CSE 403

Software Engineering

Software architecture and design

Today

- Software design theory
- Software architecture vs. software design

SW Design: Purposes, Concepts, and Misfits

Purposes, Concepts, Misfits, and a Redesign of Git

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Concept and motivating purpose

"A **concept** is something you need to understand in order to use an application (and also something a developer needs to understand to work effectively with its code) and is invented to solve a particular problem, which is called the **motivating purpose.**"

Use cases are a good starting point
for identifying concepts for motivating purposes.

Operational principle and misfit

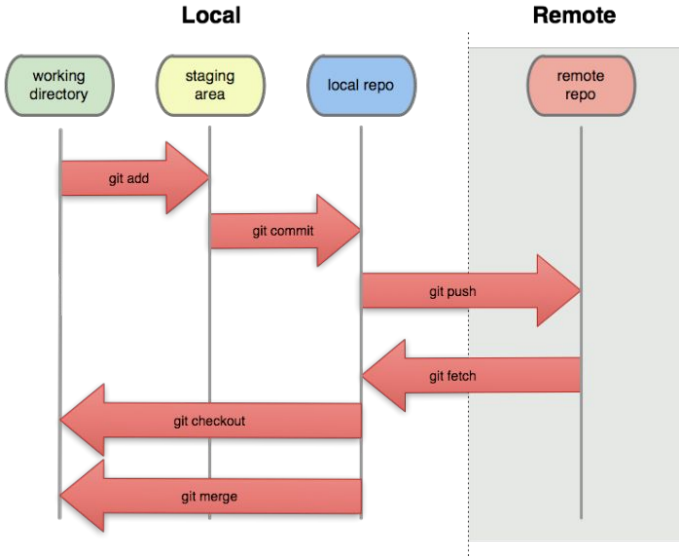
"A concept is defined by an **operational principle**, which is a scenario that illustrates how the concept fulfills its motivating purpose."

Operational principle and misfit

"A concept is defined by an **operational principle**, which is a scenario that illustrates how the concept fulfills its motivating purpose."

"A concept may not be entirely fit for purpose. In that case, one or more **operational misfits** are used to explain why. The operational misfit usually does not contradict the operational principle, but presents a different scenario in which the prescribed behavior does not meet a desired goal."

Git: another example for concepts and purposes



What concepts can we identify in Git (and version control systems in general)?

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
Each purpose should motivate at least one concept.

Non-division
Each purpose should motivate at most one concept.

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

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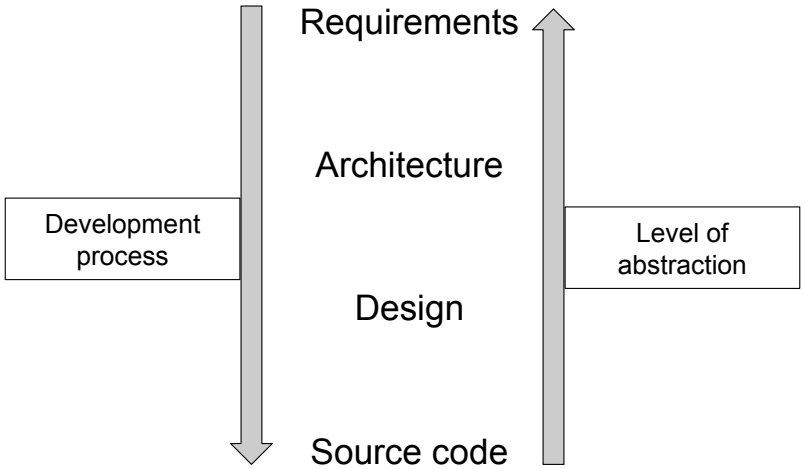
Software architecture vs. software design

Why software architecture and design?

> “There are two ways of constructing a software design:
>
> one way is to make it so simple that there are obviously no deficiencies;
>
> the other is to make it so complicated that there are no obvious deficiencies.” [Tony Hoare]

Goals: separation of concerns and modularity.

Architecture vs. design



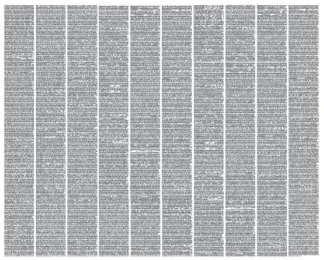
Abstraction

Building an abstract representation of reality

- Ignoring (insignificant) details.
- Focusing on the most important properties.
- Level of abstraction depends on viewpoint and purpose:
  - Communication
  - Component interfaces
  - Verification and validation

Different levels of abstraction

Source code

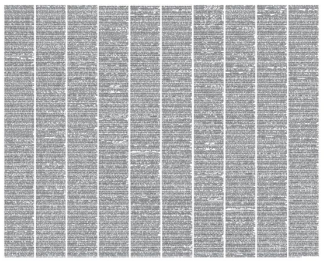


Example: Linux Kernel

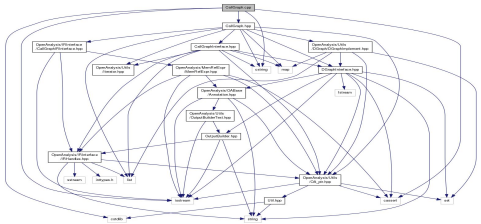
- 16 million Lines of Code!
- What does the code do?
- Are there dependencies?
- Are there different components?

Different levels of abstraction

Source code



Call graph



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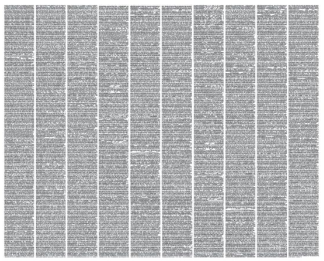

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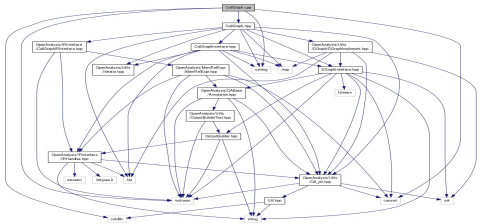
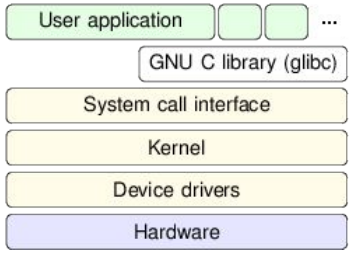


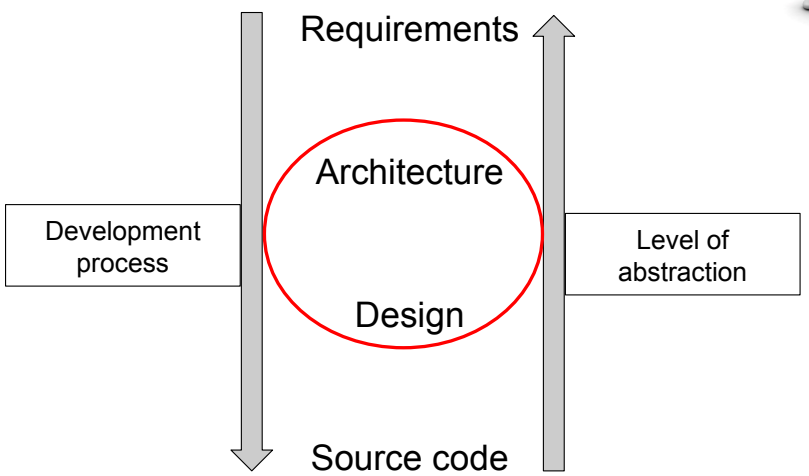
Layer diagram



Example: Linux Kernel

- 16 million Lines of Code!
- What does the code do?
- Are there dependencies?
- **Are there different components?**

Architecture vs. design



What's the difference?

Architecture vs. design

Architecture (what is developed?)

- High-level view of the overall system:
  - What components do exist?
  - What are the protocols between components?
  - What type of storage etc.?

Design (how are the components developed?)

- Considers individual components:
  - Data representation
  - Interfaces, Class hierarchy
  - …

Architecture vs. design

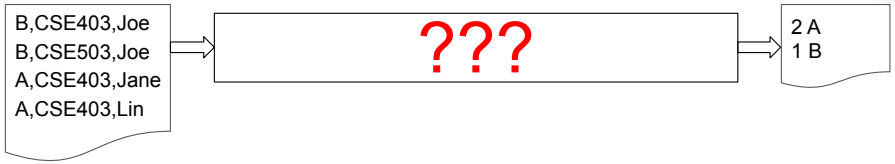
Architecture

[Gates Center Architecture, LMN]

Design

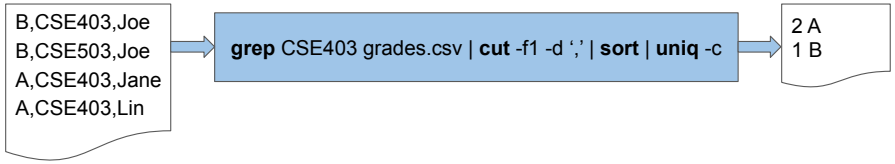
[Office design, New York Times]

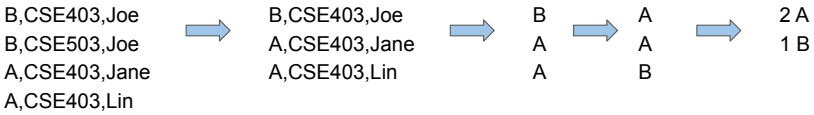
A first example



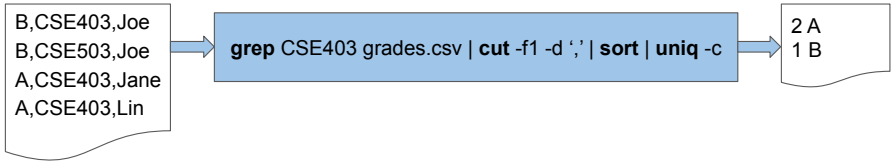
Goal: group and count CSE403 letter grades.

