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 break 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

- Single Responsibility Principle (SRP)
- Open/Closed Principle (OCP)
- Liskov Substitution Principle (LSP)
- Interface Segregation Principle (ISP)
- Dependency 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

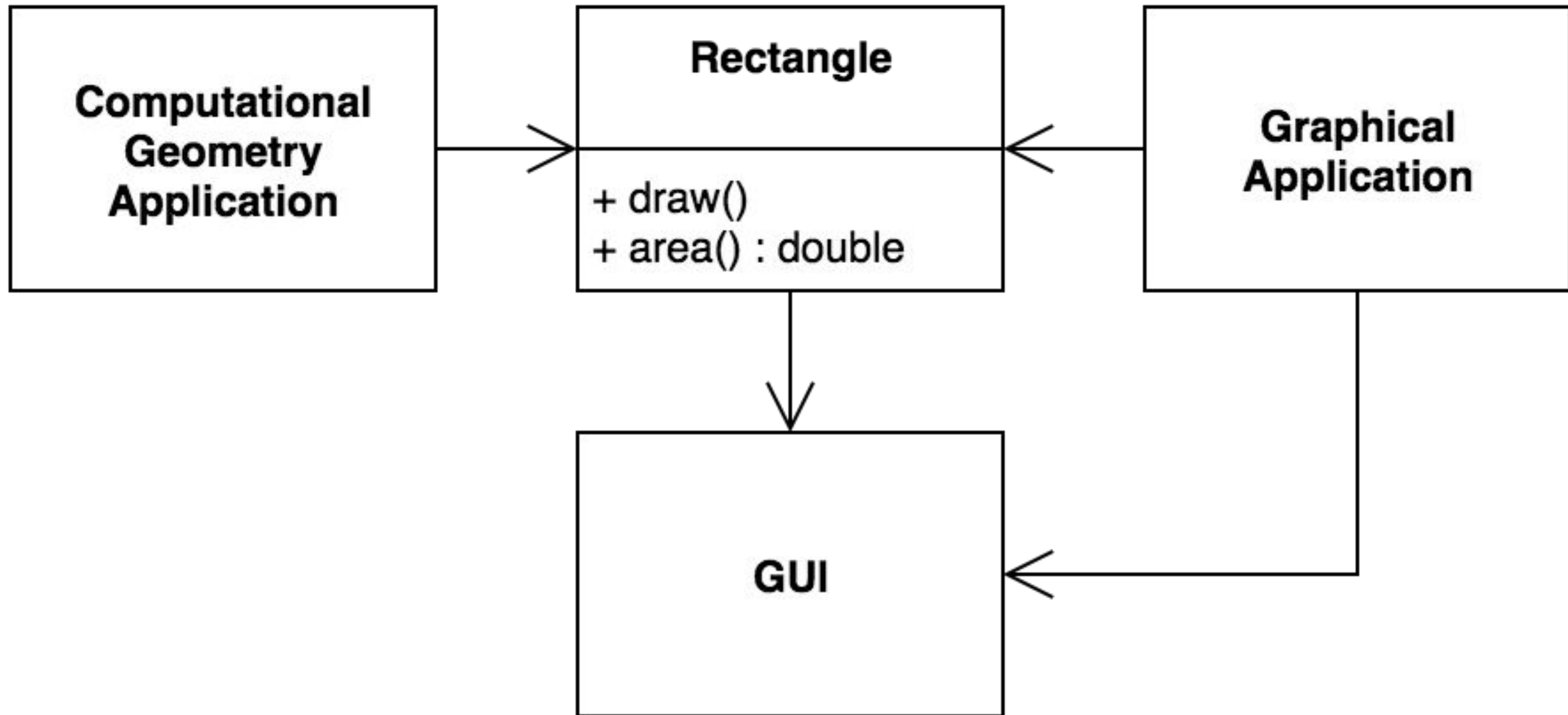
Each responsibility is an axis of change

- Changes in requirements manifest through changes in responsibility amongst classes
  - Class with more responsibilities will have more than one reason 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

