Software Design

CSE 403 Software Engineering

Winter 2026

Project Tips

Celebrate your brand – use your product name as a title in all your materials

Today's Outline

1. Quick recap – architecture vs design
2. Some practical design considerations
3. Class quiz on coding styles in PollEv ☺

Required readings are posted on the Calendar

Read ahead about doing Code Reviews – activity this Friday

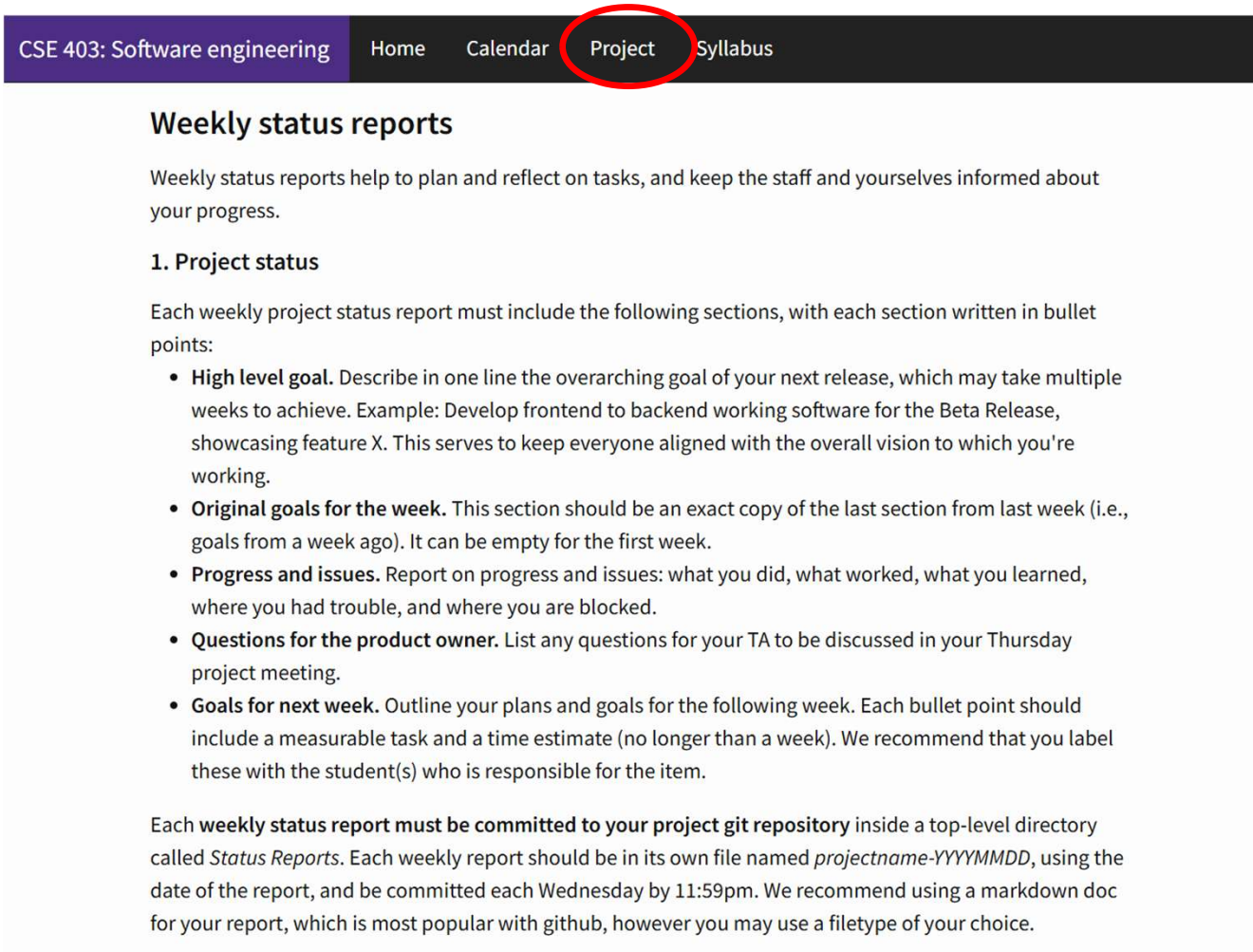
See also Appendix in this deck for a short primer on design material, including UML

Weekly status reports are now required

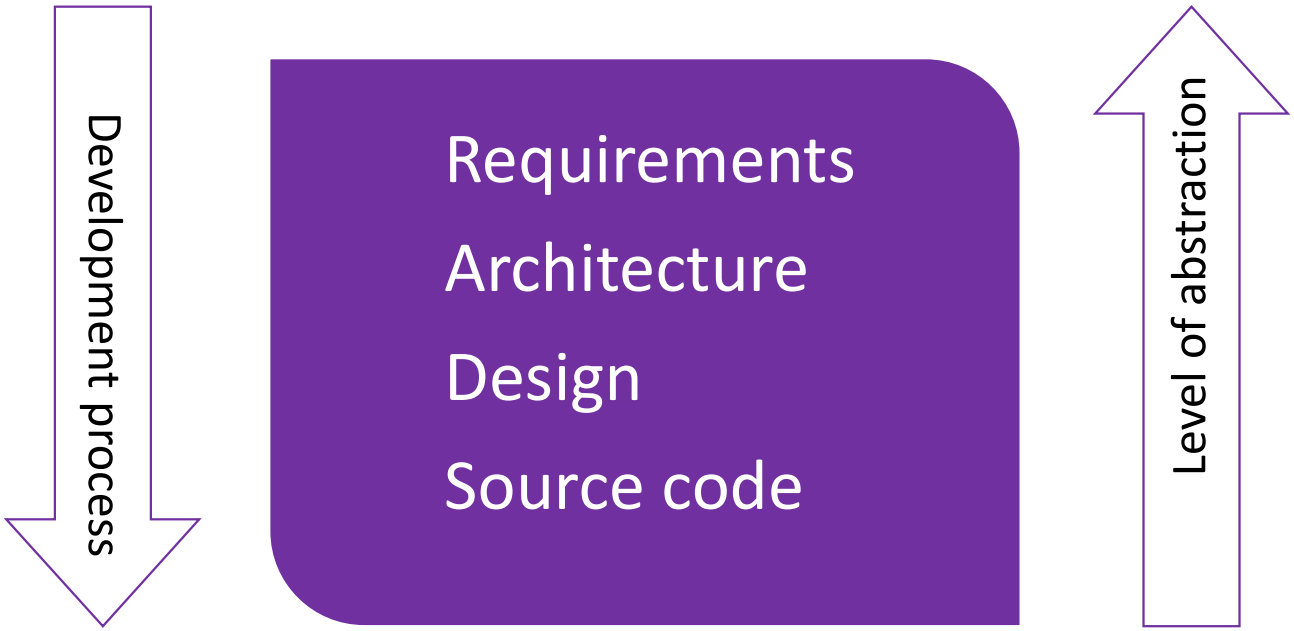
Due in github each Wednesday 11:59pm

Include any questions for staff

Details on “Project” tab of class website

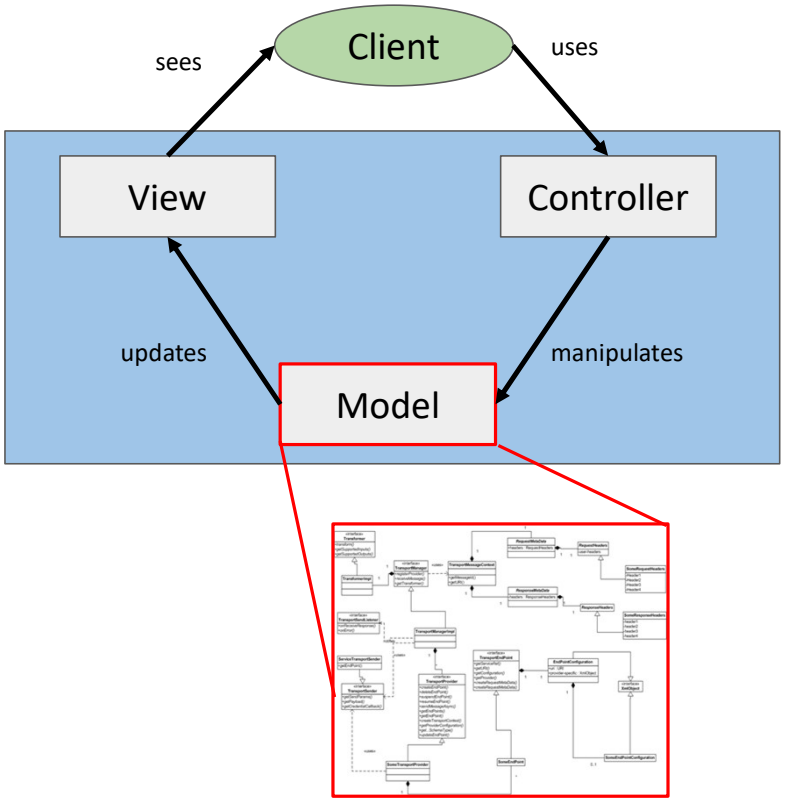


High level overview from last class



The level of abstraction is key

- With both architecture and design, we're building an abstract representation of reality
- Architecture - what components are needed, and what are their connections
- Design - how the components themselves are developed



Object-oriented design [programming]

Focus on the data during design

- Each object (class instance) represents a thing
  - Encapsulation: all information about the thing, in fields
  - Computation is handled within the object
- Information hiding
  - Behavior matters, clients aren't dependent on the implementation
  - Communication is only by sending messages
- Subtyping and subclassing
  - Subtyping: substitutability
  - Subclassing: inherit implementation

Does this differ from functional design [programming]?

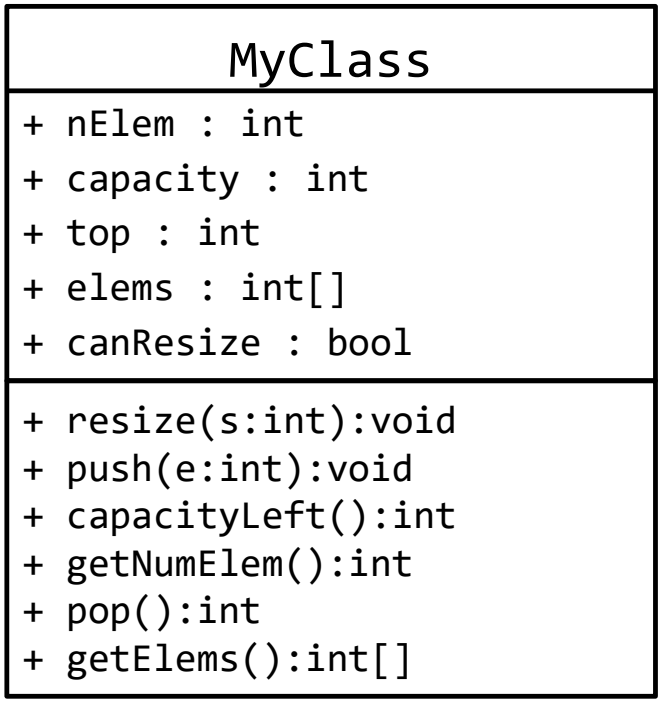
Object oriented design principles (331 refresh)

1. Information hiding (and encapsulation)
2. Polymorphism
3. Open/closed principle
4. Inheritance
5. Liskov substitution principle
6. Composition/aggregation over inheritance

1. Information hiding

private

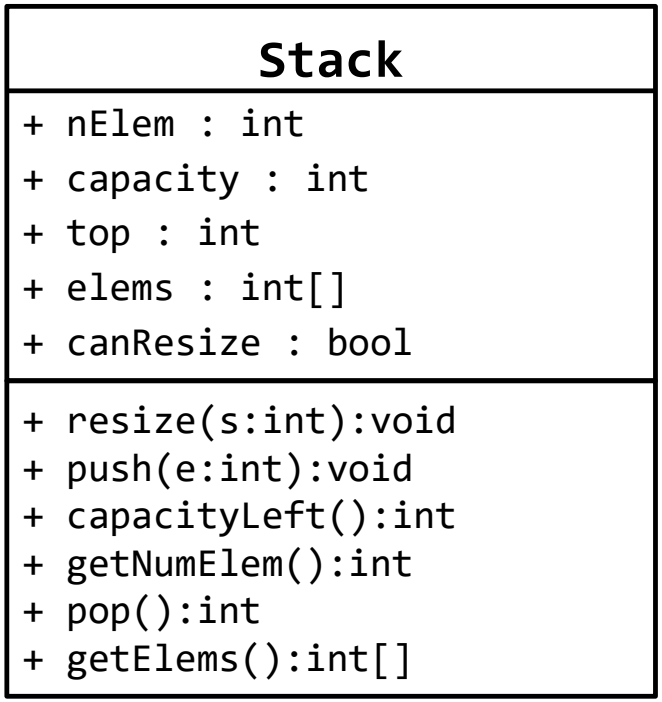
public




```
public class MyClass {
  public int nElem;
  public int capacity;
  public int top;
  public int[] elems;
  public boolean canResize;
  ...
  public void resize(int s){...}
  public void push(int e){...}
  public int capacityLeft(){...}
  public int getNumElem(){...}
  public int pop(){...}
  public int[] getElems(){...}
}
```

What does this class do?

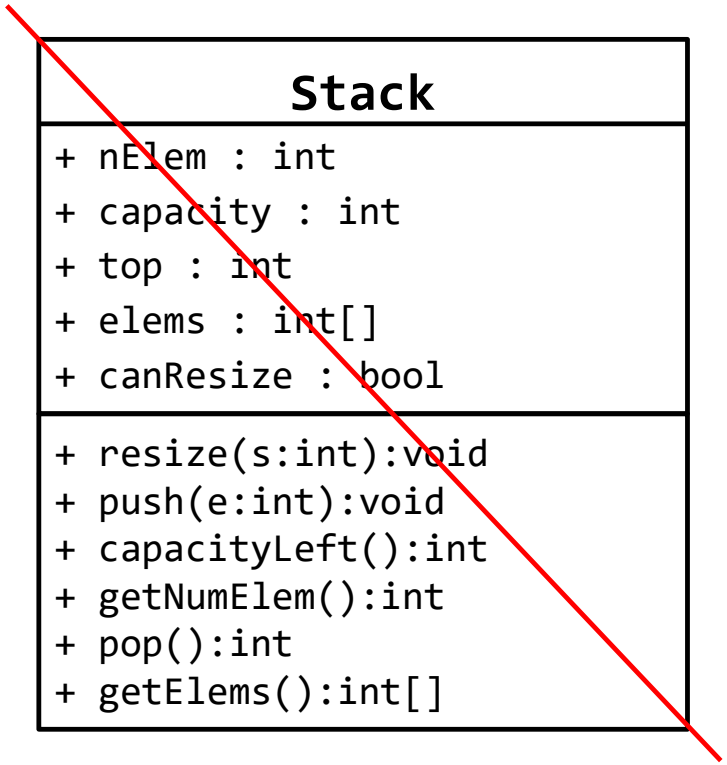
1. Information hiding

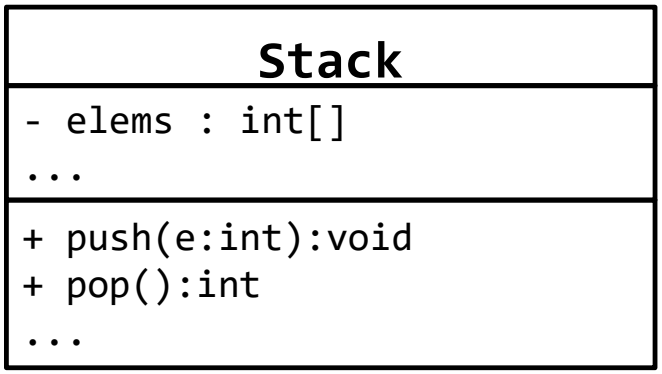



```
public class Stack {
  public int nElem;
  public int capacity;
  public int top;
  public int[] elems;
  public boolean canResize;
  ...
  public void resize(int s){...}
  public void push(int e){...}
  public int capacityLeft(){...}
  public int getNumElem(){...}
  public int pop(){...}
  public int[] getElems(){...}
}
```

Anything that could be improved in this implementation?

1. Information hiding





Information hiding:

- Reveal as little information about internals as possible
- Segregate public interface and implementation details
- Reduces complexity

2. Polymorphism

An object's ability to provide different behaviors

Types of polymorphism:

- Ad-hoc: (e.g., operator overloading)
  - a + b ⇒ string vs. int, double, etc.
- Subtype: (e.g., method overriding)
  - Object obj = ...;
obj.toString(); ⇒ toString() can be overridden in subclasses and therefore provide a different behavior
- Parametric: (e.g., Java generics)
  - class LinkedList<**E**> {
void add(**E**) {...}
E get(int index) {...} ⇒ LinkedList can store elements regardless of their type but still provide full type safety

2. Polymorphism

An object's ability to provide different behaviors

Types of polymorphism:

- Subtype: (e.g., method overriding)
  - Object obj = ...;
    obj.toString();

⇒ toString() can be overridden in subclasses and therefore provide a different behavior

Subtype polymorphism is essential to many good OO designs (and design principles)

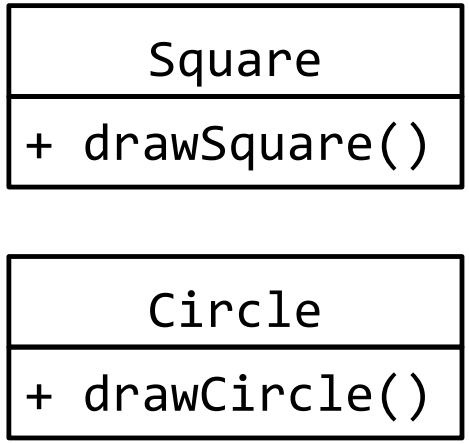
3. Open/closed principle

Software entities (classes, components, etc.) should be:

- **open** for extensions
- **closed** for modifications

```
public static void draw(Object o) {
  if (o instanceof Square) {
    drawSquare((Square) o)
  } else if (o instanceof Circle) {
    drawCircle((Circle) o);
  } else {
    ...
  }
}
```

Good or bad design?



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Software entities (classes, components, etc.) should be:

- **open** for extensions
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```
public static void draw(Object o) {
  if (o instanceof Square) {
    drawSquare((Square) o)
  } else if (o instanceof Circle) {
    drawCircle((Circle) o);
  } else {
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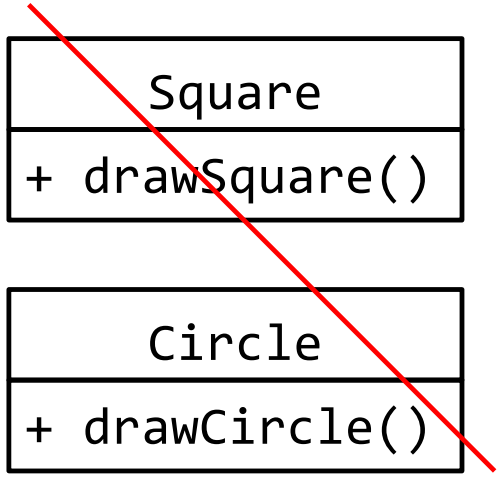
  }
}
```



Violates the open/closed principle!

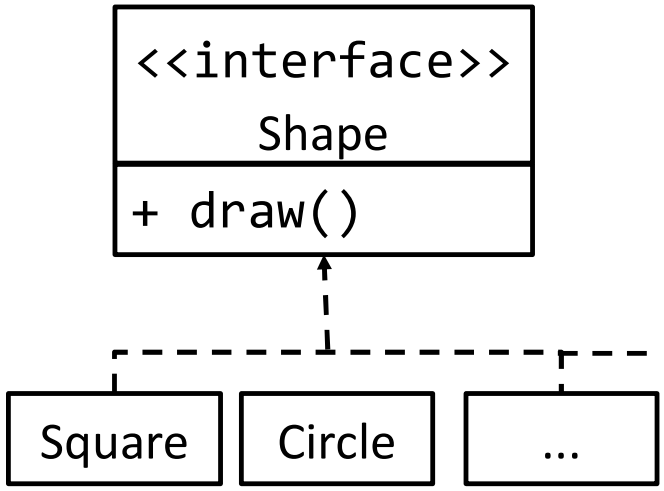
3. Open/closed principle

Software entities (classes, components, etc.) should be:

- **open** for extensions
- **closed** for modifications

```
public static void draw(Object s)
{
  if (s instanceof Shape) {
     s.draw();
  } else {
     …
   } }
```

