depend on them.

Encapsulate what changes!

Example: naive model



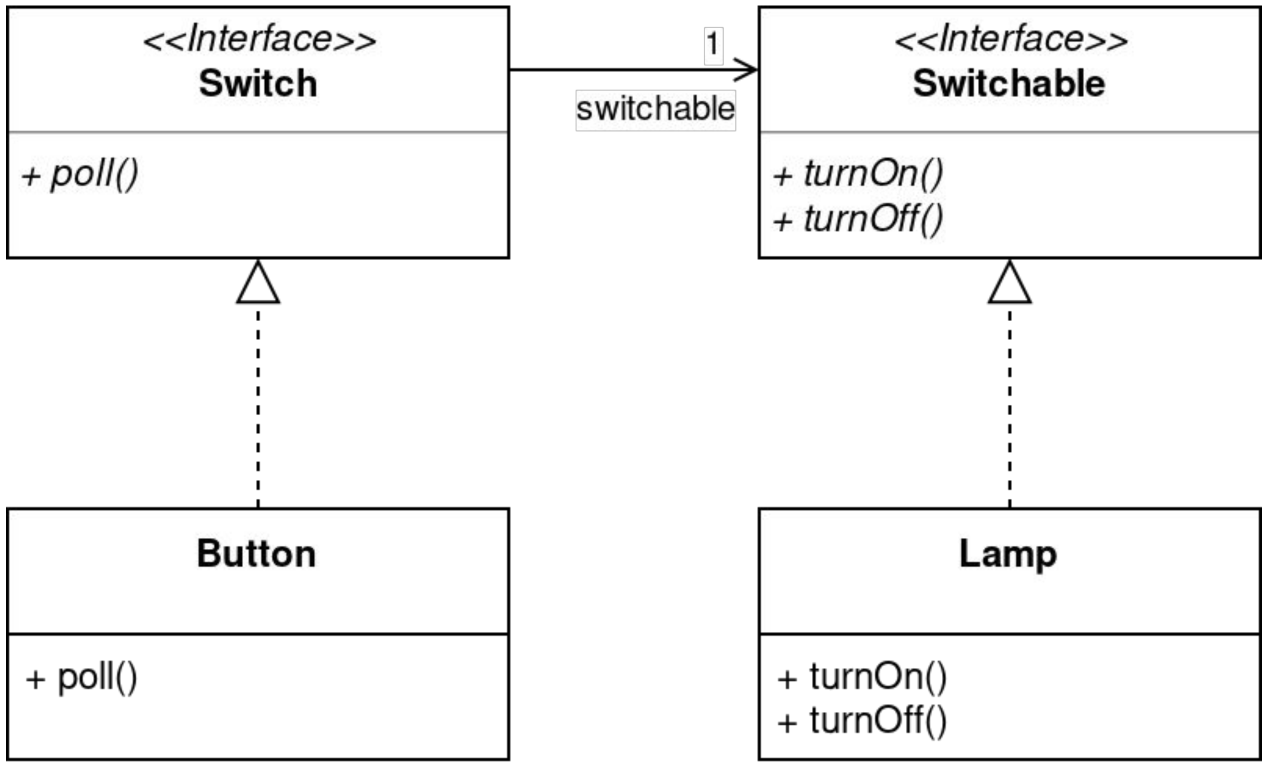
Button depends on Lamp

- Affected by changes of Lamp
- Cannot be used to control other objects.

DIP violation

- Abstraction not isolated from implementation.

Example: dependency inversion



Abstraction isolated from implementation

- Switch can control any Switchable device.
- Any kind of Switch can be used, not only a Button.

Dependency Inversion Principle

Relation to other principles

- OCP states the goal of OO architecture.
- LSP enables OCP and restricts inheritance.
- DIP provides the primary design mechanism.

References

Based on the *Engineering Notebook* columns by *Robert C. Martin* published in *The C++ Report*

- The Open-Closed Principle, 1996
- The Liskov Substitution Principle, 1996
- The Dependency Inversion Principle, 1996
- The Interface Segregation Principle, 1996

And other articles/book chapters by *Robert C. Martin*

- Design Principles and Design Patterns
- The Single Responsibility Principle