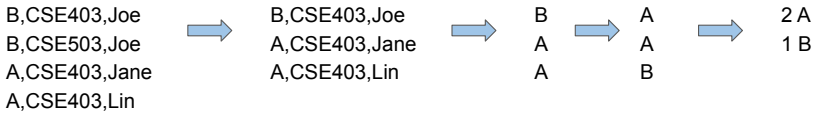
Pipe and filter





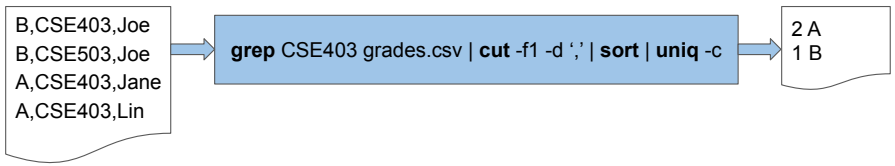
Pipe and filter





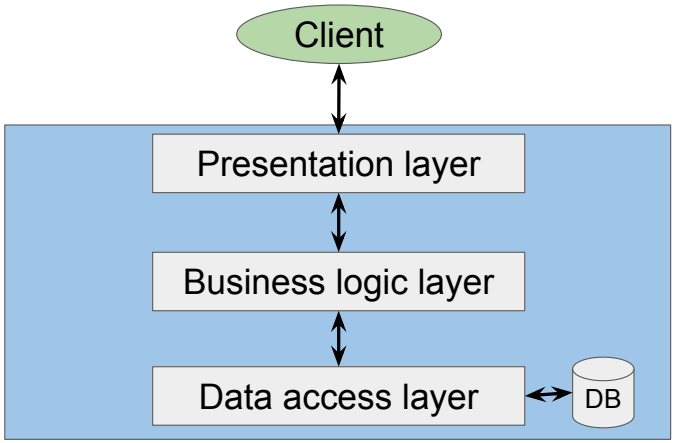
Pipe and filter is an architecture (not a design) pattern, why?

Software architecture: Pipe and Filter



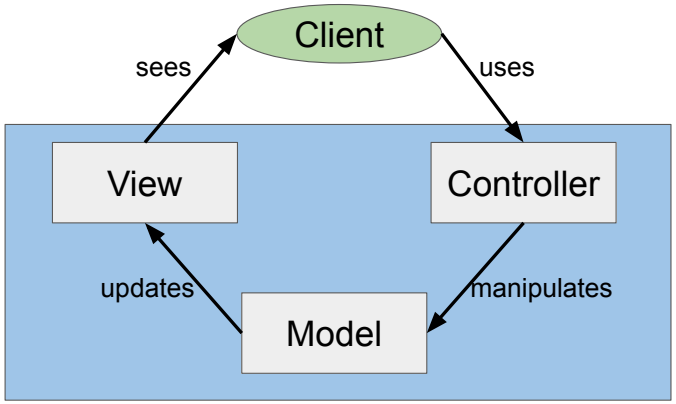
The pipe-and-filter architecture doesn't specify the design or implementation details of the individual components (filters)!

Software architecture: Client-server / n-tier



Simplifies reusability, exchangeability, and distribution.

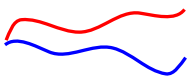
Software architecture: Model View Controller (MVC)



Separates data representation (Model), visualization (View), and client interaction (Controller)

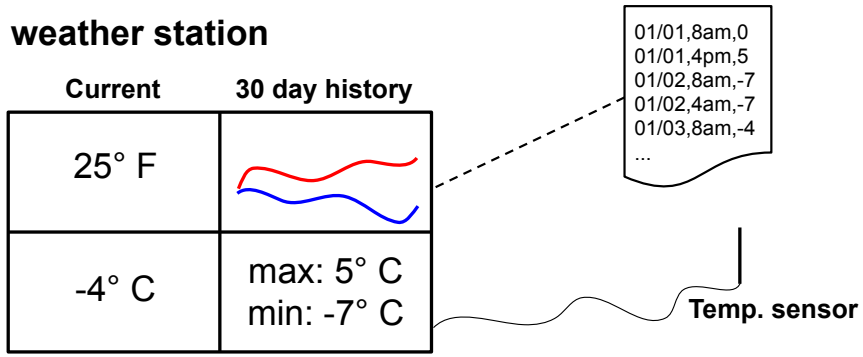
Model View Controller: example

Simple weather station

Current	30 day history
25° F	
-4° C	max: 5° C min: -7° C

Model View Controller: example

Simple weather station



Model View Controller: example

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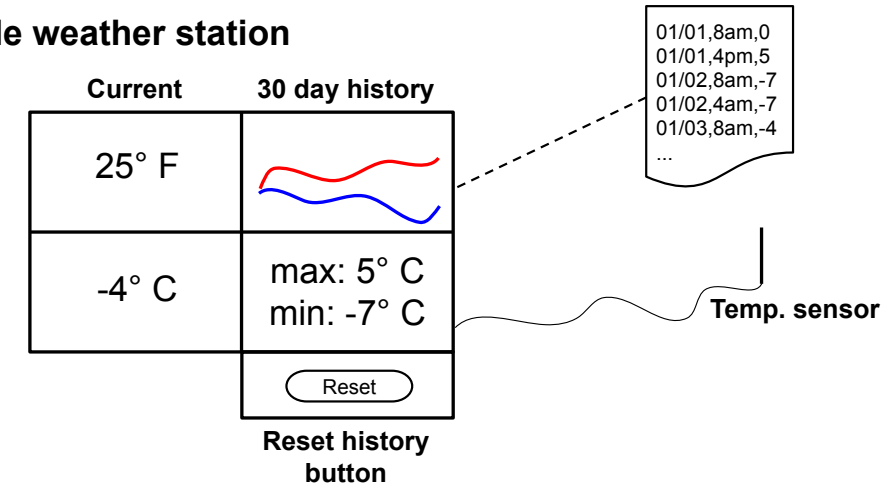
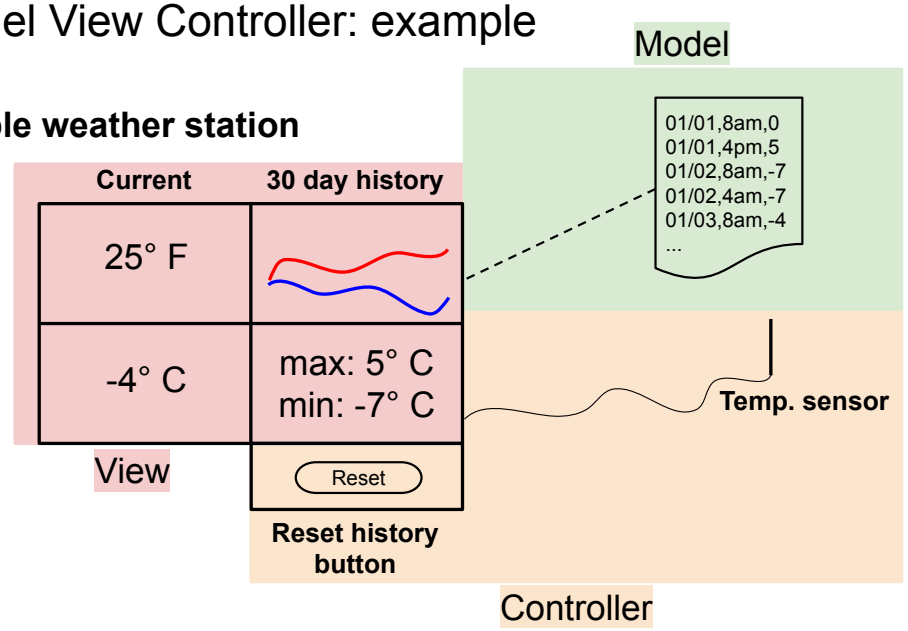


What are the **M**odel, **V**iew, and **C**ontroller components?

Model View Controller: example

Simple weather station



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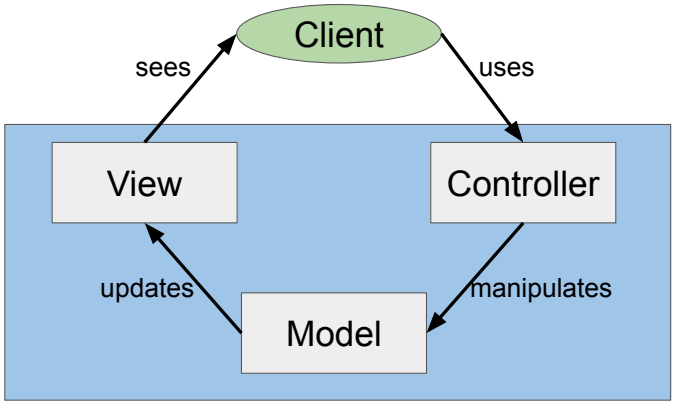

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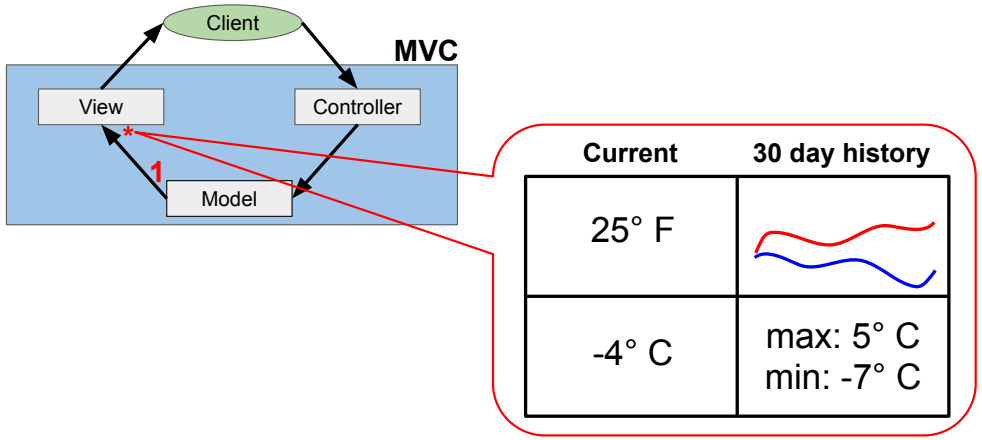
MVC: another example

https://bitbucket.org/rjust/basic-stats

MVC vs. MVP vs. MVVM



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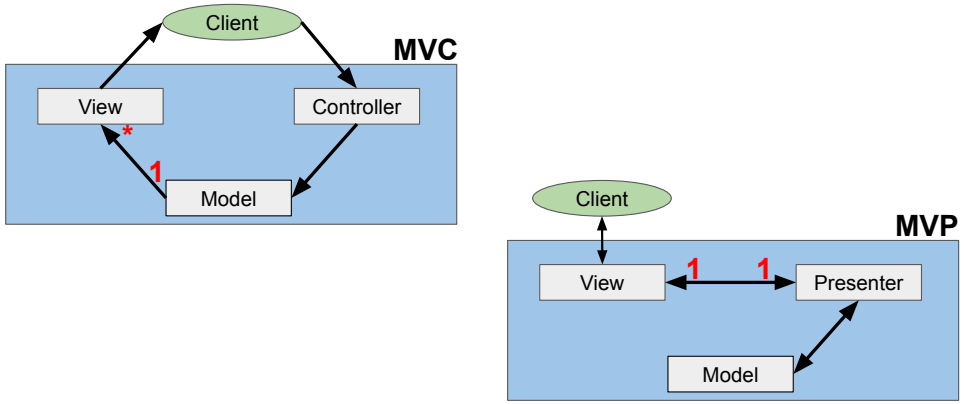