```
public static void draw(Shape s)
{
  s.draw();
}
```

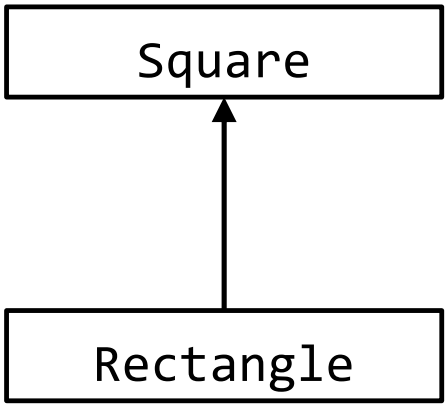


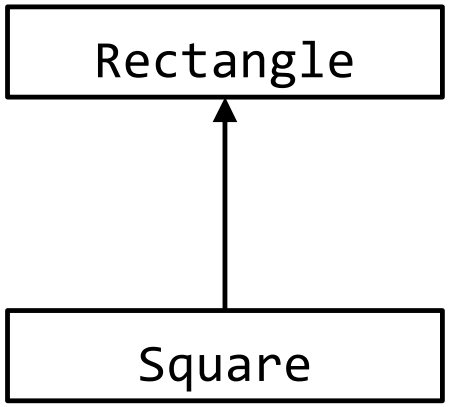
Use inheritance (specialization)

4. Liskov substitution principle

Motivating example

We know that a square is a special kind of a rectangle. So, which of the following OO designs makes sense?



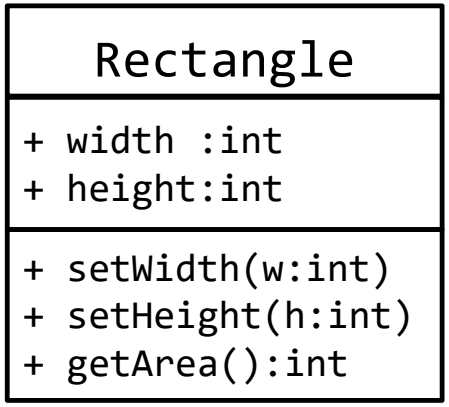


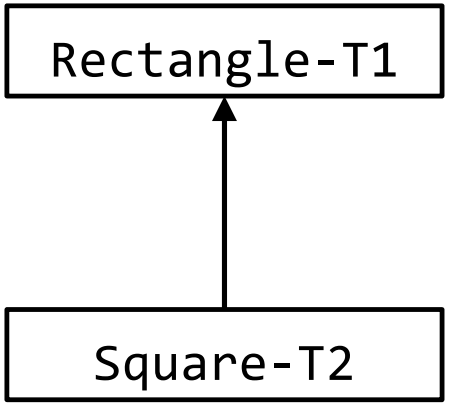
X ⟶ Y if X is a subtype of Y

4. Liskov substitution principle

Subtype requirement:

- Let object x be of type T1 and object y be of type T2
- Let T2 be a subtype of T1 (T2 <: T1)
- Any provable property about objects type T1 should be true for objects type T2





Is the subtype requirement fulfilled?

4. Liskov substitution principle

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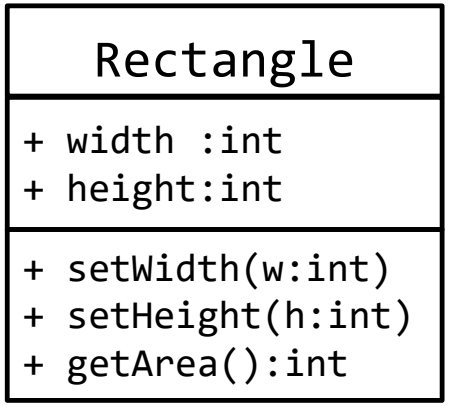
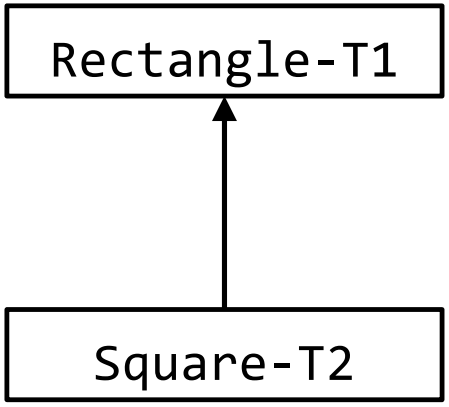



```
Rectangle r =
  new Rectangle(2,2);


int A = r.getArea();
int w = r.getWidth();
r.setWidth(w * 2);

assertEquals(A * 2,
       r.getArea());
```



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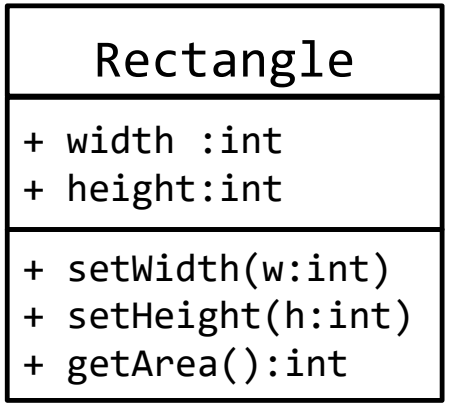
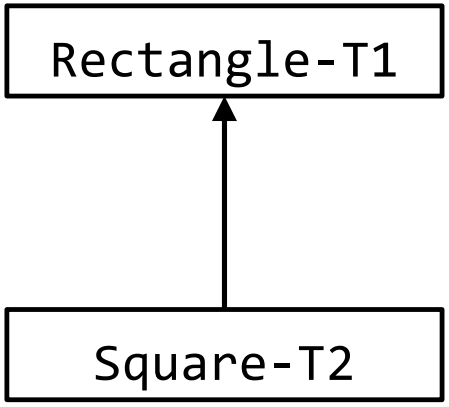



```
Rectangle r =
  new Rectangle(2,2);
  new Square(2);

int A = r.getArea();
int w = r.getWidth();
r.setWidth(w * 2);

assertEquals(A * 2,
       r.getArea());
```



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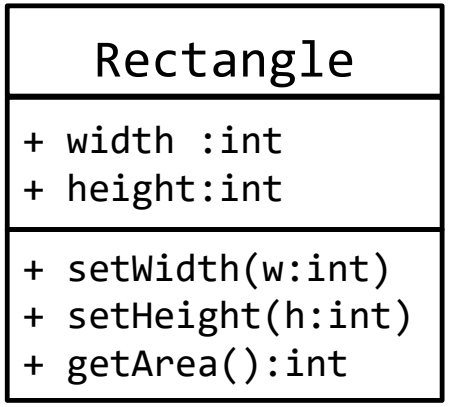


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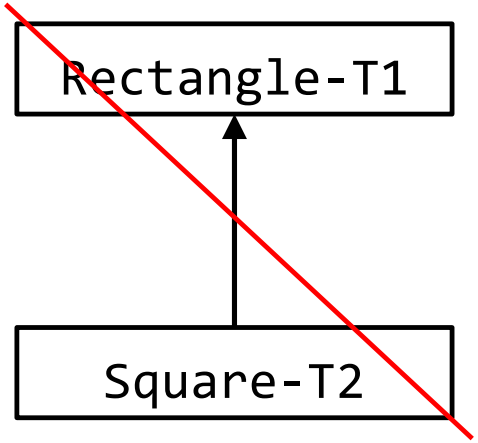

Violates the
Liskov substitution principle!

4. Liskov substitution principle

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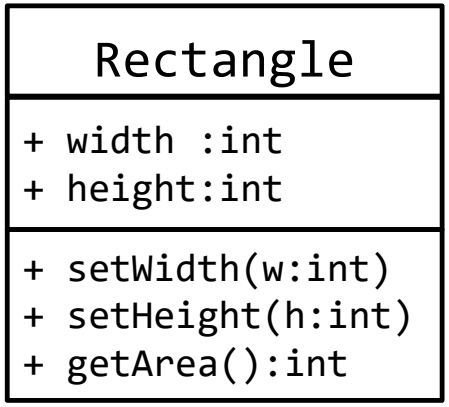

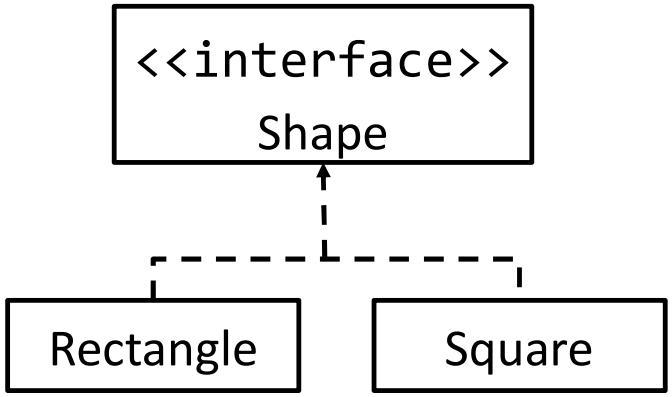

Better design

Adopt SOLID design principles

- **S**ingle-responsibility: Focus on doing one thing well. There should never be more than one reason to modify a class. Every class should have only one responsibility.
- **O**pen–closed: Can extend behavior without knowing the implementation - open for extension, closed for modification
- **L**iskov substitution: Code written to use a base class works with objects of derived classes. Subtypes have stronger specifications.
- **I**nterface segregation: Minimality and composability of interfaces. Don't force clients to depend upon or implement interfaces that they do not use.
- **D**ependency inversion: Depend upon abstractions, not concrete implementations. High-level modules should be unaware of low-level modules.

Learn more: SOLID Design Principles

Adopt more tried-and-true principles

- KISS principle (keep it simple, stupid)
- YAGNI principle (you ain't gonna need it)
- DRY principle (don't repeat yourself)
- High cohension, loose coupling principle (path to design success)

Learn more: Geeks for Geeks Design Principles

Design principles 

How about good patterns to learn and model from?

Design patterns

- Tried and true solutions to commonly occurring problems in software design
- Models that you can leverage or customize to solve design problems in your code
- Address recurring, common design problems and provide generalizable solutions – models – that you can customize
- Provide a common terminology for developers

Creational, structural and behavioral patterns

Creational Design Patterns	Structural Design Patterns	Behavioral Design Patterns
Simple Factory	Adapter	Chain of Responsibility
Factory Method	Bridge	Command
Abstract Factory	Composite	Iterator
Builder	Decorator	Mediator
Prototype	Facade	Memento
Singleton	Flyweight	Observer
	Proxy	Visitor
		Strategy
		State
		Template Method

A list from Design Patterns for Humans (see Calendar)

Creational design patterns

- Focus on the process of object creation and problems/complexity related to object creation
- Help in making a system independent of how its objects are created, composed and represented

- Example: Simple Factory pattern
  - Scenario: want to hide all the instantiation logic from the client
  - Simple Factory pattern: provides a clean way to generate an instance for a client without exposing instantiation logic to the client

```
interface Door {
        public function getWidth(): float;
        public function getHeight(): float;
}

class WoodenDoor implements Door {
        protected $width;
        protected $height;

        public function __construct(float $width,
                                    float $height){
        $this->width = $width;
        $this->height = $height;
        }

        public function getWidth(): float {
        return $this->width;
        }

        public function getHeight(): float {
        return $this->height;
}
```

```
class DoorFactory {

    public static function makeDoor($width, $height): Door
    {
            return new WoodenDoor($width, $height);
     }

}
```

```
$door1 = DoorFactory::makeDoor(100, 200);

$door2 = DoorFactory::makeDoor(50, 100);
```

Example from:
https://github.com/kamranahmedse/design-patterns-for-humans

Structural design patterns

- Solve problems related to how classes and objects are composed to form larger structures that are efficient and flexible
- Often use inheritance to compose interfaces or implementations

- Example: Fascade pattern
  - English definition: an outward appearance that is maintained to conceal a less pleasant reality
  - Scenario: provide a simple interface to a complex subsystem
  - Fascade pattern: a facade is an object that provides a simplified interface to a larger body of code

```
class Computer {
        public function getElectricShock() {..}
        public function makeSound() {..}
        public function showLoadingScreen() {..}
        public function bam() {..}
        public function closeEverything() {..}
        public function sooth() {..}
        public function pullCurrent() {..}
}
```

```
$computer = new ComputerFacade (new Computer());
$computer->turnOn();
$computer->turnOff()
```

```
class ComputerFacade {
  protected $computer;

  public function __construct (Computer $computer) {
        $this->computer = $computer;
  }
  public function turnOn() {
        $this->computer->getElectricShock();
        $this-computer->makeSound();
        $this->computer->showLoadingScreen();
        $this->computer->bam();
  }
  public function turnOff() {
        $this->compute->closeEverything();
        $this->computer->pullCurrent();
        $this->computer->sooth():
  }
```

Example from:
https://github.com/kamranahmedse/design-patterns-for-humans

Behavioral design patterns

- Solve problems related to responsibilities and communication between objects
- Describe not just patterns of objects or classes but also the patterns of communication between them
- Identify common communication patterns between objects and realize these patterns

- Example: Mediator pattern
  - Scenario: want to minimize/avoid direct complex dependencies between objects (strive for *loose coupling*), and/or have centralized coordination

```
interface Airplane {
    void requestTakeoff();
    void requestLanding();
    void notifyAirTrafficControl(String message);
}

class CommercialAirplane implements Airplane {
    private AirTrafficControlTower mediator;

    public CommercialAirplane(AirTrafficControlTower
        mediator) {
        this.mediator = mediator;
    }
    public void requestTakeoff() {
         mediator.requestTakeoff (this);
     }
    ...
}
```

```
interface AirTrafficControlTower {   // Mediator
    void requestTakeoff(Airplane airplane);
    void requestLanding(Airplane airplane);
}

class AirportControlTower implements AirTrafficControlTower {
       public void requestTakeoff(Airplane airplane) {
        //
         // Complex logic for coordinating takeoff
         //
        airplane.notifyAirTrafficControl("Requesting takeoff
                                                    clearance.");
        }
        ...
}
```

```
AirTrafficControlTower controlTower = new AirportControlTower();
Airplane airplane1 = new CommercialAirplane(controlTower);
Airplane airplane2 = new CommercialAirplane(controlTower);
airplane1.requestTakeoff();
airplane2.requestLanding();
```

Example from:
https://www.geeksforgeeks.org/mediator-design-pattern/

Like most things, design patterns have pros and cons

Pros

- Provide a common language for developers (including interviewing)
- Can improve communication and documentation
- “Toolbox” for devs to leverage known solutions to a known problems (don’t reinvent the wheel)

Cons

- Can get swept into thinking a pattern fits when it does not
- Or using one when there is a better – built in – solution in the language or dev toolkit that you’re using
- Can add complexity when it’s not needed

Some good design patterns references

- https://github.com/kamranahmedse/design-patterns-for-humans
  - Nice overview with examples
- https://www.patterns.dev
  - Java, React, Next.js, Vue.js examples
- https://refactoring.guru/design-patterns/catalog
  - Some motivating examples
- https://www.geeksforgeeks.org/software-design-patterns/
  - Tutorial like with examples

Let’s look at code
and
assess its style

Quiz setup

https: //PollEv.com/cse403wi

- Work in small groups of neighboring students
- **Individually register your answer in PollEv**
- 6 code snippets

- Round 1 (PollEv)
  - For each code snippet, decide if it represents good or bad practice
  - Discuss and reach consensus on good or bad practice and why

- Round 2 (Poll results and class discussion)
  - For each code snippet, share opinions on why it is good or bad practice
  - **Goal:** common understanding of good styles and alternatives to bad ones

Round 1: good or bad?

Snippet 1: good or bad?

```
public File[] getAllLogs(Directory dir) {
   if (dir == null || !dir.exists() || dir.isEmpty()) {
      return null;
   } else {
      int numLogs = … // determine number of log files
      File[] allLogs = new File[numLogs];
      for (int i=0; i<numLogs; ++i) {
         allLogs[i] = … // populate the array
      }
      return allLogs;
   }
}
```

Snippet 2: good or bad?

```
public void addStudent(Student student, String
course) {
   if (course.equals("CSE403")) {
      cse403Students.add(student);
   }
   allStudents.add(student)
}
```

Snippet 3: good or bad?

```
public enum PaymentType {DEBIT, CREDIT}

public void doTransaction(double amount, PaymentType payType) {
  switch (payType) {
    case DEBIT:
       … // process debit card
       break;
    case CREDIT:
       … // process credit card
       break;
    default:
       throw new IllegalArgumentException("Unexpected payment type");
   }
}
```

Snippet 4: good or bad?

```
public int getAbsMax(int x, int y) {
  if (x<0) {
    x = -x;
  }
  if (y<0) {
    y = -y;
  }
  return Math.max(x, y);
}
```

Snippet 5: good or bad?

```
public class ArrayList<E> {
    public E remove(int index) {
        …
    }
    public boolean remove(Object o) {
        …
    }
    …
}
```

Snippet 6: good or bad?

```
public class Point {
   private final int x;
   private final int y;

   public Point(int x, int y) {
      this.x = x;
      this.y = y;
   }
   public int getX() {
      return this.x;
   }
   public int getY() {
      return this.y;
   }
}
```

Design Quiz - Good or bad?

0 surveys completed

0 surveys underway

Round 1: good or bad?

Round 2: why?

Snippet 1: good or bad?

```
public File[] getAllLogs(Directory dir) {
   if (dir == null || !dir.exists() || dir.isEmpty()) {
      return null;
   } else {
      int numLogs = … // determine number of log files
      File[] allLogs = new File[numLogs];
      for (int i=0; i<numLogs; ++i) {
         allLogs[i] = … // populate the array
      }
      return allLogs;
   }
}
```

And the survey says …

Snippet1: getAllLogs

Good

Bad

Snippet 1: this is bad! why?

```
public File[] getAllLogs(Directory dir) {
   if (dir == null || !dir.exists() || dir.isEmpty()) {
      return null;
   } else {
      int numLogs = … // determine number of log files
      File[] allLogs = new File[numLogs];
      for (int i=0; i<numLogs; ++i) {
         allLogs[i] = … // populate the array
      }
      return allLogs;
   }
}
```

Snippet 1: this is bad! why?

```
public File[] getAllLogs(Directory dir) {
   if (dir == null || !dir.exists() || dir.isEmpty()) {
      return null;
   } else {
      int numLogs = … // determine number of log files
      File[] allLogs = new File[numLogs];
      for (int i=0; i<numLogs; ++i) {
         allLogs[i] = … // populate the array
      }
      return allLogs;
   }
}
```

Null references...the billion dollar mistake.

Apologies and retractions

Speaking at a software conference named QCon London[24] in 2009, he apologised for inventing the null reference:[25]

Tony Hoare

> I call it my billion-dollar mistake. It was the invention of the null reference in 1965. At that time, I was designing the first comprehensive type system for references in an object oriented language (ALGOL W). My goal was to ensure that all use of references should be absolutely safe, with checking performed automatically by the compiler. But I couldn't resist the temptation to put in a null reference, simply because it was so easy to implement. This has led to innumerable errors, vulnerabilities, and system crashes, which have probably caused a billion dollars of pain and damage in the last forty years.

- Programming languages
- Concurrent programming
- Quicksort

Snippet 1: this is bad! why?

```
public File[] getAllLogs(Directory dir) {
   if (dir == null || !dir.exists() || dir.isEmpty()) {
      return null;
   } else {
      int numLogs = … // determine number of log files
      File[] allLogs = new File[numLogs];
      for (int i=0; i<numLogs; ++i) {
         allLogs[i] = … // populate the array
      }
      return allLogs;
   }
}
```

```
File[] files = getAllLogs();
for (File f : files) {
    …
}
```

Don’t return null; return an empty array instead.

Snippet 1: this is bad! why?

```
public File[] getAllLogs(Directory dir) {
   if (dir == null || !dir.exists() || dir.isEmpty()) {
      return null;
   } else {
      int numLogs = … // determine number of log files
      File[] allLogs = new File[numLogs];
      for (int i=0; i<numLogs; ++i) {
         allLogs[i] = … // populate the array
      }
      return allLogs;
   }
}
```

No diagnostic information.

Snippet 2: good or bad?

```
public void addStudent(Student student, String
course) {
   if (course.equals("CSE403")) {
      cse403Students.add(student);
   }
   allStudents.add(student)
}
```

And the survey says …

Snippet2: addStudent

Good

Bad

Snippet 2: short but bad! why?

```
public void addStudent(Student student, String
course) {
   if (course.equals("CSE403")) {
      cse403Students.add(student);
   }
   allStudents.add(student)
}
```

Snippet 2: short but bad! why?

```
public void addStudent(Student student, String
course) {
   if (course.equals("CSE403")) {
      cse403Students.add(student);
   }
   allStudents.add(student)
}
```

Use constants and enums to avoid literal duplication.

Snippet 2: short but bad! why?

```
public void addStudent(Student student, String
course) {
   if (course.equals("CSE403")) {
      cse403Students.add(student);
   }
   allStudents.add(student)
}
```

Consider always returning a success/failure value.

Snippet 3: good or bad?

```
public enum PaymentType {DEBIT, CREDIT}

public void doTransaction(double amount, PaymentType payType) {
  switch (payType) {
    case DEBIT:
       … // process debit card
       break;
    case CREDIT:
       … // process credit card
       break;
    default:
       throw new IllegalArgumentException("Unexpected payment type");
   }
}
```

And the survey says …

Snippet3: PaymentType

Good

Bad

Snippet 3: this is good, but why?

```
public enum PaymentType {DEBIT, CREDIT}

public void doTransaction(double amount, PaymentType payType) {
  switch (payType) {
    case DEBIT:
       … // process debit card
       break;
    case CREDIT:
       … // process credit card
       break;
    default:
       throw new IllegalArgumentException("Unexpected payment type");
   }
}
```

Snippet 3: this is good, but why?

```
public enum PaymentType {DEBIT, CREDIT}

public void doTransaction(double amount, PaymentType payType) {
  switch (payType) {
    case DEBIT:
       … // process debit card
       break;
    case CREDIT:
       … // process credit card
       break;
    default:
      throw new IllegalArgumentException("Unexpected payment type");
  }
}
```

Type safety using an enum; throws an exception for unexpected cases (e.g., future extensions of PaymentType).

Snippet 4: good or bad?