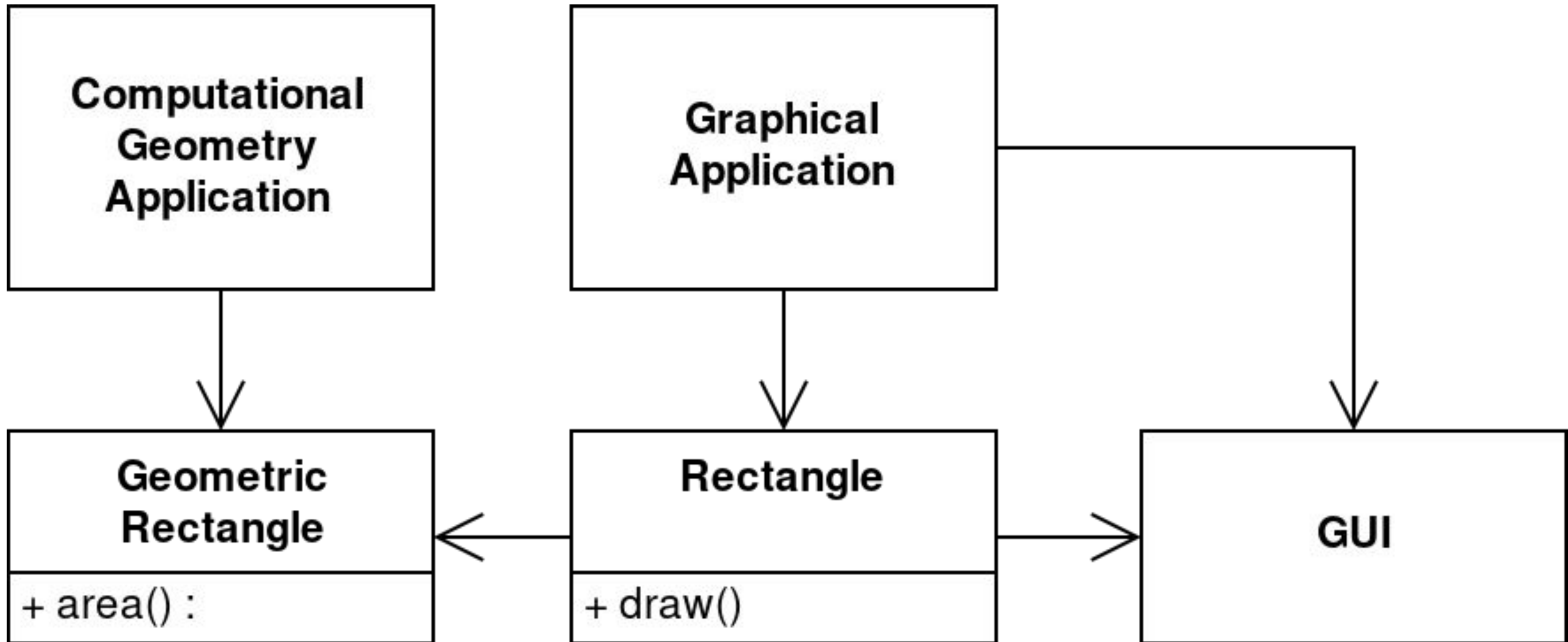
Example: SRP violation



Rectangle has 2 responsibilities

- Mathematical model
- Graphical rendering

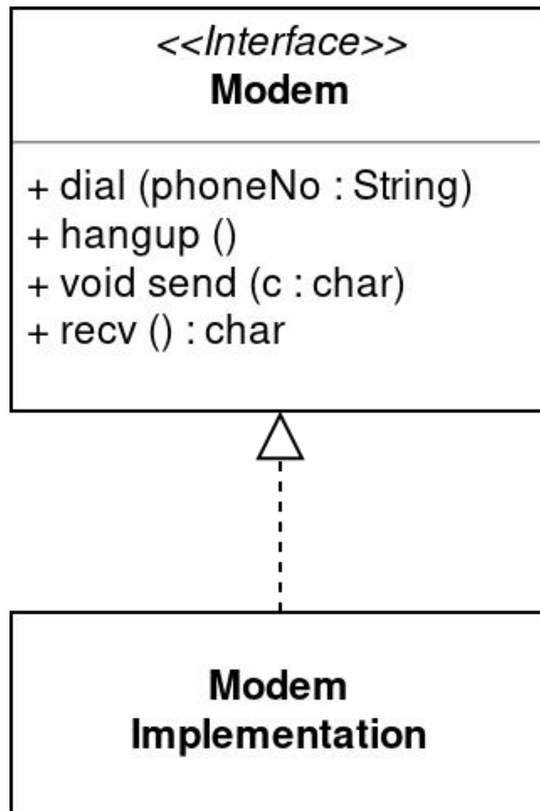
Solution: separated responsibilities



Responsibilities in two different classes

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

Example: possible SRP violation



Interface looks reasonable, but...

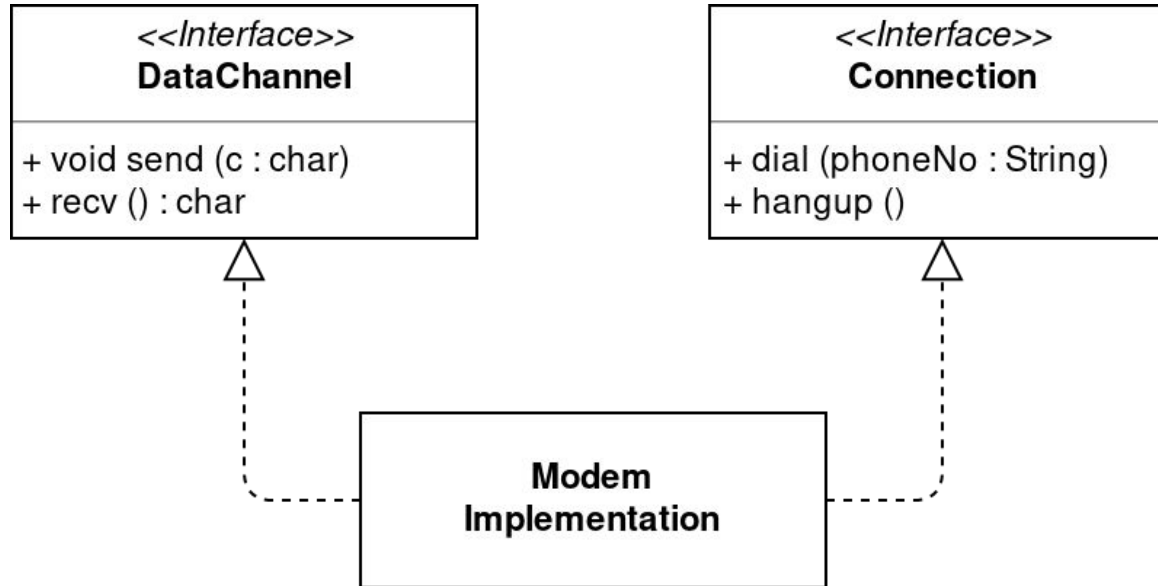
… Modem has 2 responsibilities!

- Connection management
- Data communication

Need separating? Almost certainly.

- 2 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.

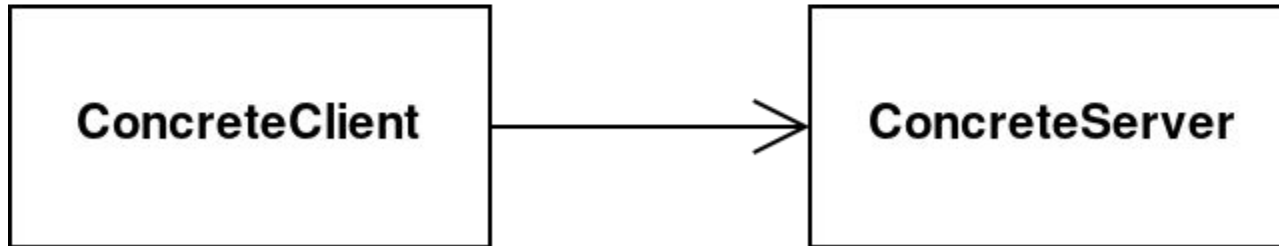
Seemingly contradictory

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

Avoid depending on concrete classes

- Abstraction
- Polymorphism (both static and dynamic)

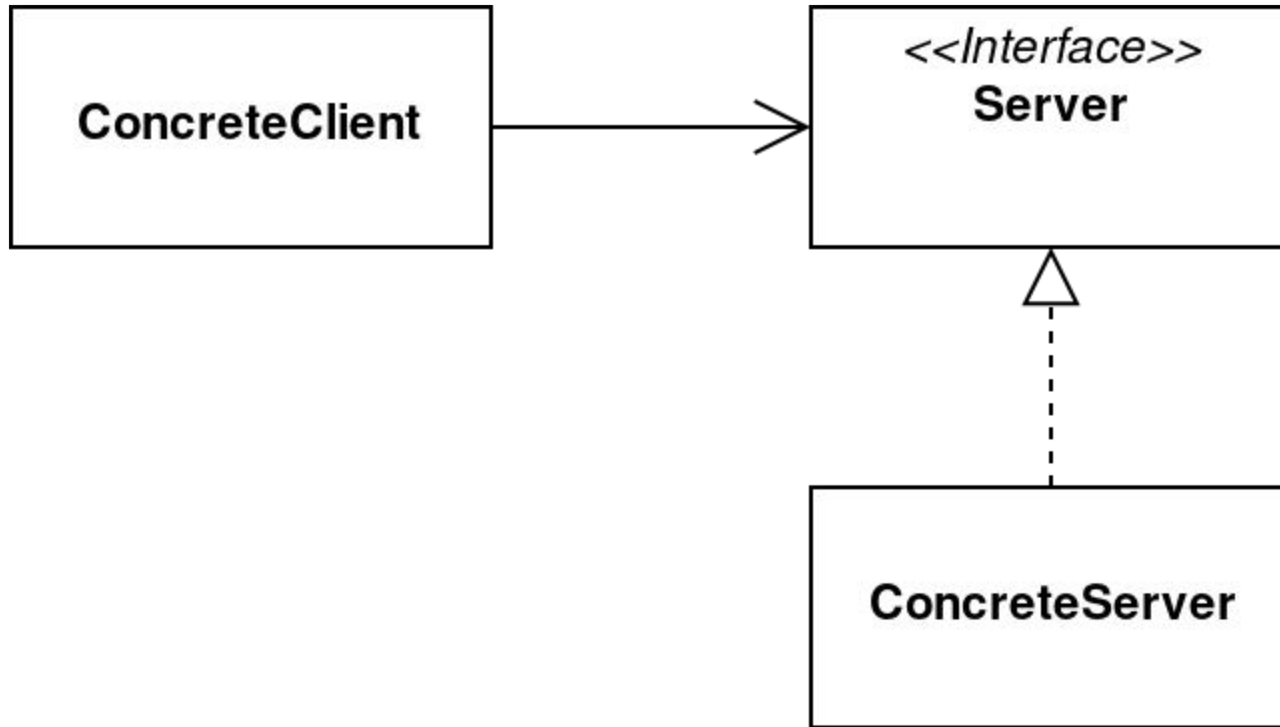
Example: OCP violation



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.

