Object Oriented Design Heuristics

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What are ***Heuristics***?

- A set of simple guidelines for a complex task
  - We create heuristics to help us think…
  - Heuristics help us to make choices
- Useful for software design
  - Like “coding rules” – they can help us get started
  - When we have two “designs” – it isn’t easy to know which one is the best

Heuristics = simple guidelines

Why Heuristics?

- All software developers know how to **code**, but they are not all equally skilled in **creating good designs** for applications or subsystems
- We all get training in programming languages, development tools, algorithms, data structures, and database tools
- But most of us have never had a formal course in design – we learn “on the job”

Why Heuristics?

Elements of flexible designs

- Design principles: good but complicated…
  - **Modularization** – divide a big design into small independent pieces (component / module)
  - **Encapsulation** – each component has a simple interface, hiding complex details (reduce the learning curve…)
  - **Low coupling** – minimize dependencies between components
  - **Extensibility** – components can be extended without changing the base code (making it easier to add new operations later…)

- Design heuristics: easier to learn and apply
  - Simple “rules of thumb”
  - They help avoid design pitfalls
  - Use them in design brainstorming and design reviews

Modules

Modules help you understand your own design later

Modules help with teamwork

- Why are modules important?
  - Modularization is a great design idea!
  - “Divide and conquer”
  - The **internal details** of each module might be complicated, but the module is designed with an **external interface** that is easier to understand
  - Instead of just “writing a program,” we should be designing the key modules of the system
  - Modules =
    - Packages, Components, Classes
- Design heuristics help us define “good” modules

Heuristics for Object Oriented Design

- We will talk about "object oriented design heuristics" today:
  - We want to define good classes (classes should encapsulate the right data and should have the right public interfaces)
  - A good distribution of responsibilities across a group of classes
    - Not too much "concentration of behavior" in one class
    - Many of our classes will "delegate" part of their work to other classes
  - Use inheritance / subtypes in a sensible way
    - Avoid major pitfalls in the use of inheritance

Classes are bundles of data and related operations

Good modular classes! (Not just functions in disguise)

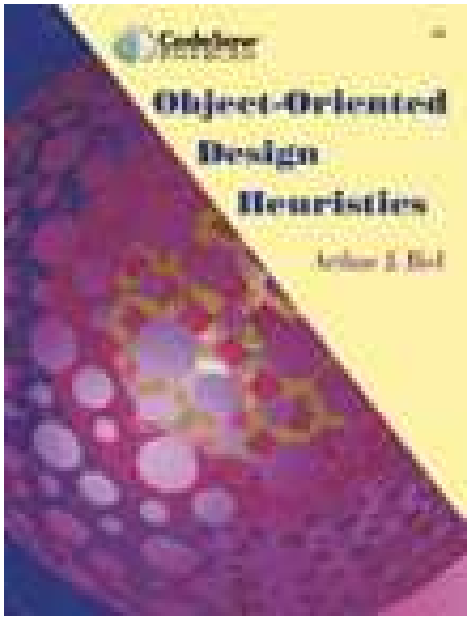
Design Heuristics can help

- Designers have to avoid many pitfalls
  - avoid building an “action-oriented” system
  - creating god classes (too much concentration of data or operations)
  - underuse of containment relationships
  - inappropriate use of inheritance
- We will talk more about:
  - *Action oriented*: centralized control, single main procedure, uncontrolled data sharing
  - *God class*: one class controls everything, lots of complexity concentrated in one place

Arthur Riel's Object Oriented Design Heuristics

- Some good design heuristics:

Object-Oriented Design Heuristics
by Arthur Riel



- This book lists 61 heuristics
  - these are "rules of thumb"
  - they are sometimes violated in designs that are considered good
  - but the heuristics help identify places where the design should be changed
- These heuristics apply to many programming languages
  - C++, Java, Python, JavaScript…

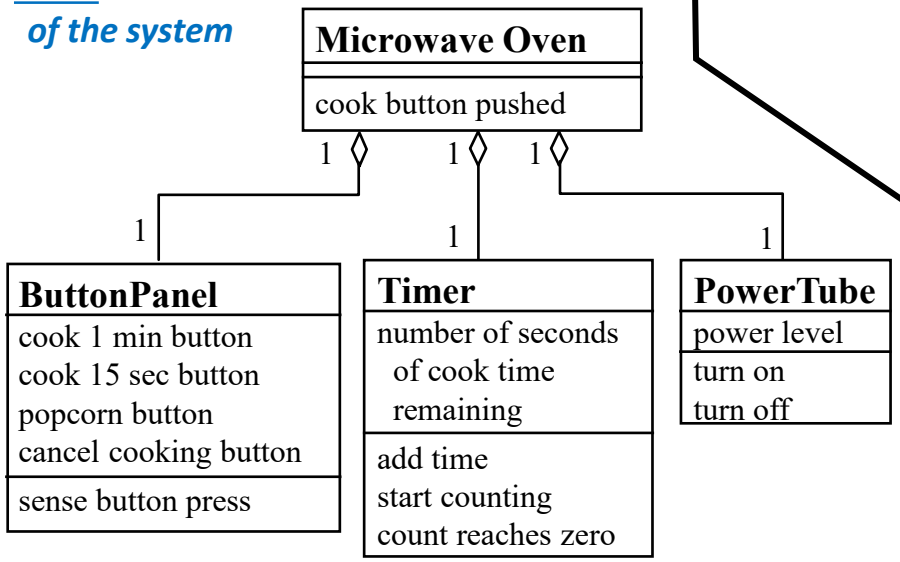
Notation for design

UML Diagrams are useful for talking about designs

- Notation
  - design will create some artifacts – and we want to everyone to be able to read them
  - a common set of notations is the Unified Modeling Language (UML), first defined back in 1997…

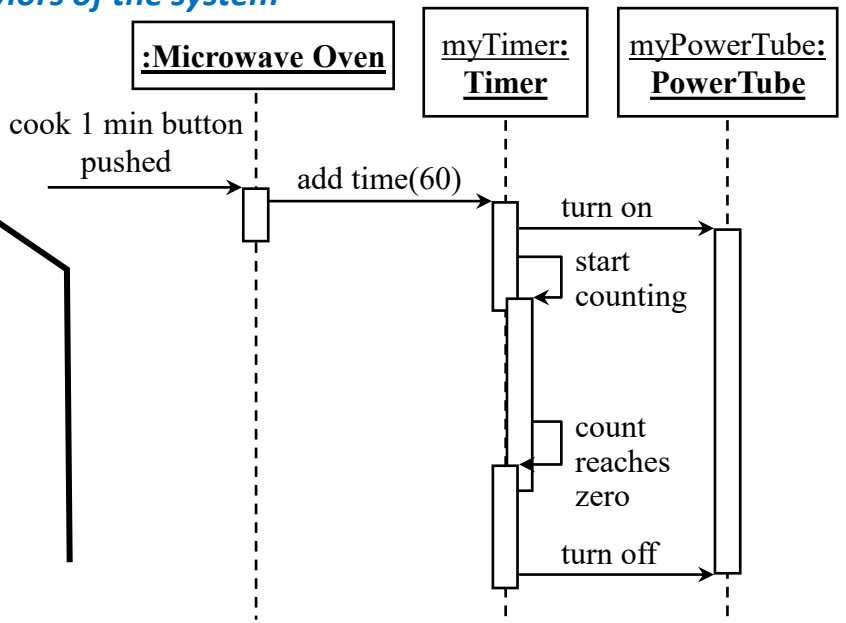
Class diagram

A picture of the static structure of the system



Sequence diagram

A diagram of one of the dynamic behaviors of the system



Categories of heuristics

- Arthur Riel's heuristics are organized into several categories:

Easy 1. Classes and objects: the basic structure of the building blocks of OO architecture

Easy 2. Object oriented "topology" (versus action-oriented topology): creating decentralized architectures

Mid 3. Designing the pattern of collaborations within a system of objects

Hard 4. The inheritance relationship: creating variations or extensions of an existing class

Easy 5. Miscellaneous heuristics: multiple inheritance, associations, use of class data and operations, and physical design considerations

Some important “basic” heuristics

- Arthur Riel’s heuristics covers some important object oriented basics:
  - Make all class data “private”
    - H2.1: All data should be hidden within its class.
  - Maintain a simple interface to a reusable class/module
    - H2.2: Users of a class must be dependent on its public interface, but a class should not be dependent on its users.
  - Don’t make a class too complicated
    - H2.6: Don’t clutter the public interface of a class with things that the user of a class can’t use, shouldn’t use, or probably won’t be interested in using.
  - Don’t mix multiple abstractions in a single class
    - H2.8: A class should capture one and only one key abstraction.

Encapsulation

- H2.1: All data should be hidden within its class.

```
class Point { /* C++ example */
private:
   int x_coordinate;
   int y_coordinate;
public:
   void setposition(int x, int y) {
      x_coordinate = x;  y_coordinate = y;
   }
   void moveposition(int delta_x, int delta_y) {
      x_coordinate += delta_x;  y_coordinate += delta_y;
   }
   int getx() const {
      return (x_coordinate);
   }
   int gety() const {
      return (y_coordinate);
   }
};
```

Data is "hidden" as private data attributes – we don't want the data to be public

Modifier

Modifier

Accessor

Accessor

In the public section of the class, we have "accessor" and "modifier" functions to be used by others

Encapsulation == we must use the public interface to read and write data

Encapsulation

Encapsulation in Java!!

- H2.1: All data should be hidden within its class.

```
public class Point { /* Java example */
  private int x_coordinate;
  private int y_coordinate;

  public void setposition(int x, int y) {
    x_coordinate = x;  y_coordinate = y;
  }

  public void moveposition(int delta_x, int delta_y) {
    x_coordinate += delta_x;  y_coordinate += delta_y;
  }

  public int getx(){
    return (x_coordinate);
  }

  public int gety(){
    return (y_coordinate);
  }
}
```

Modifier

Modifier

Accessor

Accessor

Data is "hidden" as private data attributes – we don't want the data to be public

In the public section of the class, we have "accessor" and "modifier" functions to be used by others

Encapsulation == we must use the public interface to read and write data

Encapsulation

Encapsulation in Python!!

- H2.1: All data should be hidden within its class.

Initialization

```
class Point:
  def _ _init_ _(self):
    self._ _x_coordinate = 0
    self._ _y_coordinate = 0
```

Data is "hidden" as private data attributes – we don't want the data to be public

Modifier

```
def setposition(self, x, y):
  self._ _x_coordinate = x;  self._ _y_coordinate = y
```

Modifier

```
def moveposition(self, delta_x, delta_y):
  self._ _x_coordinate += delta_x
  self._ _y_coordinate += delta_y
```

Accessor

```
def getx(self):
  return self._ _x_coordinate
```

Accessor

```
def gety(self):
  return self._ _y_coordinate
```

We have public "accessor" and "modifier" functions to be used by others

Python naming convention for data hiding: attributes beginning with two underscores are "private"

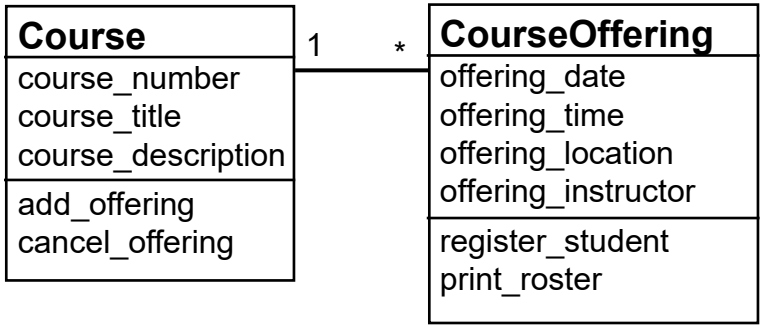
Encapsulation == we must use the public interface to read and write data

Keep the public interface clean

- H2.6: Don't clutter the public interface of a class with things that the user of a class can't use, shouldn't use, or probably won't be interested in using.

```
class Course {
private:
    string course_number;
    string course_title;
    string course_description;
    vector<CourseOffering*> course_offerings;
public:
    Course(string cnum, string ctitle, string cdesc);
    void add_offering(CourseOffering *coffering);
private:
    Course *find_position_to_insert(CourseOffering *coffering);
};
void Course::add_offering(CourseOffering *c)  {
    Course *insert_pos =
        find_position_to_insert(c);
    if (position_to_insert != 0) {
        course_offerings.insert(insert_pos, c);
    }
}
```

Maintain a sorted list of all offerings for this course



This private function is a helper function – it will search for the position to insert the new CourseOffering object into the list.

It would be a mistake to make it a "public" function, because external users of the Course class should never need to call it…

- "ordering" of the list is an Internal Secret

Action oriented program

- What is an “action-oriented” program?
  - the application has *centralized control* – there is a single main procedure that is “in command” of the control flow
  - the application’s data may be *shared* between many different procedures
- Action-oriented programs don’t always evolve gracefully...
  - watch for “accidental complexity”
  - accidental complexity ==
    complexity that is due to the structure of the implementation rather than the structure of the problem
  - when we add new functionality to an already-designed system, we often create accidental complexity

Action-oriented =>
maintenance problems

Action oriented program

- Main program controls everything

```
/* Main program – it gives orders to all of the function */
int main(int argc, char **argv) {

    initialize_data_structures();
    open_main_database();

    connect_to_external_system_1();
    connect_to_external_system_2();
    connect_to_external_system_3();

    verify_connections();

    while (forever) {
        display_user_interface_screen();
        req = receive_user_request();
        update_database(req);
        send_message_to_external_system(req);
    }
};
```

If any new internal structures are needed, or if we need to connect to a new external system, we must update the main program.