```
public int getAbsMax(int x, int y) {
  if (x<0) {
    x = -x;
  }
  if (y<0) {
    y = -y;
  }
  return Math.max(x, y);
}
```

And the survey says …

Snippet4: getAbsMax

Good

Bad

Snippet 4: also bad! huh?

```
public int getAbsMax(int x, int y) {
  if (x<0) {
    x = -x;
  }
  if (y<0) {
    y = -y;
  }
  return Math.max(x, y);
}
```

Snippet 4: also bad! huh?

```
public int getAbsMax(int x, int y) {
  if (x<0) {
    x = -x;
  }
  if (y<0) {
    y = -y;
  }
  return Math.max(x, y);
}
```

Consider if these are pass by reference…

Method parameters should be final (sacred); use local variables to sanitize inputs.

Snippet 5: good or bad?

```
public class ArrayList<E> {
    public E remove(int index) {
        …
    }
    public boolean remove(Object o) {
        …
    }
    …
}
```

And the survey says …

Snippet5: ArrayList

Good

Bad

Snippet 5: Java API, but still bad! why?

```
public class ArrayList<E> {
    public E remove(int index) {
        …
    }
    public boolean remove(Object o) {
        …
    }
    …
}
```

Snippet 5: Java API, but still bad! why?

```
public class ArrayList<E> {
   public E remove(int index) {
      …
   }
   public boolean remove(Object o) {
      …
   }
   …
}
```

```
ArrayList<String> a = new ArrayList<>();
Integer index = Integer.valueOf(1);
a.add("Hello");
a.add("World");
a.remove(index);
```

What does the last call return (`a.remove(index)`)?

Snippet 5: Java API, but still bad! why?

```
public class ArrayList<E> {
    public E remove(int index) {
        …
    }
    public boolean remove(Object o) {
        …
    }
    …
}
```

```
ArrayList<String> a = new ArrayList<>();
Integer index = Integer.valueOf(1);
a.add("Hello");
a.add("World");
a.remove(index);
```

Avoid overloading with different return values.

Snippet 5: Java API, but still bad! why?

```
public class ArrayList<E> {
   public E remove(int index) {
      …
   }
   public boolean remove(Object o) {
      …
   }
   …
}
```

```
ArrayList<String> a = new ArrayList<>();
Integer index = Integer.valueOf(1);
a.add("Hello");
a.add("World");
a.remove(index);
```

Avoid method overloading, which is statically resolved.

Snippet 6: good or bad?

```
public class Point {
   private final int x;
   private final int y;

   public Point(int x, int y) {
      this.x = x;
      this.y = y;
   }
   public int getX() {
      return this.x;
   }
   public int getY() {
      return this.y;
   }
}
```

And the survey says …

Snippet6: Point

Good

Bad

Snippet 6: this is good, but why?

```
public class Point {
   private final int x;
   private final int y;

   public Point(int x, int y) {
      this.x = x;
      this.y = y;
   }
   public int getX() {
      return this.x;
   }
   public int getY() {
      return this.y;
   }
}
```

Snippet 6: this is good, but why?

```
public class Point {
   private final int x;
   private final int y;

   public Point(int x, int y) {
      this.x = x;
      this.y = y;
   }
   public int getX() {
      return this.x;
   }
   public int getY() {
      return this.y;
   }
}
```

Good encapsulation; immutable object.

All for now on design and style

- We'll do a light look at **UI/UX design** later in the course – see also, CSE 440 – Intro to HCI (Human Computer Interaction)

- Review the readings on the Calendar and the design primer in the following slides to refresh your knowledge of design considerations for your project and assignment: **03 Architecture and design milestone**

Additional Design Material

Provided by René Just, UW CSE Professor

Concepts traditionally covered in CSE 331 – Software design and implementation

UML crash course

UML crash course

The main questions

- What is UML?
- Is it useful, why bother?
- When to (not) use UML?

What is UML?

- Unified Modeling Language.
- Developed in the mid 90's, improved since.
- Standardized notation for modeling OO systems.
- A collection of diagrams for different viewpoints:
  - Use case diagrams
  - Component diagrams
  - Class and Object diagrams
  - Sequence diagrams
  - Statechart diagrams
  - ...

What is UML?

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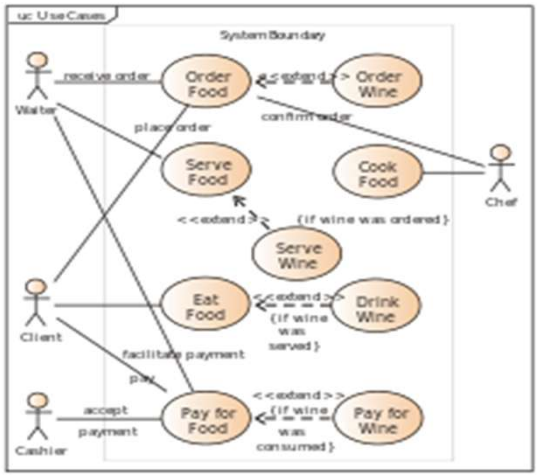
  - **Use case diagrams**
  - Component diagrams
  - Class and Object diagrams
  - Sequence diagrams
  - Statechart diagrams
  - ...



What is UML?

- Unified Modeling Language.
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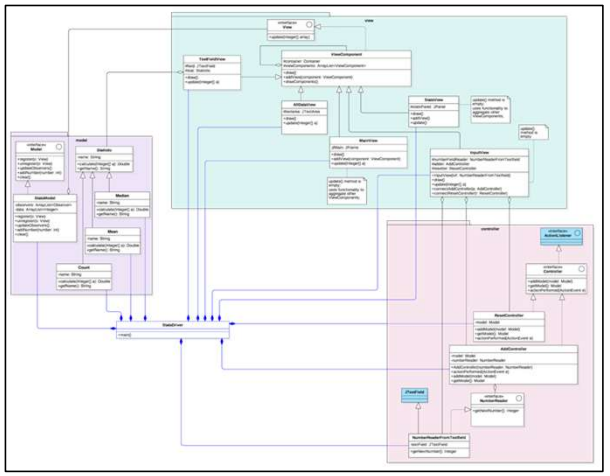
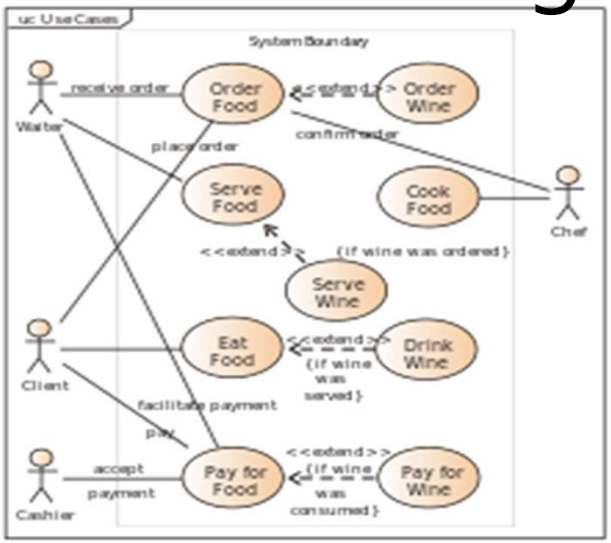
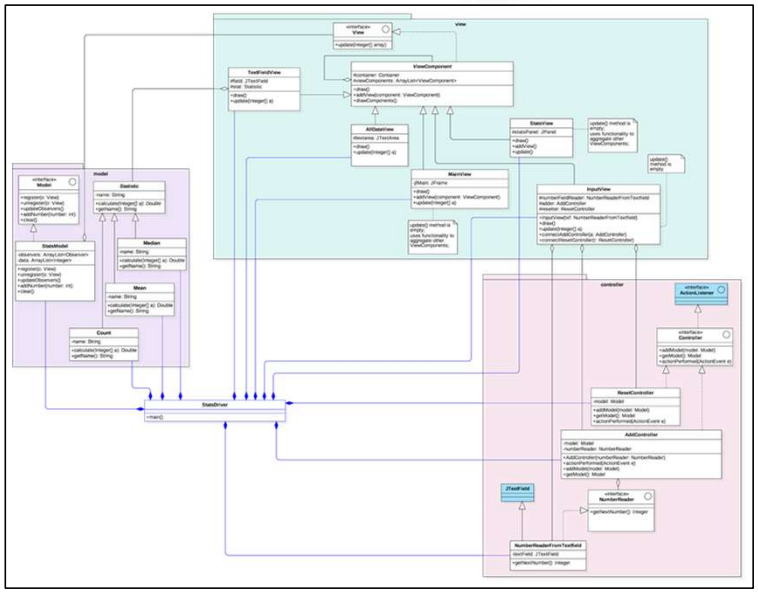
  - **Class and Object diagrams**
  - Sequence diagrams
  - Statechart diagrams
  - ...



Are UML diagrams useful?





Are UML diagrams useful?

Communication

- Forward design (before coding)
  - Brainstorm ideas (on whiteboard or paper).
  - Draft and iterate over software design.

Documentation

- Backward design (after coding)
  - Obtain diagram from source code.

In this class, we will use UML class diagrams mainly for visualization and discussion purposes.

Classes vs. objects

Class

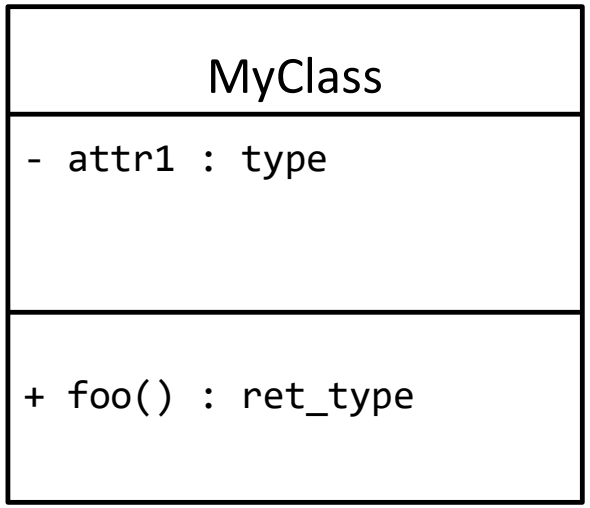
- Grouping of similar objects.
  - Student
  - Car
- Abstraction of common properties and behavior.
  - Student: Name and Student ID
  - Car: Make and Model

Object

- Entity from the real world.
- Instance of a class
  - Student: Joe (4711), Jane (4712), …
  - Car: Audi A6, Honda Civic, ...

UML class diagram: basic notation

UML class diagram: basic notation



Name

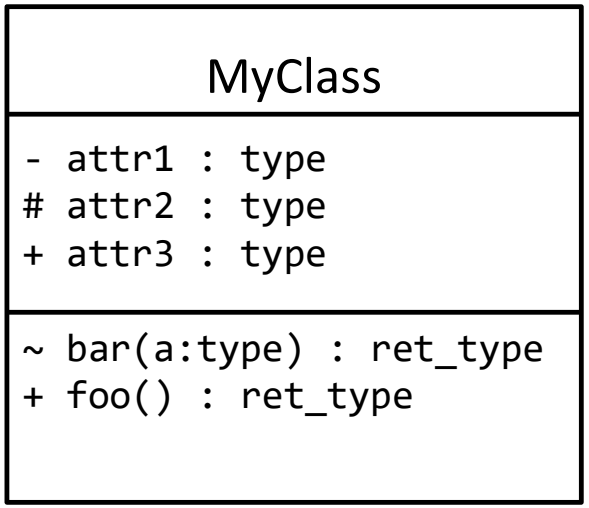
Attributes

<visibility> <name> : <type>

Methods

<visibility> <name>(<param>) :*
<return type>
<param> := <name> : <type>

UML class diagram: basic notation



Name

Attributes

<visibility> <name> : <type>

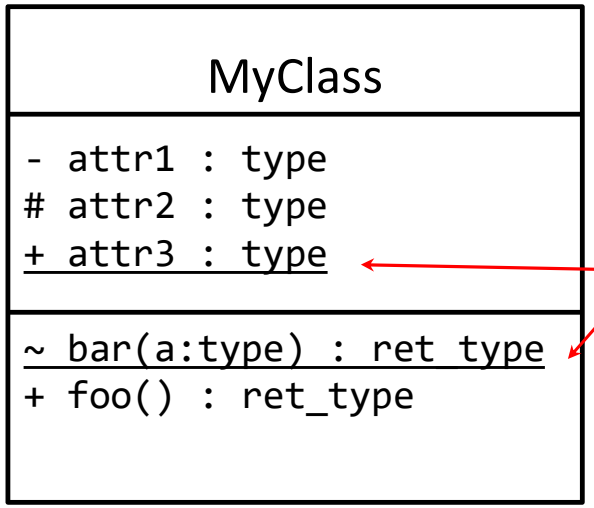
Methods

<visibility> <name>(<param>) :*
<return type>
<param> := <name> : <type>

Visibility

- private
~ package-private
 # protected
+ public

UML class diagram: basic notation



Name

Attributes

<visibility> <name> : <type>

Static attributes or methods are underlined

Methods

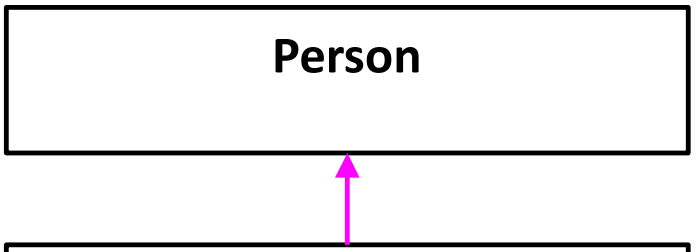
<visibility> <name>(<param>) :*
<return type>
<param> := <name> : <type>

Visibility

- private
~ package-private
 # protected
+ public

UML class diagram: concrete example

```
public class Person {
  …
}
```

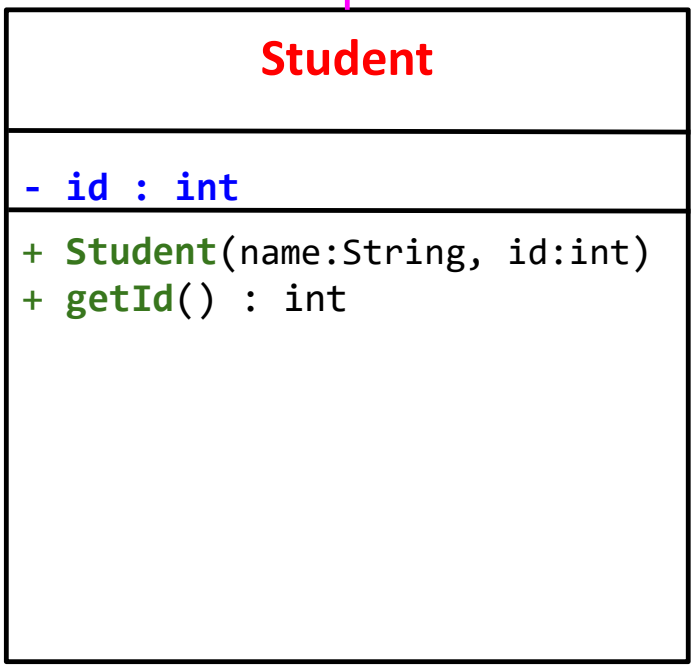



```
public class Student
    extends Person {

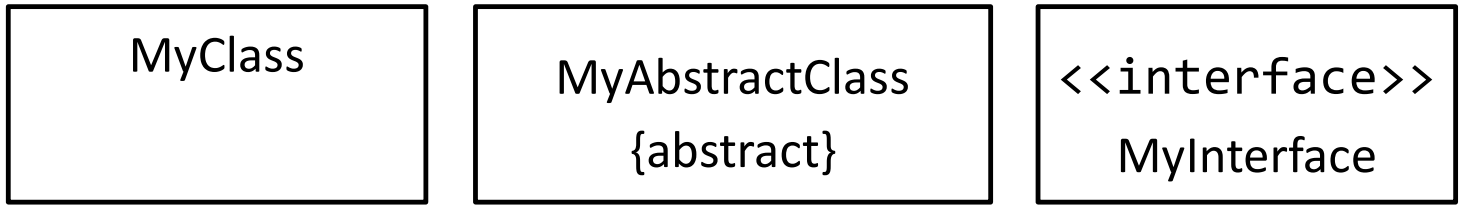
  private int id;

  public Student(String name,
                 int id) {
    ...
  }

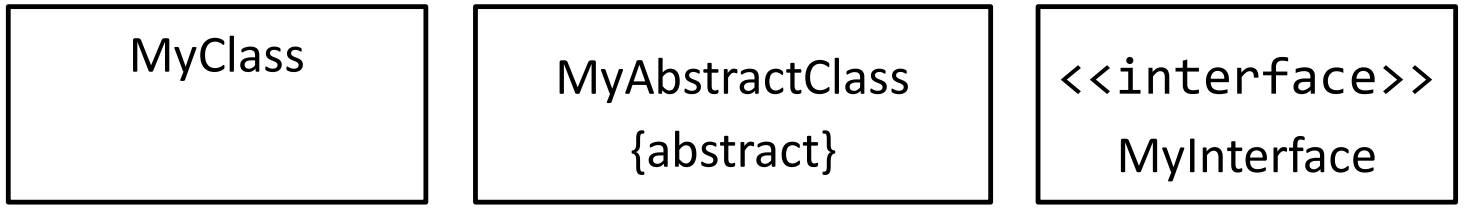
  public int getId() {
    return this.id;
  }
}
```



Classes, abstract classes, and interfaces



Classes, abstract classes, and interfaces




```
public class MyClass {


  public void op() {
    ...
  }

  public int op2() {
    ...
  }
}
```

```
public abstract class
     MyAbstractClass {

  public abstract void op();



  public int op2() {
    ...
  }
}
```

```
public interface
     MyInterface {

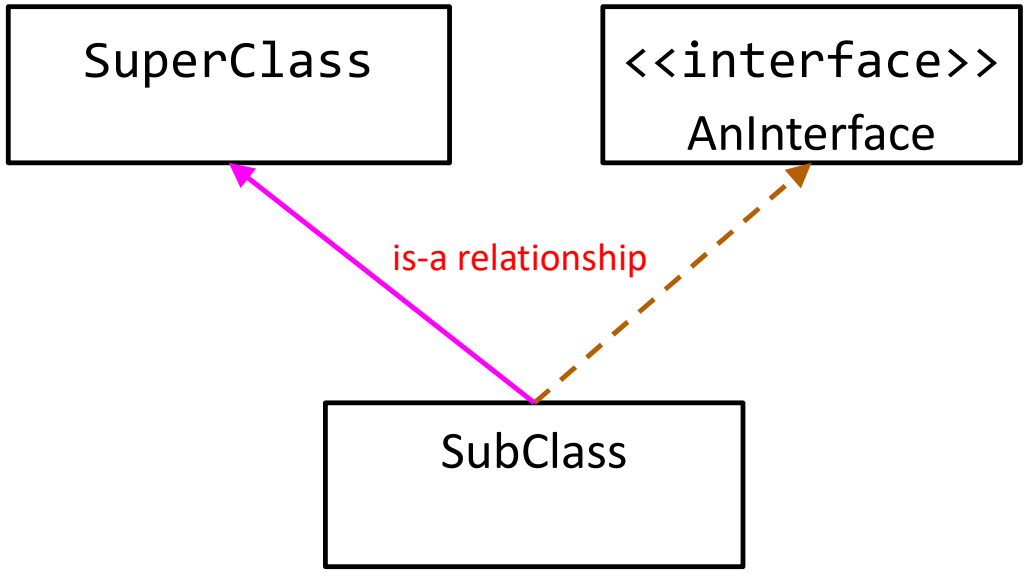
  public void op();



  public int op2();
}
```

Level of detail in a given class or interface may vary and depends on context and purpose.

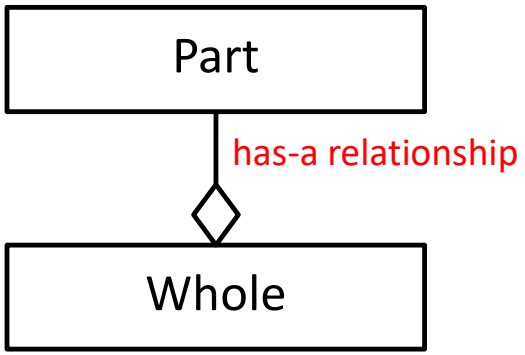
UML class diagram: Inheritance




