UML & OO Fundamentals

CSCI 4448/5448: Object-Oriented Analysis & Design

Lecture 8

Acknowledgement & Materials Copyright

- I'd like to start by acknowledging Dr. Ken Anderson
- Ken is a Professor and the Chair of the Department of Computer Science
- Ken taught OOAD on several occasions, and has graciously allowed me to use his copyrighted material for this instance of the class
- Although I will modify the materials to update and personalize this class, the original materials this class is based on are all copyrighted © Kenneth M. Anderson; the materials are used with his consent; and this use in no way challenges his copyright

Goals of the Lecture

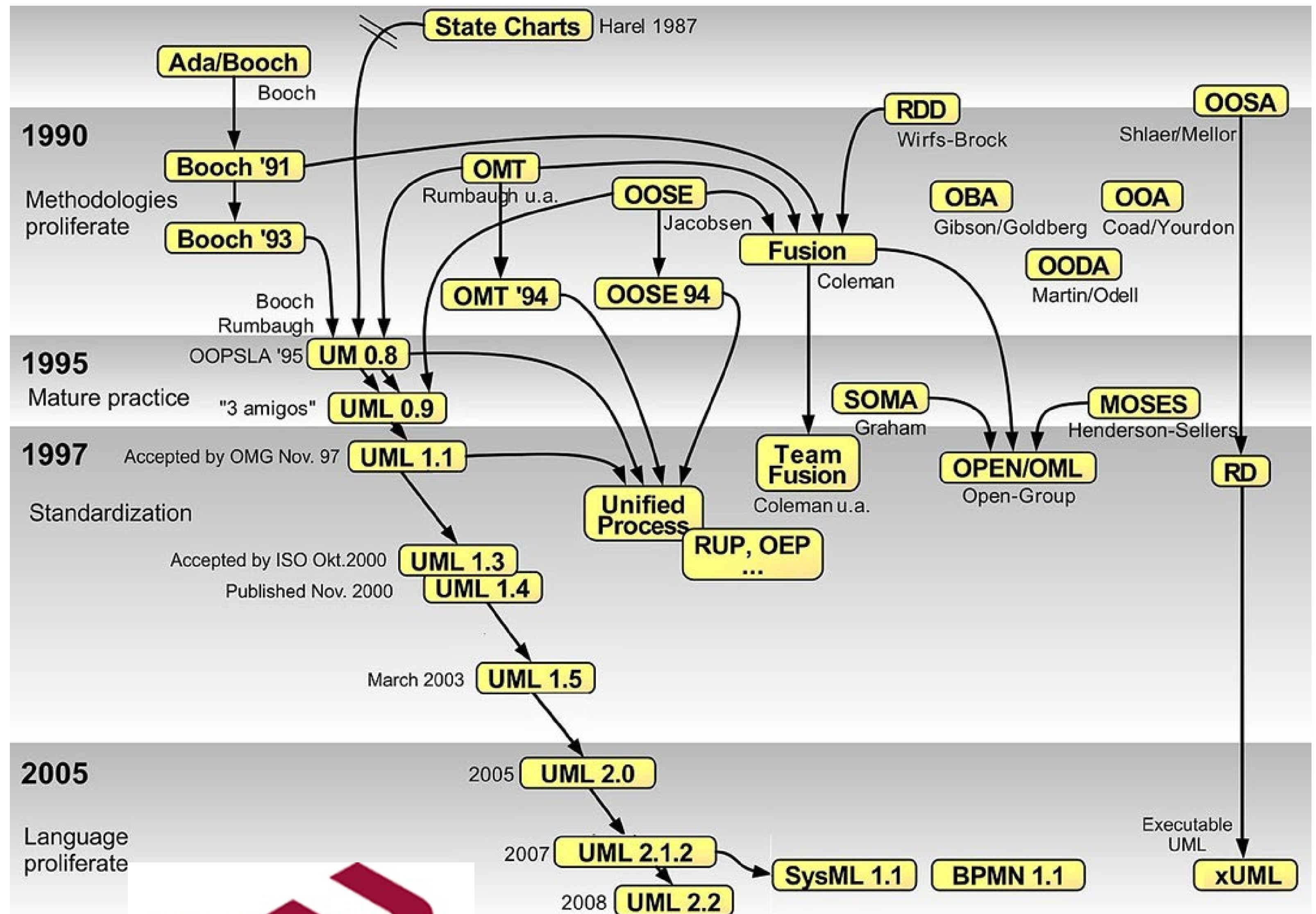
- Review using UML for OO Design
  - Cover key parts of the UML notation
  - Demonstrate some ways in which UML is useful
  - Give you a chance to apply the notation yourself to several examples
- Warning: important information is repeated several times in this lecture
  - this is a hint to the future you when you are studying for the midterm