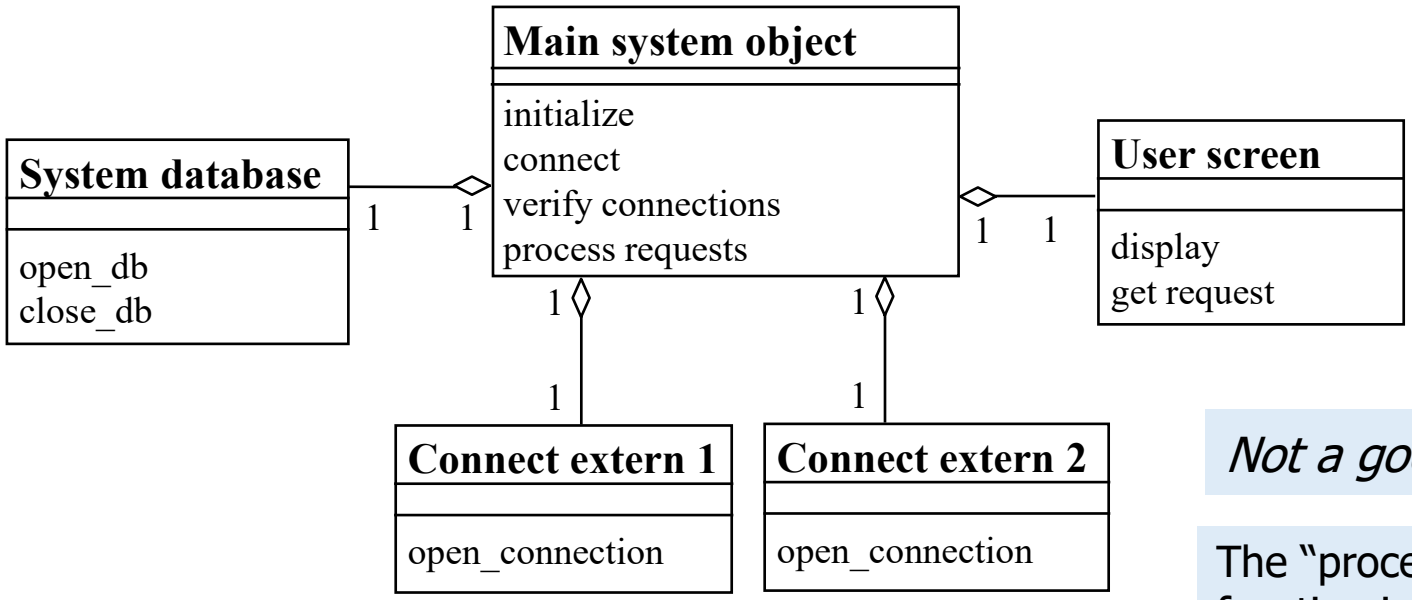
Every critical event must pass through the main program.

Lower-level functions may update global data structures and the database – with no constraints.

Big maintenance headaches…

Object oriented software

- Object oriented software design says: "define classes"
  - the design attempts to group together each important data structure and the operations that manipulate it into a single class
  - ***but***: just because a design is "object-oriented" (the design is composed completely of classes) doesn't mean that it is automatically "good"
  - an application might be superficially object-oriented, while still having the structural problems of an action-oriented application



Not a good design!

The "process requests" function is still huge!

Two design problems

- the “god class” problem
  - one class controls everything
- the “proliferation of classes” problem
  - the functionality is spread out over too many small classes

We want our classes to be “balanced”

Some heuristics

These heuristics are from Chapter 3 of Riel's book:

- When you develop the main functionality of a system, use multiple classes
  - H3.2: Do not create god classes/objects in your system.
  - A "god class" is a class that has a "concentration" of data or functionality
- Watch out for classes with many "get" and "set" operations
  - H3.3: Beware of classes that have many accessor methods defined in their public interface. Having many accessor methods implies that related data and behavior are not being kept in one place.
- Avoid big classes that "combine" multiple abstractions
  - H3.4: Beware of classes that have too much noncommunicating behavior (operations that operate on a proper subset of the data members of a class).

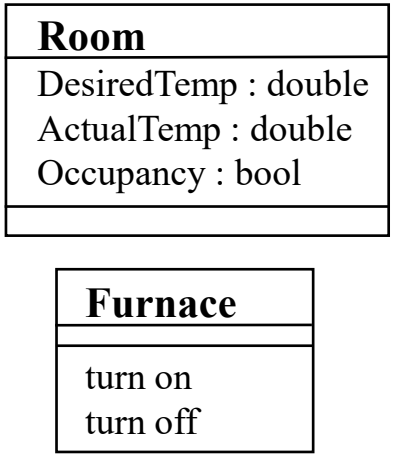
Central control versus object design

- These three heuristics might be violated when a designer:
  - has a centrally-controlled architecture in mind at the beginning of the design process, and
  - tries to maintain that centrally-controlled structure during the initial design of the main classes in the system.
- What's going on?
  - The designer is still thinking in the action-oriented paradigm
  - But the designer is trying to recast the design in object-oriented terminology (without really making the transition to an object oriented architecture)

Central control: code updates can be complex

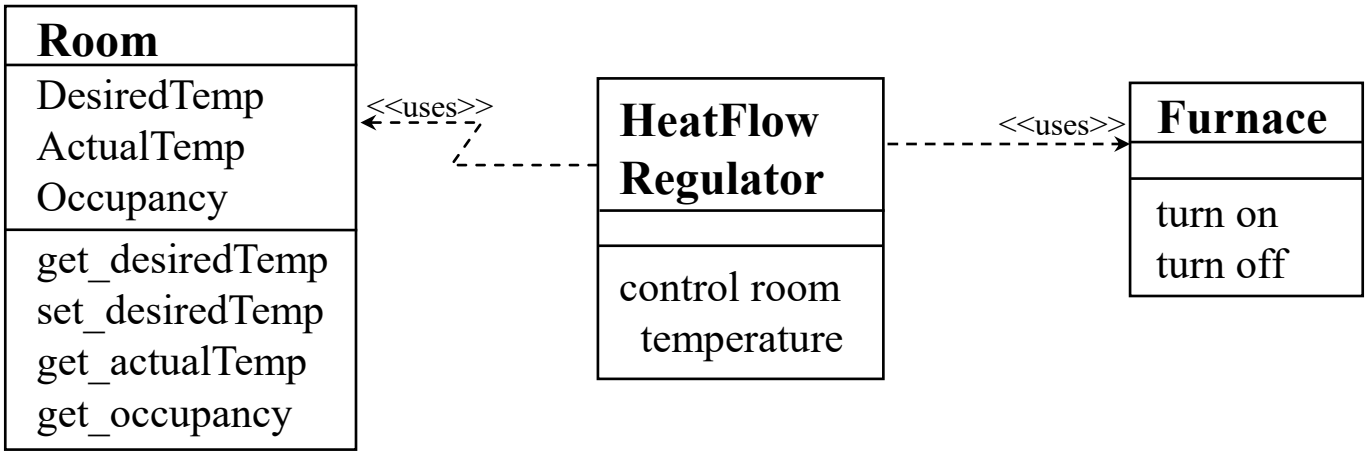
Example

- Arthur Riel's home heating system example (an object oriented design with poor distribution of behavior):
  - The system has two main physical classes: **Room** and **Furnace**
    - **Room** has three important attributes:
      - the current temperature in the room (ActualTemp)
      - the thermostat setting for the room (DesiredTemp)
      - whether the room is currently occupied (Occupancy)
    - **Furnace** can be turned on and off.
  - We introduce a new class called **HeatFlowRegulator**:
    - **HeatFlowRegulator** mediates between the **Room** and the **Furnace**.
    - It calls on the services of the **Room** class
      - It checks on the values of DesiredTemp, ActualTemp, and Occupancy
      - It performs some computations
      - Then it invokes operations on **Furnace** (if needed)



Example (continued)

- Initial ("god class") version of the home heating system



Questions about the example

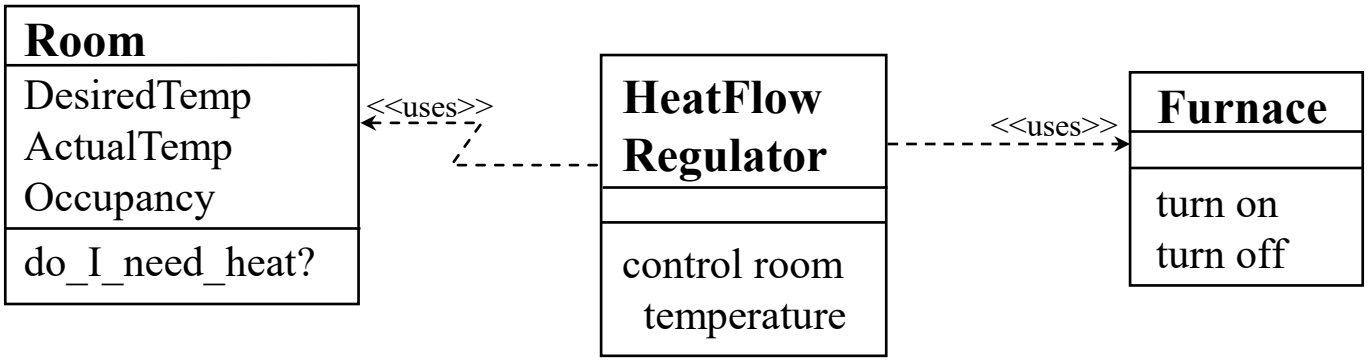
- Is this system “object-oriented”?
  - Sure, because we have put all of the data and control into classes.
- Are there problems with this design?
  - Yes. The **HeatFlowRegulator** is a “god class”.
  - It is the “omnipotent controller” that pulls in all of the information needed to make a decision, and then calls all of the operations that affect the physical objects.
- Is there a better way?
  - Eliminate the “god class” by making the **Room** smarter.

We are going to change the “distribution of responsibilities”

The Room class will be “smarter”

Questions about the example

- Improved version of home heating system
  - Let the **Room** do the computation to determine whether it needs heat.
  - This makes the **HeatFlowRegulator** class much simpler
  - It only needs to call the **Room::do_I_need_heat?( )** function (instead of all of the other accessor functions), so it doesn't depend so much on the structure of the information in **Room**.



Is this a better design? What do you think?

Distribution of functionality

- There are many different kinds of classes in a big system
- And, of course, a system may be designed to use a collection of dumb lower-level classes
  - classes that provide specialized services such as hardware interfaces, formatting of data, database access, and so on
- But in most good object oriented systems, the designers can point to several classes in the design that are “peers”
  - and there ought to be a good distribution of intelligence among these classes
  - *not* just one big god class

Is the Room class a fundamental part of the home heating system design? Or should it be a “dumb lower-level class”? What do you think?

What is a god class?

- A “god class” indicates that there is a poor distribution of responsibility:
- Some discussion questions:

Is a god class good or bad?

Good for building the initial design quickly?

Bad for long-term maintenance? Difficult to implement clean modifications and extensions?

What do you think?

Heuristics to detect god classes

- A warning sign that you might have a god class:
  - H3.3: too many get and set operations
    - If you are writing a class A that calls several get and set functions in another class B, you might ask the question: "What am I doing with the information that I am getting from class B, and why doesn't class B do it for me?"
  - H3.4: too much noncommunicating behavior
    - This is a sign of poor cohesion (the list of operations is not well-thought-out). You may have combined two or more classes into one.

```
… time to check the thermostat …
  myRoom.getDesiredTemp()
  myRoom.getActualTemp()
  myRoom.getOccupancy()
… Decide what to do …
```

In the first design, why did HeatFlowRegulator have to call three "get" functions? Room can do the calculations instead – this makes the HeatFlowRegulator simpler.