```
public class SubClass extends SuperClass implements AnInterface
```

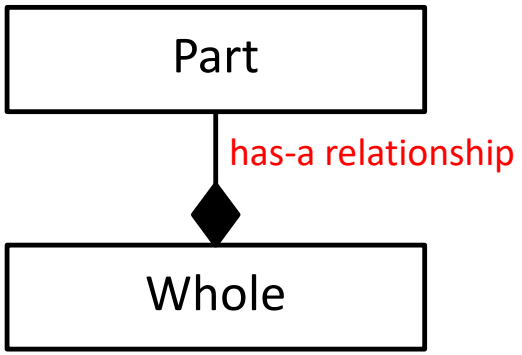
UML class diagram: Aggregation and Composition

Aggregation



- Existence of Part does not depend on the existence of Whole.
- Lifetime of Part does not depend on Whole.
- No single instance of whole is the unique owner of Part (might be shared with other instances of Whole).

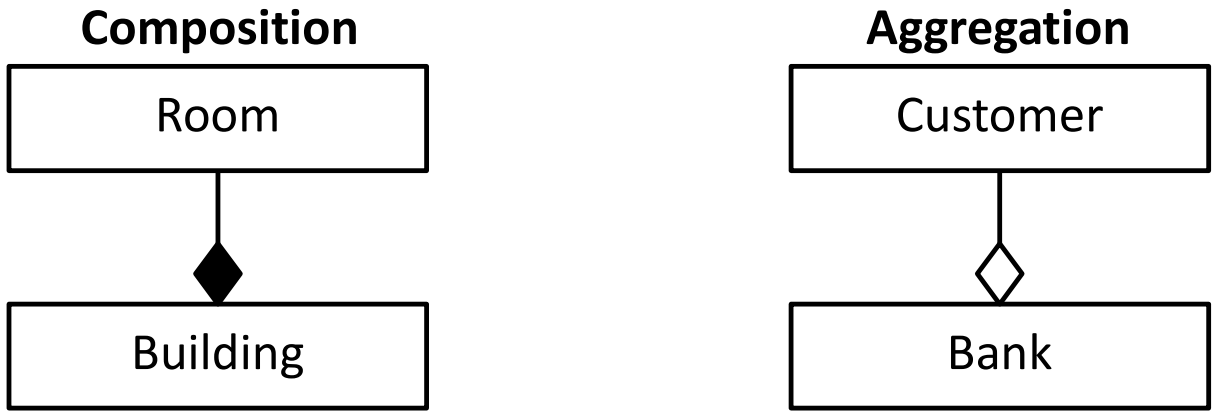
Composition



- Part cannot exist without Whole.
- Lifetime of Part depends on Whole.
- One instance of Whole is the single owner of Part.

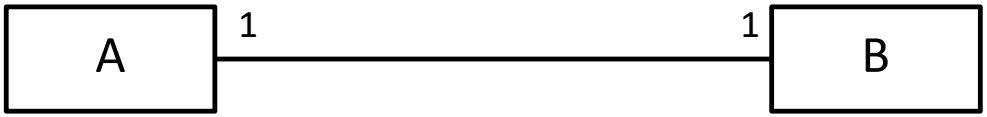
Aggregation or Composition?

Aggregation or Composition?

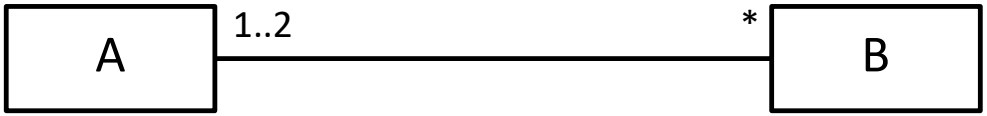


What about class and students or body and body parts?

UML class diagram: multiplicity

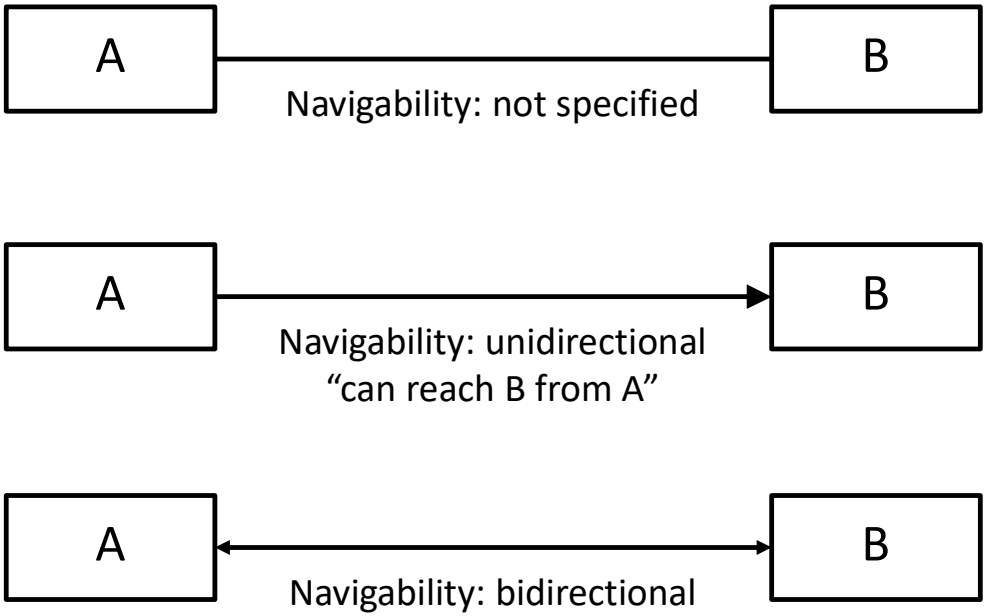


Each A is associated with exactly one B
Each B is associated with exactly one A

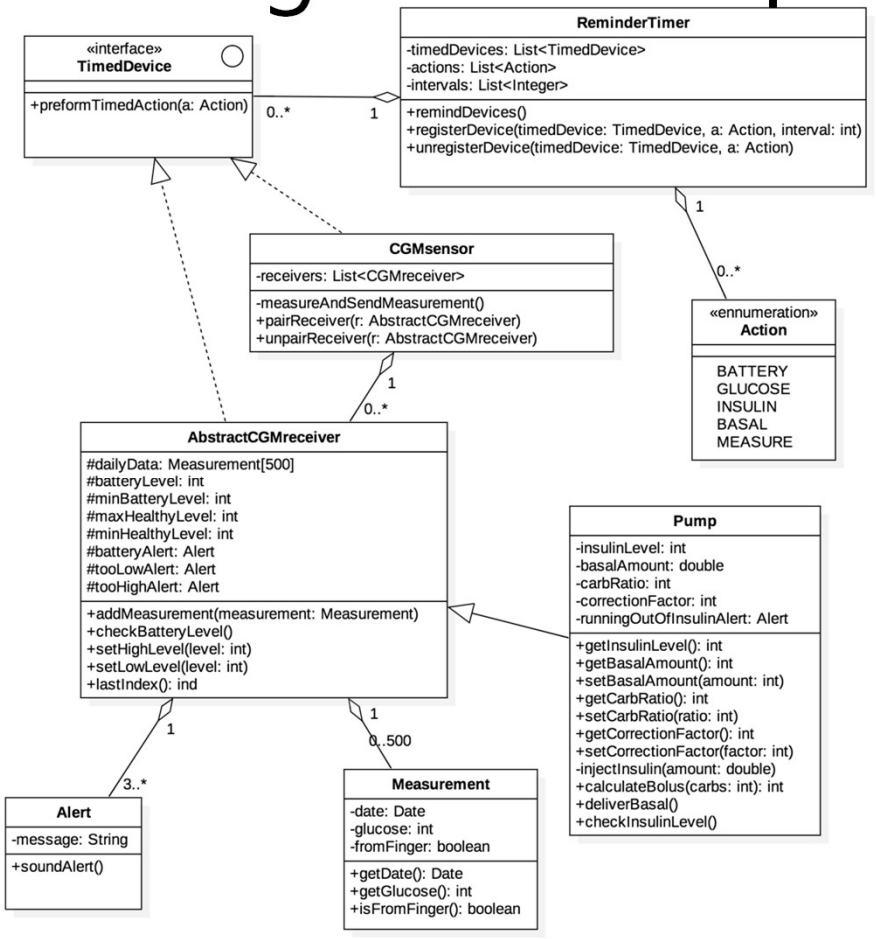


Each A is associated with any number of Bs
Each B is associated with exactly one or two As

UML class diagram: navigability



UML class diagram: example



Summary: UML

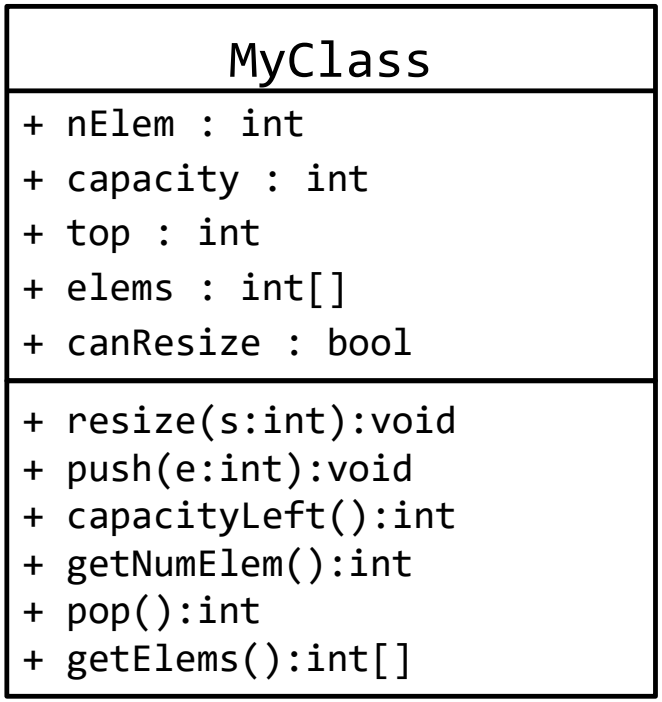
- Unified notation for modeling OO systems.
- Allows different levels of abstraction.
- Suitable for design discussions and documentation.

OO design principles

OO design principles

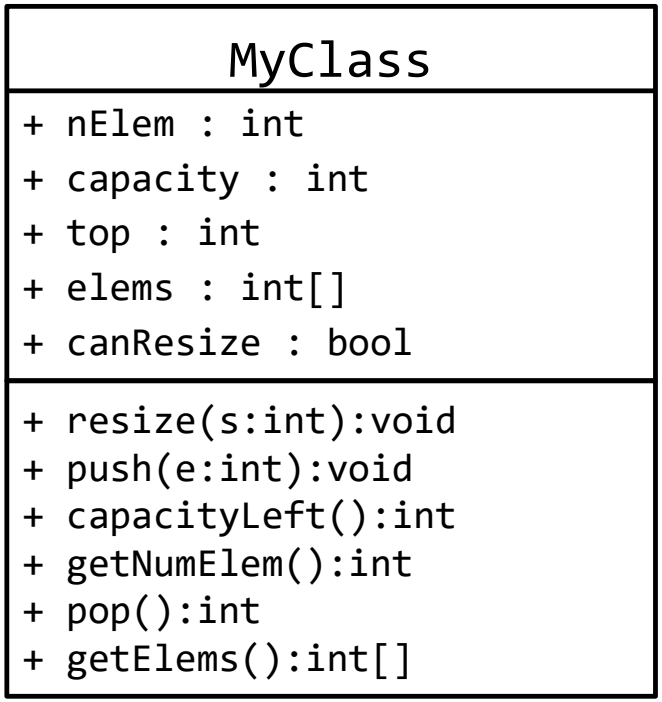
- **Information hiding (and encapsulation)**
- Polymorphism
- Open/closed principle
- Inheritance in Java
- The diamond of death
- Liskov substitution principle
- Composition/aggregation over inheritance

Information hiding




```
public class MyClass {
  public int nElem;
  public int capacity;
  public int top;
  public int[] elems;
  public boolean canResize;
  ...
  public void resize(int s){...}
  public void push(int e){...}
  public int capacityLeft(){...}
  public int getNumElem(){...}
  public int pop(){...}
  public int[] getElems(){...}
}
```

Information hiding

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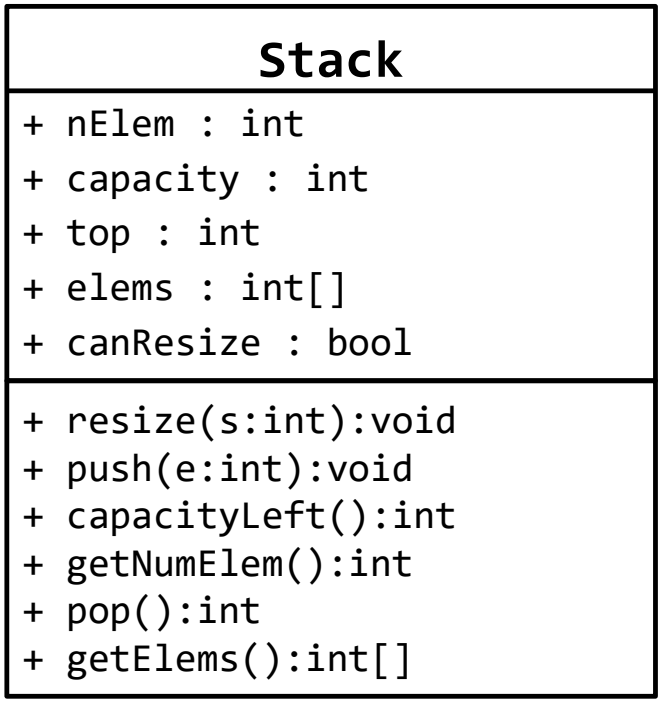
  public int nElem;
  public int capacity;
  public int top;
  public int[] elems;
  public boolean canResize;
  ...
  public void resize(int s){...}
  public void push(int e){...}
  public int capacityLeft(){...}
  public int getNumElem(){...}
  public int pop(){...}
  public int[] getElems(){...}
}
```

What does MyClass do?

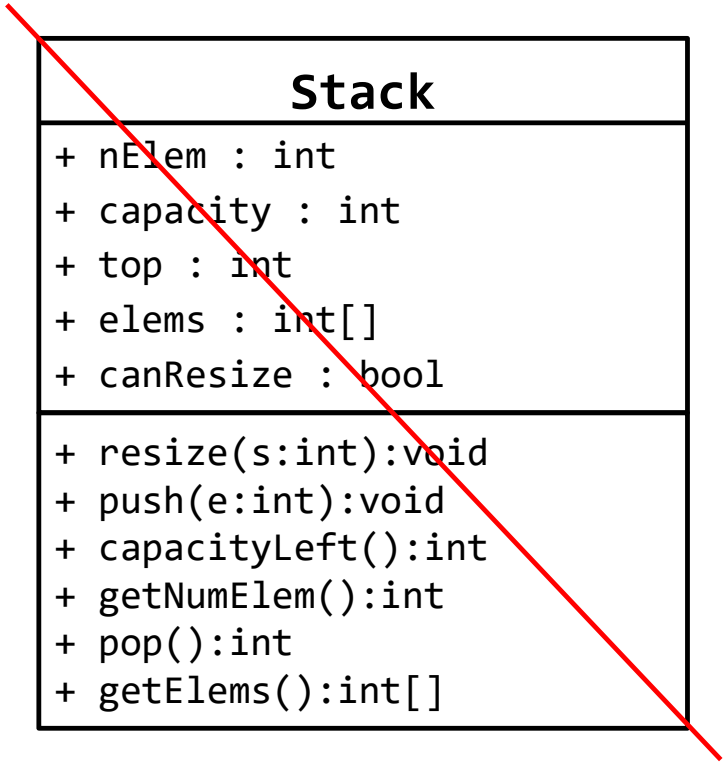
Information hiding

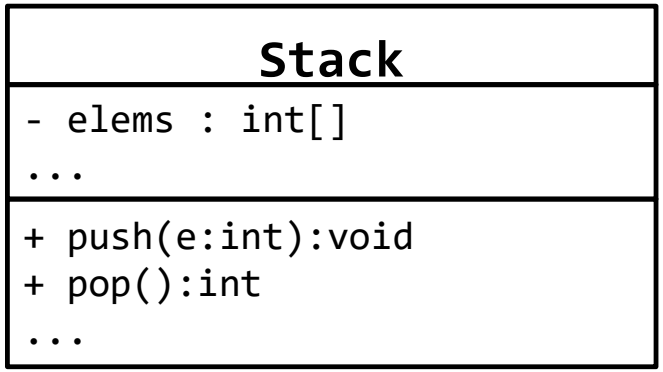



```
public class Stack {
  public int nElem;
  public int capacity;
  public int top;
  public int[] elems;
  public boolean canResize;
  ...
  public void resize(int s){...}
  public void push(int e){...}
  public int capacityLeft(){...}
  public int getNumElem(){...}
  public int pop(){...}
  public int[] getElems(){...}
}
```

Anything that could be improved in this implementation?

Information hiding

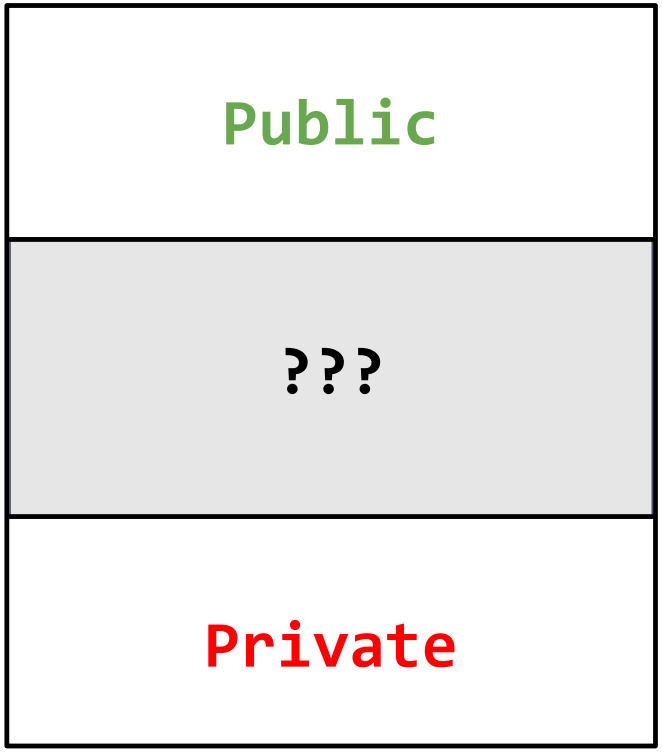




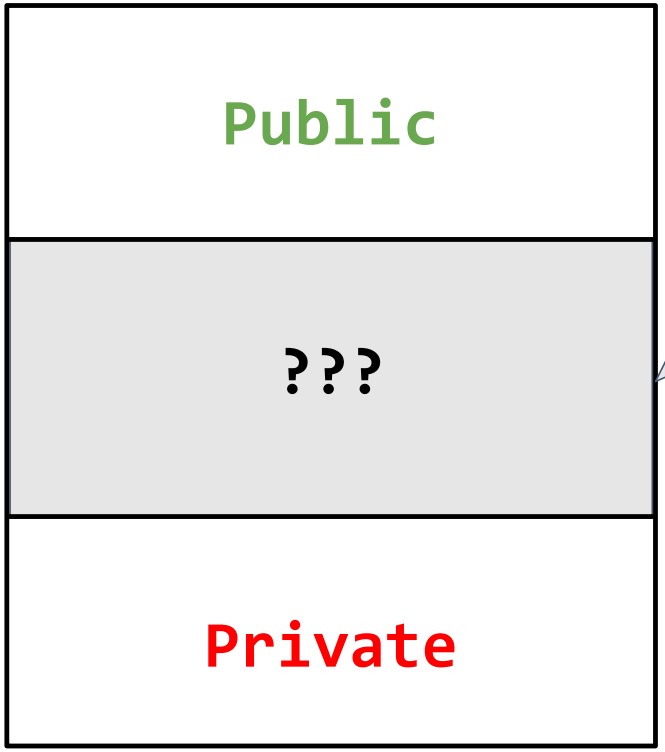
Information hiding:

- Reveal as little information about internals as possible.
- Segregate public interface and implementation details.
- Reduces complexity.

Information hiding vs. visibility



Information hiding vs. visibility



- Protected, package-private, or friend-accessible (C++).
- Not part of the public API.
- Implementation detail that a subclass/friend may rely on.

OO design principles

- Information hiding (and encapsulation)
- **Polymorphism**
- Open/closed principle
- Inheritance in Java
- The diamond of death
- Liskov substitution principle
- Composition/aggregation over inheritance

A little refresher: what is Polymorphism?

A little refresher: what is Polymorphism?

An object's ability to provide different behaviors.

Types of polymorphism

- Ad-hoc polymorphism (e.g., operator overloading)
  - `a + b` ⇒ String vs. int, double, etc.
- Subtype polymorphism (e.g., method overriding)
  - `Object obj = ...;` ⇒ toString() can be overridden in subclasses and therefore provide a different behavior.
    `obj.toString();`
- Parametric polymorphism (e.g., Java generics)
  - `class LinkedList<E> {` ⇒ A LinkedList can store elements regardless of their type but still provide full type safety.
    `void add(E) {...}`
    `E get(int index) {...}`

A little refresher: what is Polymorphism?

An object's ability to provide different behaviors.

Types of polymorphism

- Subtype polymorphism (e.g., method overriding)
  - `Object obj = ...;` ⇒ toString() can be overridden in subclasses
    `obj.toString();` and therefore provide a different behavior.

Subtype polymorphism is essential to many OO design principles.

OO design principles

- Information hiding (and encapsulation)
- Polymorphism
- **Open/closed principle**
- Inheritance in Java
- The diamond of death
- Liskov substitution principle
- Composition/aggregation over inheritance

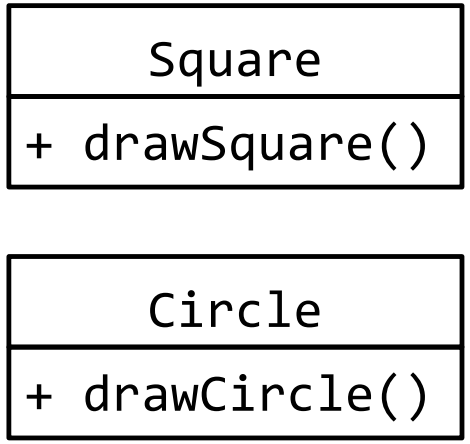
Open/closed principle

Software entities (classes, components, etc.) should be:

- **open** for extensions
- **closed** for modifications

```
public static void draw(Object o) {
  if (o instanceof Square) {
    drawSquare((Square) o)
  } else if (o instanceof Circle) {
    drawCircle((Circle) o);
  } else {
    ...
  }
}
```

Good or bad design?