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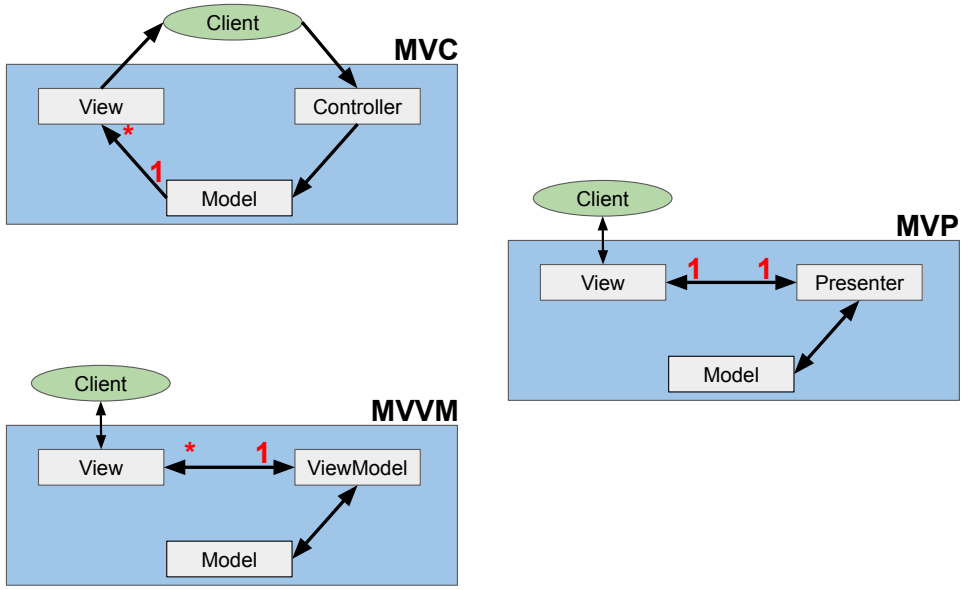
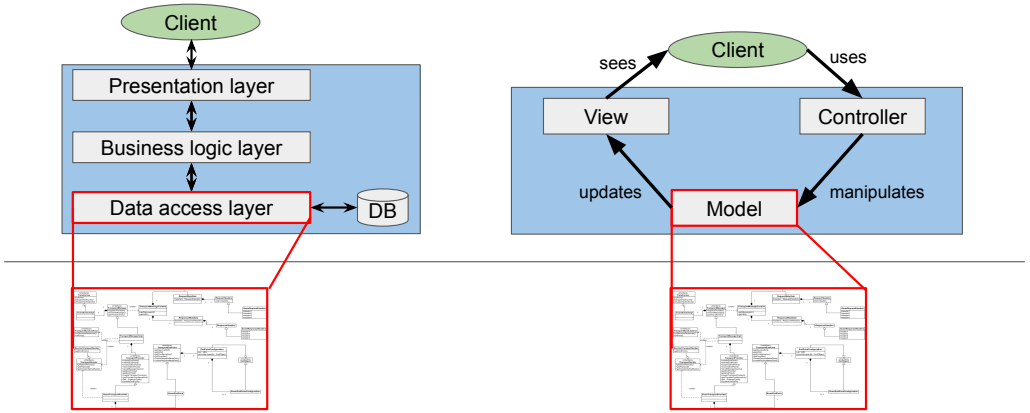


Software architecture vs. design: summary



Architecture and design

- Components and interfaces: understand, communicate, reuse
- Manage complexity: modularity and separation of concerns
- Process: allow effort estimation and progress monitoring

Additional material, not discussed in class

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
  - ...

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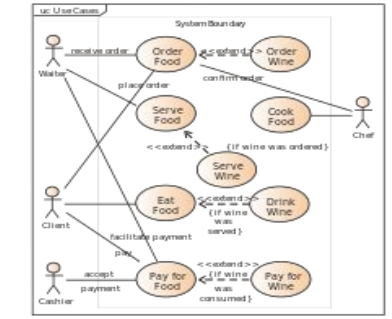

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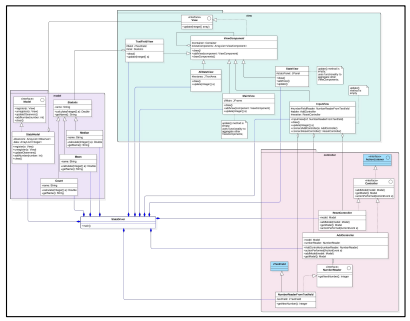
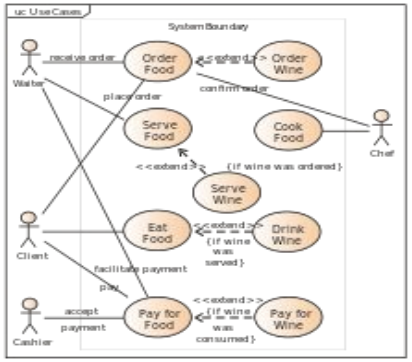
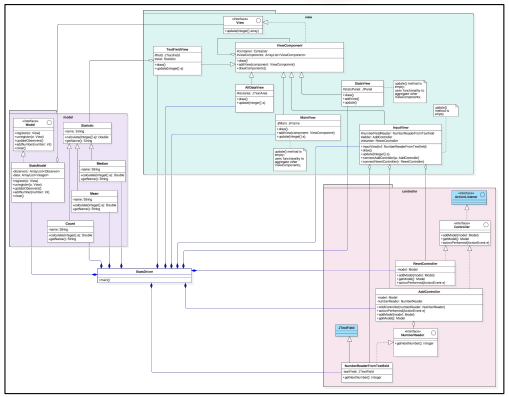


Are UML diagrams useful?





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

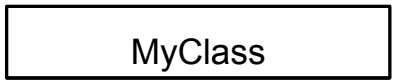
Class

- 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



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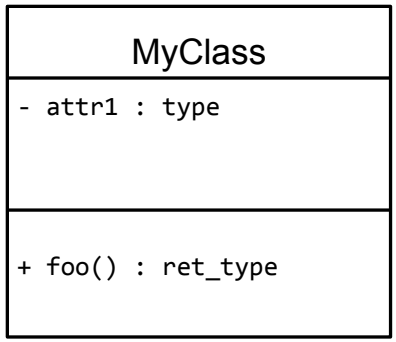


Name

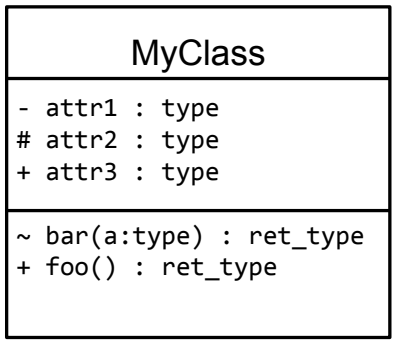
Attributes

<visibility> <name> : <type>

Methods

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

UML class diagram: basic notation



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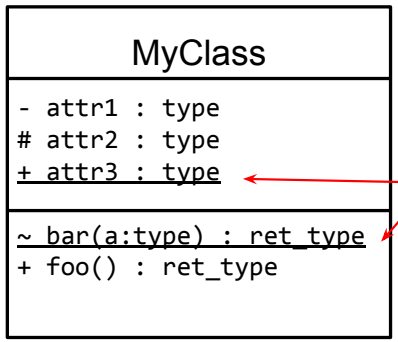
Visibility