Definition of "noncommunicating behavior" is on the next page…

Noncommunicating behavior

- Problem: a small subset of the public member functions of the class are implemented only in terms of a small subset of the data attributes

```
class CustomerOrder {
private:
    string customer_name;
    string customer_billing_address;
    string customer_shipping_address;
    Money order_cost;
    vector<string> order_item_names;
    vector<Money> order_item_costs;

public:
    void set_customer_info(string name,
        string addr1, string addr2);
    void print_mailing_label() const;
    void add_new_item(string item_name, Money item_cost);
    void clear_all_items();
    Money get_cost() const;
};
```

A CustomerOrder record is an object that contains all of the information needed to prepare an order for shipment to a customer

We want to avoid "poor cohesion" (the list of operations is not well-thought-out)

Noncommunicating behavior

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   ....
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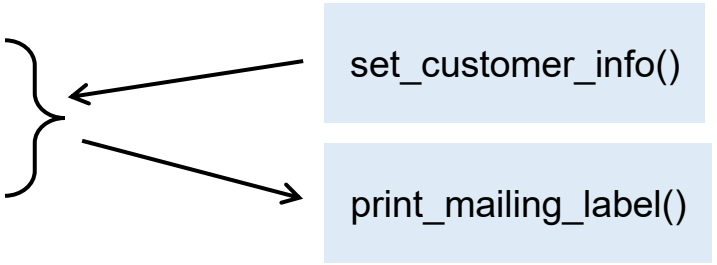

Note: these two functions only act on the "customer" information, not the "item" or "cost" information

Noncommunicating behavior

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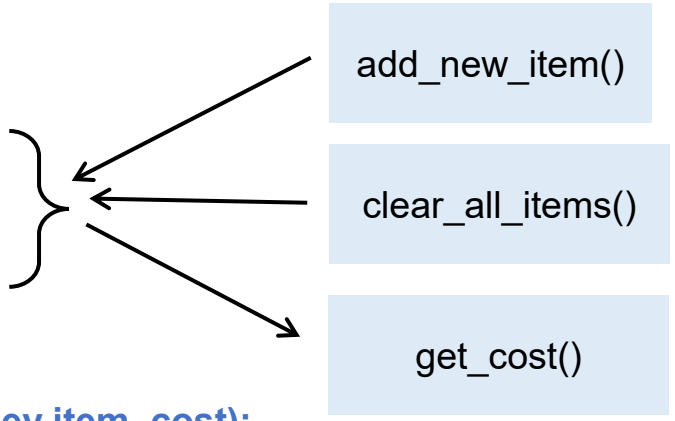


Note: these three functions only act on the "item" and "cost" information

How to fix non-communicating behavior: make smaller classes

- A Solution: The design can be improved by creating two new classes:

```
class Customer {
private:
   string name;
   string billing_address;
   string shipping_address;
public:
   Customer(string cust_name,
      string cust_billaddr,
      string cust_mailaddr);
   void print_mailing_label() const;
};

class Item {
private:
   string name;
   Money cost;
public:
   Item(string item_name, Money cost);
   Money get_item_cost() const;
};
```

- The new CustomerOrder class will now contain a Customer (by reference) and Items (by value):

```
class CustomerOrder {
private:
   Customer *cust;
   vector<Item> items;
   Money order_cost;

public:
   CustomerOrder(Customer *c);
   void add_new_item(const Item &it);
   void clear_all_items();
   Money get_cost() const;
};
```

Customer and Item are helper classes – do they make the design simpler and better? What do you think?

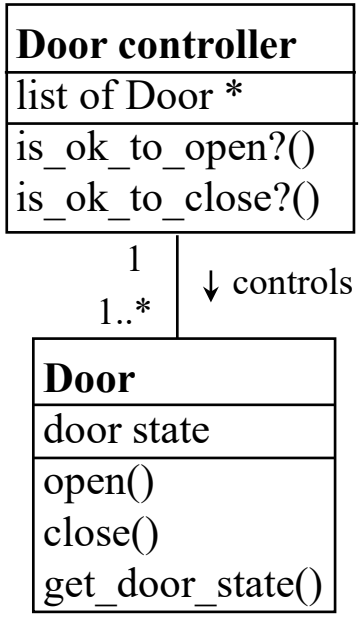
When to violate the noncommunicating behavior heuristic

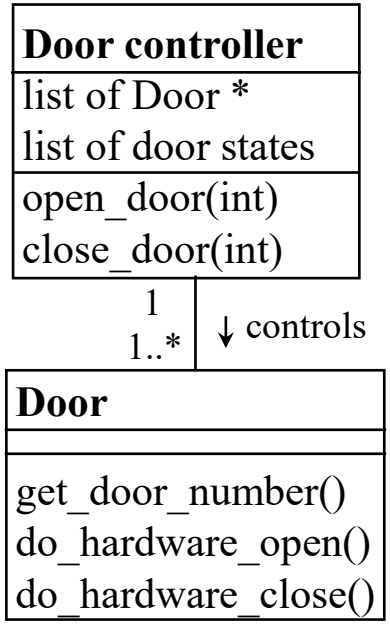
- This is a heuristic – not a rule
- Some classes just have a large number of attributes
  - but there are no logical classes that can be split off
- Creating many small classes can create performance problems in some environments
  - for example, Java classes that need to be downloaded from the Web
- When a designer decides to use a wrapper class approach, it is common to define a single class that describes a particular “interface” that communicates with other subsystems
  - this technique is commonly used with various forms of “component technology”

Example: Design of a Door system

- A simple design example – using design heuristics to evaluate two design alternatives
- In this system, there will be a set of Doors that are being controlled by a Door controller object. The Doors in this system might be the doors of a subway train, the doors of a supermarket, or the doors in a secure building.

Design 1:
Door controller is only responsible for policy

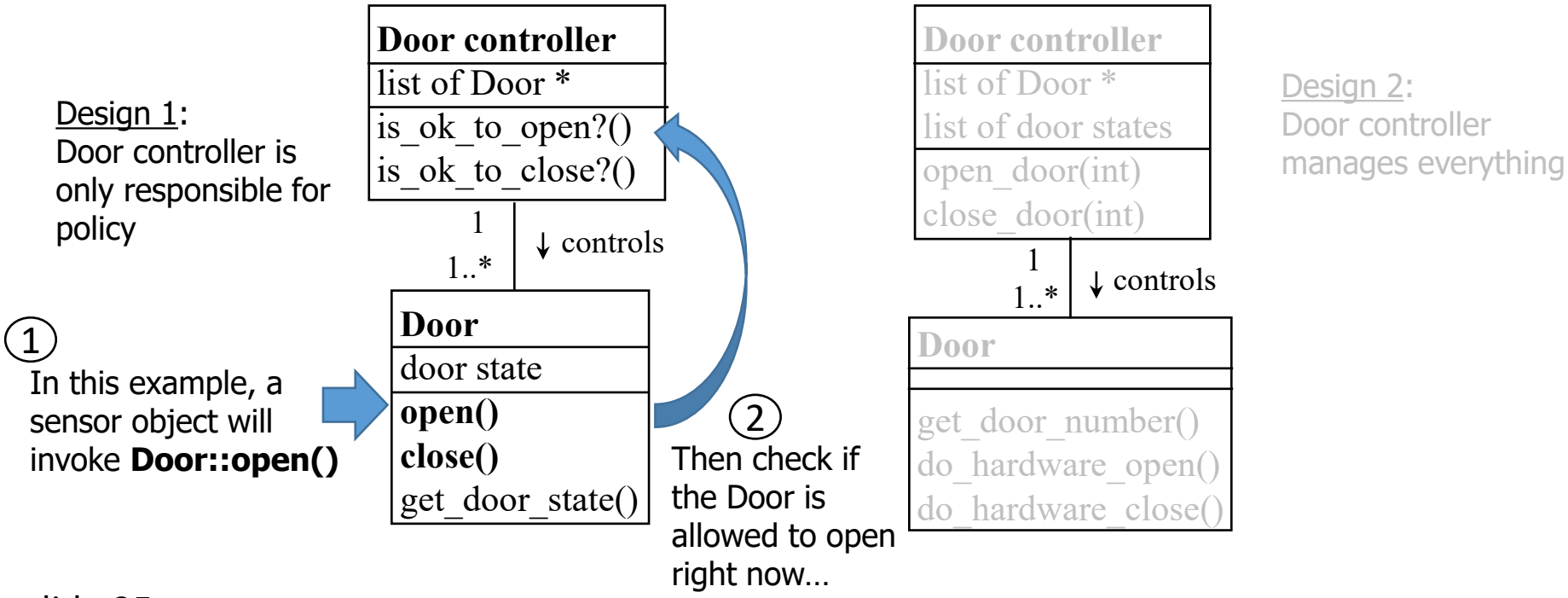




Design 2:
Door controller manages everything

Example: Design of a Door system

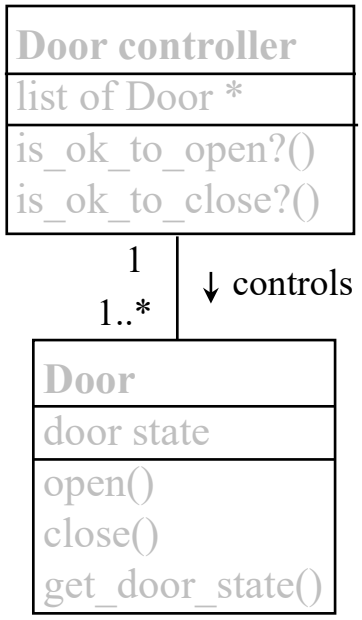
- In Design 1, the Door class provides the public interface.
  - User presses a button on the Door; the Door will ask the Door controller if it is OK to open; if it is OK the open() function will complete successfully
  - The Door controller needs to check the "rules" – can't open a train door unless the train is stopped and in a station…
  - Can't open the door of a secure building unless you have the access code or your ID is in the database



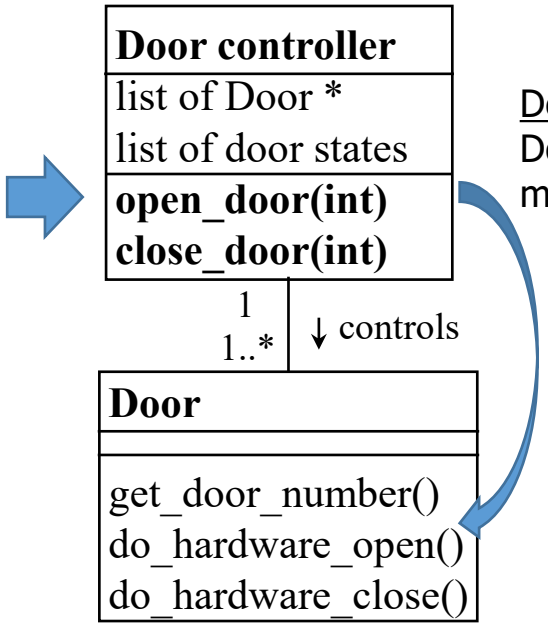
Example: Design of a Door system

- In Design 2, the Door controller class provides the public interface.
  - User sends a command directly to the Door controller; the Door controller checks its rules internally; if everything is OK, it will tell the Door to execute its do_hardware_open()
  - We can say that the Door controller is "directly controlling" each of the Doors

Design 1:
Door controller is only responsible for policy



① In this example, a sensor object will invoke **Door controller::open_door() – Door controller** checks the rules



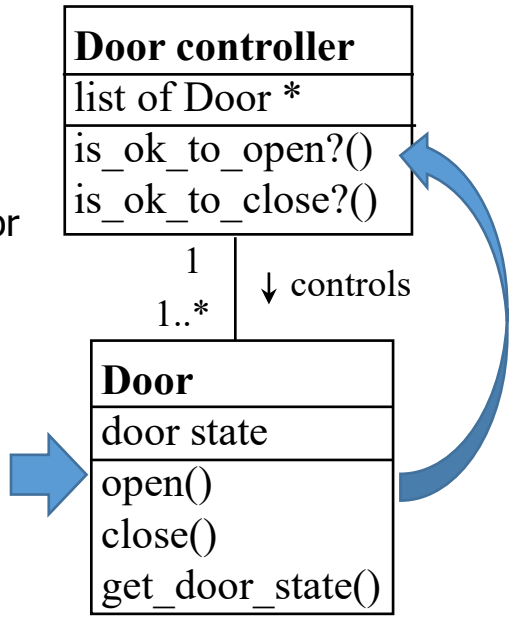
Design 2:
Door controller manages everything

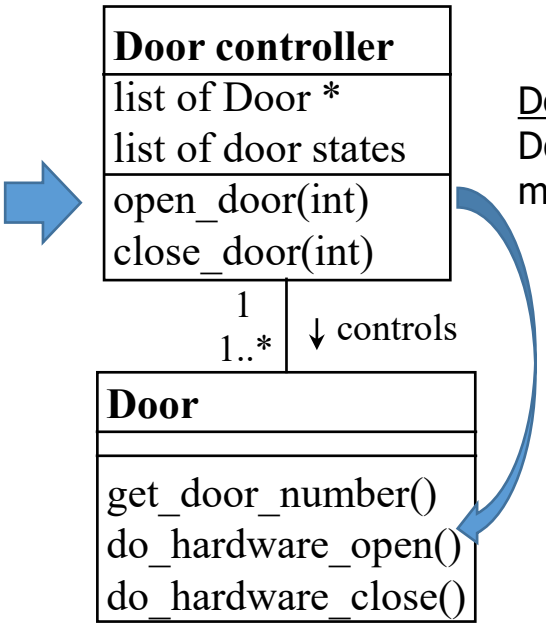
② **Door controller** delegates the low-level operation to the **Door** class

Example: Design of a Door system

- Question: Which of the two designs do you prefer?
  - It's your opinion – there is no "right" answer
  - How would you explain your preference in a design review meeting?