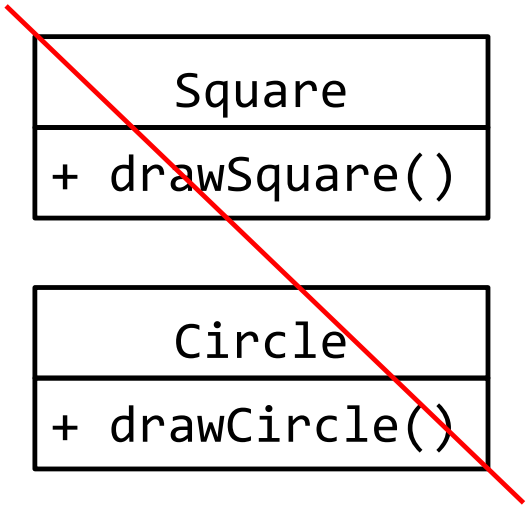
Open/closed principle

Software entities (classes, components, etc.) should be:

- **open** for extensions
- **closed** for modifications

```
public static void draw(Object o) {
  if (o instanceof Square) {
    drawSquare((Square) o)
  } else if (o instanceof Circle) {
    drawCircle((Circle) o);
  } else {
    ...
  }
}
```

Violates the open/closed principle!



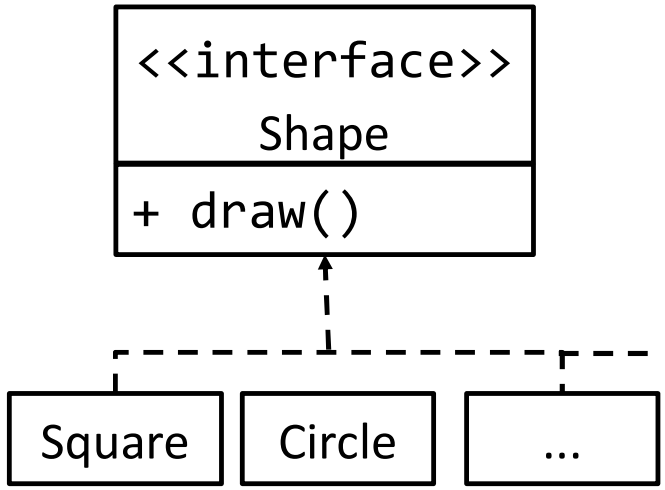
Open/closed principle

Software entities (classes, components, etc.) should be:

- **open** for extensions
- **closed** for modifications

```
public static void draw(Object s) {
  if (s instanceof Shape) {
     s.draw();
  } else {
     …
  }
}
```

```
public static void draw(Shape s) {
  s.draw();
}
```



OO design principles

- Information hiding (and encapsulation)
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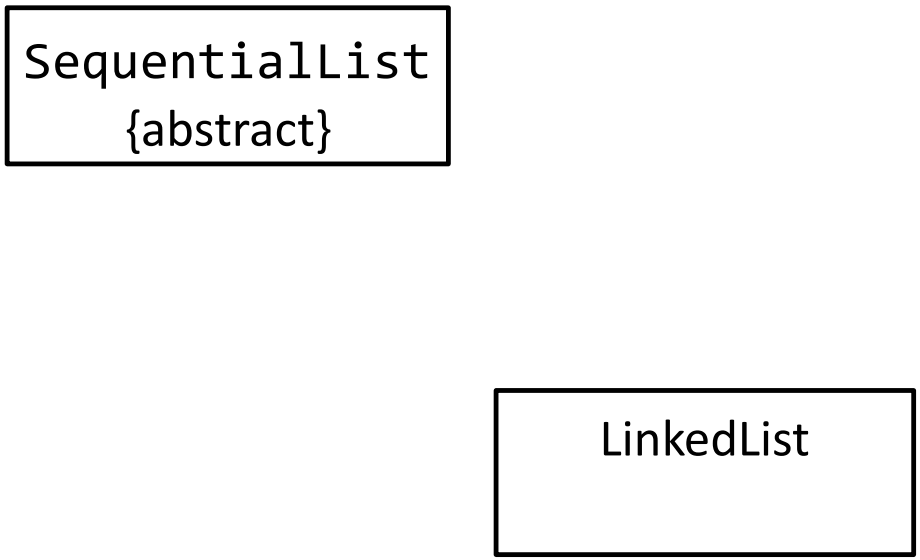
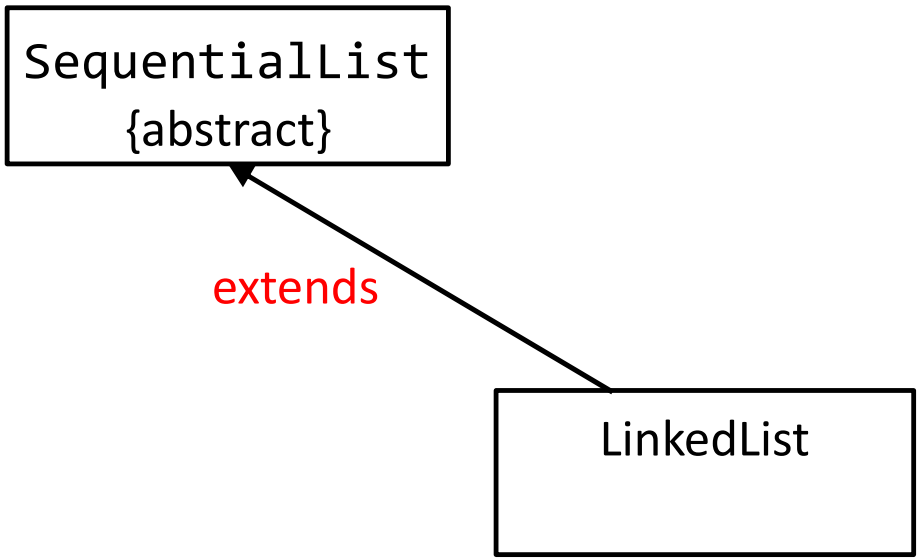
Inheritance: (abstract) classes and interfaces



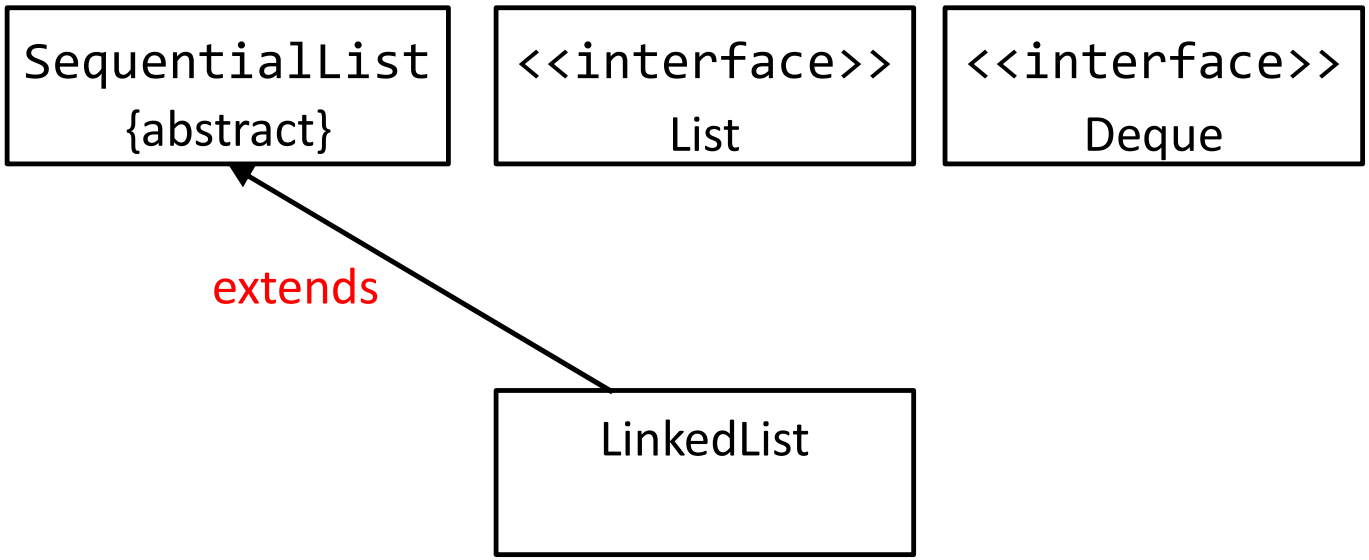
Inheritance: (abstract) classes and interfaces

LinkedList extends SequentialList



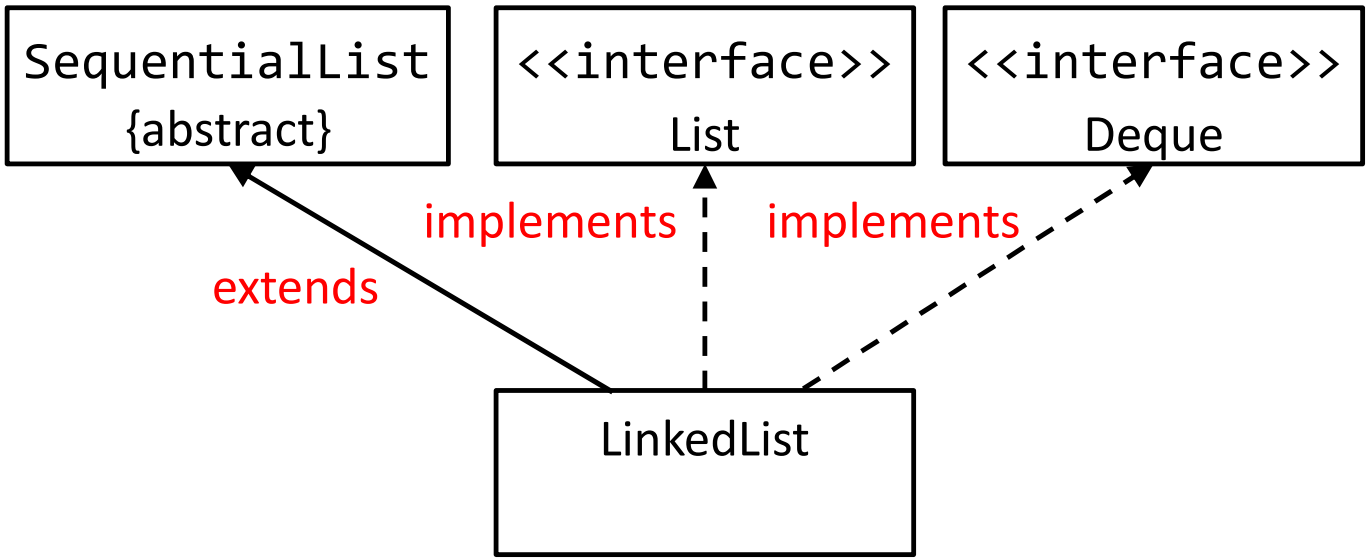
Inheritance: (abstract) classes and interfaces

LinkedList extends SequentialList

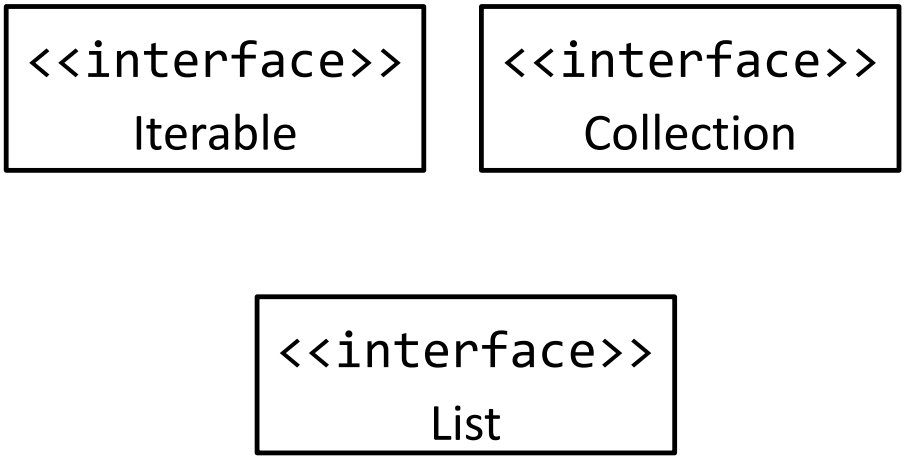


Inheritance: (abstract) classes and interfaces

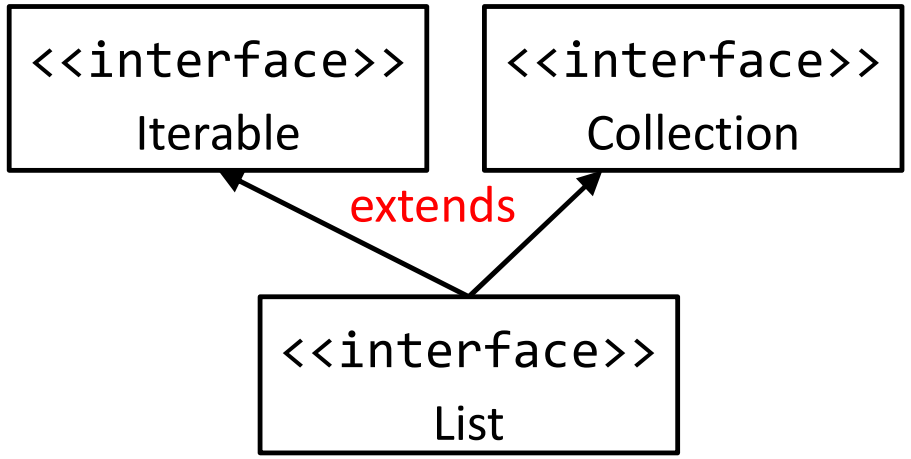
LinkedList extends SequentialList implements List, Deque



Inheritance: (abstract) classes and interfaces

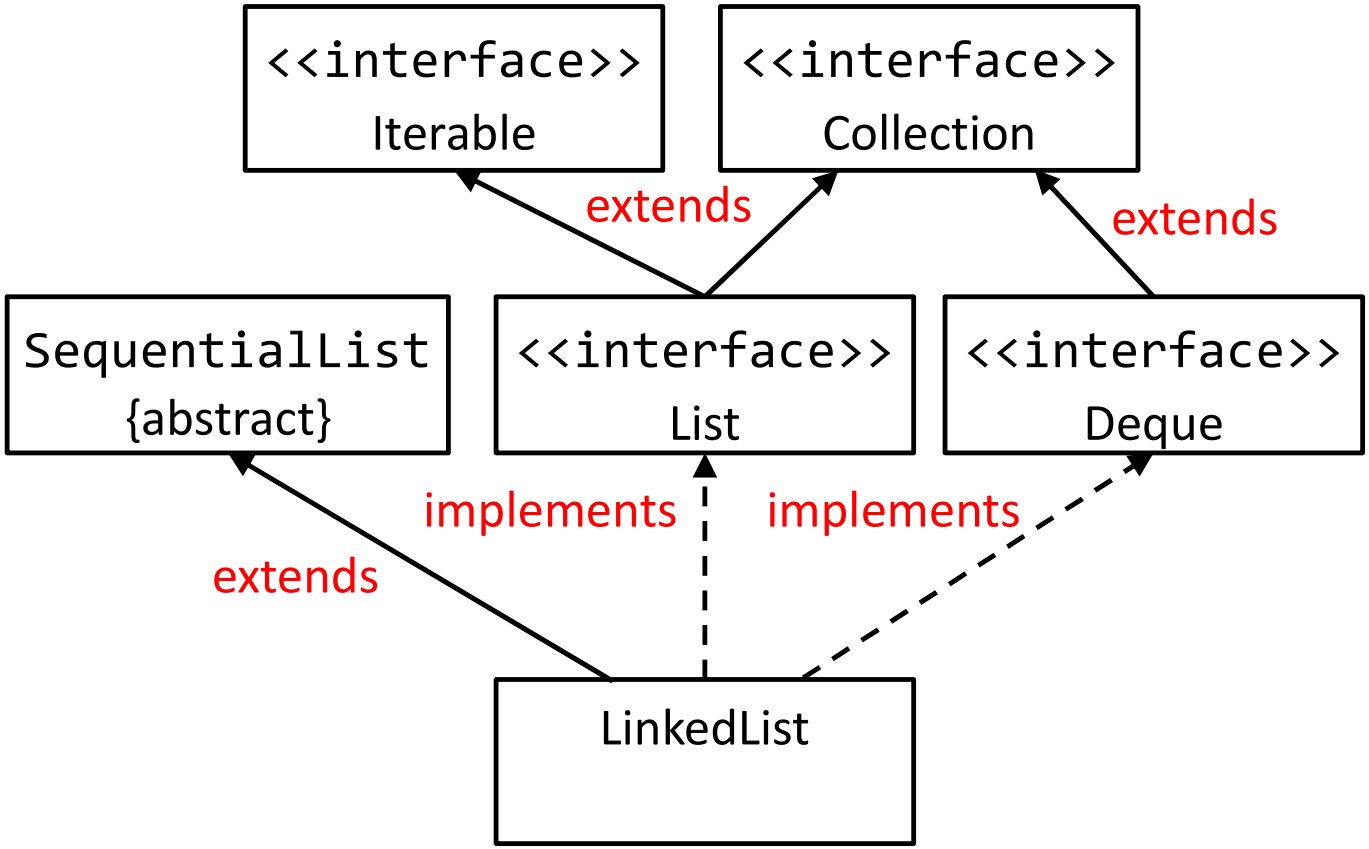


Inheritance: (abstract) classes and interfaces



List extends Iterable, Collection

Inheritance: (abstract) classes and interfaces

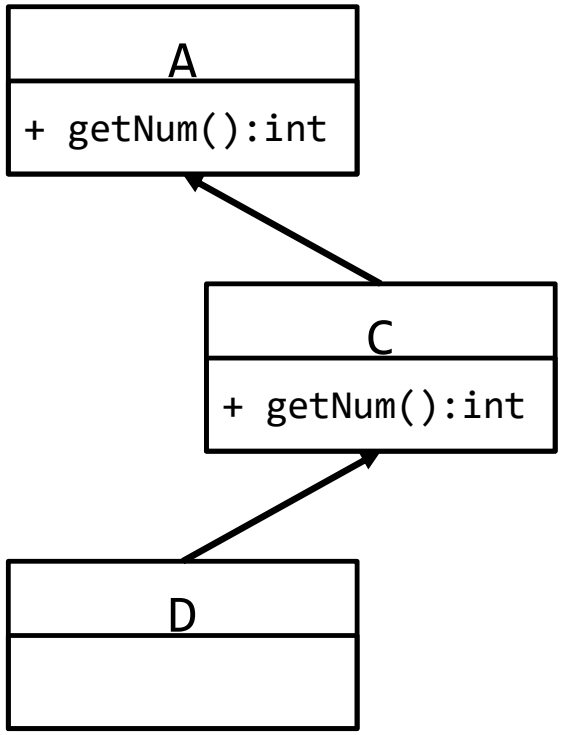


OO design principles

- Information hiding (and encapsulation)
- Polymorphism
- Open/closed principle
- Inheritance in Java
- **The diamond of death**
- Liskov substitution principle
- Composition/aggregation over inheritance

The “diamond of death”: the problem

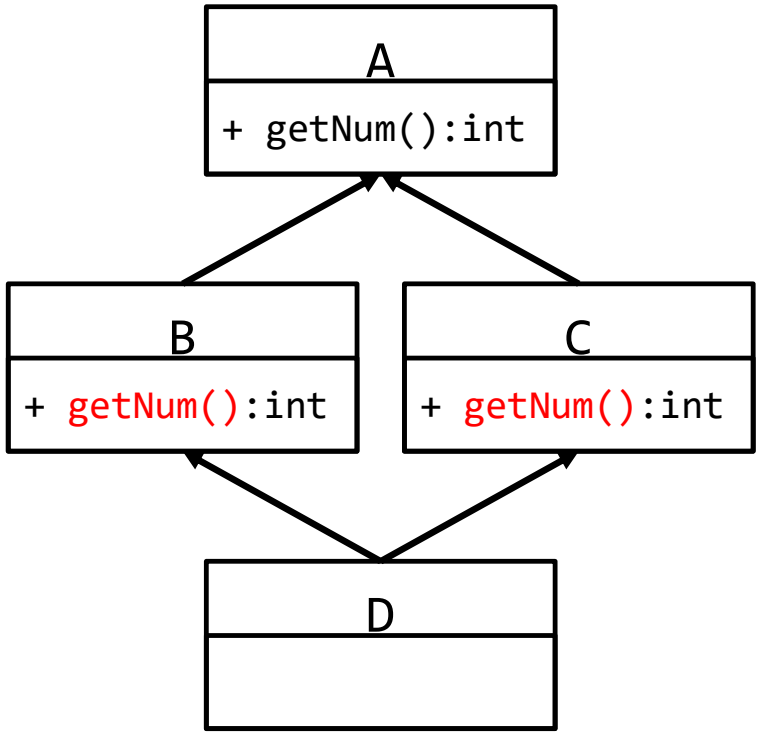
```
...
A a = new D();
int num = a.getNum();
...
```



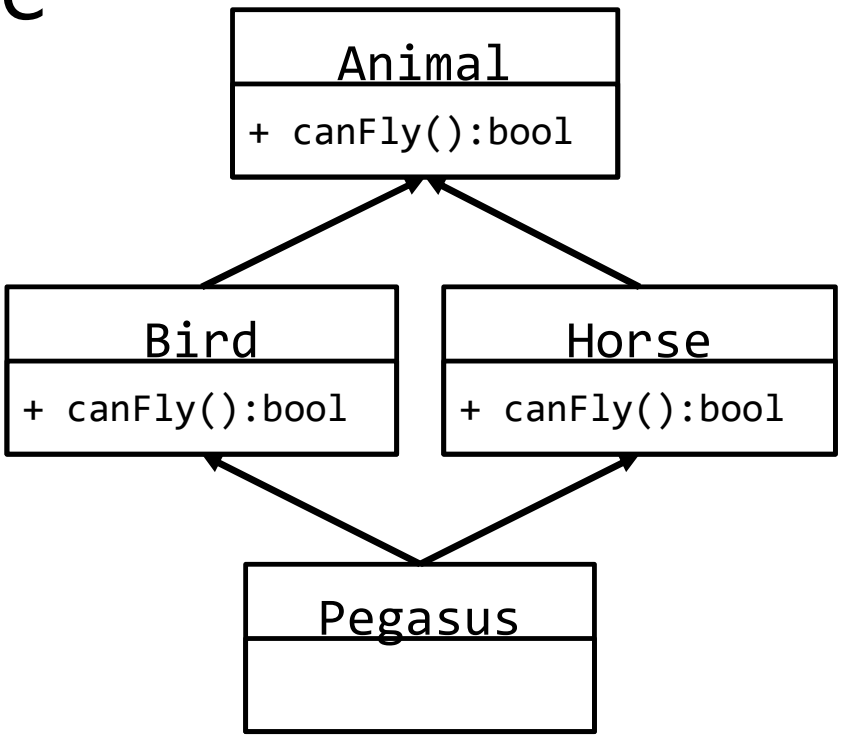
The “diamond of death”: the problem

```
...
A a = new D();
int num = a.getNum();
...
```

Which getNum() method should be called?