- private
~ package-private
 # protected
+ public

UML class diagram: basic notation



Static attributes or methods are underlined

Name

Attributes

<visibility> <name> : <type>

Methods

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

Visibility

- private
~ package-private
 # protected
+ public

UML class diagram: concrete example

```
public class Person {
  ...
}
```

Person

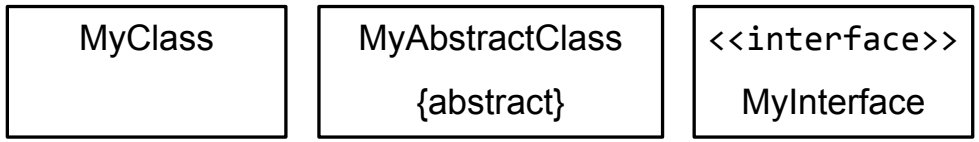
```
public class Student
    extends Person {
  private int id;
  public Student(String name,
                 int id) {
    ...
  }

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

Student

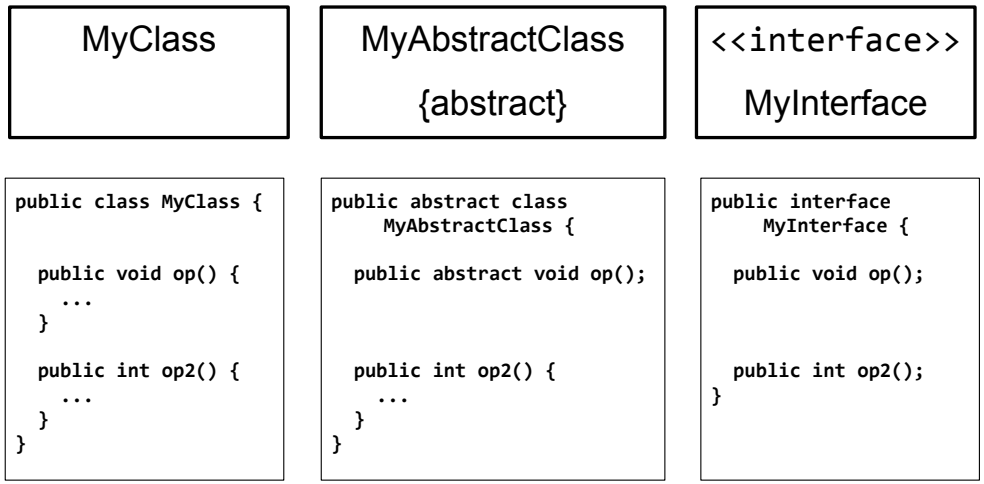
- id : int

+ Student(name:String, id:int)
+ getId() : int

Classes, abstract classes, and interfaces

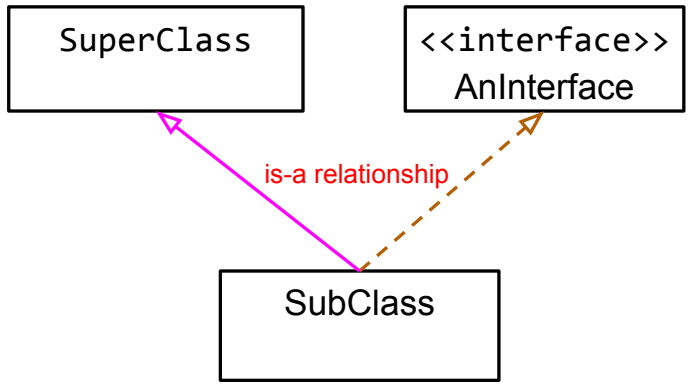


Classes, abstract classes, and interfaces



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

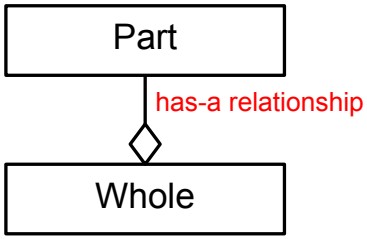
UML class diagram: Inheritance




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

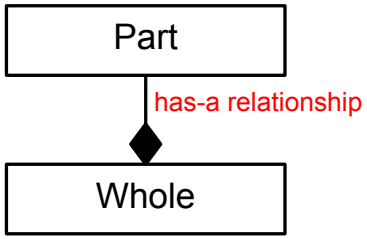
UML class diagram: Aggregation and Composition

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).

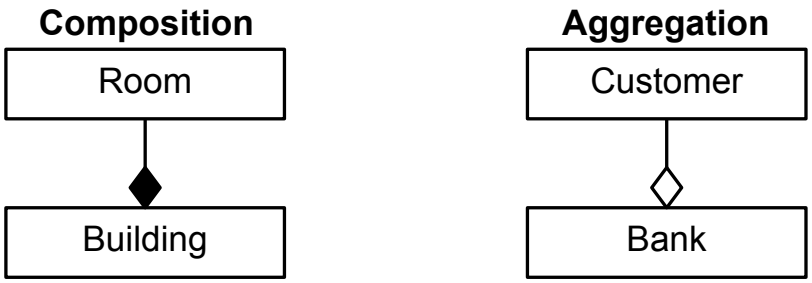
Composition



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

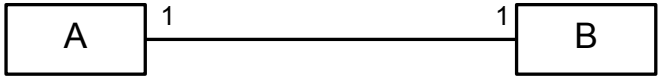
Aggregation or Composition?

Aggregation or Composition?

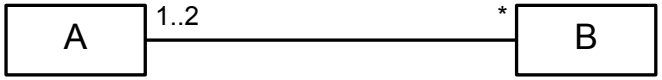


What about class and students or body and body parts?

UML class diagram: multiplicity

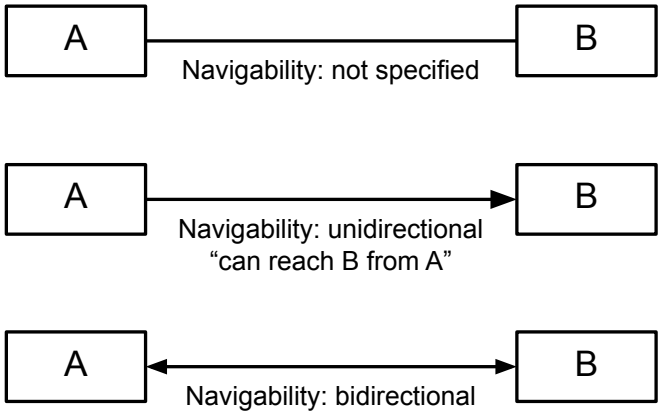


Each A is associated with exactly one B
Each B is associated with exactly one A

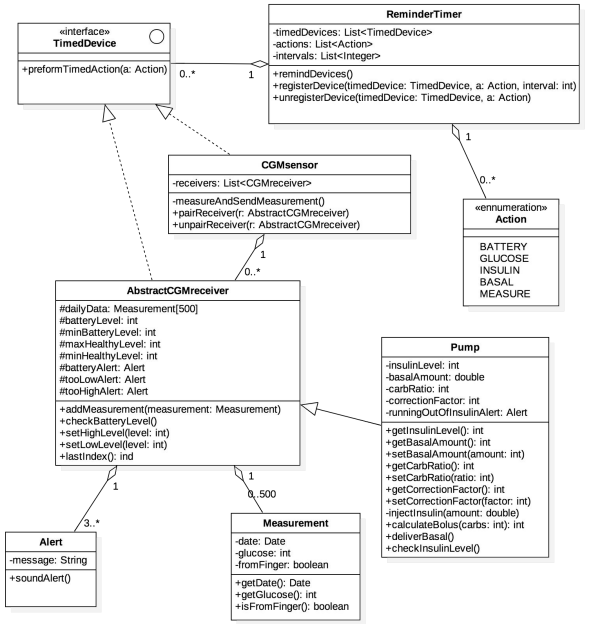


Each A is associated with any number of Bs
Each B is associated with exactly one or two As

UML class diagram: navigability



UML class diagram: example



Summary: UML

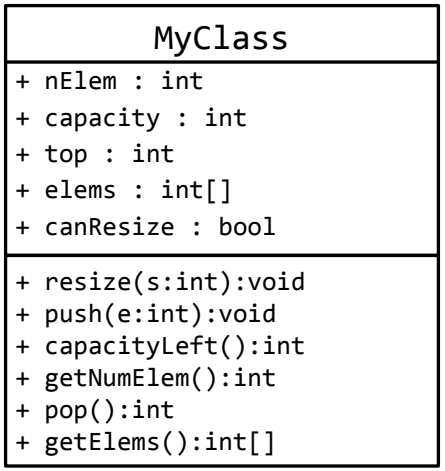
- Unified notation for modeling OO systems.
- Allows different levels of abstraction.
- Suitable for design discussions and documentation.

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

MyClass
+ nElem : int + capacity : int + top : int + elems : int[] + canResize : bool
+ resize(s:int):void + push(e:int):void + capacityLeft():int + getNumElem():int + pop():int + getElems():int[]

```
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 MyClass do?