Design 1:
Door controller is only responsible for policy





Design 2:
Door controller manages everything

Some possible arguments for each design

- Why is Design 1 better?
  - In Design 2, the Door controller is a “god class”
  - If we make changes to the Door class interface, Design 1 might be better
    - We could have many different models of Door, with different ways for users to make requests: a button on the Door, a motion detector to sense the user moving towards the Door, a wireless interface to allow users to use their cell phones to request opening or closing a Door
    - Each variation could be a “subclass” of the Door class – the interaction with the Door controller is unchanged
- Why is Design 2 better?
  - In Design 2, the scenarios for opening and closing a Door are shorter (and maybe faster)
    - If performance or security is a concern, maybe it is OK to have a god class…
    - Some parts of the Door controller functionality might be built directly in hardware

Design 1 = more flexible; easier to extend

Design 2 = more secure; better performance

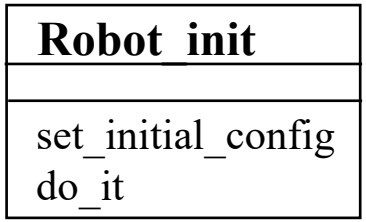
Heuristics are a good way to discuss design alternatives

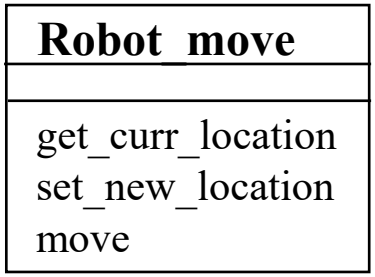
- We had two possible design alternatives for the Door controller
- In a design review, the participants need to talk about tradeoffs
  - When we see that our design has a god class, we might decide to change it – to keep the design flexible
  - On the other hand, if flexibility is less important than performance, we might choose the god class design – even though it violates one of the design heuristics
- Design heuristics are not absolute rules: they are guidelines that help us think about design alternatives
  - The heuristics are sometimes violated in designs that are considered good

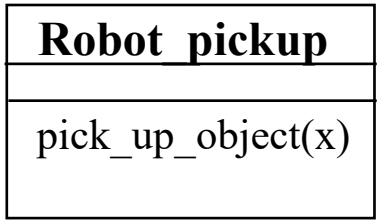
Heuristics help us "critique" a design

Don’t promote an operation into a class

- Before we leave the “distribution of responsibilities section, there is one more useful heuristic to help make a better design:
  - H3.9: Do not turn an operation into a class. Be suspicious of any class whose name is a verb or derived from a verb. Especially those which have only one piece of meaningful behavior (i.e. do not count sets, gets, and prints).
- This is a common pitfall for many software developers…
- Designing good classes can be difficult – “procedural thinking” often creeps into our design







Probably a violation of H3.9!

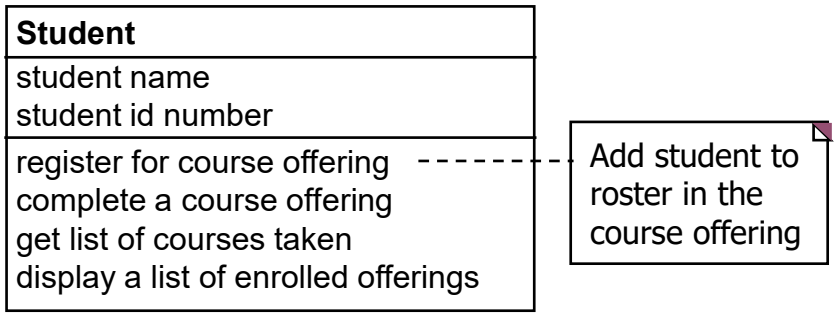
Don’t promote an operation into a class (cont.)

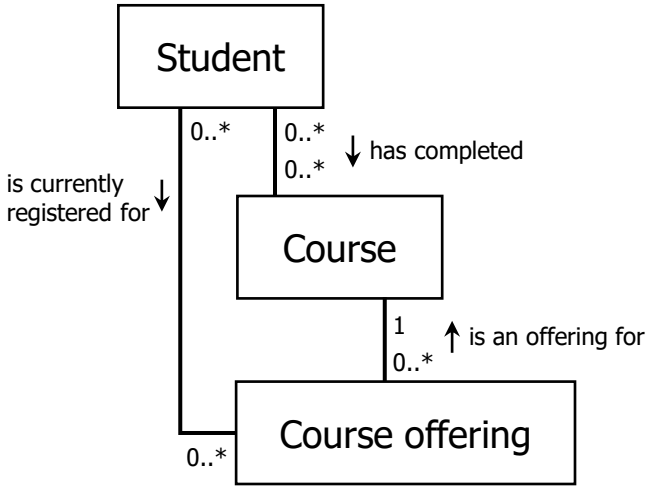
- An operation might be inadvertently promoted into a class when a designer asks the question:

“I need a class that does X”

- This isn’t an “object-oriented” view of a problem
- Most good classes have more than one public operation
- Each class “is” something (rather than “does” something)
  - You need to step back and ask yourself the question “which abstraction does this operation really belong to?” in order to avoid violations of Heuristic H3.9

Collaboration between classes





Student is the class that represents the information within the system contains relating to a specific student.

- How many Student objects will there be in the system??

The **operations** in the Student class will execute some of the scenarios are triggered by a human user of the registration system:

- Register for a course offering
- Get information about current and past courses

In order to execute these **scenarios**, a Student object will need to collaborate with other objects in the system: Course and Course offering objects.

- How do we find the right objects?

How to find the object to collaborate with

- Navigation within an object-oriented system
- How do you know which object to send a message to?
  1. the object may be a local object (an embedded attribute in the current object) [Container class]
  2. the object may be a parameter that was passed into the currently running operation (by name, value, or reference) [Parameter]
  3. the object may be found by requesting it from another object (for example, finding it in a map or within another data structure that the object knows about) [Special navigation object]
  4. the object may be a global object
  5. you might create a new local object to send the message to [Temporary object]
  6. the object may be pointed to by a local referential attribute [Association]
- Each one of these situations may occur in an object oriented design

Six ways to collaborate

- Example of the six ways to "find the collaborating object" (from Arthur Riel's book):

⇒Suppose you are a Car object and you want to collaborate with a Gas station to call the give_gasoline() operation:

1. **local embedded object** (a mini-gas station attribute within the current object – such as a "reserve gas tank")
2. **passed as a parameter** (someone called the Car's get_gasoline() function and passed as an argument the name and location of a gas station)
3. **requesting it from another object** (you have the name of the station, and you look it up in a data structure class to get an address or pointer)

Six ways to collaborate

- Example of the six ways to "find the collaborating object" (from Arthur Riel's book):

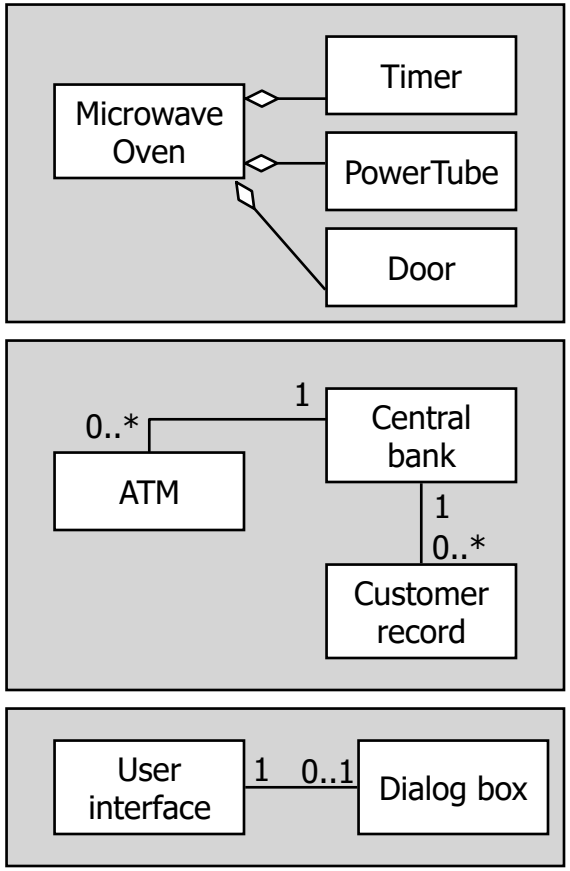
⇒Suppose you are a Car object and you want to collaborate with a Gas station to call the give_gasoline() operation:

4. **global object** (only one gas station, and everyone knows where it is)
5. **create a new local object** (whenever you need gas, you build a gas station on the spot, get gasoline from it, and destroy it when you're done)
6. **a local referential attribute** (when the car is built or sold, it contains a pointer that has been initialized to the right gas station to go to for gas – the car dealer gives you a discount card for a specific local gas station)

Collaboration examples

How to find the object to collaborate with??

- Internal
  - a **Microwave Oven** sets its **Timer** to 1 minute (and **Timer** is contained within the **Microwave Oven**)
  - Collaboration with an "internal component"
- Search
  - an **Automated Teller Machine** asks the central bank for a **Customer record** so it can verify the id number
  - Ask a well-known global object to help navigate to the right object to collaborate with
- Temporary
  - a **User interface** object may create a temporary **Dialog box** object to display a warning message
  - Creating a special temporary object



Some collaboration heuristics

These heuristics are from Chapter 4 of Arthur Riel's book:

- H4.1: Minimize the number of classes with which another class collaborates.
- H4.2: Minimize the number of message sends between a class and its collaborator.
- H4.3: Minimize the amount of collaboration between a class and its collaborator, that is, the number of different messages sent.

Riel makes two observations about this set of heuristics:

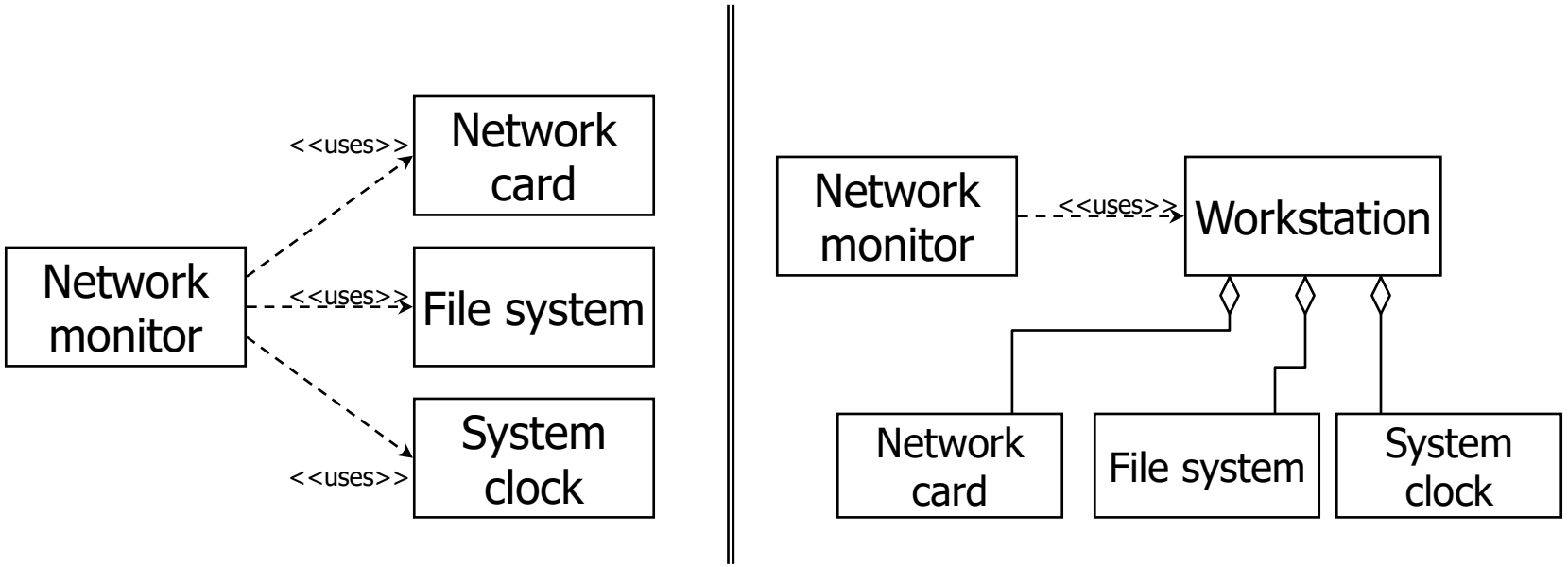
- Heuristic H4.1 is the most important of the three: the main factor in the "complexity" of a class is the number of other classes it needs to use
- It is silly to set absolute limits for each of these metrics: it is better to exercising good judgment rather than blindly following an absolute rule

Controlling complexity

- We use these three heuristics to help make the design simpler…
- These three heuristics might be violated when a designer:
  - creates mega-classes with large numbers of unrelated responsibilities
  - creates a behavioral god class, which requires other classes to abdicate their responsibilities to the central class
  - breaks up a class too far, so that many of the algorithms require continually requesting information from another object
- The designer is trying to create a set of cooperating classes, but the set of services offered by each class may be poorly coordinated with the other classes in the design.