The “diamond of death”: concrete example



Can this happen in Java? Yes, with default methods in Java 8.

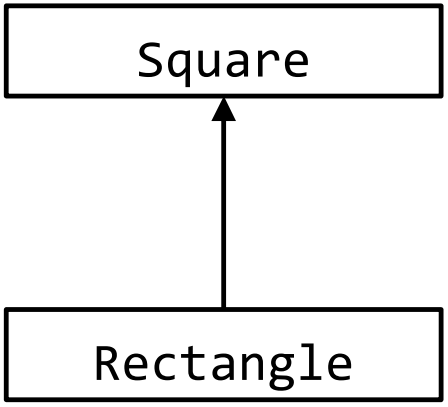
OO design principles

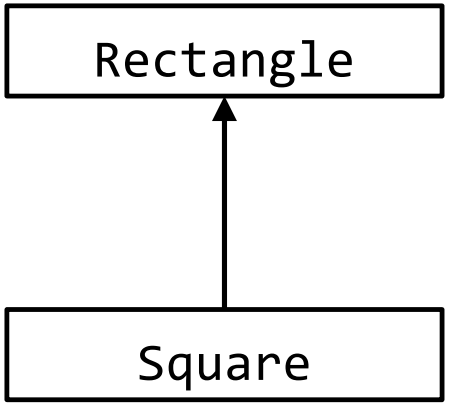
- Information hiding (and encapsulation)
- Polymorphism
- Open/closed principle
- Inheritance in Java
- The diamond of death
- **Liskov substitution principle**
- Composition/aggregation over inheritance

Design principles: Liskov substitution principle

Motivating example

We know that a square is a special kind of a rectangle. So, which of the following OO designs makes sense?

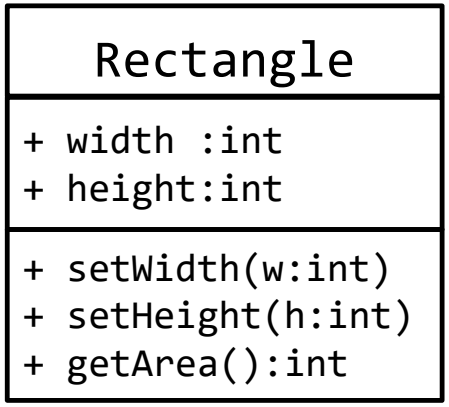


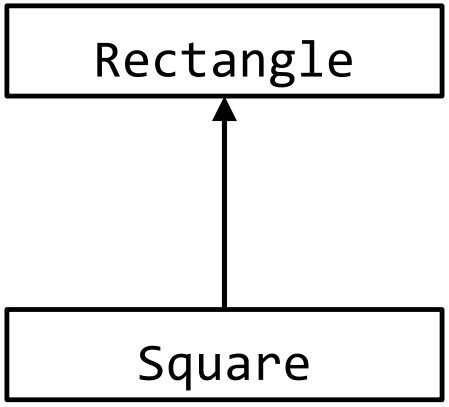


Design principles: Liskov substitution principle

Subtype requirement

Let object x be of type T1 and object y be of type T2. Further, let T2 be a subtype of T1 (T2 <: T1). Any provable property about objects of type T1 should be true for objects of type T2.





Is the subtype requirement fulfilled?

Design principles: Liskov substitution principle

Subtype requirement

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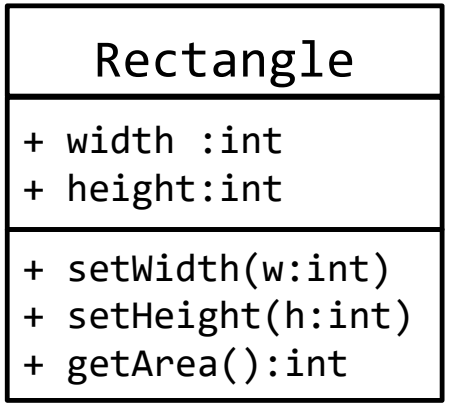
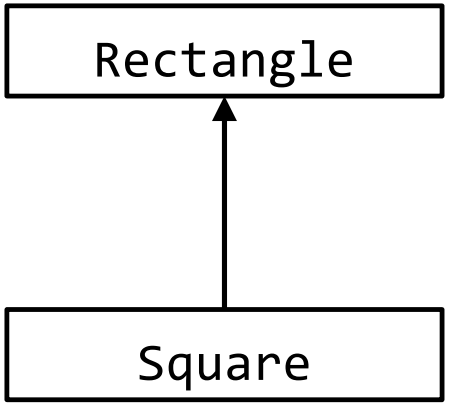



```
Rectangle r =
  new Rectangle(2,2);


int A = r.getArea();
int w = r.getWidth();
r.setWidth(w * 2);

assertEquals(A * 2,
       r.getArea());
```



Design principles: Liskov substitution principle

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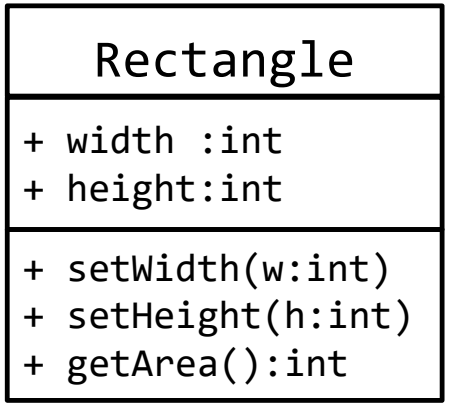
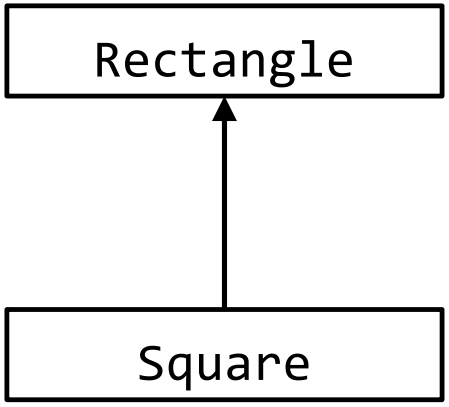



```
Rectangle r =
  new Rectangle(2,2);
  new Square(2);

int A = r.getArea();
int w = r.getWidth();
r.setWidth(w * 2);

assertEquals(A * 2,
       r.getArea());
```



Design principles: Liskov substitution principle

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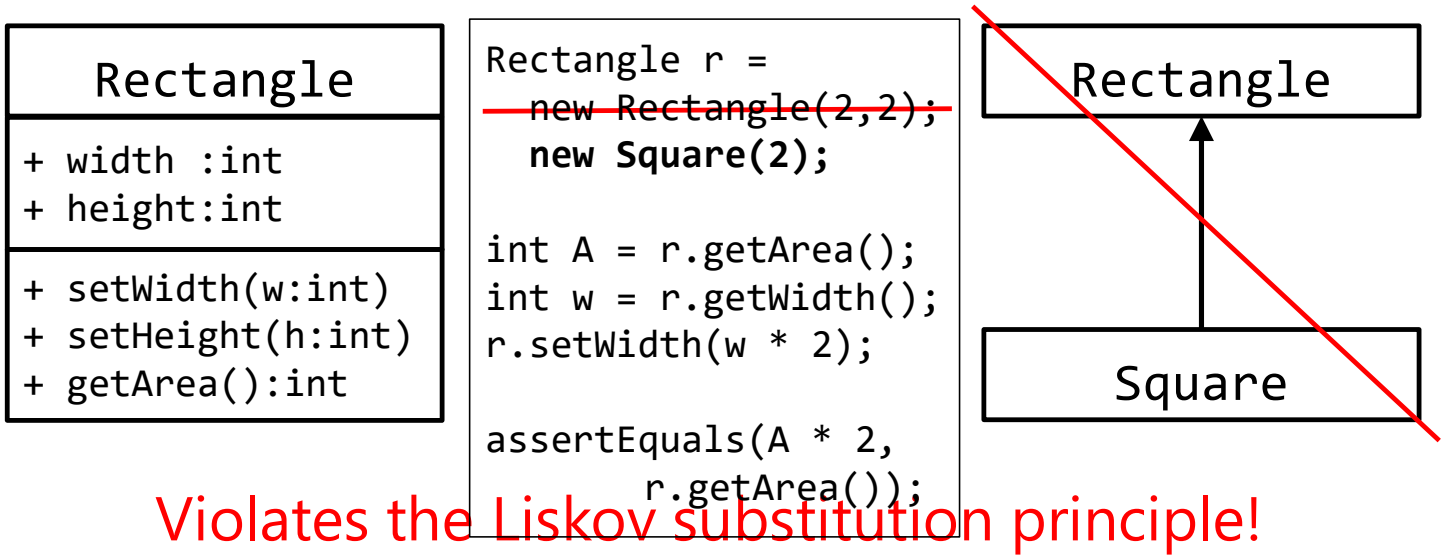
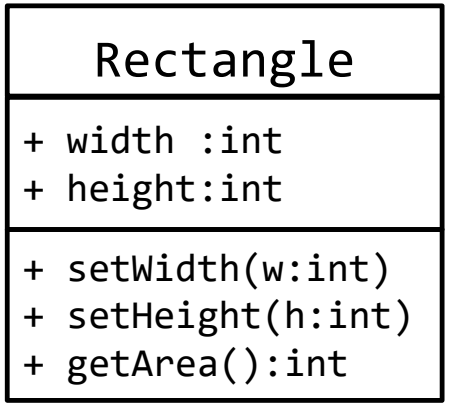


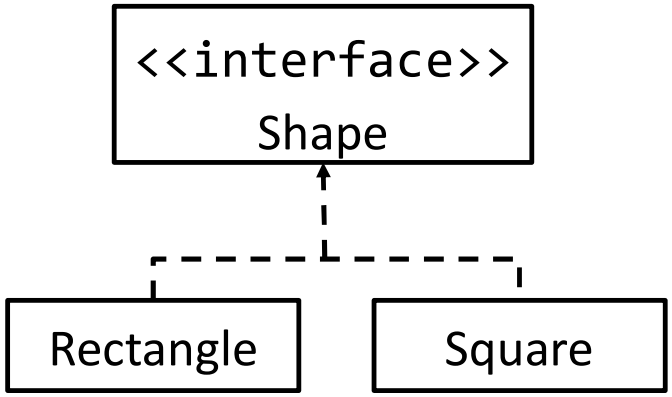
Violates the Liskov substitution principle!

Design principles: Liskov substitution principle

Subtype requirement

Let object x be of type T1 and object y be of type T2. Further, let T2 be a subtype of T1 (T2 <: T1). Any provable property about objects of type T1 should be true for objects of type T2.





OO design principles

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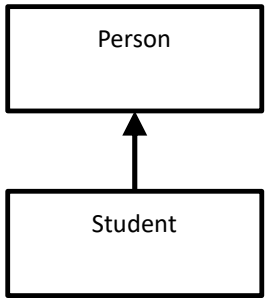
- **Composition/aggregation over inheritance**

Inheritance vs. (Aggregation vs. *Composition*)

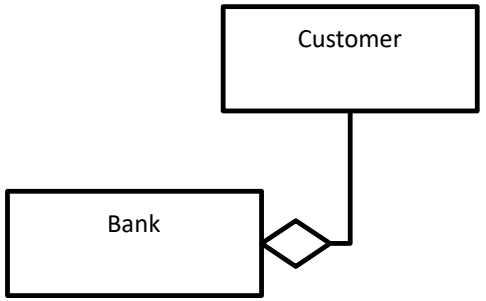



```
public class Student
    extends Person{

 public Student(){
 }

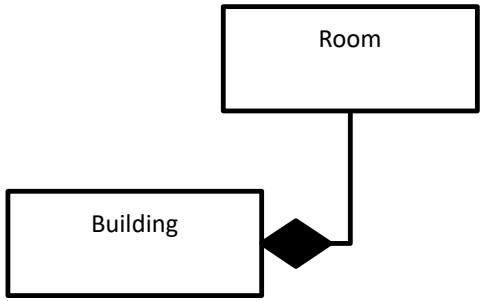
 ...
}
```

is-a relationship




```
public class Bank {
 Customer c;

 public Bank(Customer c){
  this.c = c;
 }
 ...
}
```

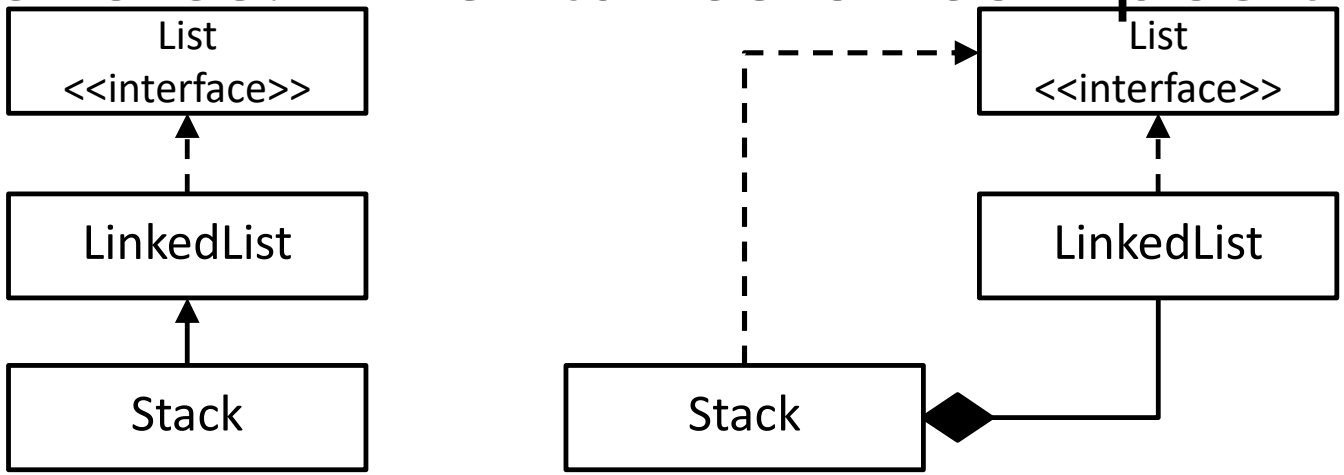



```
public class Building {
 Room r;

 public Building(){
  this.r = new Room();
 }
 ...
}
```

has-a relationship

Design choice: inheritance or composition?

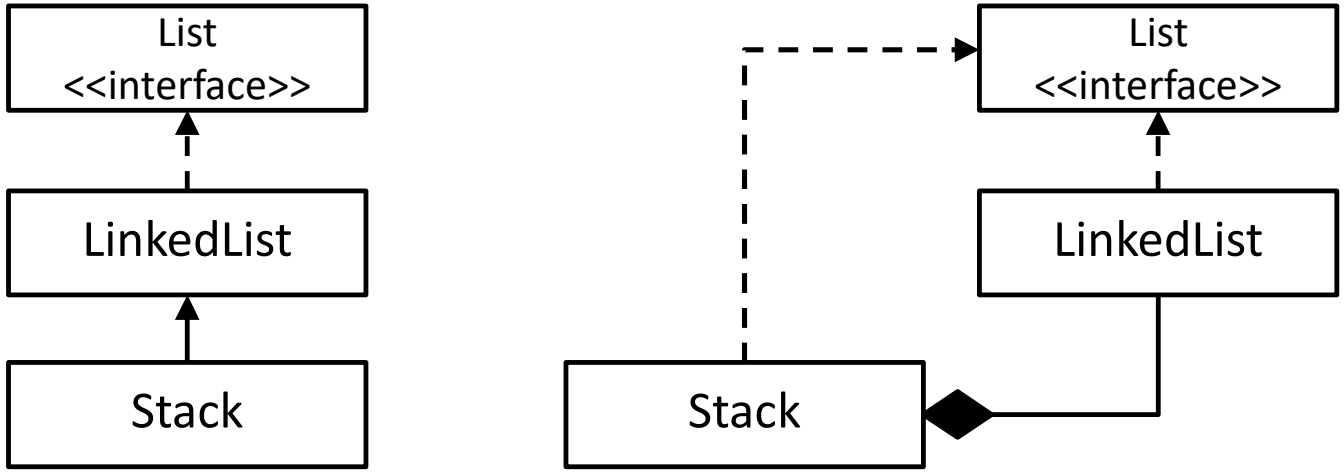



```
public class Stack<E>
    extends
LinkedList<E> {
  ...
}
```

```
public class Stack<E> implements
List<E> {
  private List<E> l = new
LinkedList<>();
  ...
}
```

Hmm, both designs seem valid -- what are pros and cons?

Design choice: inheritance or composition?



Pros

- No delegation methods required.
- Reuse of common state and behavior.

Cons

- Exposure of all inherited methods (a client might rely on this particular superclass -> can't change it later).
- Changes in superclass are likely to break subclasses.

Pros

- Highly flexible and configurable: no additional subclasses required for different compositions.

Cons

- All interface methods need to be implemented -> delegation methods required, even for code reuse.

Composition/aggregation over inheritance allows more flexibility.