UML

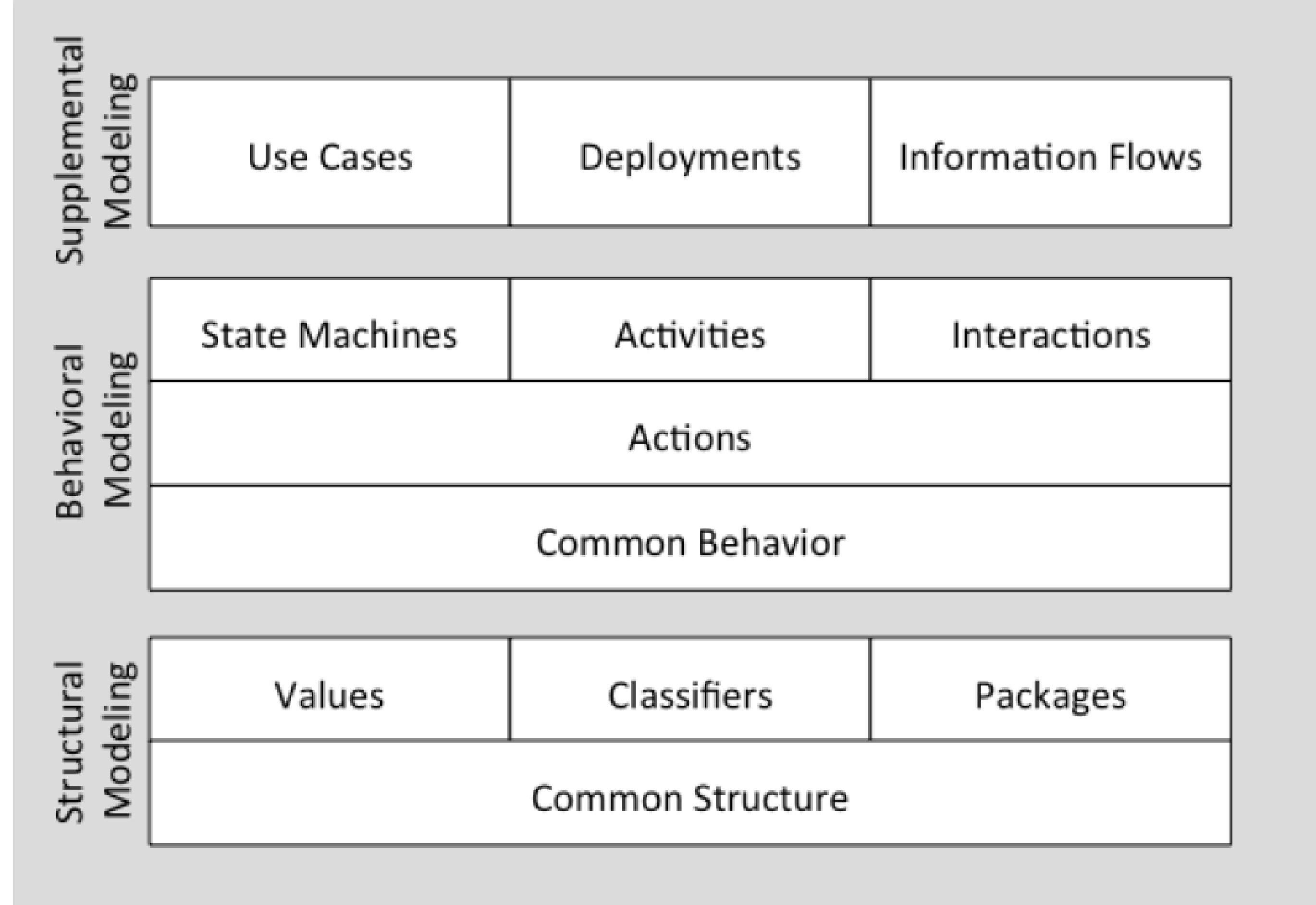
- UML is short for **Unified Modeling Language**
  - The UML defines a standard set of notations for use in modeling object-oriented systems
- Throughout the semester we will encounter UML in the form of
  - class diagrams
  - sequence/collaboration diagrams
  - state diagrams
  - activity diagrams, use case diagrams, and more

Brief History of the UML

- In the 80s and early 90s, there were multiple OO A&D approaches (each with their own notation) available
- Three of the most popular approaches came from
  - James Rumbaugh: OMT (Object Modeling Technique)
  - Ivar Jacobson: Wrote “OO Software Engineering” book
  - Grady Booch: Booch method of OO A&D
- In the mid-90’s all three were hired by Rational and together developed the UML; known collectively as the “three amigos”
- Latest UML 2.5.1 Dec 2017 https://www.omg.org/spec/UML/