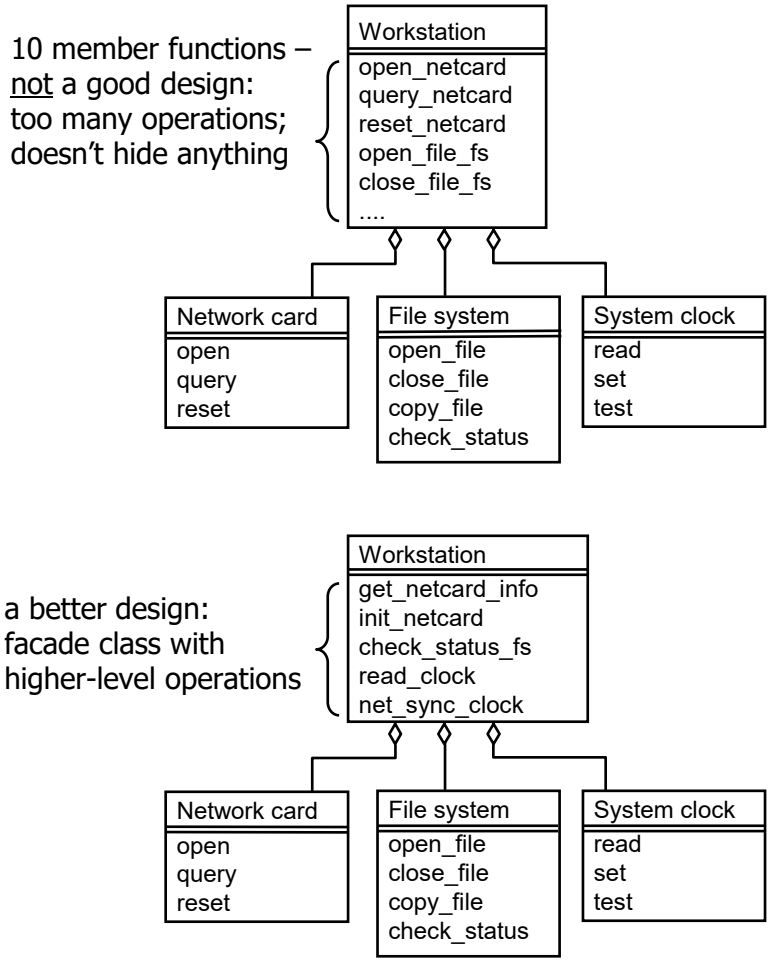
Using containment

- One way to simplify the “uses” (“collaborates with”) relationships in a design is to combine several objects into a single aggregate object:



Containment plus some abstraction

- If you create an aggregate object in your design, you might put all of the public operations in the contained classes into the aggregate object
  - not a good practice
  - we are providing too much detailed information to other classes – there is a good chance that we might create a god class
- A better idea is to do a little bit of abstraction
  - the only public functions in the **Workstation** class will be the information that needs to be fed to the **Network monitor**
- This is the Facade pattern (from the *Design Patterns* book)



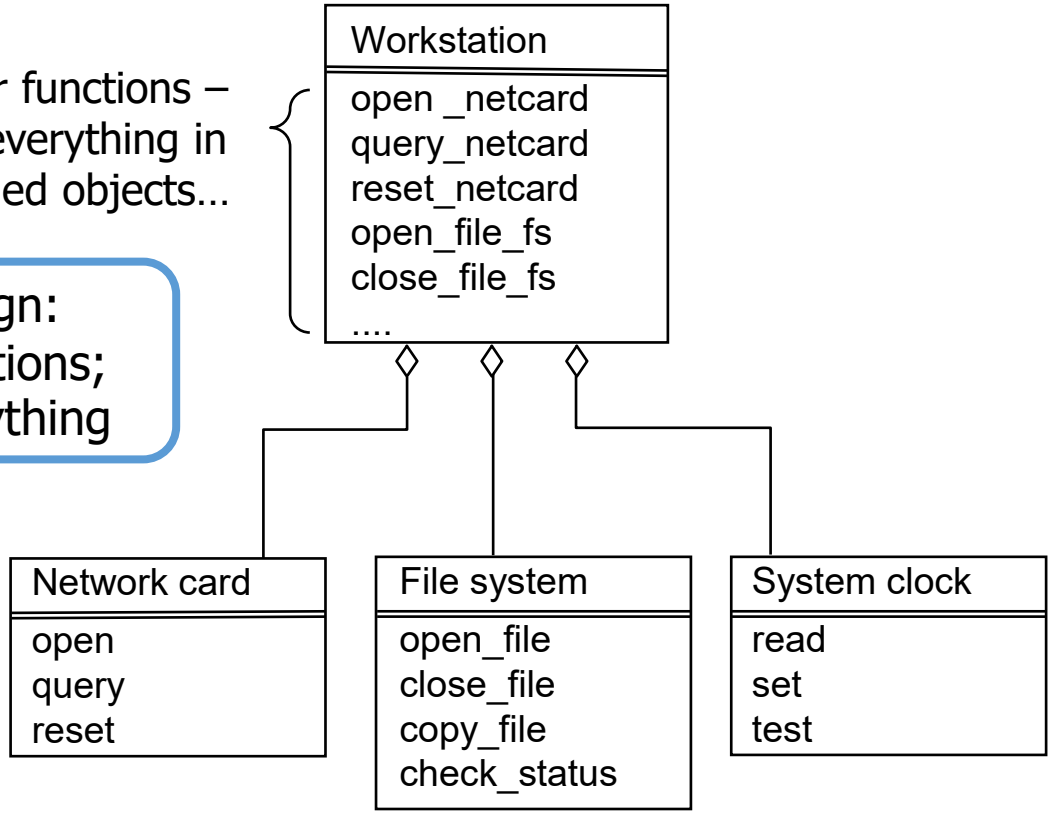
Facade class public interface should "raise the level of abstraction" – don't repeat all primitive operations

Containment plus some abstraction

- A closer look…

10 member functions – repeating everything in the contained objects…

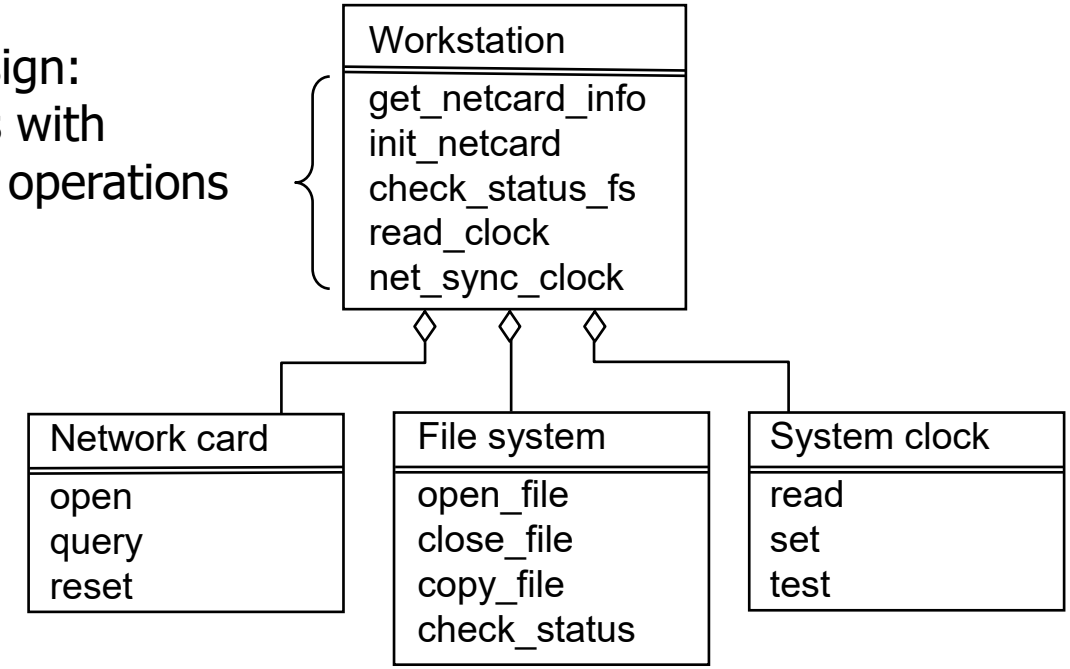
Not a good design: too many operations; doesn't hide anything



Containment plus some abstraction

- A closer look…

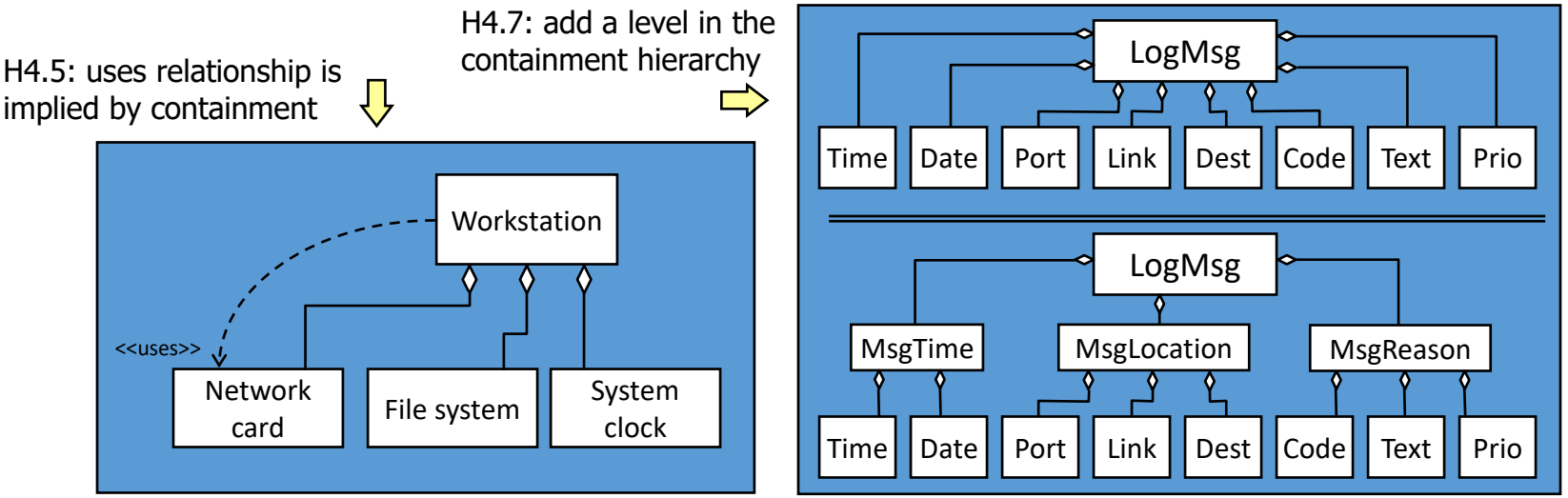
a better design:
facade class with
higher-level operations



The top level is a simpler API (smaller interface)

Heuristics related to containment

- Here are two more collaboration heuristics:
  - H4.5: If a class contains objects of another class, then the containing class should be sending messages to the contained objects, that is, the containment relationship should always imply a uses relationship.
  - H4.7: Classes should not contain more objects than a developer can fit in his or her short-term memory. A favorite value for this number is six.

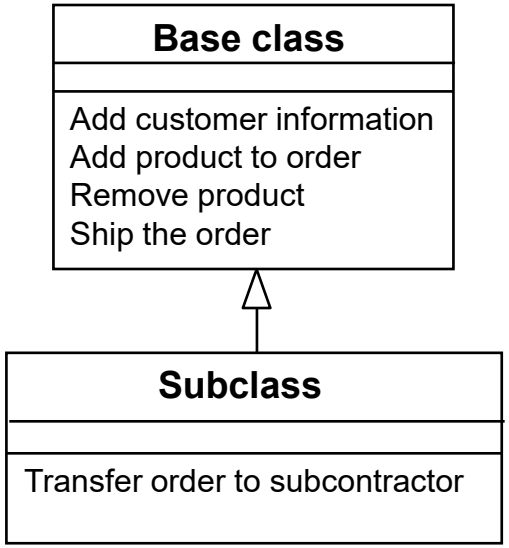


Heuristics related to containment

- “Use Containment” – to build complex software designs
  - Build the lower level components to be reusable
  - Minimize dependencies from “contained object” to “container”

Inheritance – four ways

- Inheritance (and "subclasses") is a useful way to define a group of related classes



A subclass "extends" the base class.
A subclass can add new operations
and it can redefine base class functions

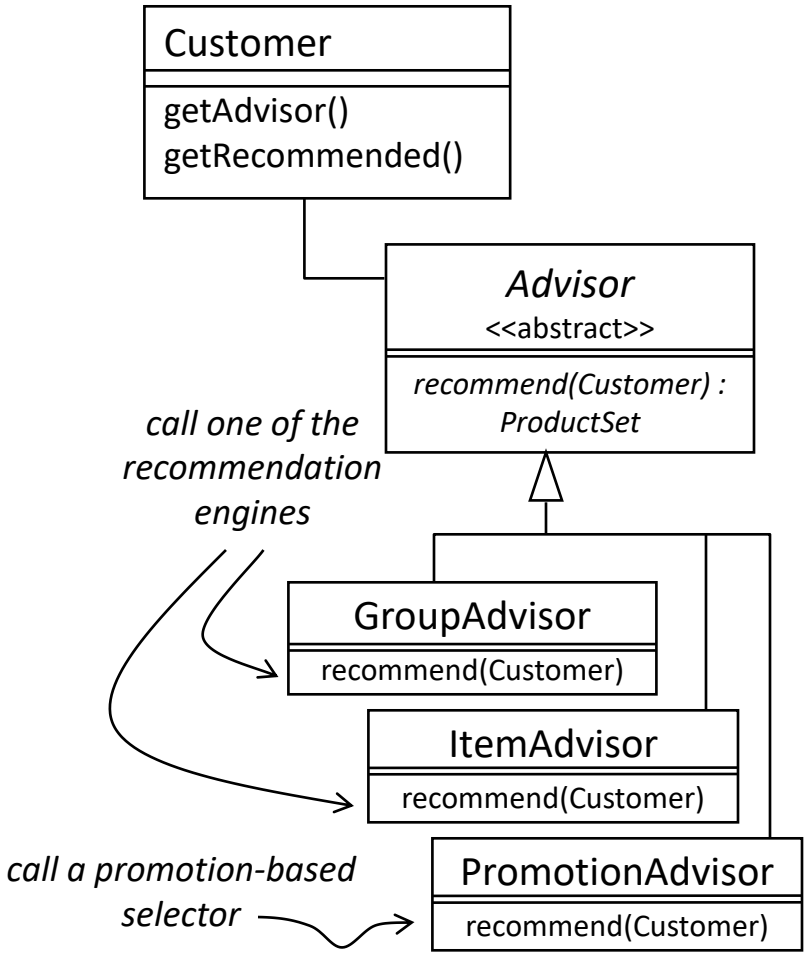
1. Many standard **Design Patterns** use inheritance as a mechanism to invoke "different behavior in different cases"
2. Many **software frameworks** require developers to build application-specific subclasses
3. **Commonality analysis**: Abstract interfaces can be defined to support the common behavior in multiple related classes
4. Inheritance to **extend the functionality** of a concrete class