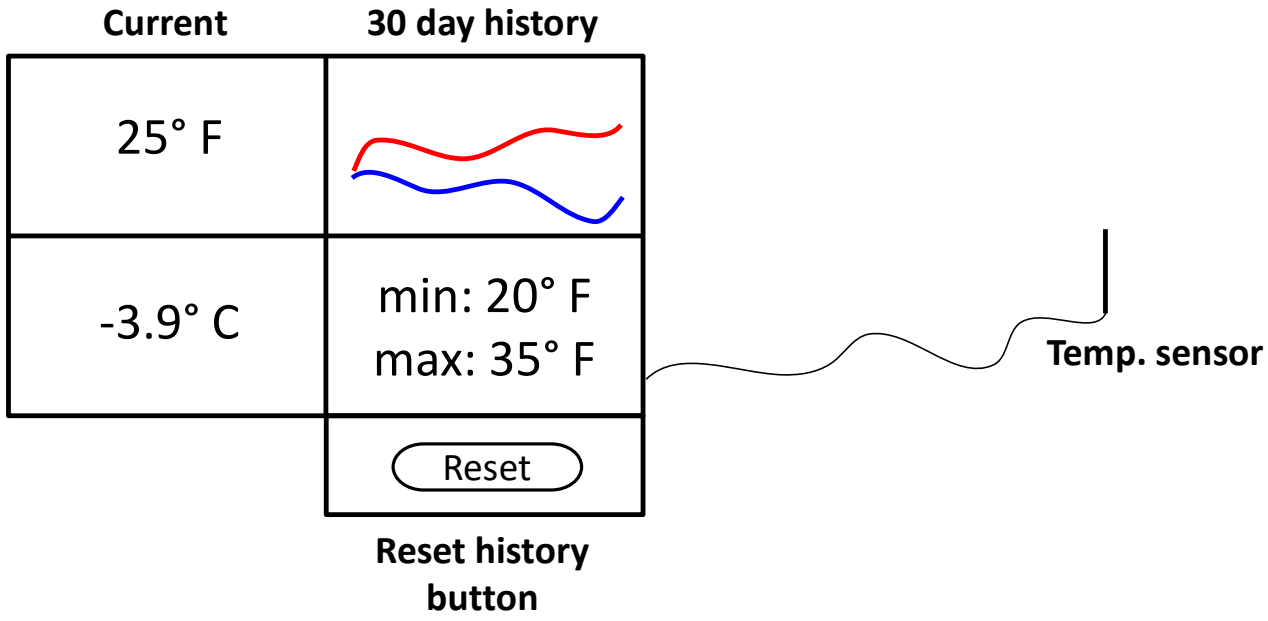
OO design principles: summary

- Information hiding (and encapsulation)
- Open/closed principle
- Liskov substitution principle
- Composition/aggregation over inheritance

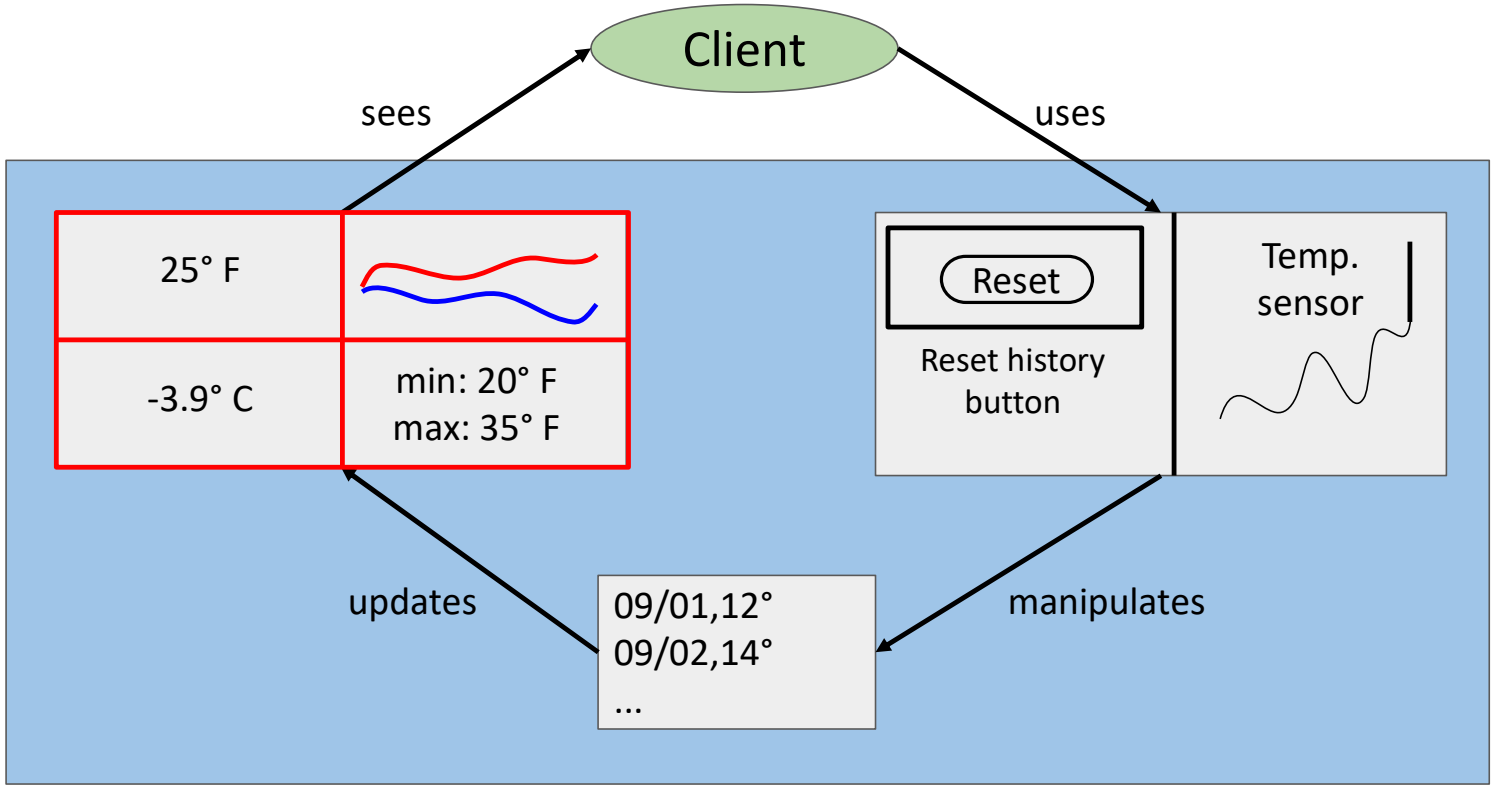
OO design patterns

A first design problem

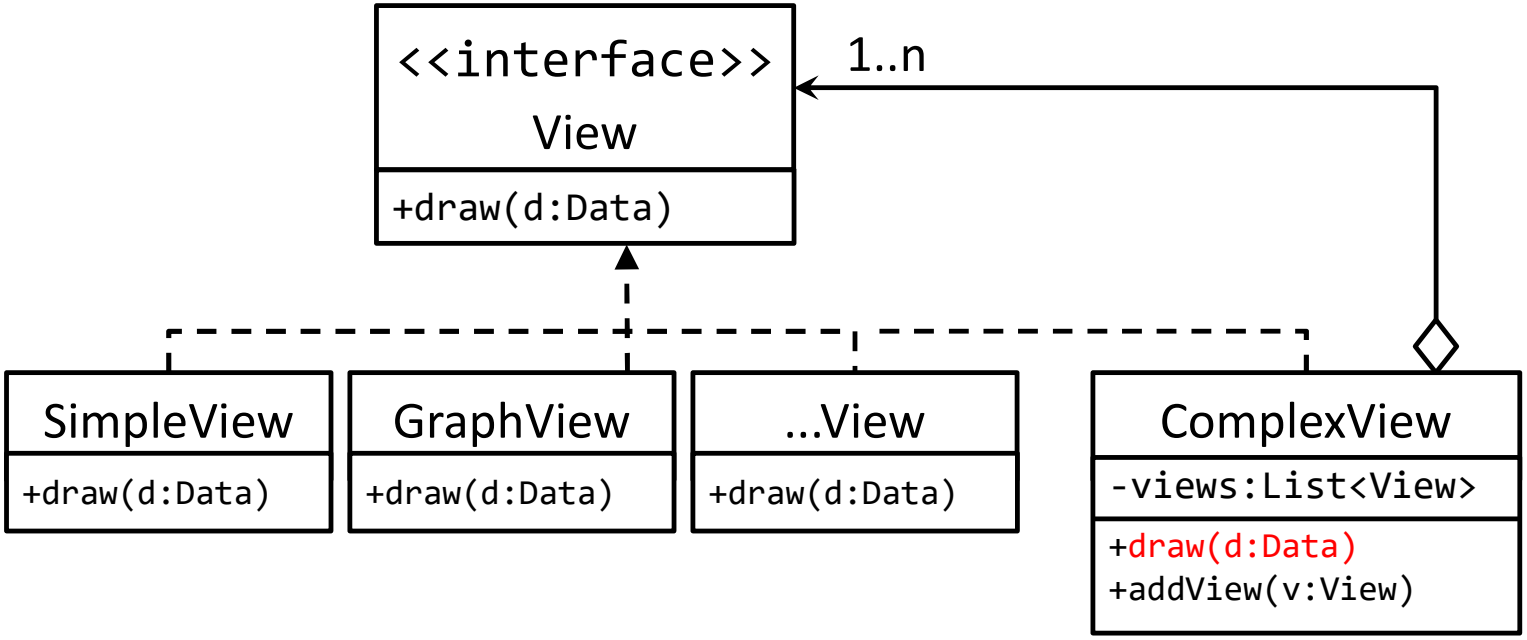
Weather station revisited

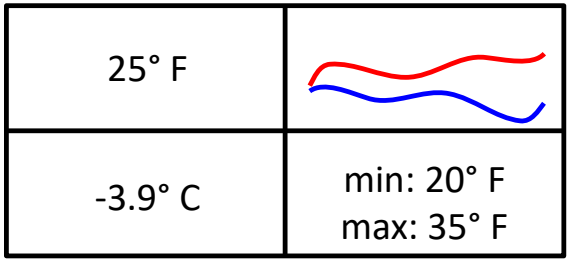


What's a good design for the view component?



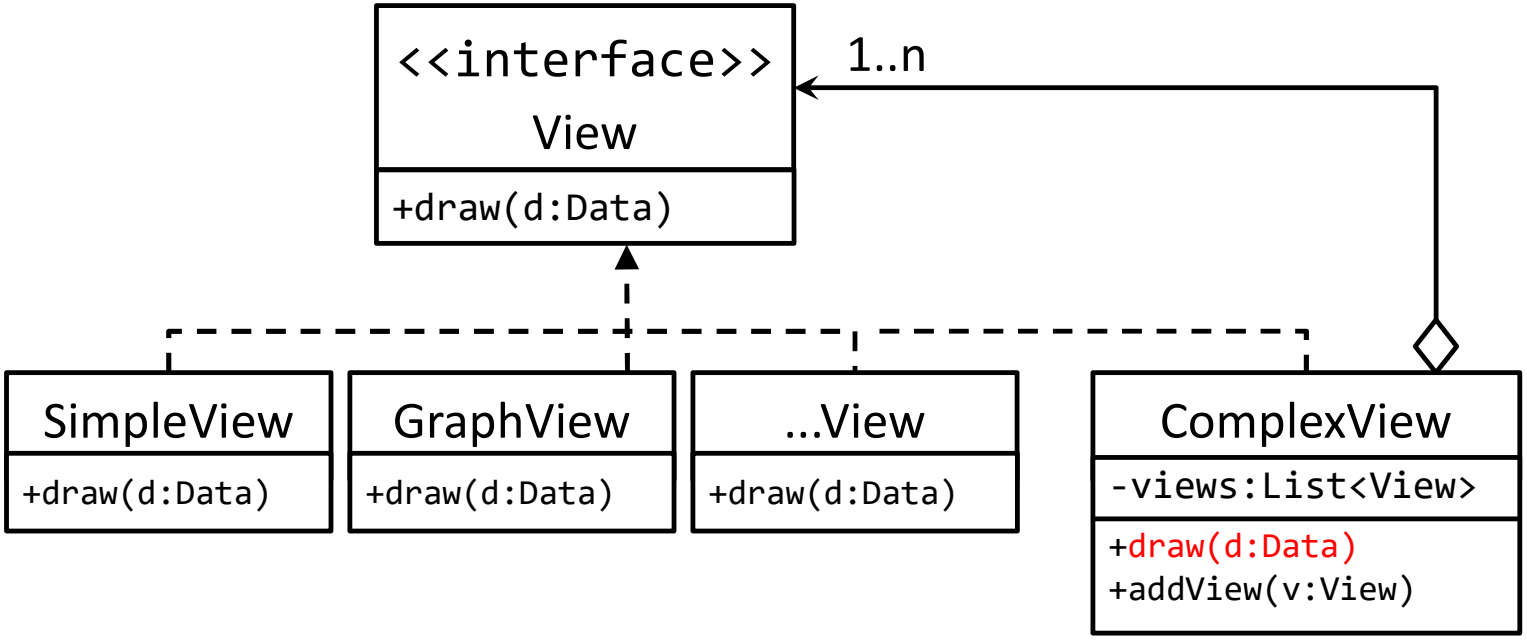
Weather station: view

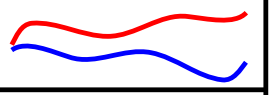




How do we need to implement draw(d:Data)?

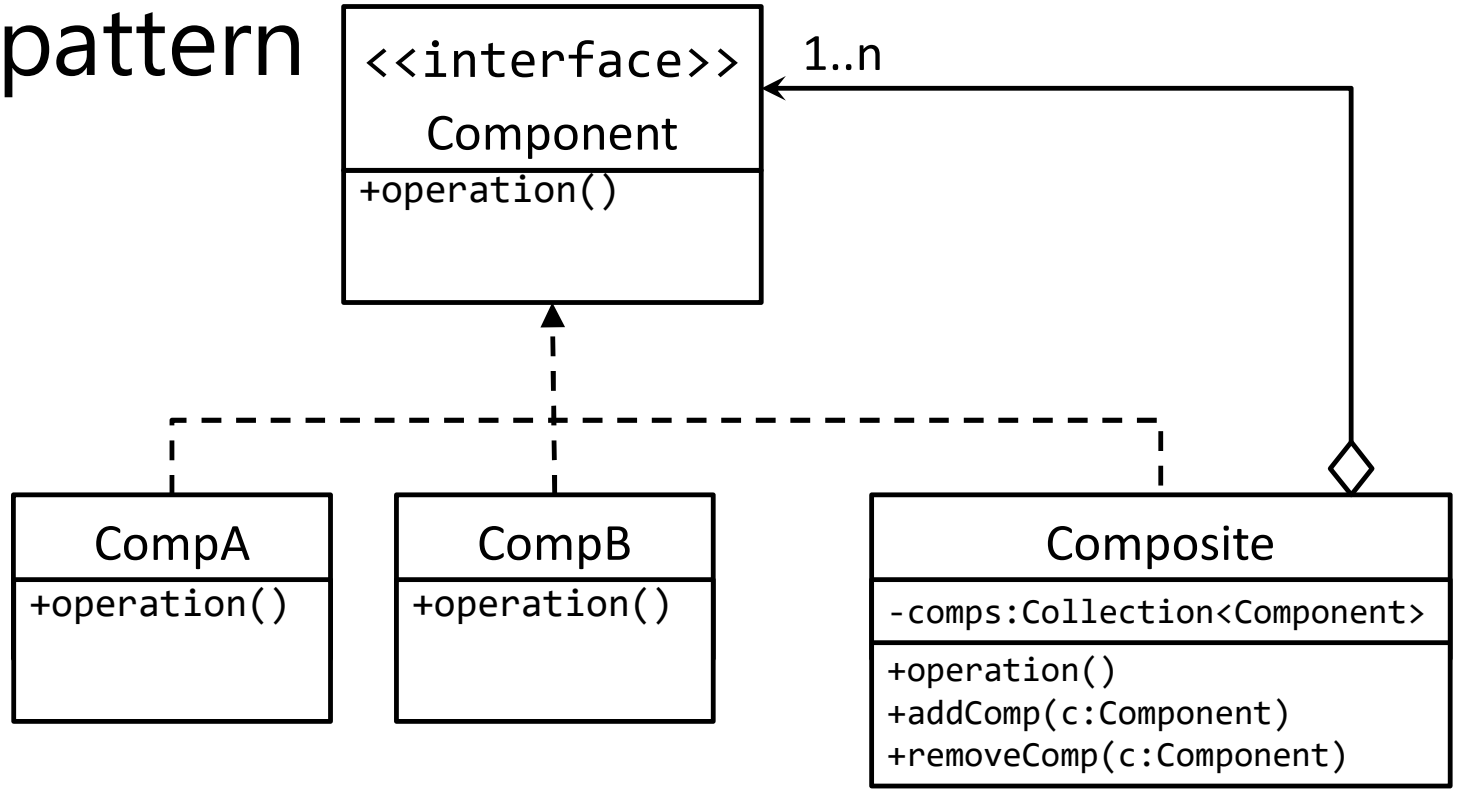
Weather station: view



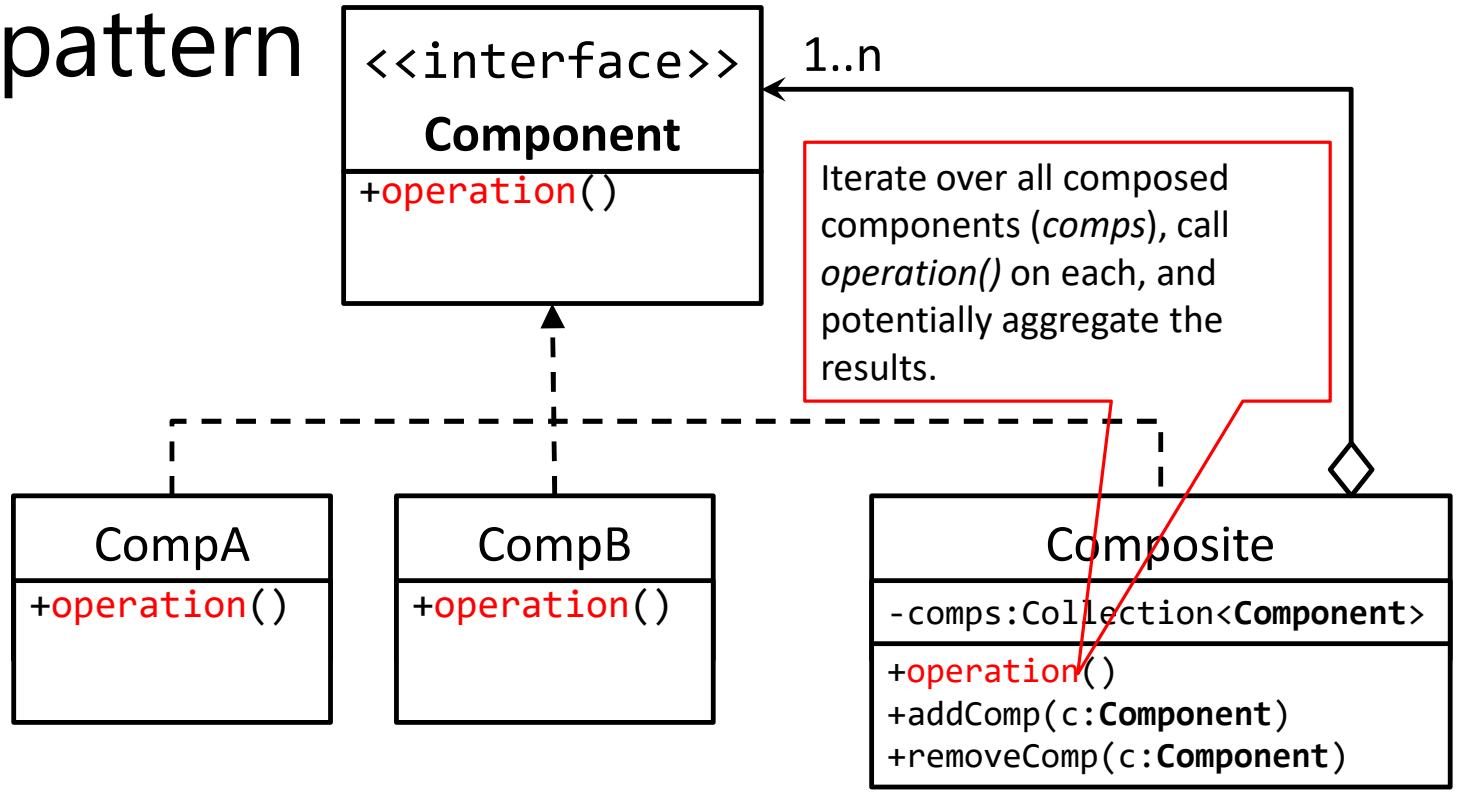
25° F	
-3.9° C	min: 20° F max: 35° F

```
public void draw(Data d) {
  for (View v : views) {
    v.draw(d);
  }
}
```