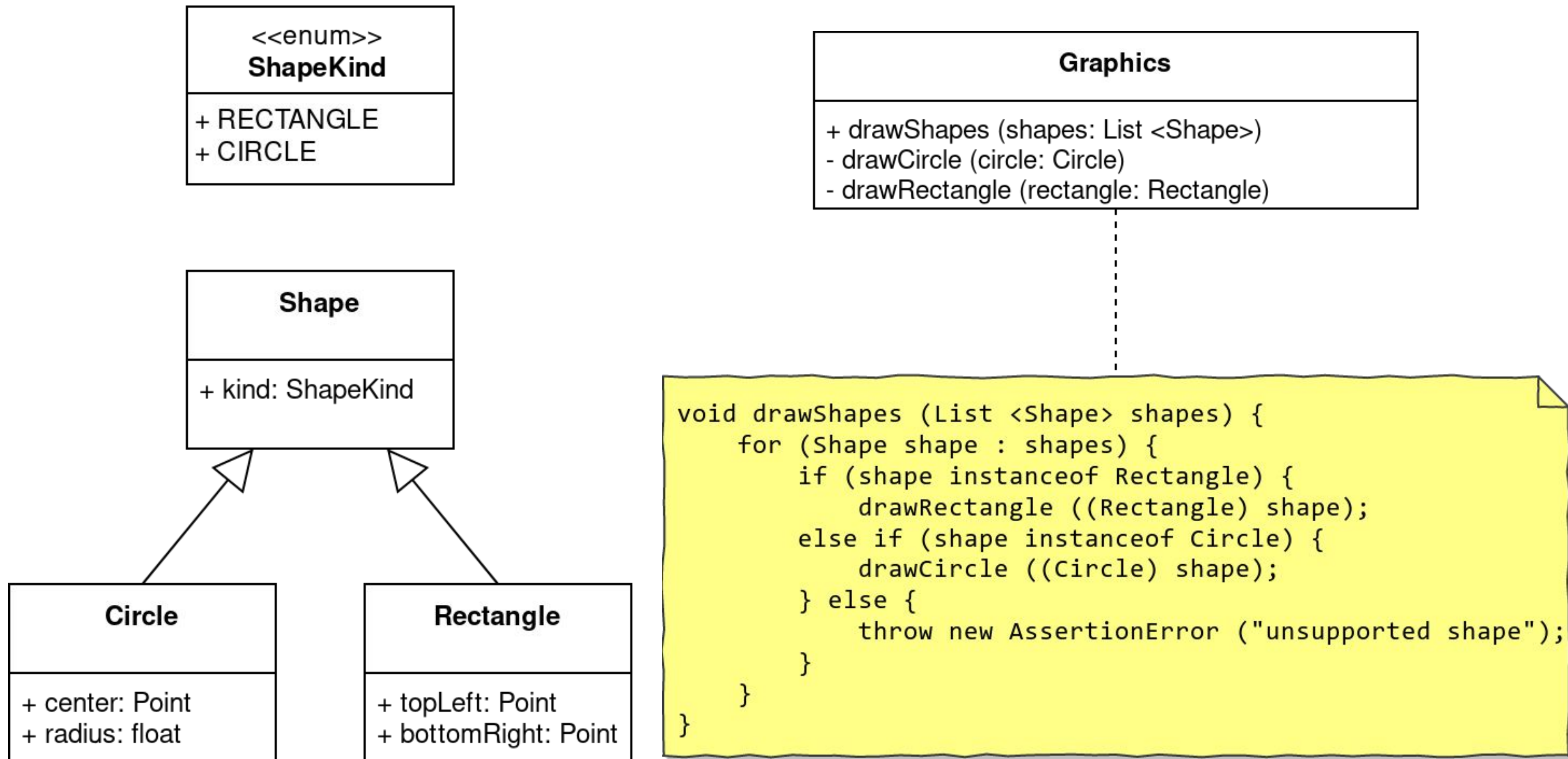
Which changes to close against?