Design Patterns

- Design Patterns are “bigger” than heuristics
- Design Patterns are used to “solve design problems”
- They describe the “design structure” and the “set of collaborations” between a small group of modules
  - In object oriented design patterns, the modules are “classes”
  - And in many patterns, the classes are “subclasses” of an abstract base class
  - We will talk about the Strategy pattern (very simple), Facade pattern (also very simple), and the Observer pattern (a bit more complicated, but it is used a lot!)
- Note: when we use these design patterns, we don’t just “make function calls to a library” – we need to build some classes that follow the pattern…

Strategy pattern

- **<u>Problem</u>: An application needs to use a family of similar algorithms**
  - the selection of which algorithm depends on the client making the request or some characteristics in the data
- **<u>Solution</u>: Define a family of algorithms, encapsulate each one, and make them interchangeable**
  - there will be a family of classes, one per algorithm variation

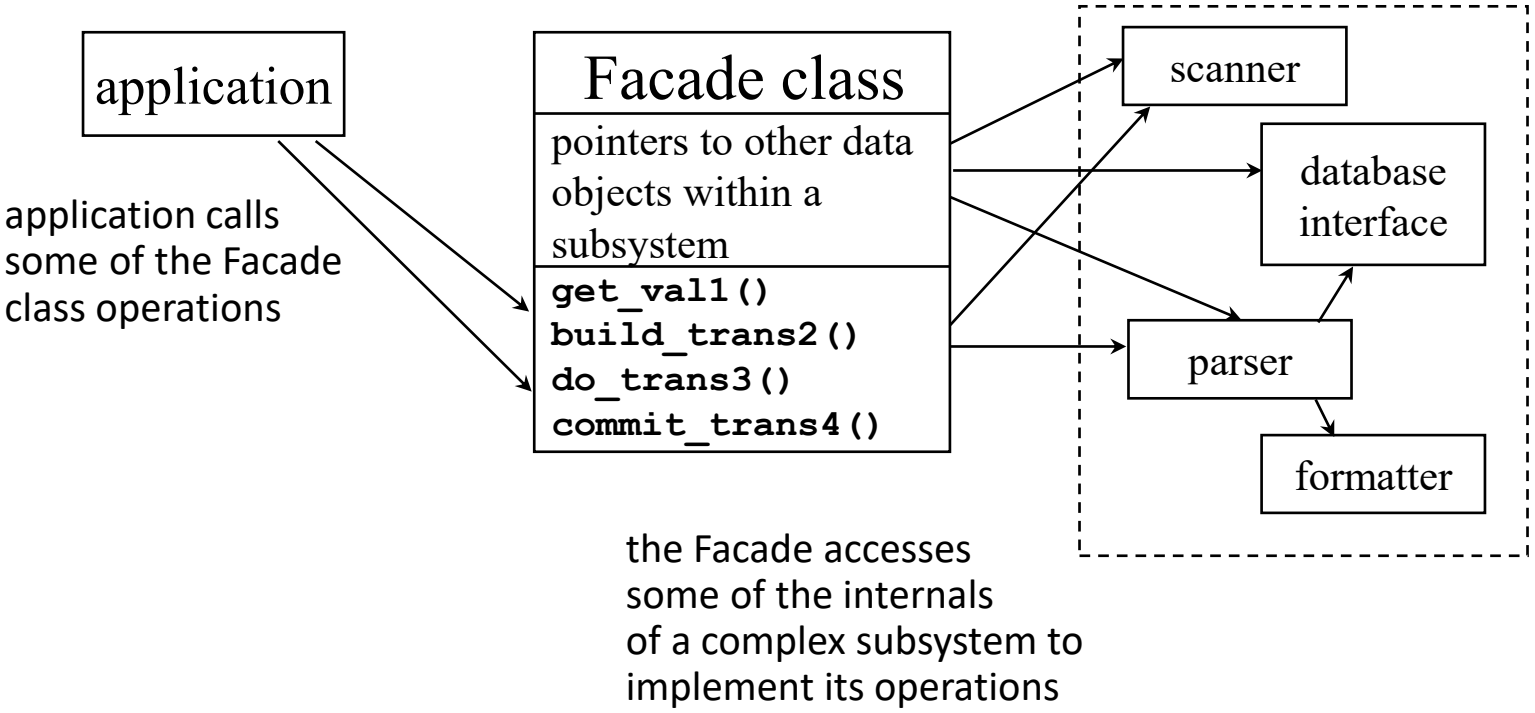


Example: Each subclass contains **<u>a different implementation</u>** of the "abstract" recommend function – the function uses information in the Customer class to build a set of recommendations

- ***GroupAdvisor:*** *Use data from an "interest survey"*
- ***ItemAdvisor:*** *Use data from customer's previous purchases*
- ***PromotionAdvisor:*** *Seasonal choices*

Facade pattern

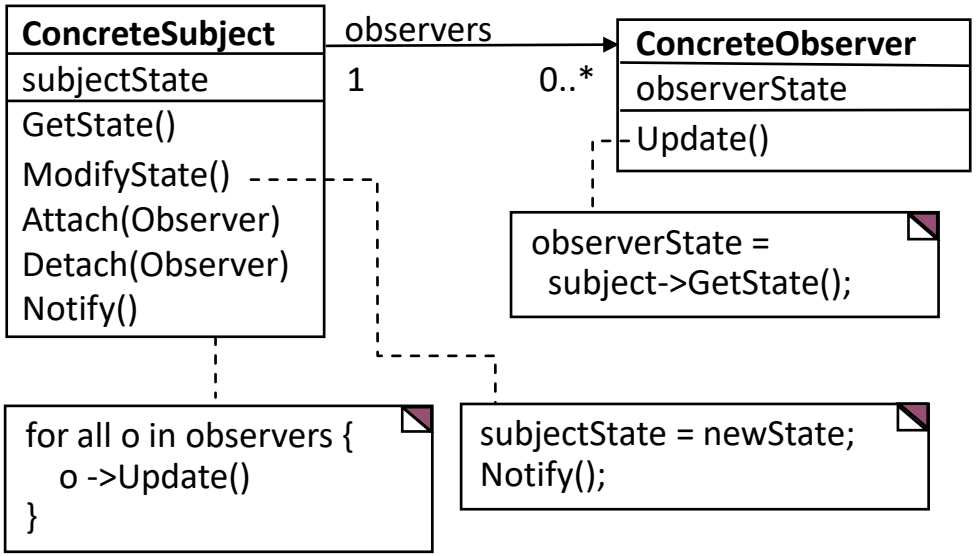
- **Problem**: The application needs a **simple interface** to a complex subsystem
- **Solution**: Create a Facade class provides a simple to use interface – the application developers only need to understand the interface, not the internal details



Observer pattern

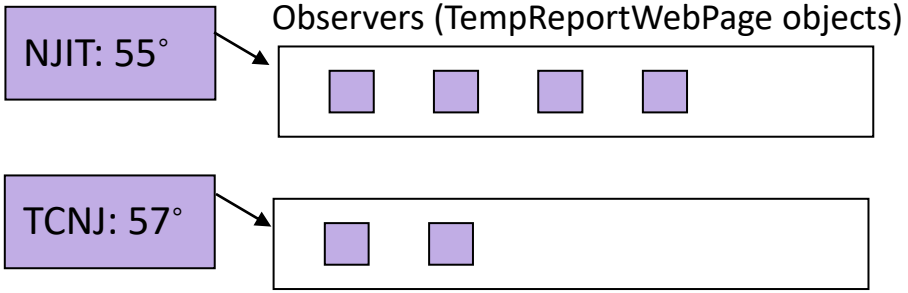
Observer's Update function is a kind of "callback"

- Subject classes contain changing data
- Any Observer object can "register for interest" with one or more Subject objects
- Each Observer object will have its Update() operation called whenever its subject changes state



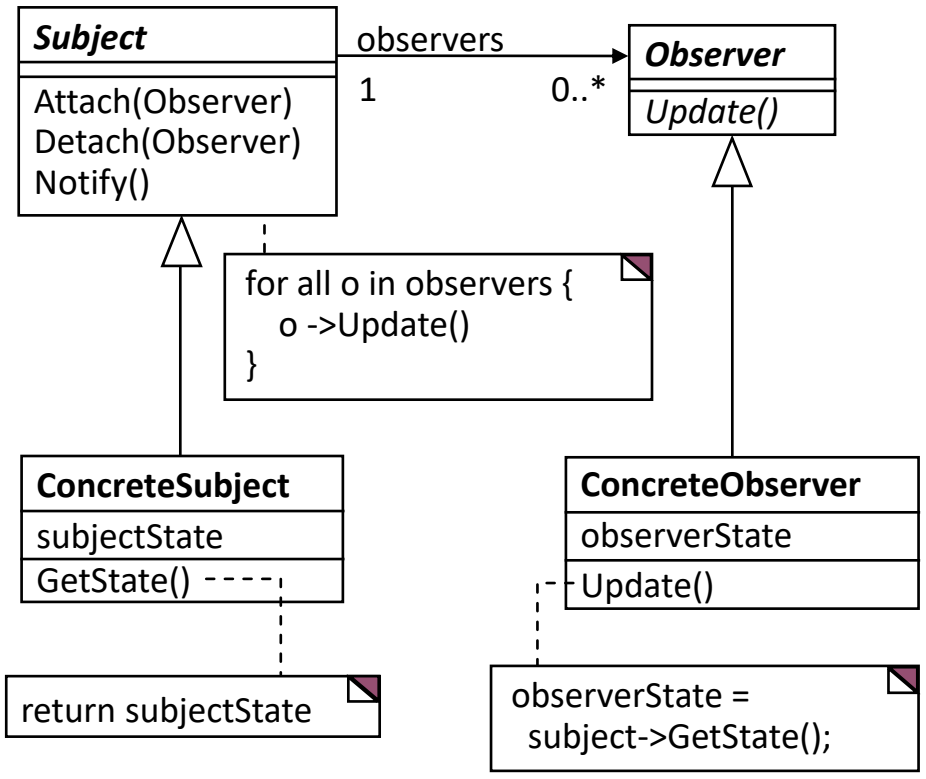
The Update() function can do many things: **trigger a real-world event**

- turn on air conditioning
- repaint a user screen
- send a message to another system



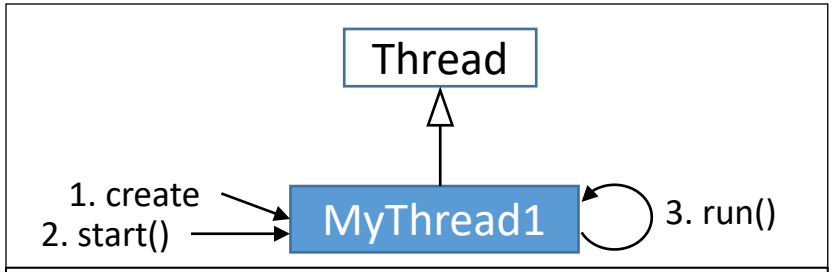
Complete class diagram for Observer

- **Observer** is an abstract interface that each **ConcreteObserver** must implement (must implement an Update() function)
- Observer objects still register by calling the Attach() operation on a **ConcreteSubject** object
- Each ConcreteObserver object will have its Update() operation called whenever its ConcreteSubject changes state



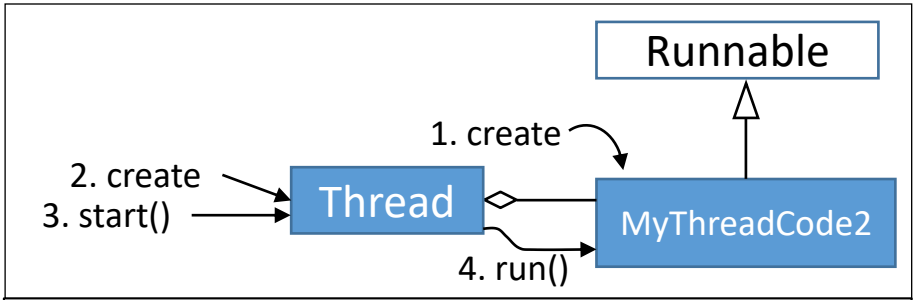
Inheritance and “callbacks” in frameworks