The general solution: Composite pattern



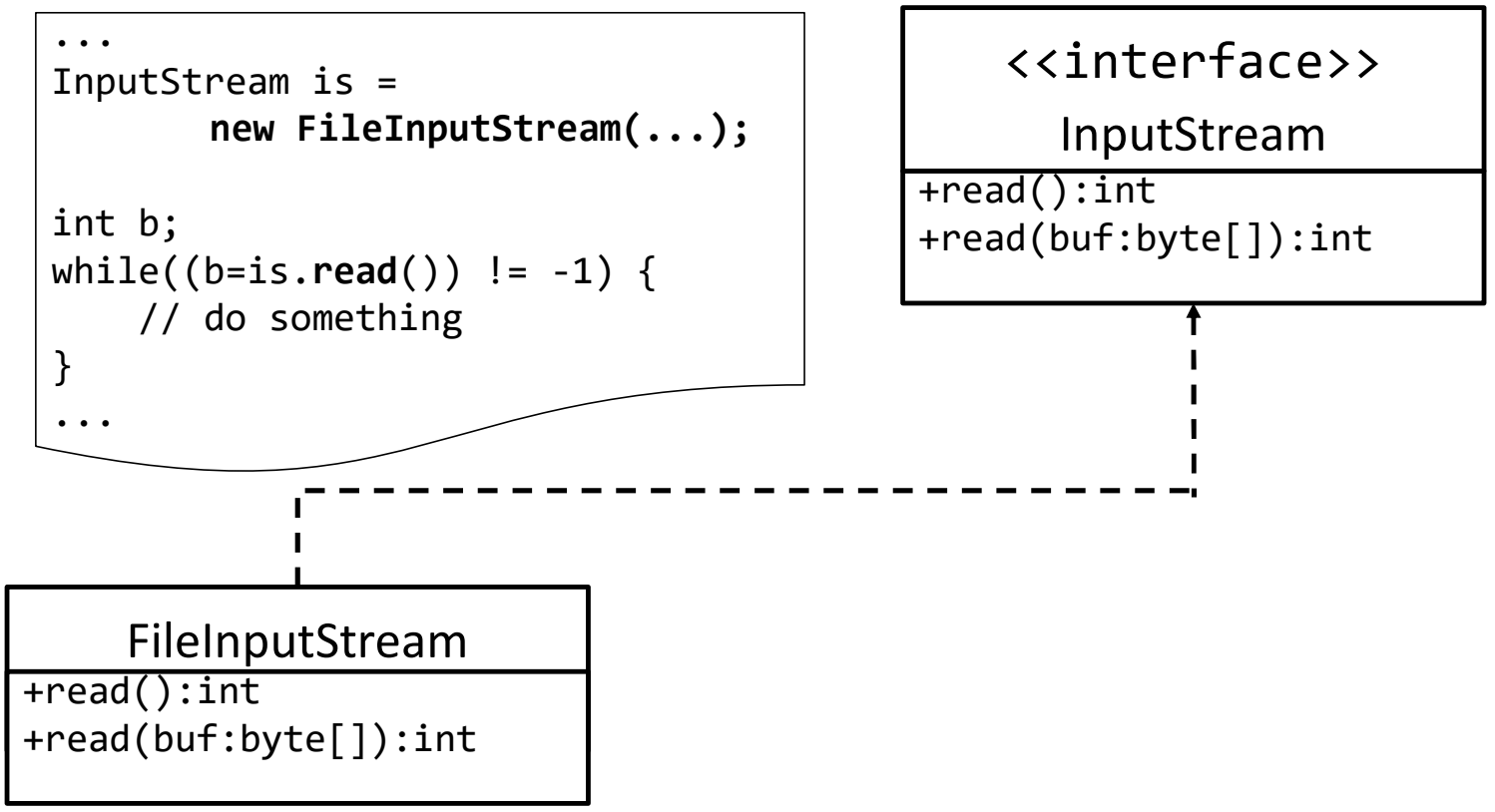
The general solution: Composite pattern



Another design problem: I/O streams

```
...
InputStream is =
        new FileInputStream(...);

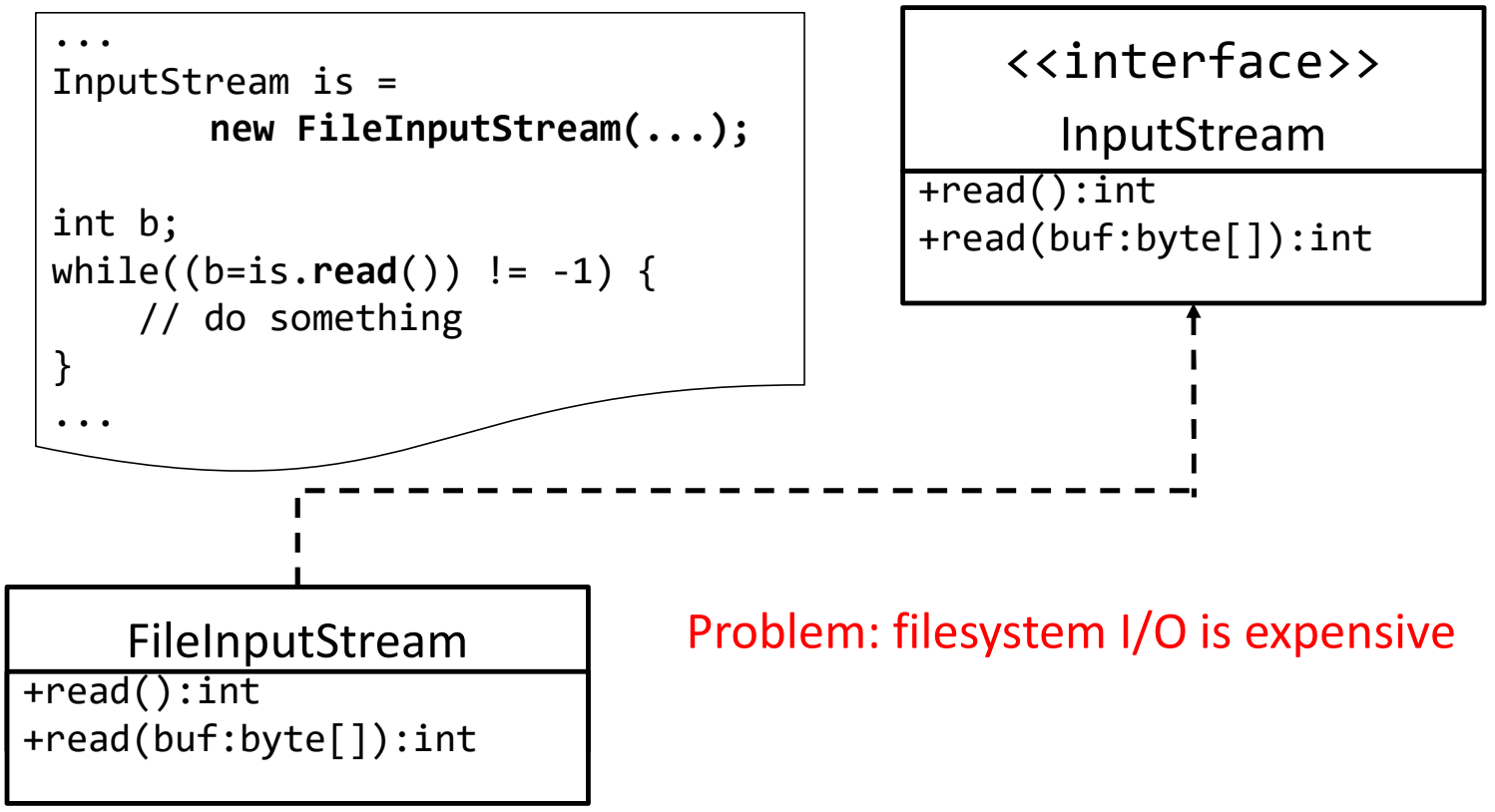
int b;
while((b=is.read()) != -1) {
    // do something
}
...
```



Another design problem: I/O streams

```
...
InputStream is =
        new FileInputStream(...);

int b;
while((b=is.read()) != -1) {
    // do something
}
...
```

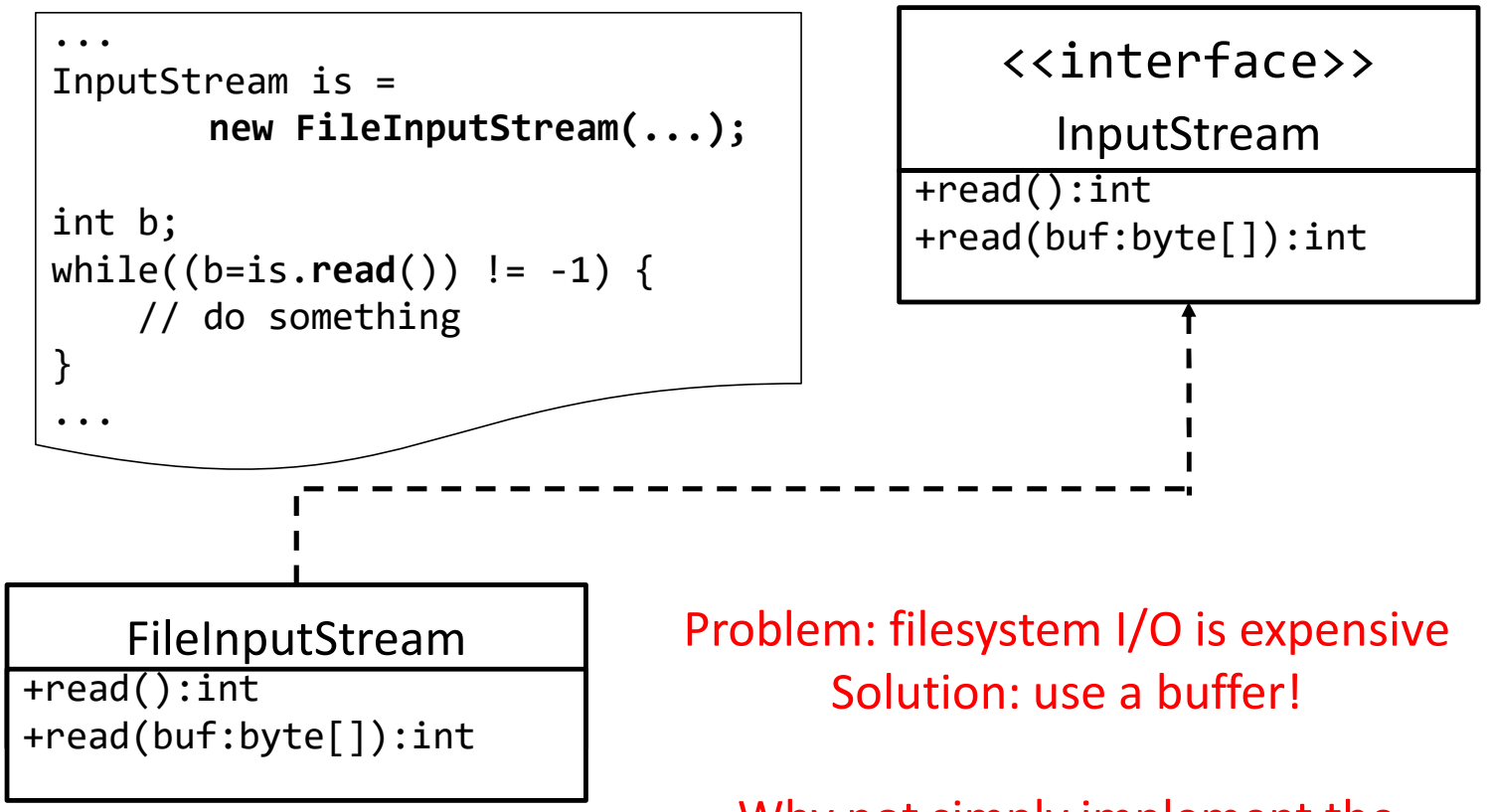


Problem: filesystem I/O is expensive

Another design problem: I/O streams

```
...
InputStream is =
        new FileInputStream(...);

int b;
while((b=is.read()) != -1) {
    // do something
}
...
```

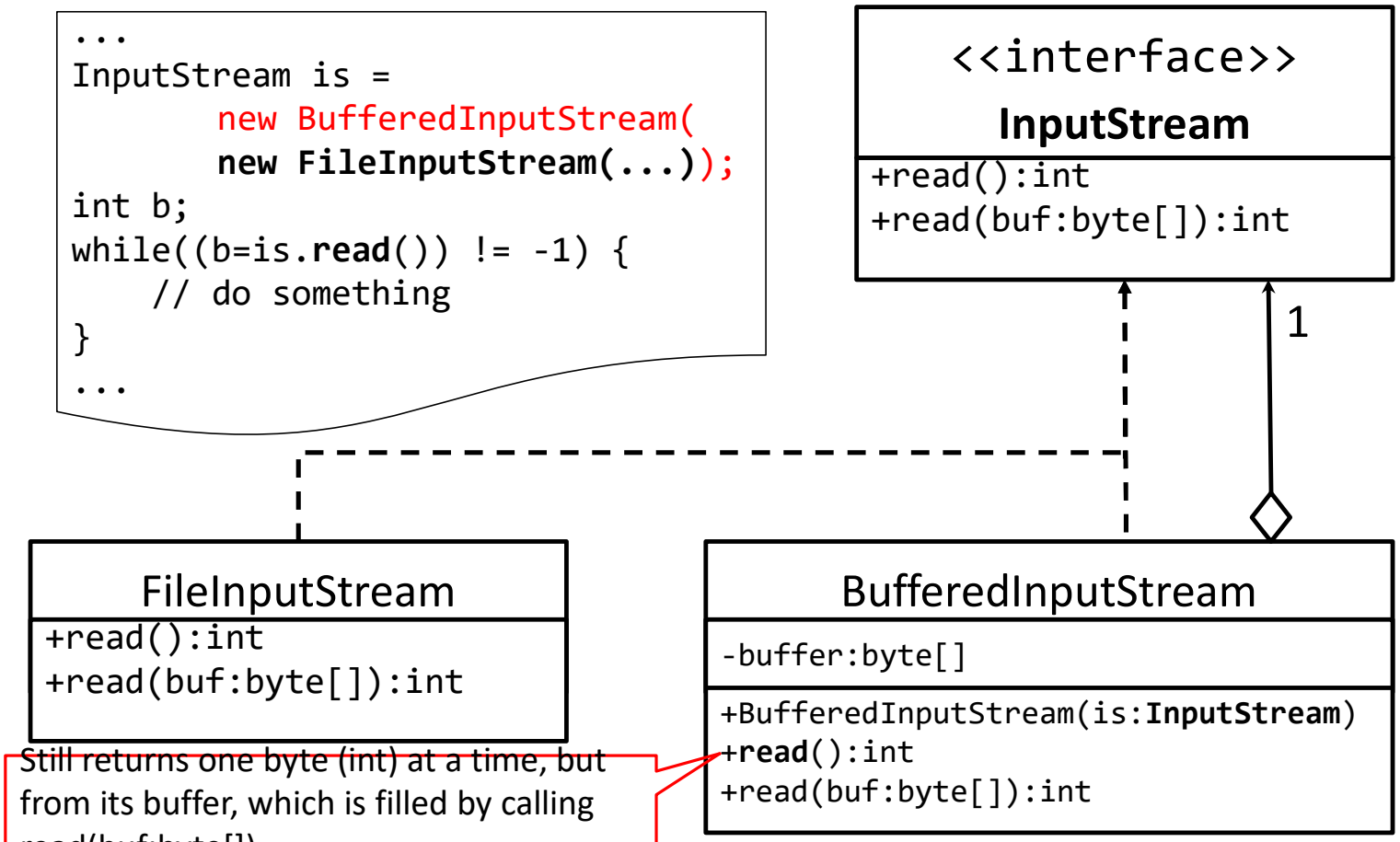


Problem: filesystem I/O is expensive
Solution: use a buffer!

Why not simply implement the buffering in the client or subclass?

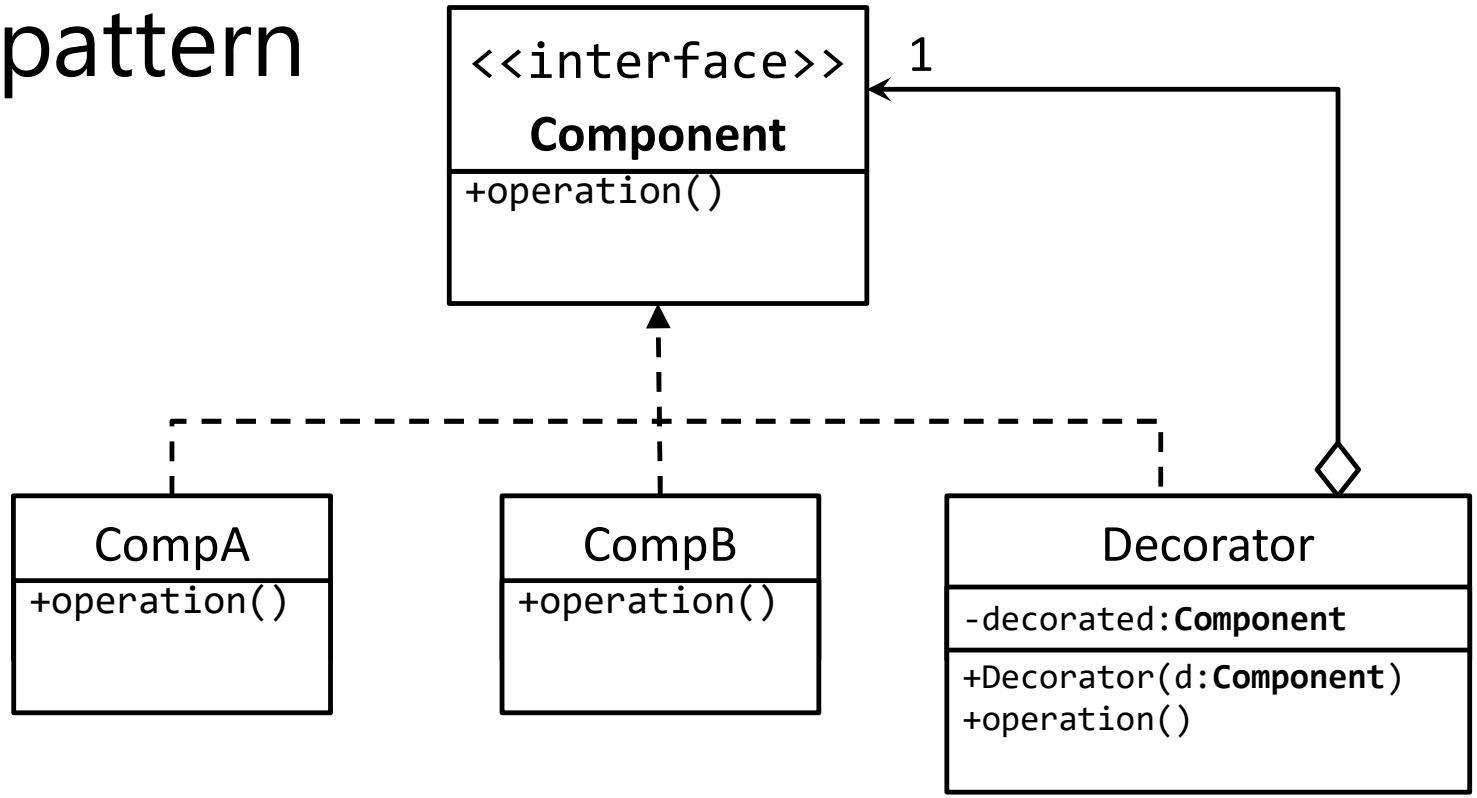
Another design problem: I/O streams

```
...
InputStream is =
        new BufferedInputStream(
        new FileInputStream(...));
int b;
while((b=is.read()) != -1) {
    // do something
}
...
```

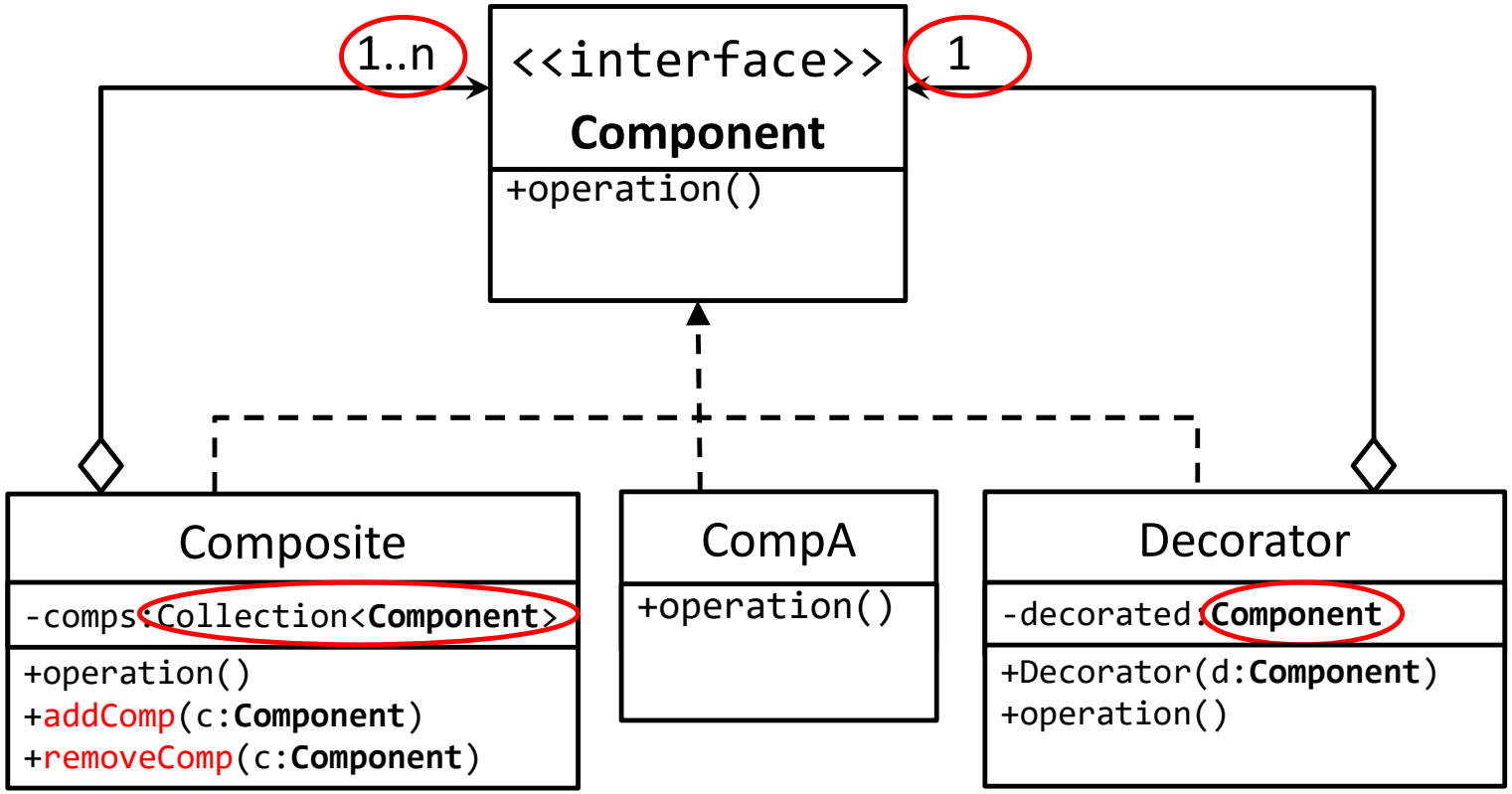


Still returns one byte (int) at a time, but from its buffer, which is filled by calling read(buf:byte[]).

The general solution: Decorator pattern



Composite vs. Decorator



Properties of a good software design

Motivation

Each concept should be motivated by at least one purpose

Coherence

Each concept should be motivated by at most one purpose

Fulfillment

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Non-division

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Concepts should not interfere with one another's fulfillment of purpose

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