- 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

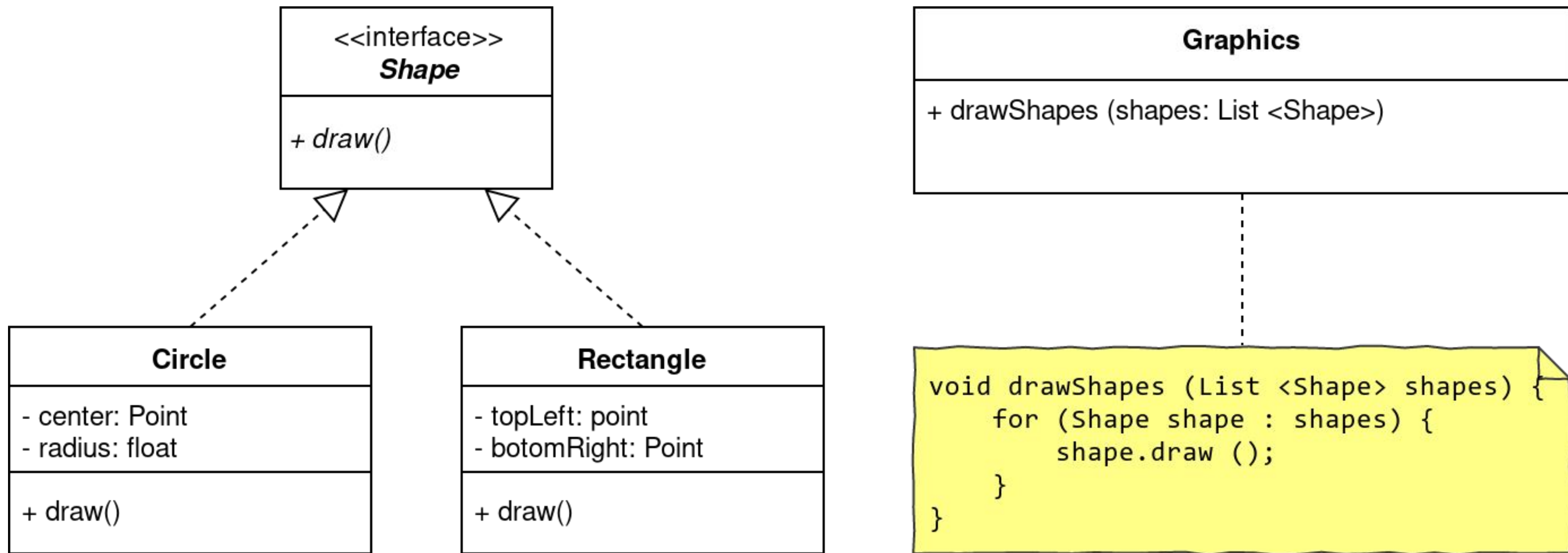
Example: OCP violation



The `drawShapes()` method violates OCP

- Not closed against new shape types

Solution: abstraction & polymorphism

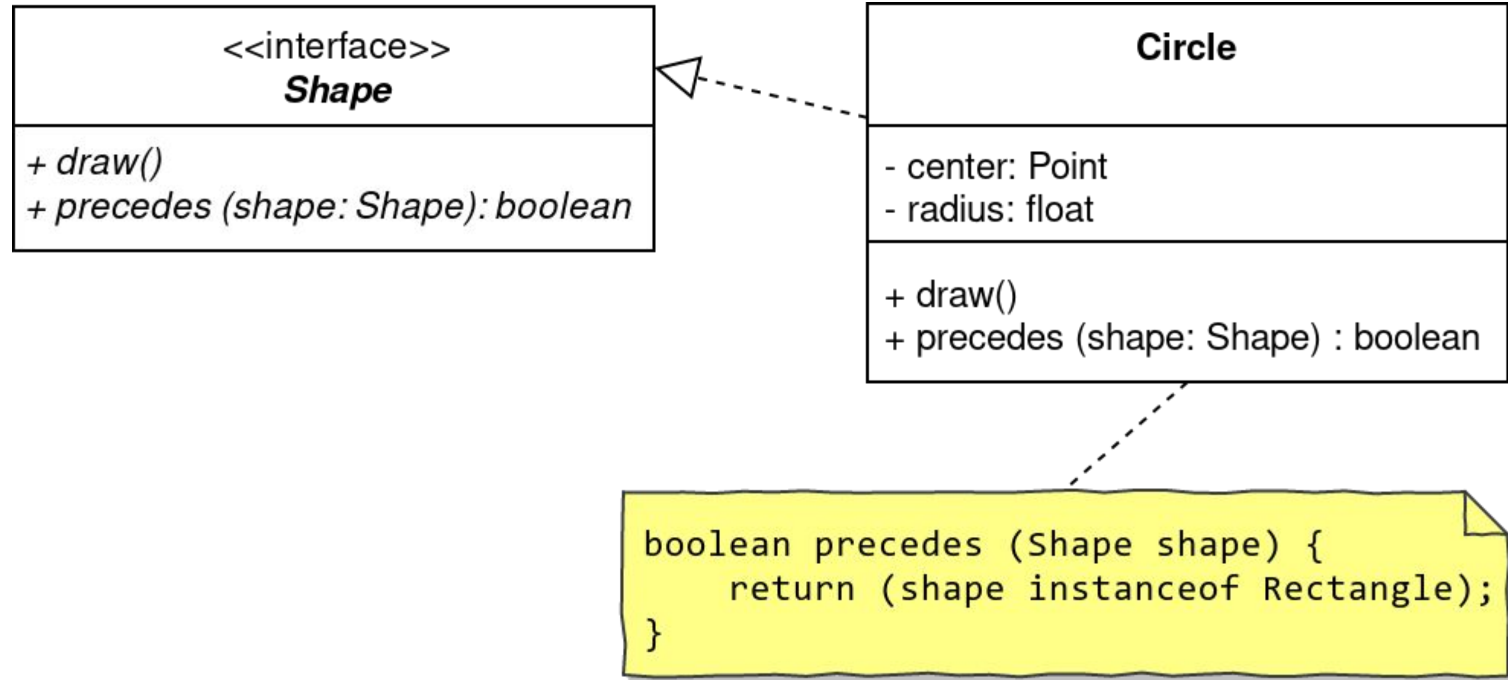


Closed against adding new shapes...

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

What if circles need to be drawn before rectangles?

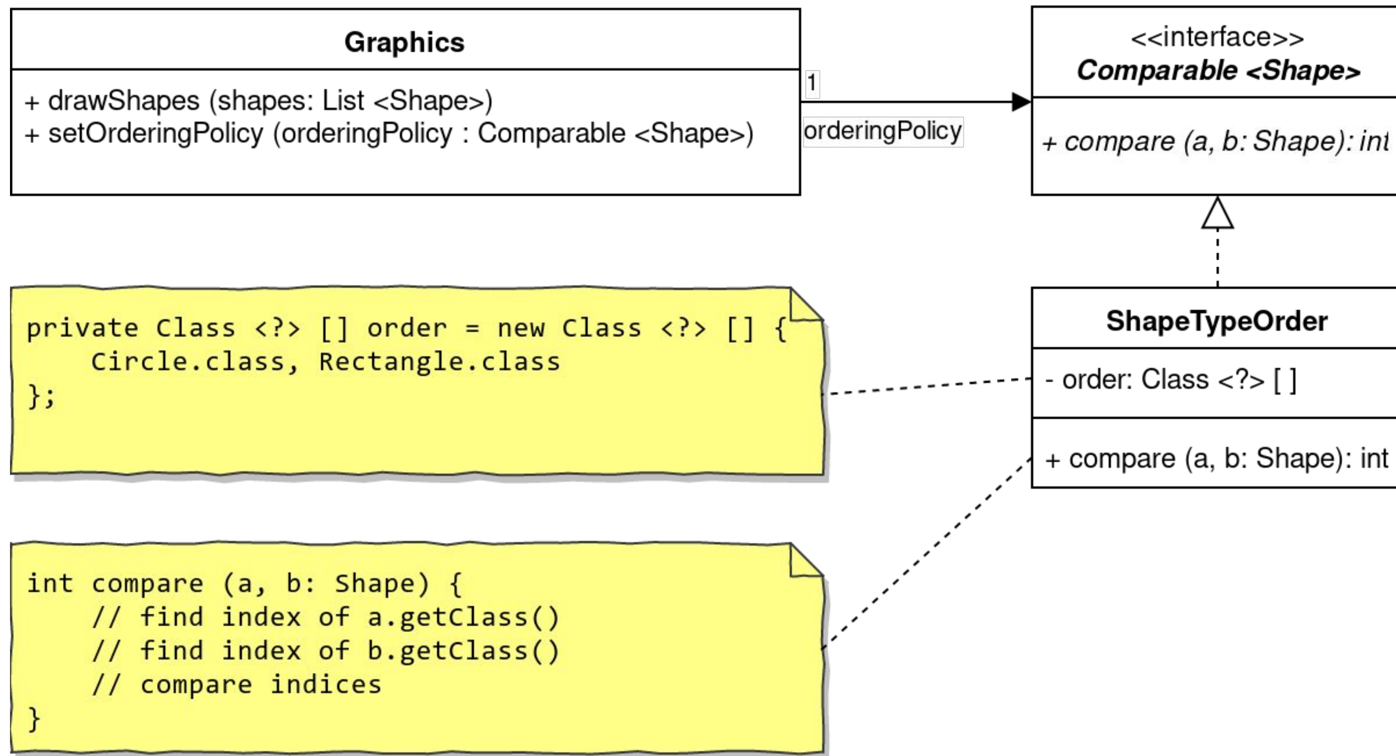
Solution: abstraction



Shapes can be ordered before drawing

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

Solution: data driven approach



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

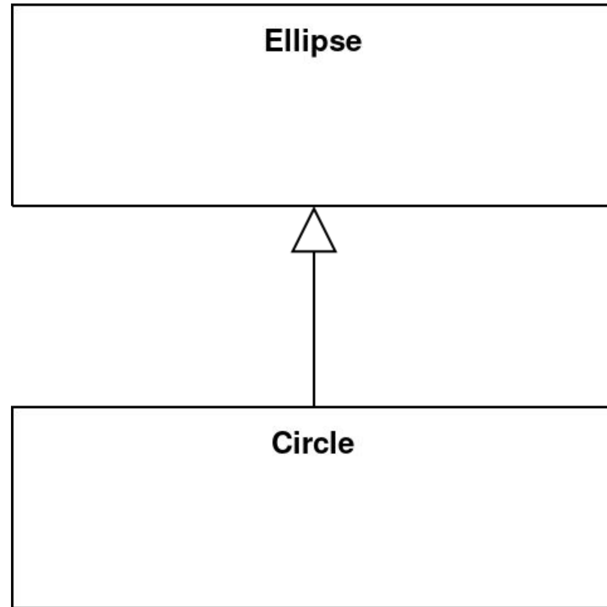
Functions should not know about derived classes