- In some programming languages and libraries, “building subclasses” is expected:
  - Your subclass needs to define certain functions – to call directly or to use as a “callback”
  - In Java: if you want to write code that runs in a separate thread, you must create a **class with a “run()” function**
  - Two options – inherit from Thread or implement Runnable:




```
class MyThread1 extends Thread {
  public void run(){
    System.out.println("thread is running...");
  }
  public static void main(String args[]){
    MyThread1 t1 = new MyThread1();
    t1.start();
  }
}
```

start() will make a “callback” to MyThread1.run()

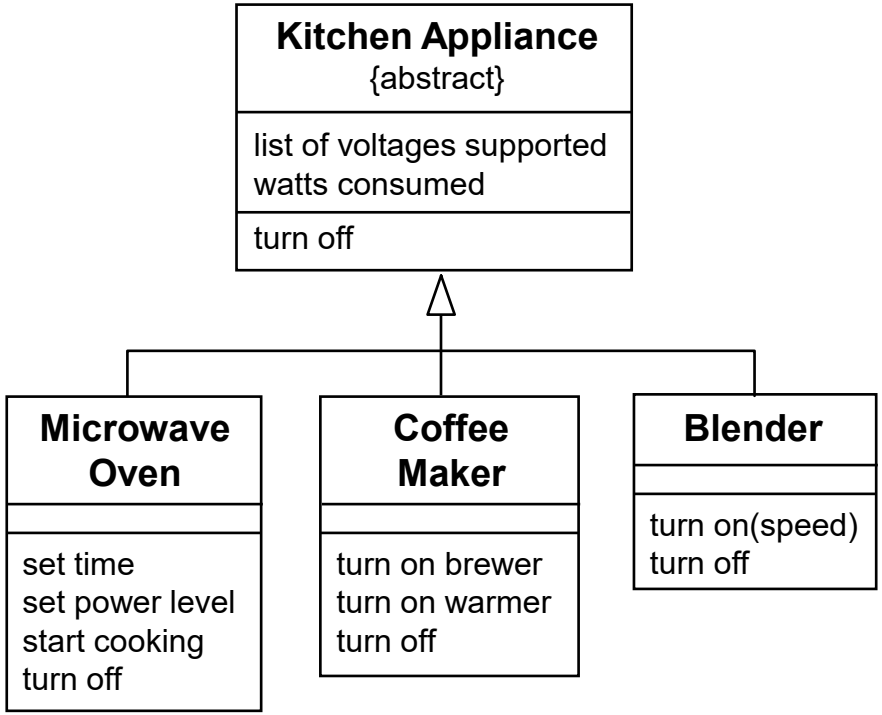



```
class MyThreadCode2 implements Runnable {
  public void run(){
    System.out.println("thread is running...");
  }
  public static void main(String args[]){
    MyThreadCode2 m1 = new MyThreadCode2();
    Thread t1 = new Thread(m1);
    t1.start();
  }
}
```

start() will make a “callback” to MyThreadCode2.run()

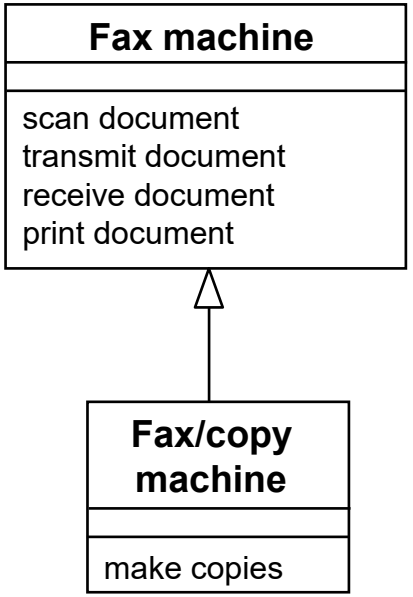
Two more ways to use inheritance

- To define…. **Families of similar classes** with some attributes and operations in common (often found in the initial analysis):



Note that Kitchen Appliance is "abstract" (just defines the common characteristics)

- To define…. **New classes** that are added to an existing design (by extending an existing concrete class):



Note that both Fax machine and Fax/copy machine are "concrete" classes

The most important inheritance heuristic

- The first heuristic in Chapter 5 of Arthur Riel's book:
  - H5.1: Inheritance should be used only to model a specialization hierarchy.
- H5.1 is a restatement of the Liskov Substitution Principle
  - Liskov Substitution Principle: Whenever you define a subtype, you should be able to safely substitute an object of the supertype with an object of the subtype.
  - In other words, although derived classes might have "extra" behavior, they must also implement the **full set** of base class behaviors.
- This principle is sometime called the "is-a" rule...
- This is a very important heuristic, because it affects other software designers that may want to add to an existing inheritance hierarchy
  - If you violate the "is-a" rule, existing code might be broken by the addition of new subclasses

Barbara Liskov, computer science professor at MIT, inventor of the CLU programming language (with support for "data abstraction" and subtyping)

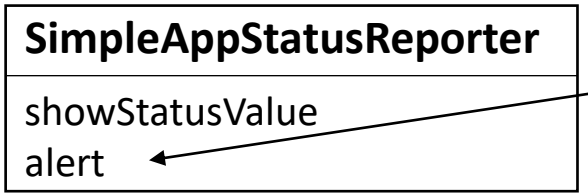
The “is-a” rule

The behavior of a subclass must conform to the superclass interface:

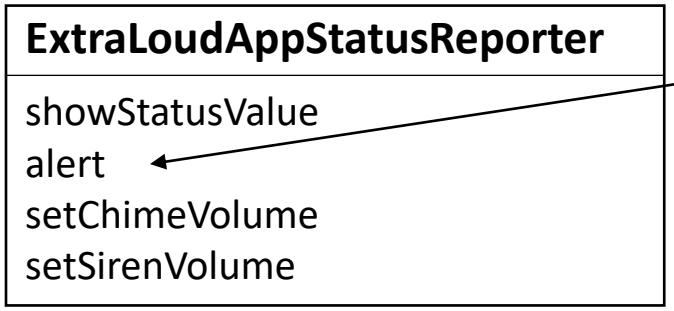
List of operations

- Each subclass has every operation that is defined in the superclass… but it is OK to add new functions to the subclass that aren’t supported by the superclass

Each of the subclass functions “expects no more, delivers no less”



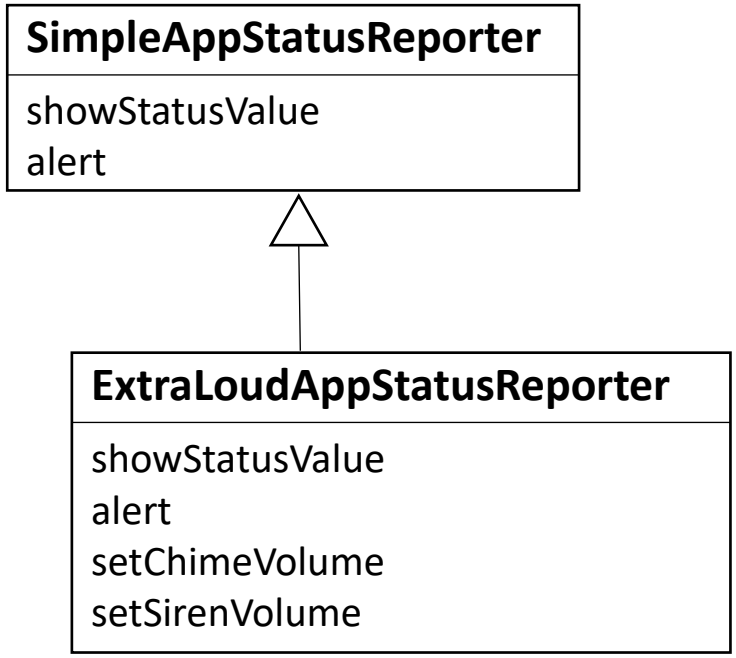
- The alert() function uses the current “volume setting”
- Postcondition: when alert() is done, phone volume setting is unchanged



- When alert() is called, the volume may be temporarily increased
- When alert() is done, phone volume setting is set back to the original volume

The “is-a” rule

Look carefully at each subclass function:



Preconditions

- The preconditions for any subclass operation are only allowed to be “weaker”
  - if a function operates on a **SimpleAppStatusReporter**, then it shouldn’t crash when we pass in an **ExtraLoudAppStatusReporter**

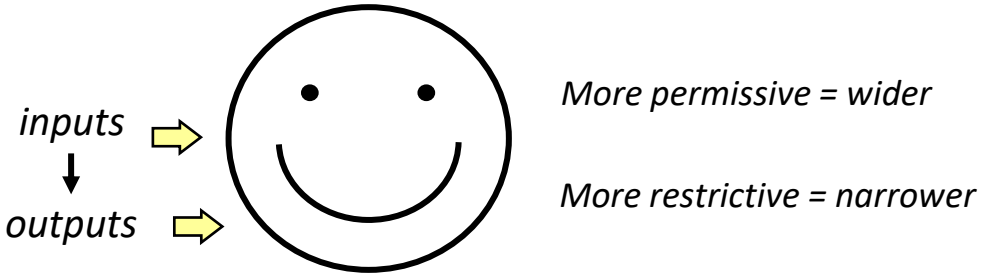
Postconditions

- The postconditions for any subclass operation are only allowed to be “stronger”
  - If **Simple** ends its “alert” operation with the device volume at the same level, then **Extra** should meet the same restriction
  - So calling “s.alert()” five times shouldn’t get progressively louder…

Smiley face – one way to check a subclass

For each function in the subclass that is a "redefinition" of the superclass function:

- compare the preconditions for the subclass function and the superclass function
  - wider means "more permissive precondition"
- compare the postconditions
  - narrower means "more restrictive postcondition"



Source: Elisa Banniassad, "Making the Liskov Substitution Principle Happy and Sad," https://2017.splashcon.org/event/splash-2017-splash-e-making-the-liskov-substitution-principle-happy-and-sad

Smiley face – one way to check a subclass

Let's do an example – can we substitute a SkateboardDeliveryPerson for a DeliveryPerson?

OK = wider preconditions, narrower postconditions

OK = preconditions and postconditions are unchanged

Not OK = narrower preconditions, wider postconditions

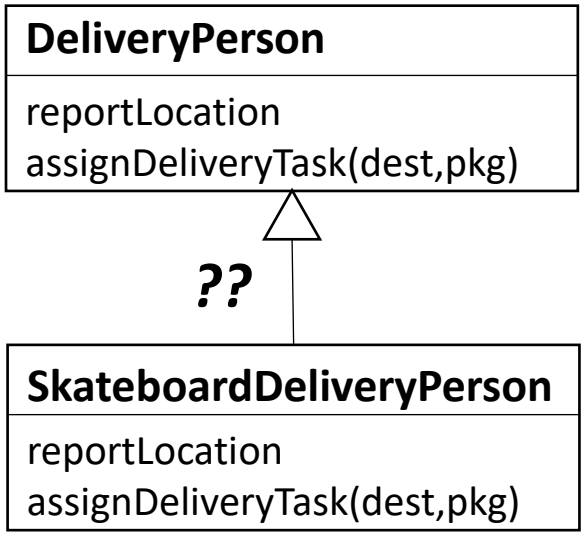
reportLocation

*For a Skateboard delivery, the **reportLocation** preconditions and postconditions are unchanged*

assignDeliveryTask

*For a Skateboard delivery, **assignDeliveryTask** precondition is narrower:*

- *5 pound weight limit for package*
- *Address must be within 3 miles*



Well… maybe this isn't a good subclass!

Violations of the is-a rule

- The most common violation of H5.1 is the use of inheritance to model a "has-a" relationship instead of an "is-a" relationship

```
public class Customer {
    private String cust_name;
    ....
}

public class CustomerOrder extends Customer {
    // this permits the Customer.getname() operation
    // to be invoked on a CustomerOrder object
    //  --- this is *not* a good design!! ---
    ....
}
```

Java example:

Notice that you won't get a compiler error for the CustomerOrder class. It is a "design-level" problem.

Complexity and inheritance depth

- Some thoughts on inheritance depth:
  - H5.4: In theory, inheritance hierarchies should be deep – the deeper the better.
  - H5.5: In practice, inheritance hierarchies should be no deeper than an average person can keep in his or her short-term memory. A popular value for this depth is six.
- This isn't an absolute rule: the warning flags should go up at six…

Arthur Riel's explanation for Heuristic 5.5 (page 84):

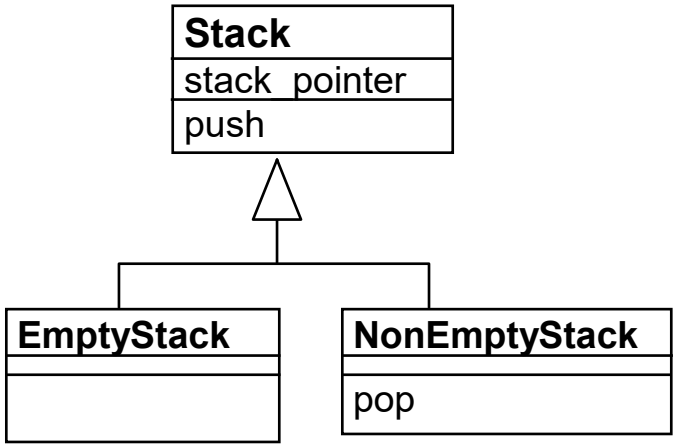
> "Developers get lost in the levels if the hierarchy is too deep. This problem can be partly alleviated with support from tools (tools that let you see the entire public interface from a class, including inherited operations)."