Information hiding

Stack
+ nElem : int + capacity : int + top : int + elems : int[] + canResize : bool
+ resize(s:int):void + push(e:int):void + capacityLeft():int + getNumElem():int + pop():int + getElems():int[]

```
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

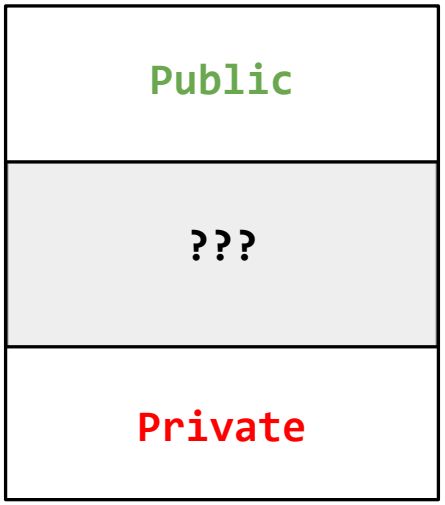
Stack
+ nElem : int + capacity : int + top : int + elems : int[] + canResize : bool
+ resize(s:int):void + push(e:int):void + capacityLeft():int + getNumElem():int + pop():int + getElems():int[]

Stack
- elems : int[] ...
+ push(e:int):void + pop():int ...

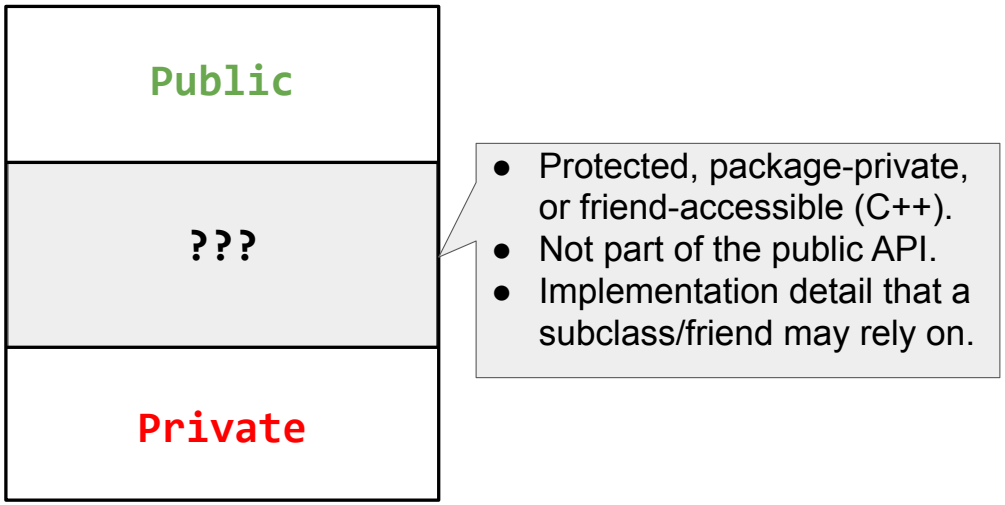
Information hiding:

- 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**
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- 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 = ...;` `obj.toString();` ⇒ toString() can be overridden in subclasses and therefore provide a different behavior.
- Parametric polymorphism (e.g., Java generics)
  - `class LinkedList<E> { void add(E) {...} E get(int index) {...}` ⇒ A LinkedList can store elements regardless of their type but still provide full type safety.

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
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- Composition/aggregation over inheritance

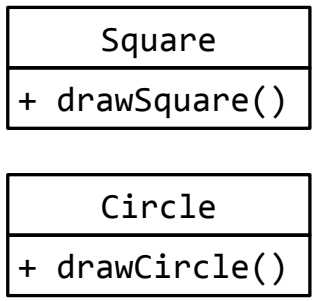
Open/closed principle

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?



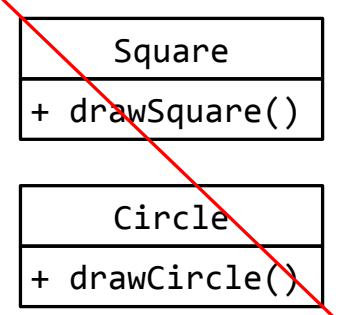
Open/closed principle

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!



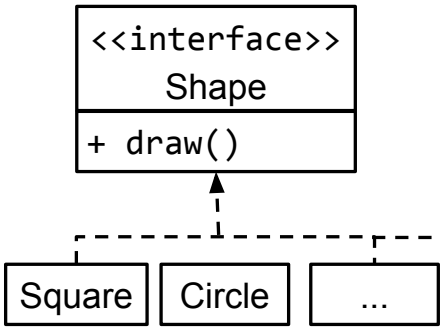
Open/closed principle

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

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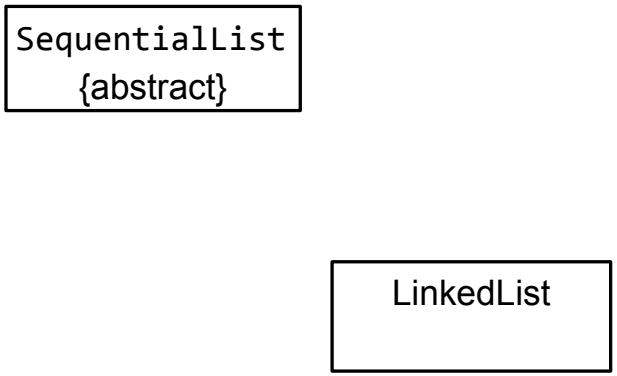
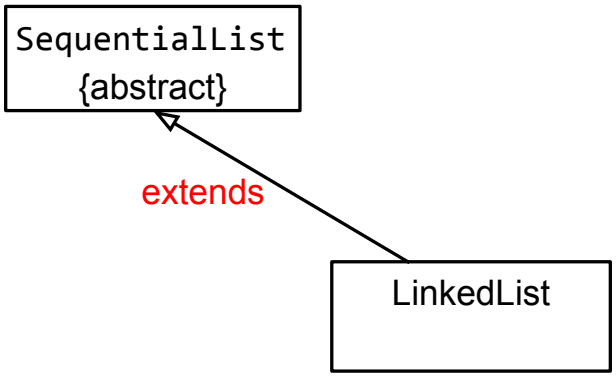
Inheritance: (abstract) classes and interfaces



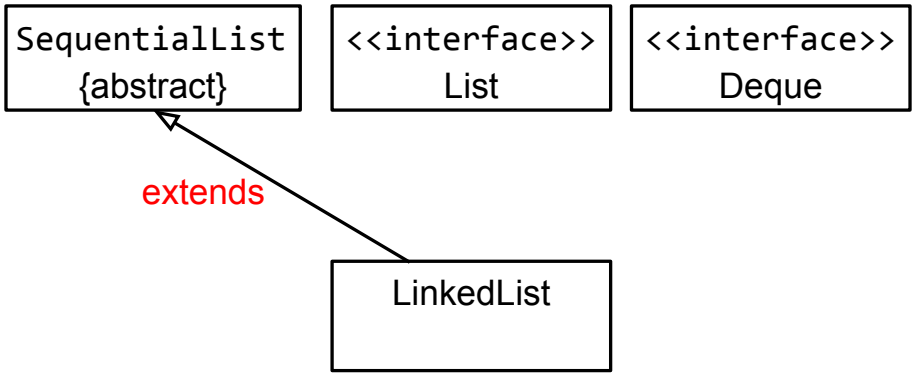
Inheritance: (abstract) classes and interfaces

LinkedList extends SequentialList



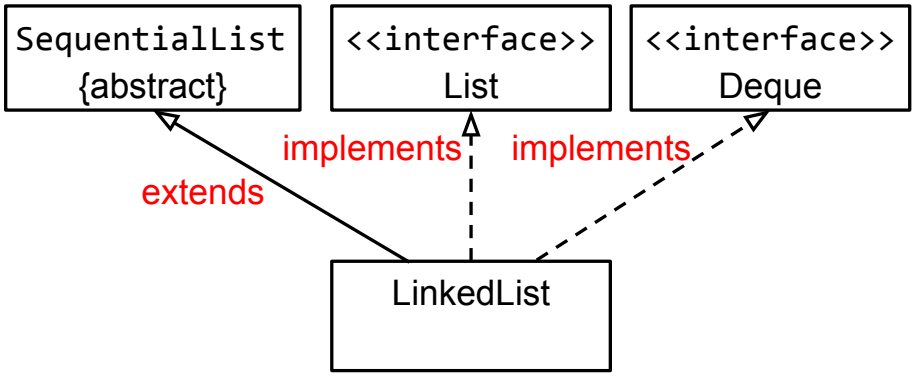
Inheritance: (abstract) classes and interfaces

LinkedList extends SequentialList

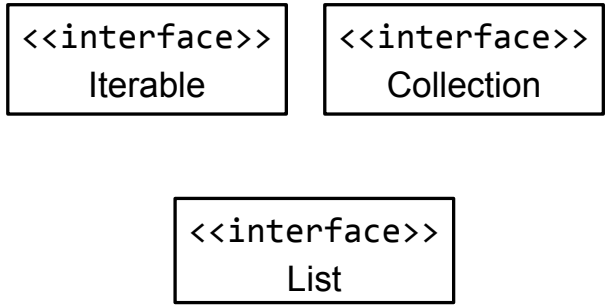


Inheritance: (abstract) classes and interfaces

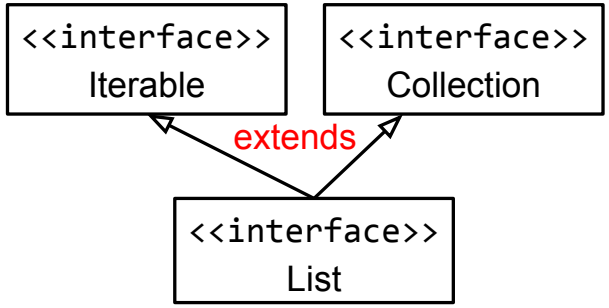
LinkedList extends SequentialList implements List, Deque



Inheritance: (abstract) classes and interfaces

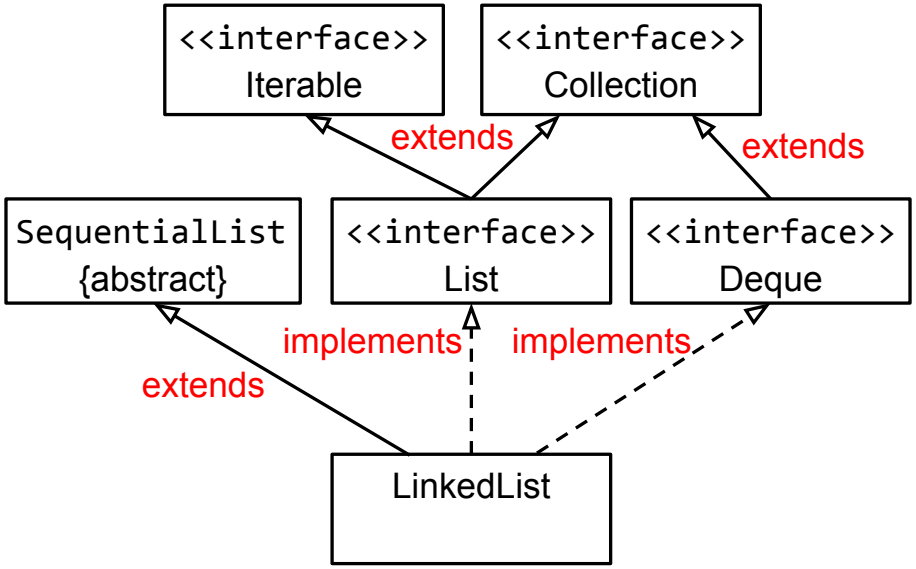


Inheritance: (abstract) classes and interfaces



List extends Iterable, Collection

Inheritance: (abstract) classes and interfaces



OO design principles

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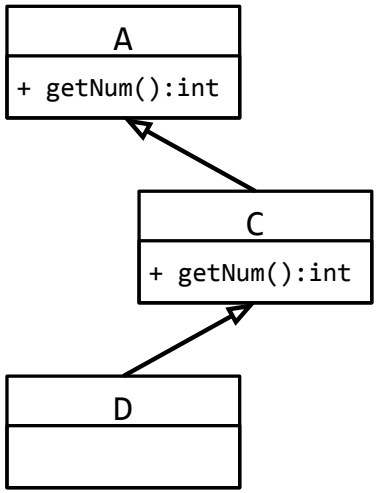
- Inheritance in Java
- **The diamond of death**
- Liskov substitution principle
- Composition/aggregation over inheritance

The “diamond of death”: the problem

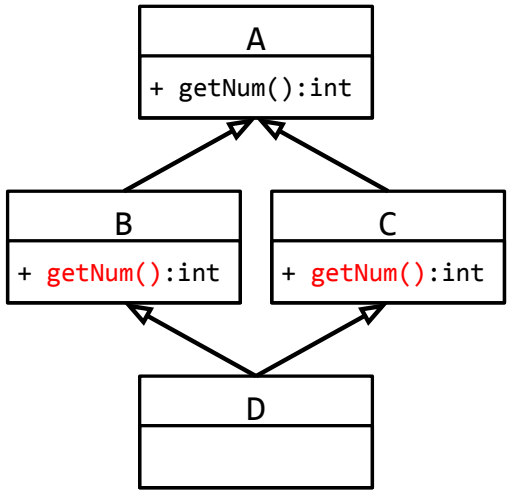
```
...
A a = new D();
int num = a.getNum();
...
```



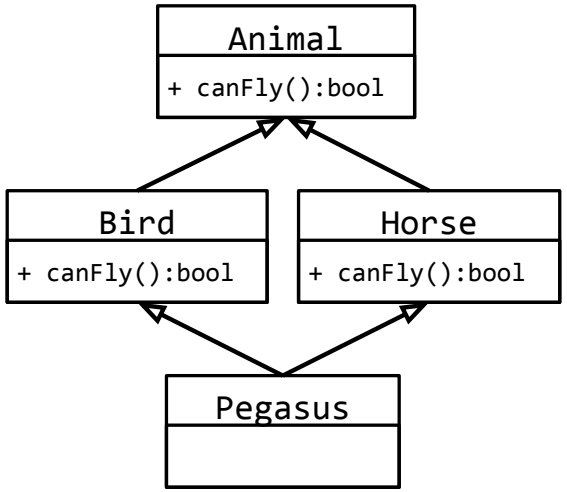
The “diamond of death”: the problem