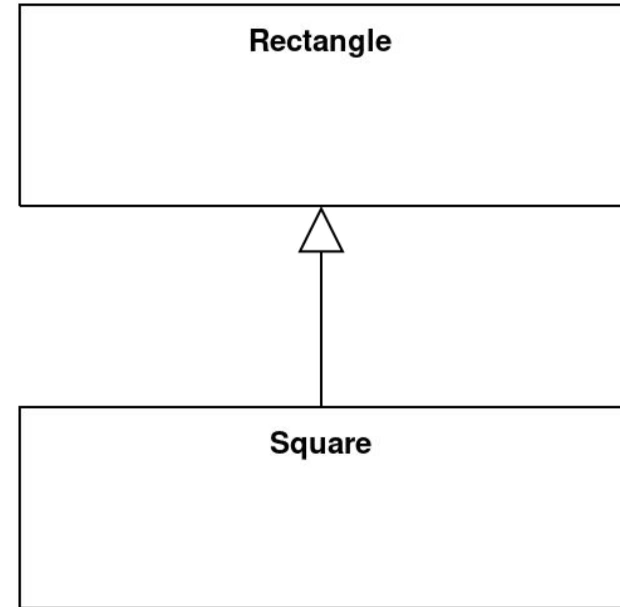
- User of a base class should continue to function properly if a derived class is passed to it.
  - Both existing and future derived classes.