The problem with deeply-nested class hierarchies:

- there can be a big semantic difference between objects at different levels of the tree
- subclasses may have special internal states and complicated rules

Inheritance pitfalls

- One inheritance pitfall – defining several derived classes that are actually "states" of the main class:

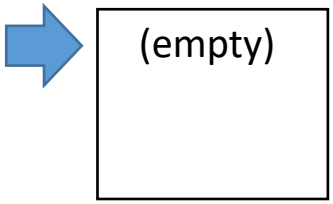


⇒ A **Stack** object gets created as a **EmptyStack** (so you can't pop it), but it becomes a **NonEmptyStack** after the first element is added – this is not a good design!

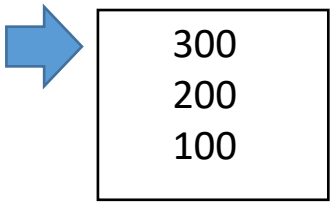
⇒ The problem is: in most cases, an object should never change its class.

How did stack1 turn into a NonEmptyStack?;

```
Stack stack1 = new EmptyStack;
```




```
stack1.push(100);
stack1.push(200);
stack1.push(300);
```



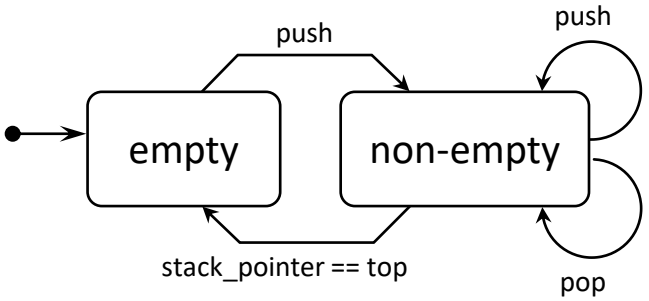
Correct way to model a stateful class

- The **Stack** class hierarchy can be collapsed into a single class by including a state model:

class model

Stack
stack_pointer cur_state
push pop get_state

state model

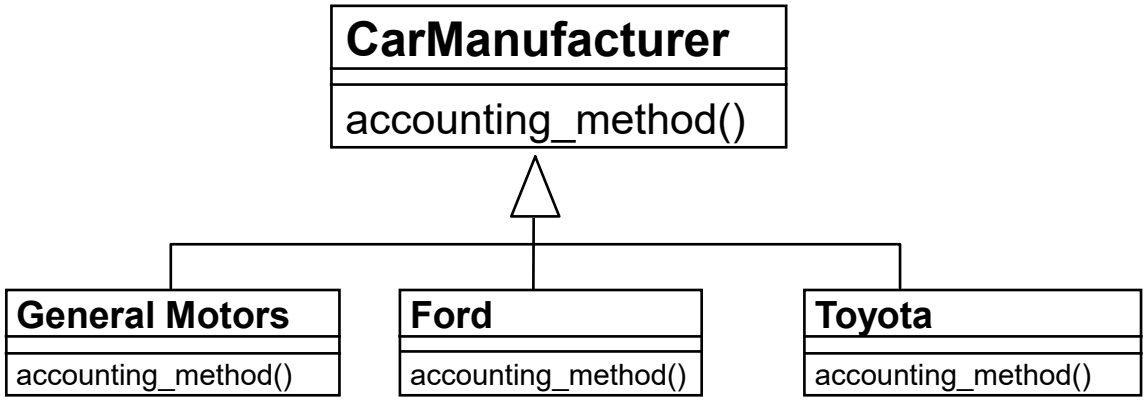


⇒ The state model can show which operations are legal and which are illegal at various points in the object's lifecycle

```
/* one possible implementation of the pop() operation */
int Stack::pop() {
   int val = -1;
   if (cur_state == empty) {
       // do nothing, set an error code, or throw an exception
   }
   else {  stack_pointer--;  val = *stack_pointer;   }
   if (stack_pointer == top) {  cur_state = empty;  }
   return (val);
}
```

Another inheritance pitfall

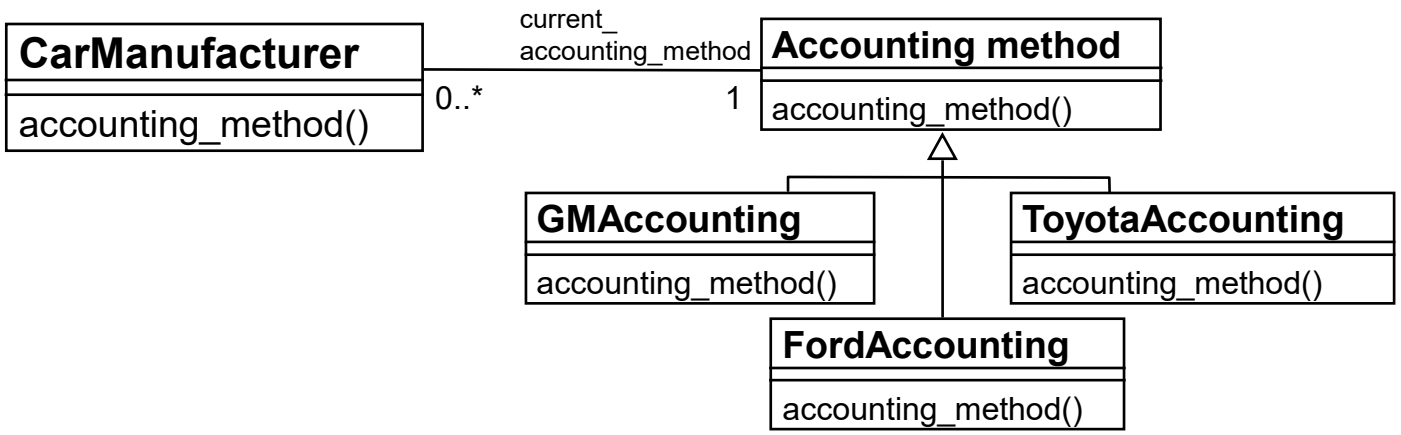
- Defining derived classes that have only one instance:



⇒ each class can only have one instance, so each class is not very reusable… it would be better to make the base class accounting_method() operation collaborate with an **AccountingMethod** class hierarchy

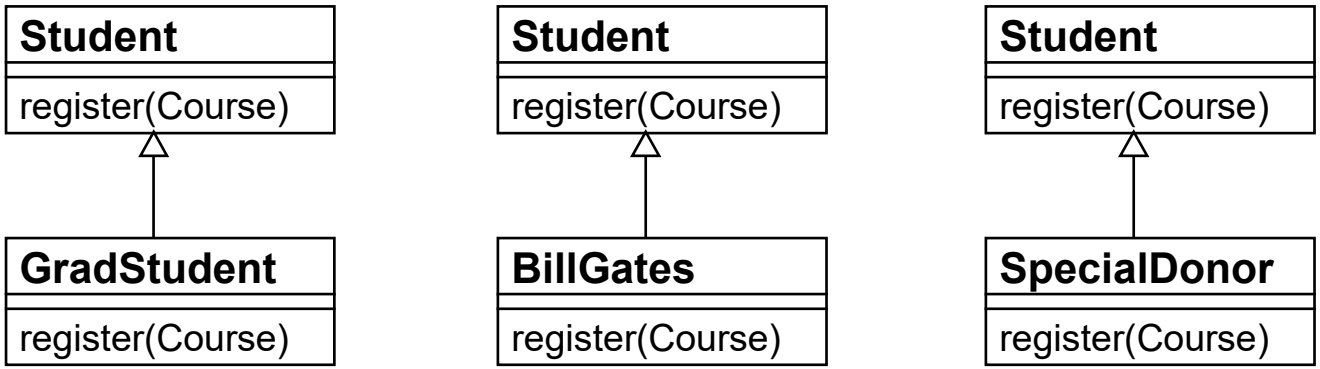
Another inheritance pitfall

- The Accounting method behavior may be factored into a separate class, so you don't need subclasses of **CarManufacturer**:



Watch for singleton objects

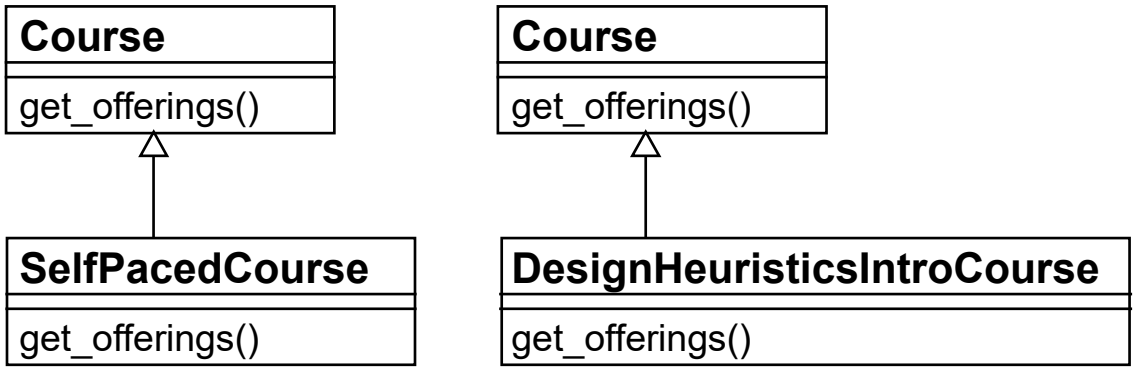
- Classes that are really singleton objects are usually not what we want in a simple and extensible design:



OK Not OK Probably OK

Watch for singleton objects

- Classes that are really singleton objects are usually not what we want in a simple and extensible design:



OK

Not OK

Heuristics for avoiding inheritance pitfalls

- Arthur Riel has turned these two problems into heuristics:
  - H5.14: Do not model the dynamic semantics of a class through the use of the inheritance relationship. An attempt to model dynamic semantics with a static semantic relationship will lead to a toggling of types at runtime.
  - H5.15: Do not turn objects of a class into derived classes of the class. Be very suspicious of any derived class for which there is only one instance.
- Note: these two heuristics are sometimes violated for good design reasons…

– H5.14 may be violated in the "virtual constructor" idiom:
  - a "factory method" creates new objects
  - if the factory method is creating objects that have been stored in a file, it might create an object with an initial interim datatype and then transform the object to the correct datatype when all of the data section is complete

– H5.15 is sometimes violated when you need a singleton object in a framework

Summary

- What have we learned? How are we going to change the way we design and implement our software?
  - C++ and Java programming guidelines are OK, but they are not enough to assure software quality
    - it is easy to write superficially object oriented software
    - but we need to apply some of the design heuristics
- The main pitfalls to watch for are:
  - god classes: classes that steal all of the decision-making ability of the classes around them
  - combining several classes into one: look for non-communicating behavior and find opportunities to make more cohesive classes
  - complex collaborations: breaking up the responsibilities too far can create a maintenance headache
  - improper inheritance: violations of the “is-a” rule

References

The book:

- *Object Oriented Design Heuristics* by Arthur Riel (Addison-Wesley, 1996)

Top 20 heuristics:

- http://manclswx.com/talks/top_heuristics.html

Vince Huston – listing of Arthur Riel's heuristics:

- http://www.vincehuston.org/ood/oo_design_heuristics.html

Design Principles (Bob Martin)

- https://manclswx.com/talks/Principles_and_Patterns.pdf

https://manclswx.com/talks - talks on legacy software, design patterns, technical debt, and design heuristics

Last modified: November 9, 2021

Books and articles about Design Patterns

Books

- Erich Gamma, Richard Helm, Ralph Johnson, John Vlissides, *Design Patterns* (Addison-Wesley, 1994)
- Eric Freeman and Elisabeth Robson, *Head First Design Patterns,* second edition (O'Reilly, 2021)
- Joshua Kerievsky, *Refactoring to Patterns* (Addison-Wesley, 2005)
- *Pattern Oriented Software Architecture, volume 2* by Doug Schmidt, Michael Stal, Hans Rohnert, and Frank Buschmann (Wiley, 2000)

Websites

- wiki.c2.com/?DesignPatternsBook
- hillside.net/patterns/patterns-catalog
- www.martinfowler.com/articles/enterprisePatterns.html

OO Design Heuristics: List of topics

What did we talk about today?

Topics:

- Modularization
- Heuristics to help evaluate designs
- Data hiding
- Action oriented versus object oriented
- God class
- Too many get and set operations
- Avoid non-communicating behavior
- Don't turn an operation into a class
- Six ways to collaborate
- Use containment to control complexity

More Topics:

- Using inheritance in patterns (Strategy, Observer)
- Inheritance in software frameworks
- Abstract classes
- Inheritance "is-a" rule = Liskov Substitution Principle
- Expect no more, deliver no less
- Smiley face analysis of preconditions and postconditions
- Inheritance complexity
- Inheritance pitfalls: don't use a subclass to represent a state
- Inheritance pitfalls: avoid singleton subclasses