```
...
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)
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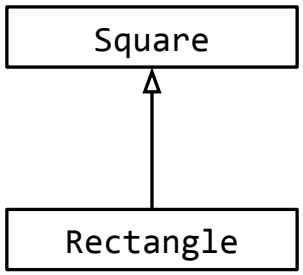
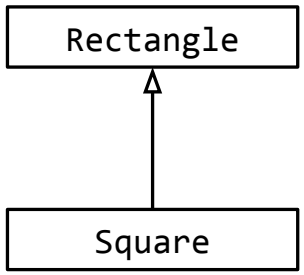
Design principles: Liskov substitution principle

Motivating example

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

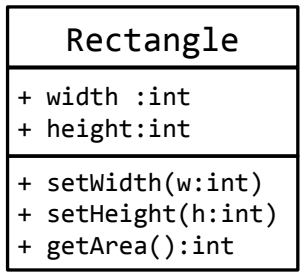


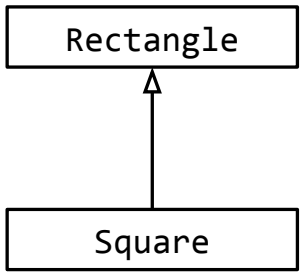


Design principles: Liskov substitution principle

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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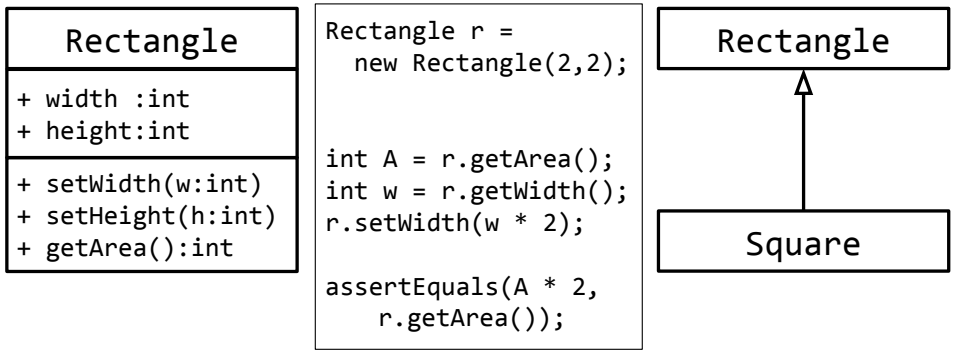

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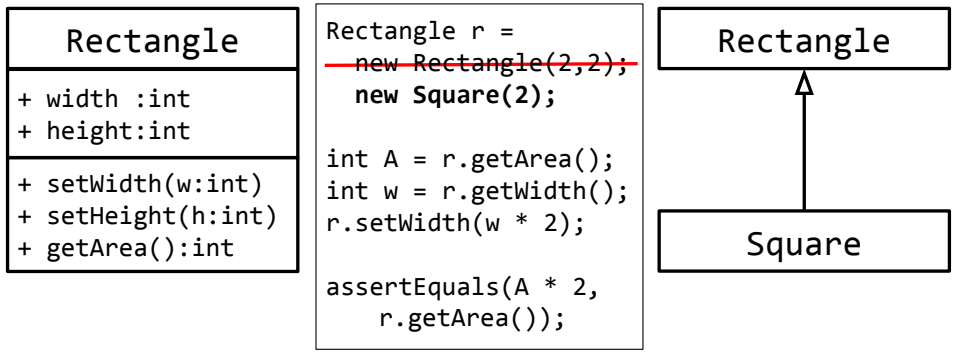

Design principles: Liskov substitution principle

Subtype requirement

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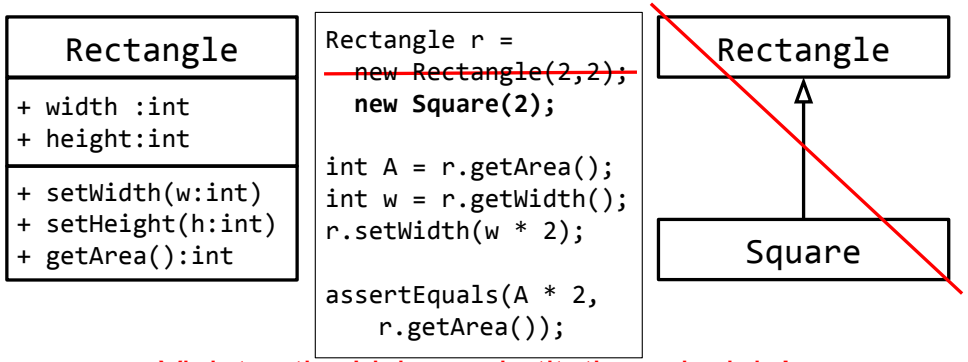
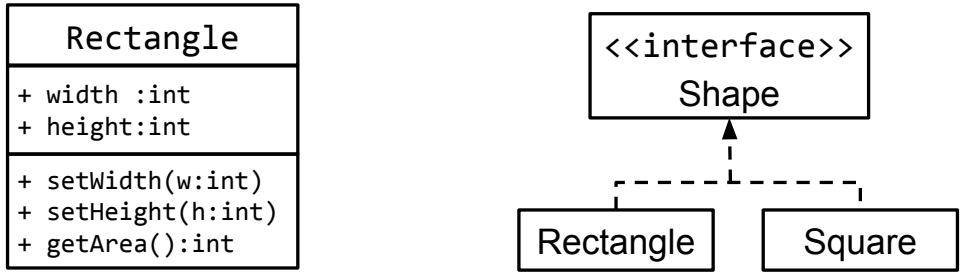


Violates the Liskov substitution principle!

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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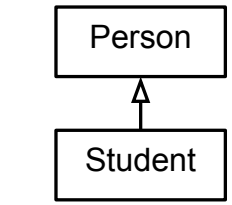
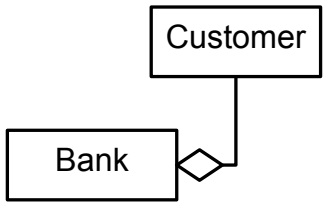
- **Composition/aggregation over inheritance**

Inheritance vs. (Aggregation vs. *Composition*)

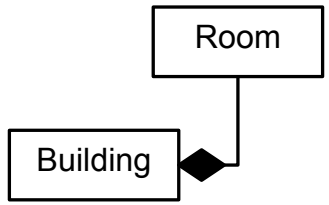



```
public class Student
    extends Person{
 public Student(){
 }
 ...
}
```

is-a relationship



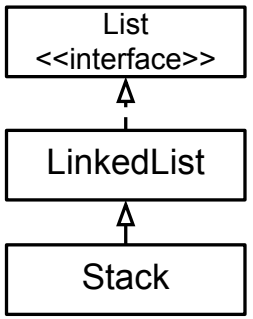

```
public class Bank {
 Customer c;
 public Bank(Customer c){
  this.c = c;
 }
 ...
}
```



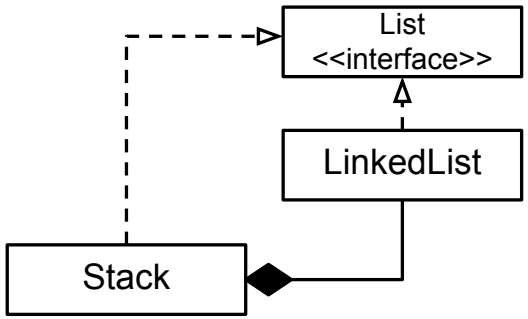

```
public class Building {
 Room r;
 public Building(){
  this.r = new Room();
 }
 ...
}
```

has-a relationship

Design choice: inheritance or composition?