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

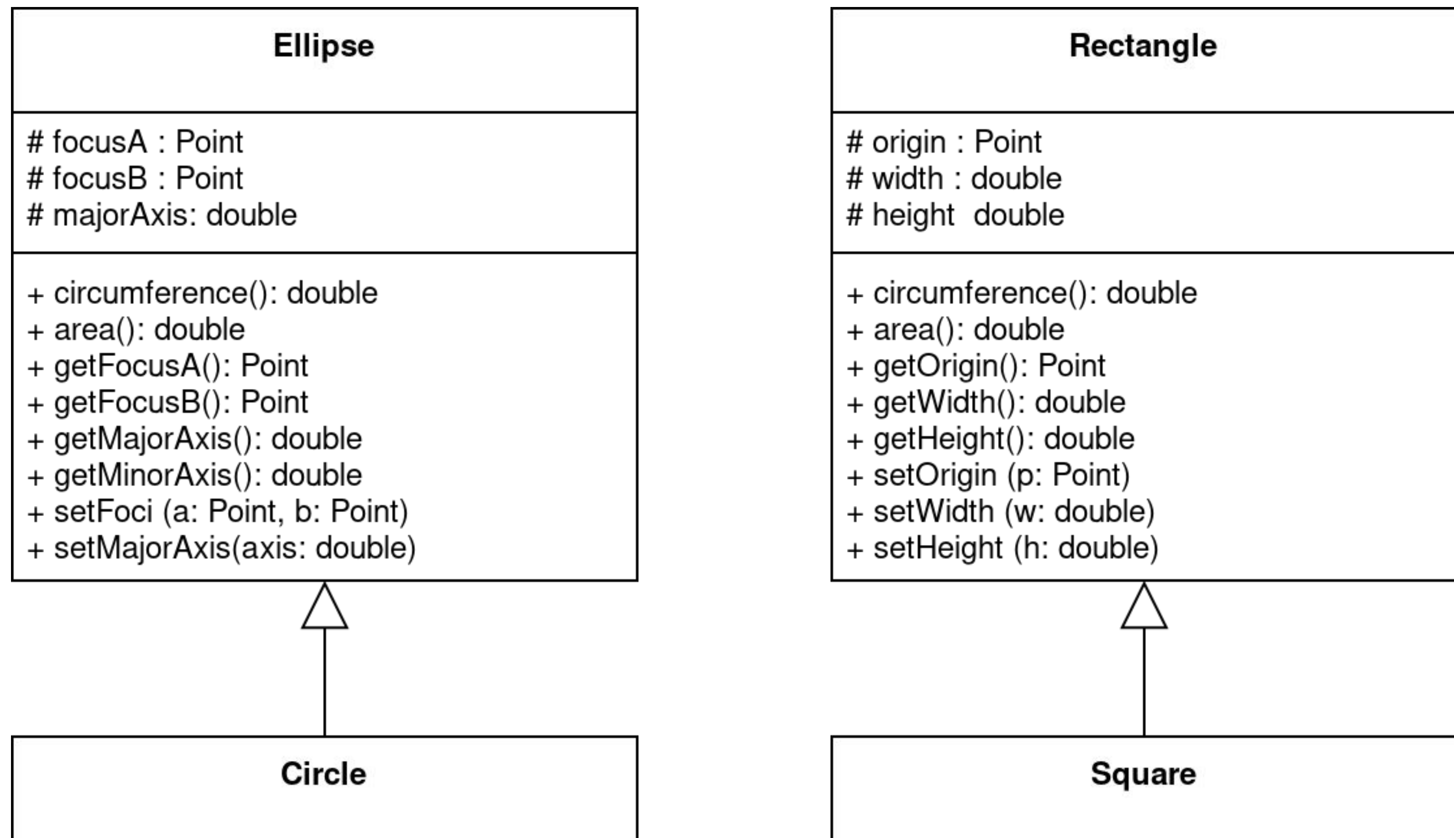




Classic Circle/Ellipse (Square/Rectangle) dilemma

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

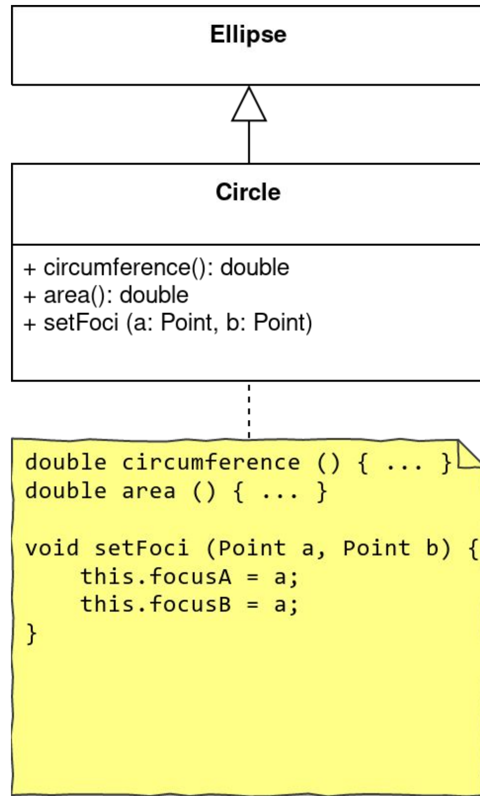
Example: LSP violation

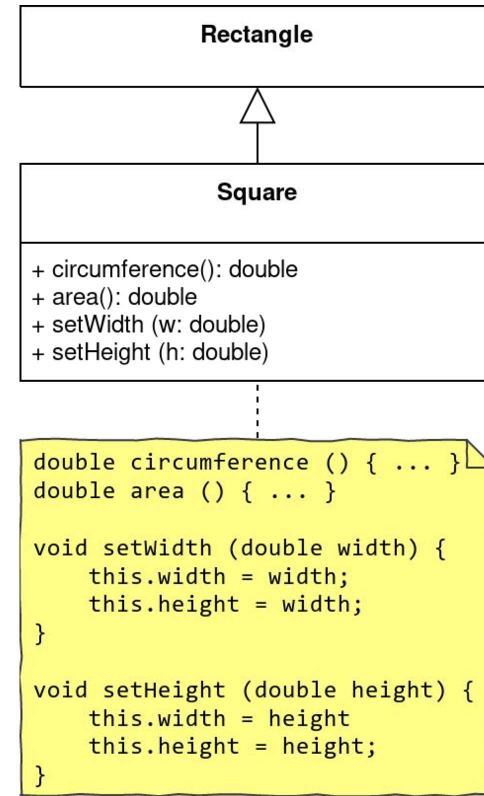


Minor issue: inheriting unnecessary attributes

- Nothing a bit of creative overriding could not fix...

Example: LSP violation





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.
  - 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.

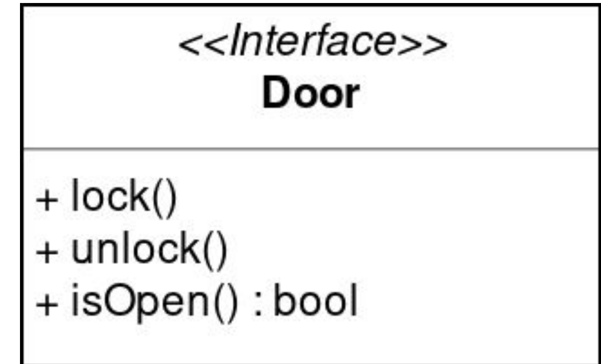
Create client-specific interfaces

- 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

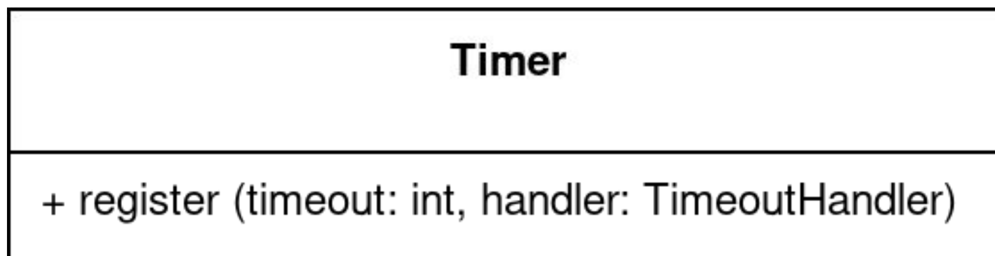
Security door

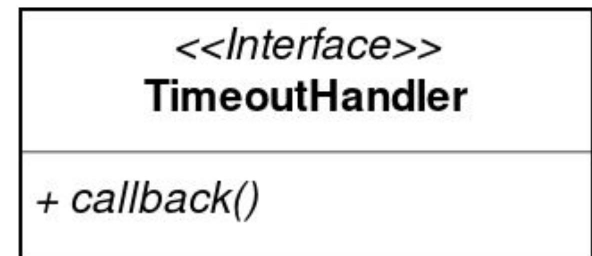
- Can be locked and unlocked, and knows whether it is open or closed.



We need a `TimedDoor`

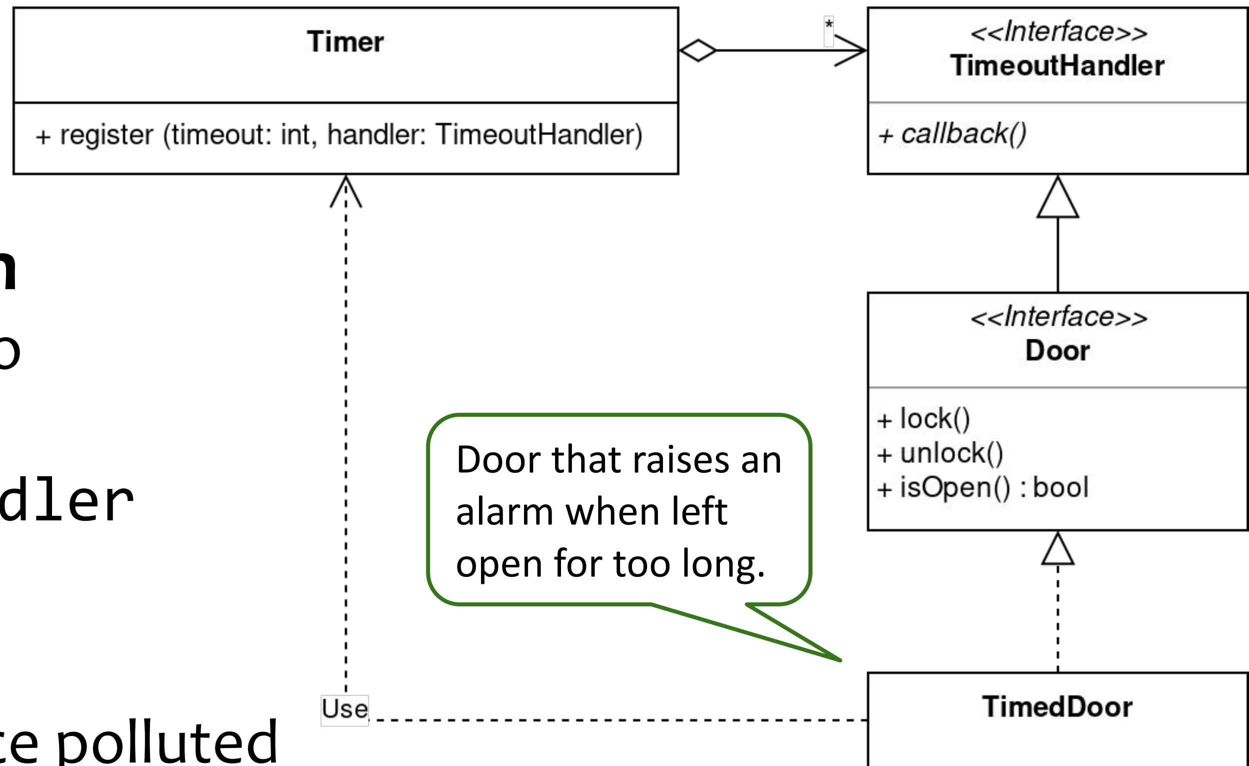
- Raises an alarm if it remains open for too long.
- Uses a `Timer` object to implement timeout.





How can `TimeoutHandler` notify `TimedDoor`?