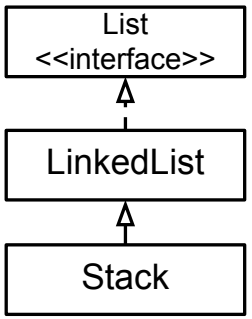

```
public class Stack<E>
     extends LinkedList<E> {
  ...
}
```




```
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?

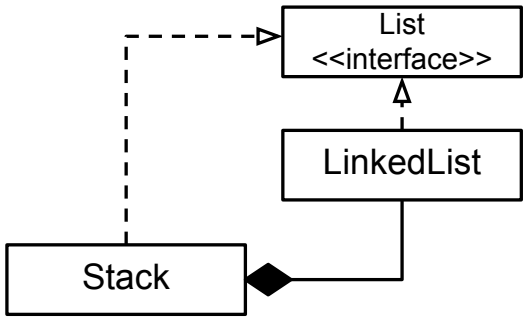


Pros

- 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.

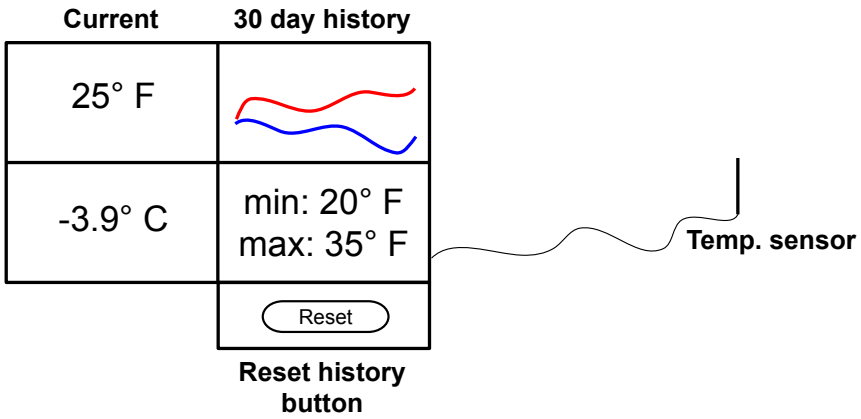
OO design principles: summary

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

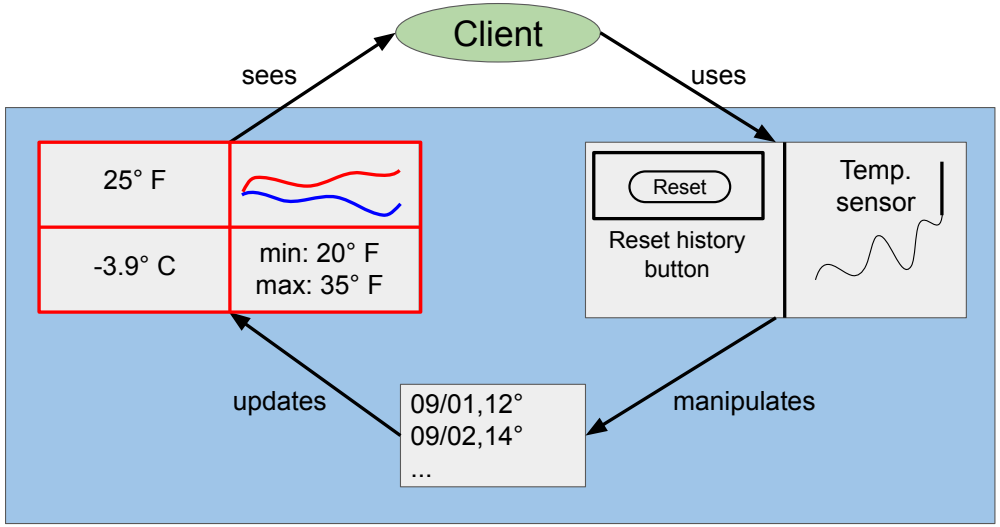
OO design patterns

A first design problem

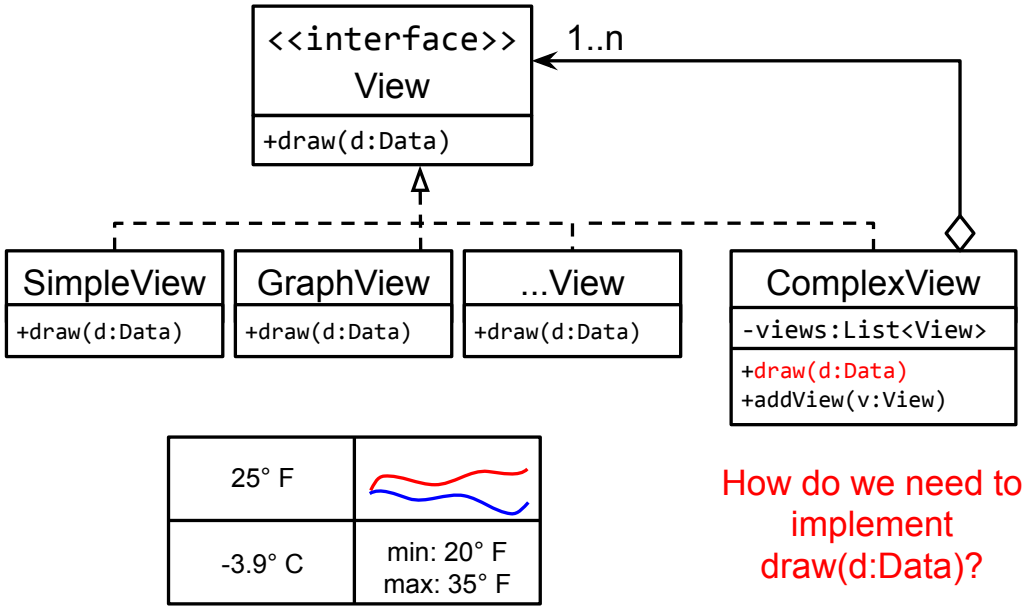
Weather station revisited



What's a good design for the view component?

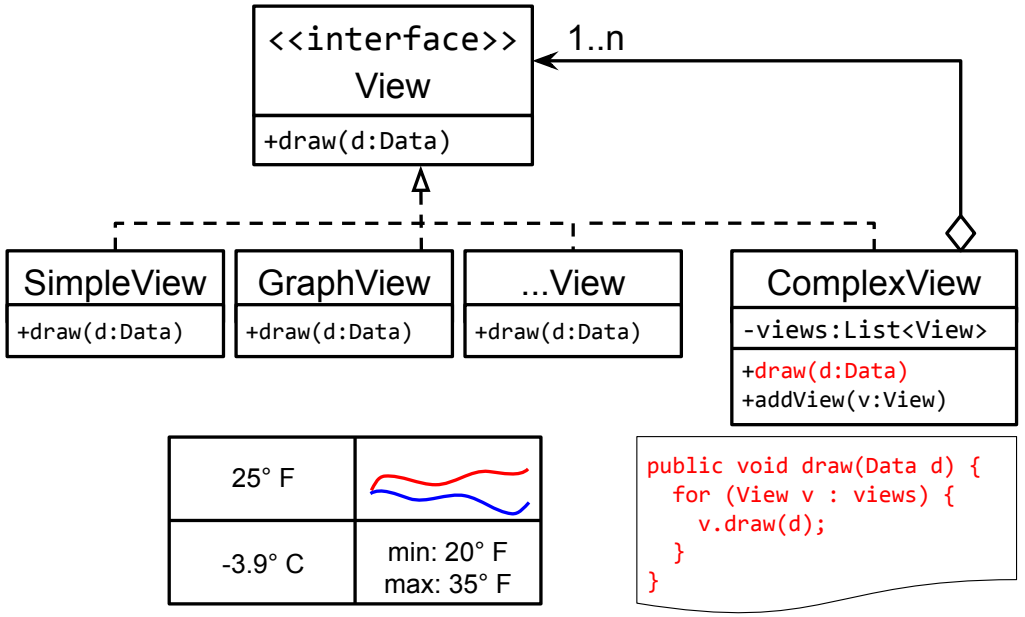


Weather station: view



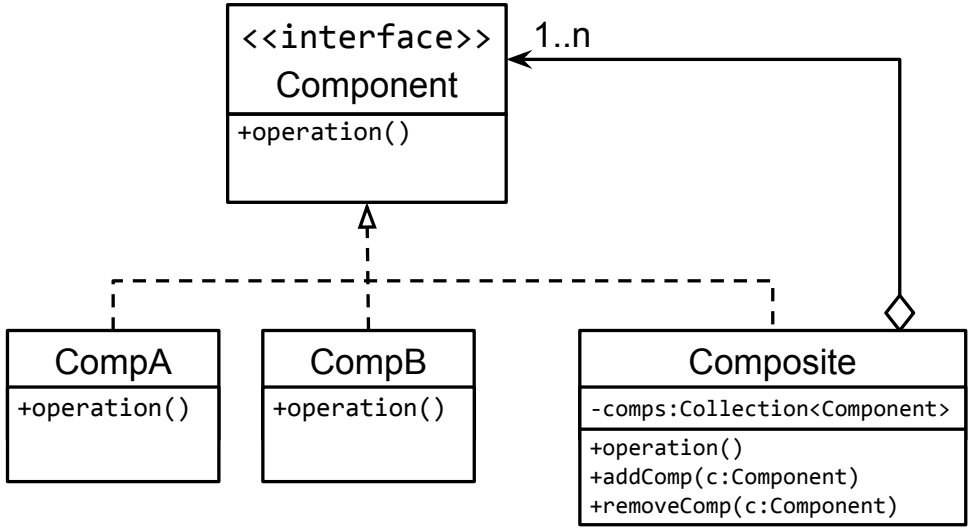
How do we need to implement draw(d:Data)?

Weather station: view

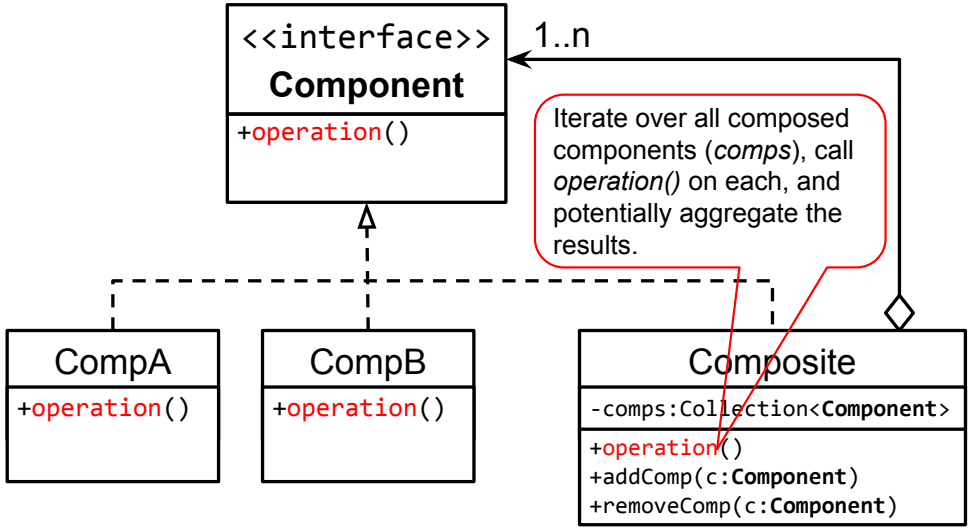