Example: interface pollution



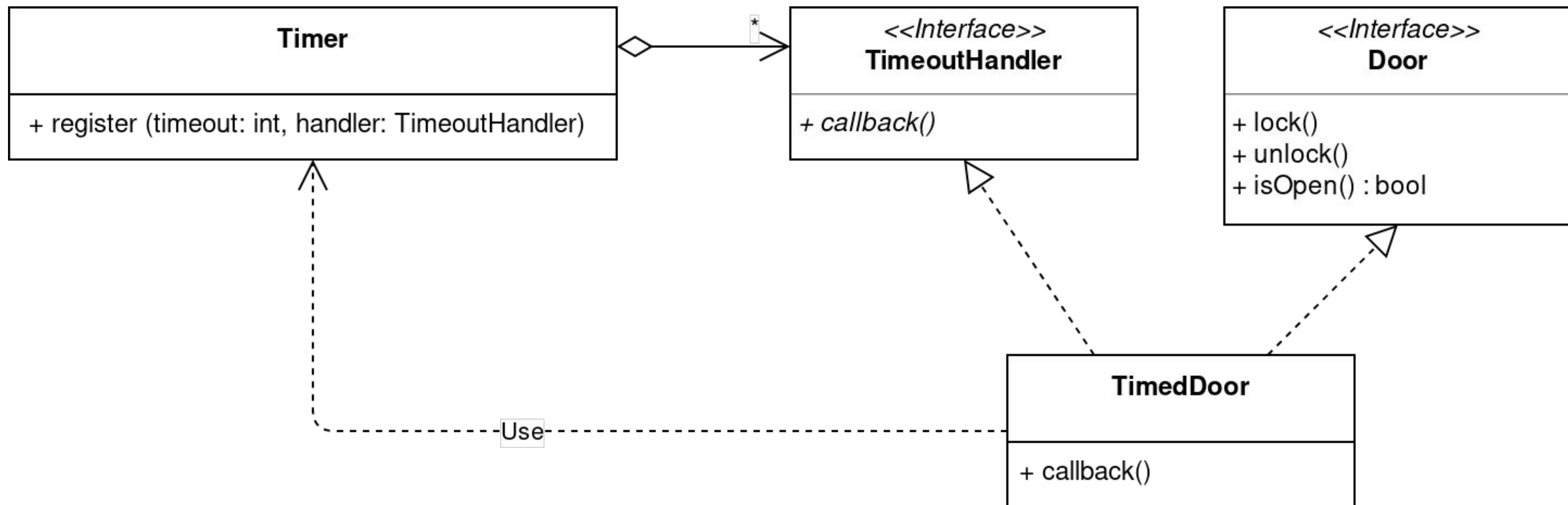
Common solution

- 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

Design interface service user viewpoint

- Not from service provider viewpoint
- Recall: clients own interfaces

Interfaces should represent client roles

- Classes implement many interfaces.
- Interfaces implemented by many classes.

Client/role version control

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

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).

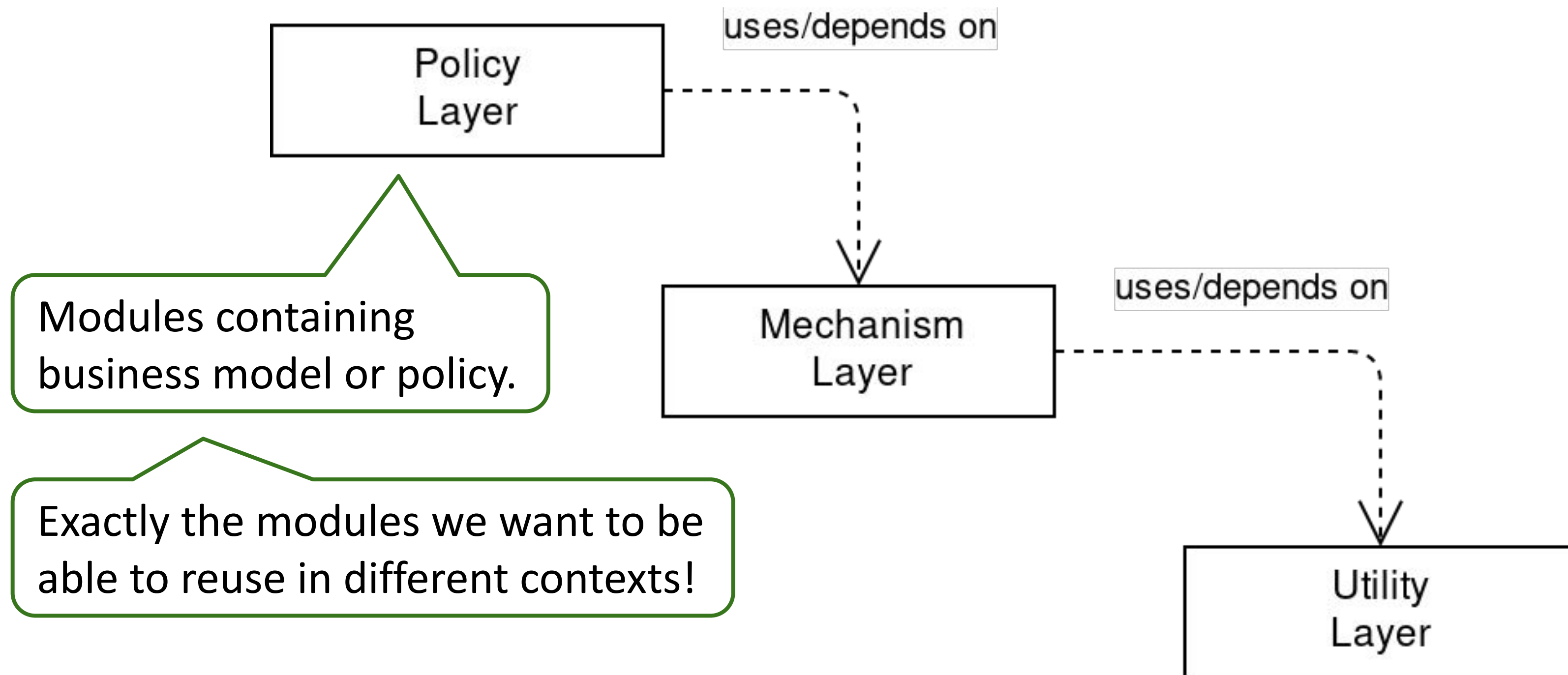
Overall purpose

- Prevent dependency on volatile modules.

Why dependency inversion?

Traditional (structural, procedural) design

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

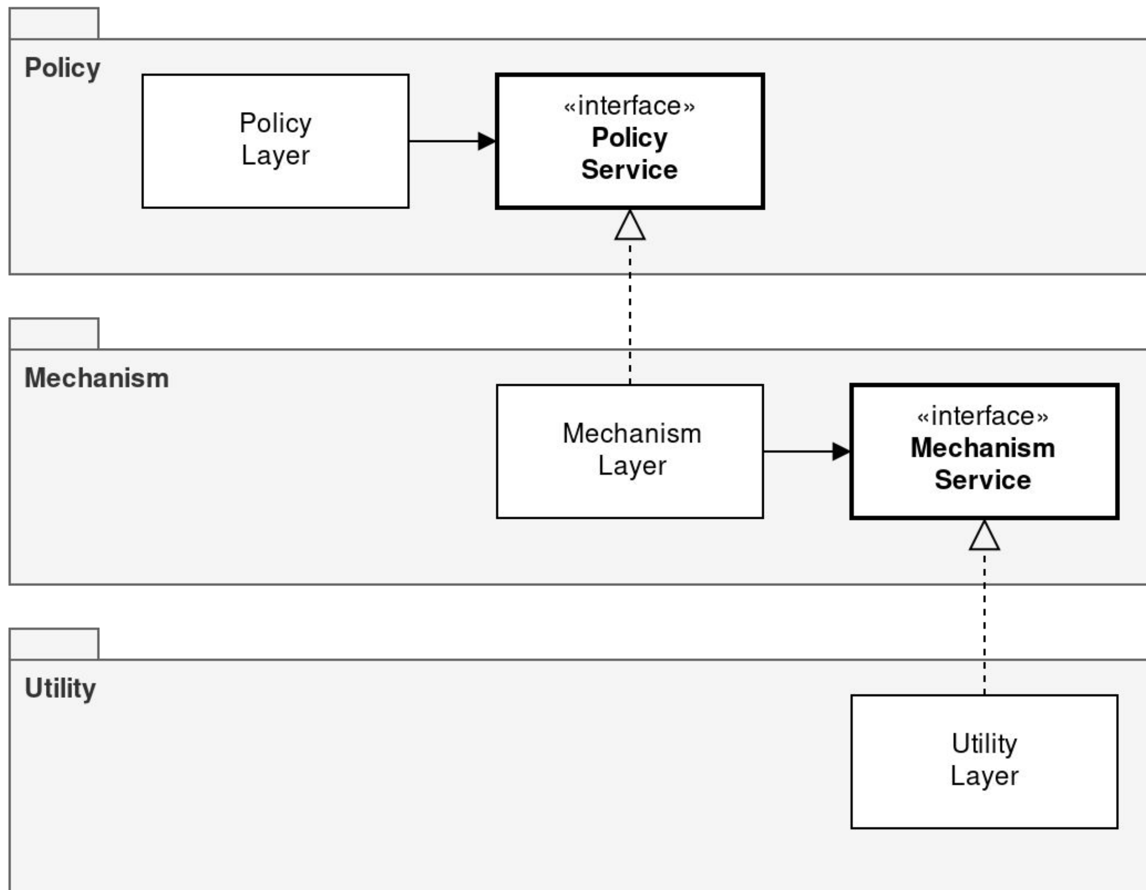


Changes in low-level modules can ***force*** high-level modules to change.... Preposterous!

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

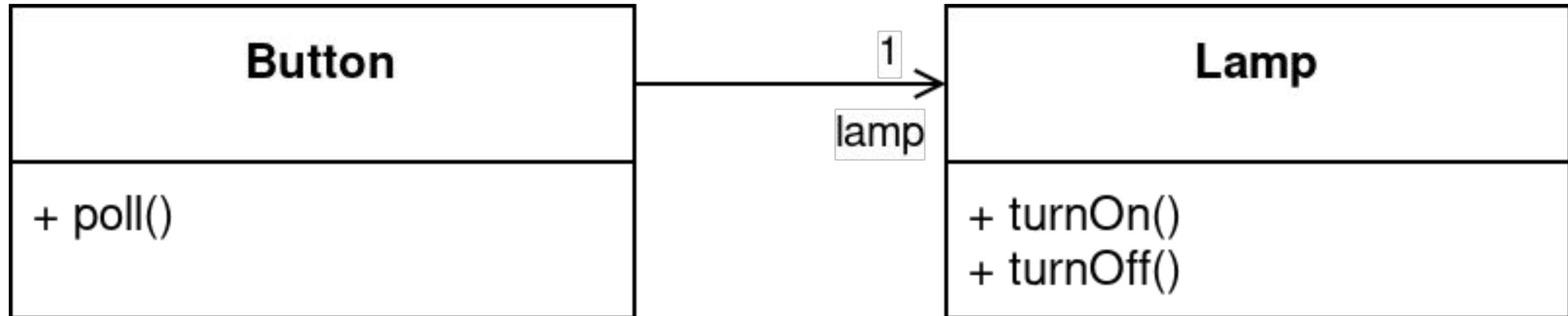
- Every dependency in a design should target an interface or an abstract class.
  - No variable should refer to concrete class.
  - No class should derive from concrete class.
  - No method should override an implemented method in any of its base classes.

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



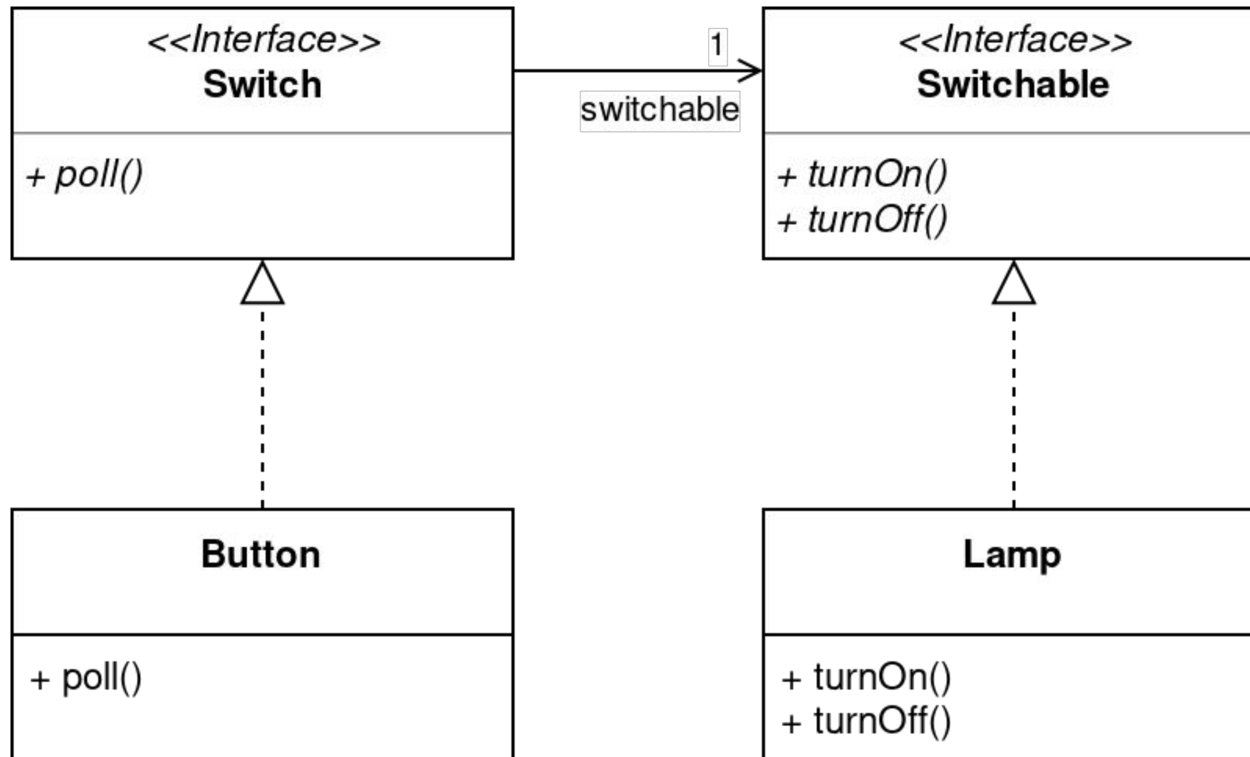
Button depends on Lamp

- 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