```
public void draw(Data d) {
  for (View v : views) {
    v.draw(d);
  }
}
```

The general solution: Composite pattern



The general solution: Composite pattern



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- Addresses a recurring, common design problem.
- Provides a generalizable solution.
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Pros

- Improves communication and documentation.
- “Toolbox” for novice developers.

Cons

- Risk of over-engineering.
- Potential impact on system performance.

More than just a name for common sense and best practices.

Design patterns: categories

1. Structural
   - Composite
   - Decorator
   - ...
2. Behavioral
   - Template method
   - Visitor
   - ...
3. Creational
   - Singleton
   - Factory (method)
   - ...

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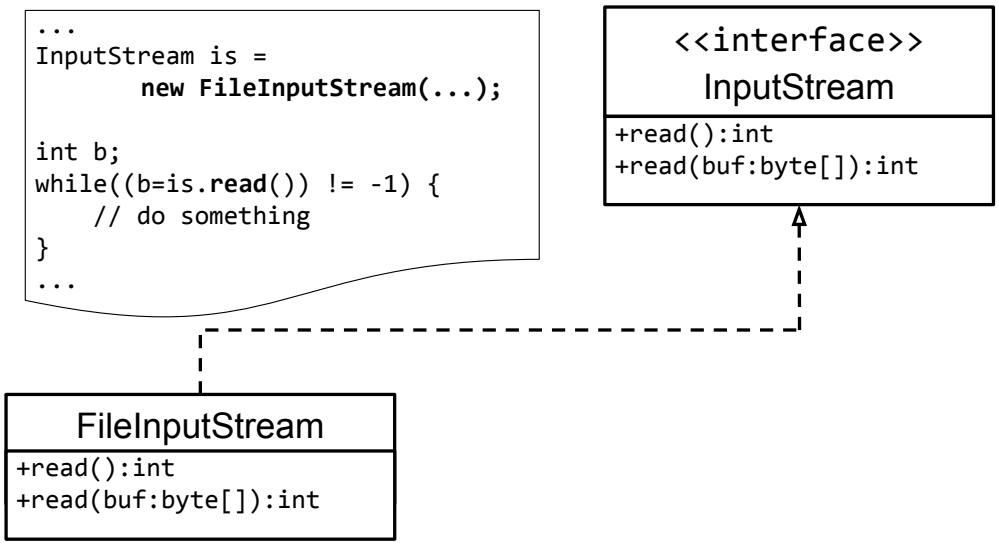
Another design problem: I/O streams



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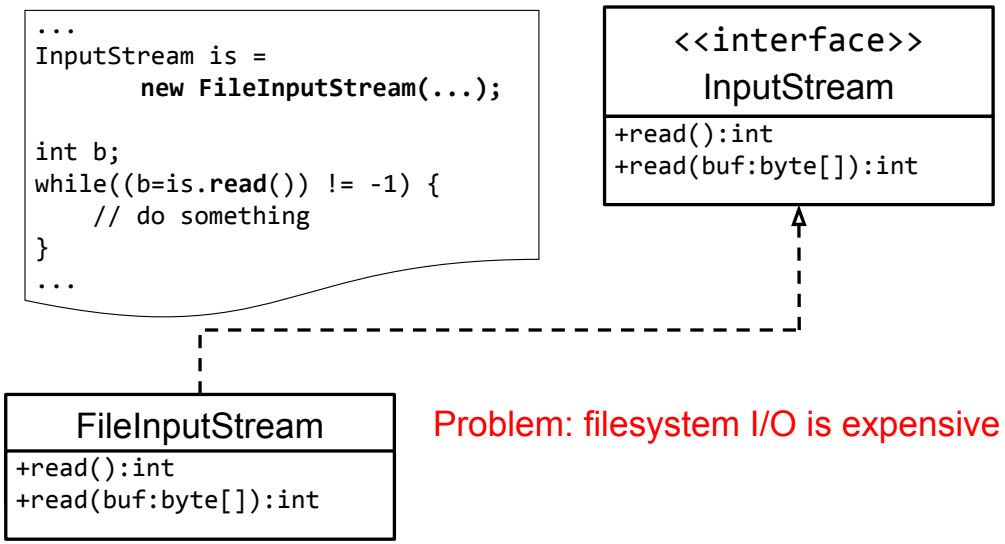

Problem: filesystem I/O is expensive

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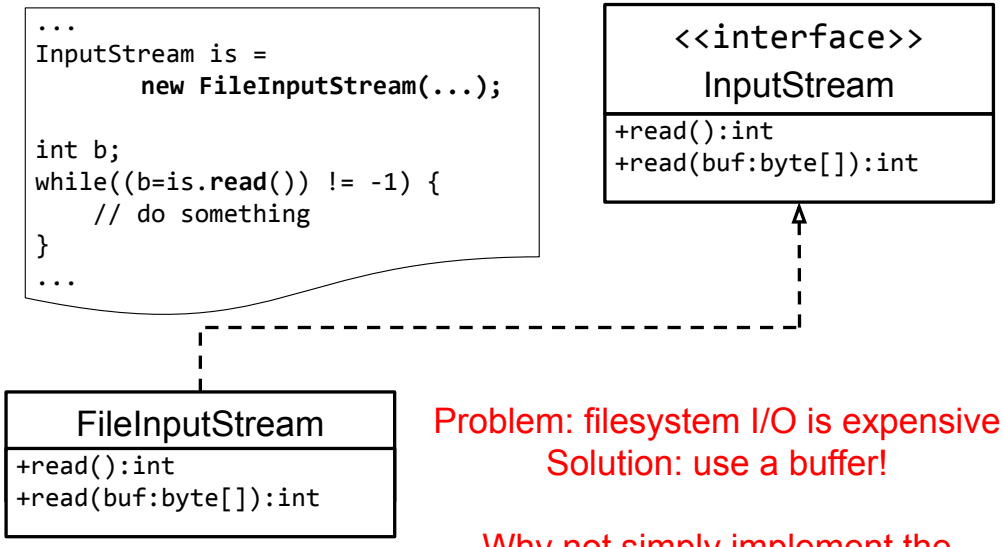
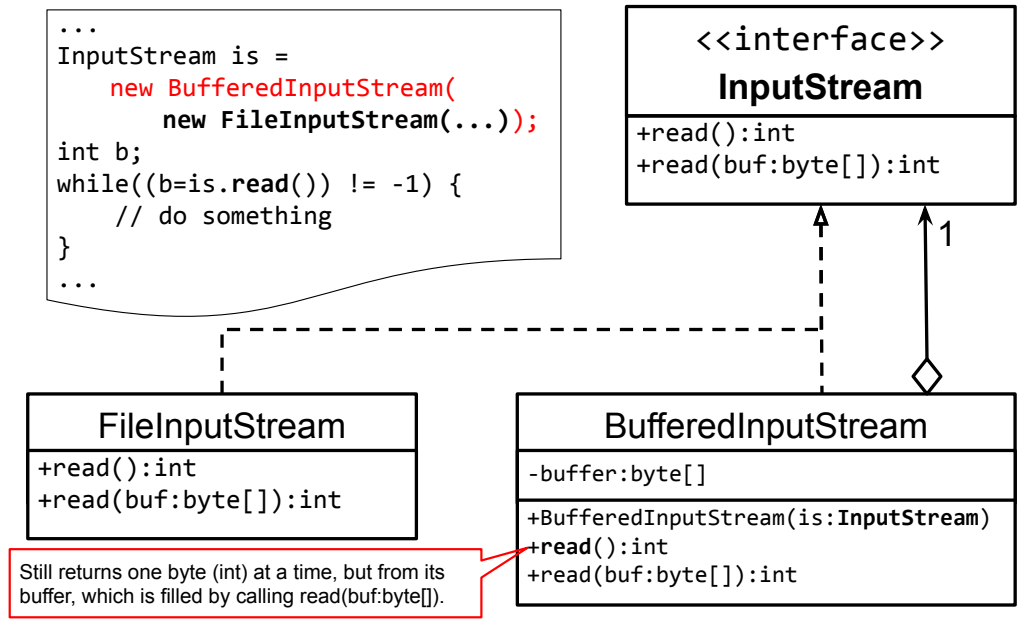


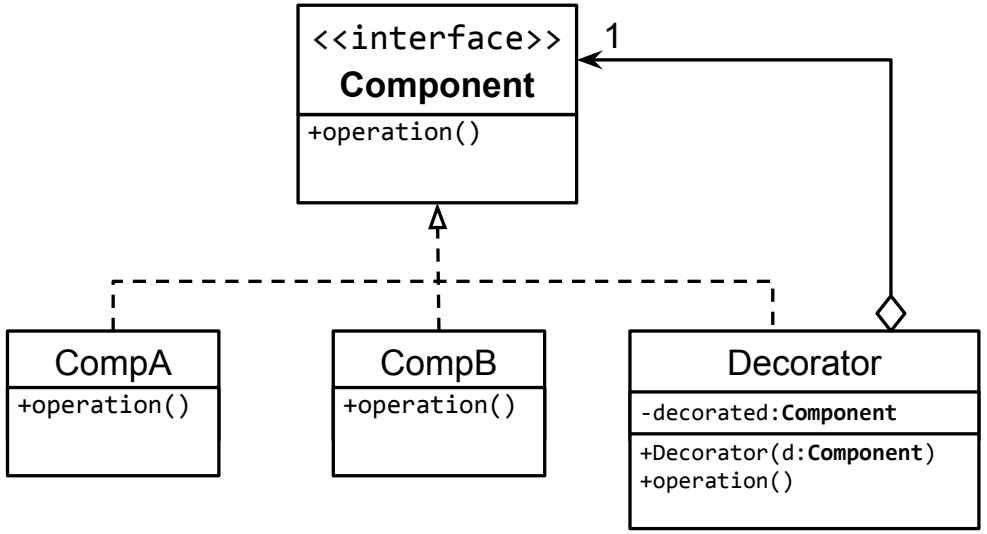
Problem: filesystem I/O is expensive
Solution: use a buffer!

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

Another design problem: I/O streams



The general solution: Decorator pattern



Composite vs. Decorator