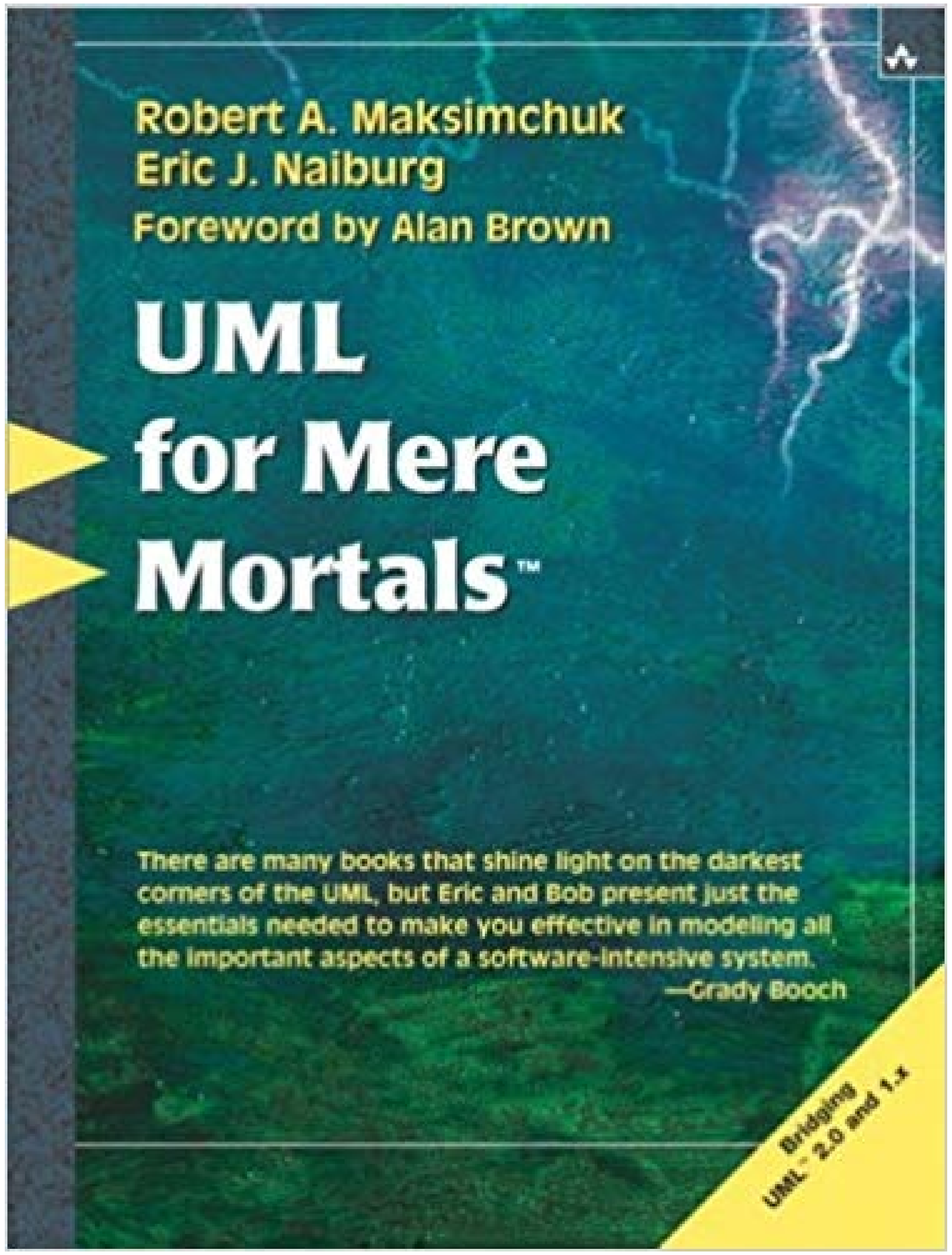
UML Diagrams



- Diagrams from the current UML release (https://www.omg.org/spec/UML/2.5.1/PDF)
- Structural
  - **Class**
  - Object
  - Package
  - Model
  - Composite Structure
  - Internal Structure
  - Collaboration Use
  - Component
  - Manifestation
  - Network Architecture
  - Profile
- Supplemental (both structural and behavioral elements)
  - **Use Case**
  - Information Flow
  - Deployment
- Behavior
  - **Activity**
  - **Sequence**
  - **State (Machine)**
  - Behavioral State Machine
  - Protocol State Machine
  - Interaction
  - Communication (was Collaboration)
  - Timing
  - Interaction Overview
- Diagrams we’ll review are **BOLD**

UML Tools

- References
  - Tutorials
    - https://www.tutorialspoint.com/uml/index.htm
  - Book
    - UML for Mere Mortals, Maksimchuk & Naiburg, 2005, Addison Wesley
- Tools
  - **Draw.io/Diagrams.net – has UML tools/templates (Free!)**
  - Lucidchart.com – UML Templates
    - (Free access available)
  - TopCoder UML Tool
    - sequence, class, use case, and activity diagrams
    - Free - Requires registration
    - https://www.topcoder.com/tc?module=Static&d1=dev&d2=umltool&d3=description
  - StarUML - https://staruml.io/
  - Visio
  - Whiteboards and a phone/camera
  - Paper & pencil



Big Picture View of OO Paradigm

- OO techniques view software systems as
  - **networks of communicating objects**
- Each **object** is **an instance of** a **class**
  - All objects of a class share similar **features**
    - **attributes**
    - **methods**
  - Classes can be **specialized** by **subclasses**
- Objects communicate by **sending messages**

Objects (I)

- Objects are **instances of classes**
  - They have **state** (attributes) and **exhibit behavior** (methods)
- We would like objects to be
  - **highly cohesive**
    - have a single purpose; make use of all features
  - **loosely coupled**
    - be dependent on only a few other classes

Objects (II)

- Objects interact by **sending messages**
  - Object A sends a message to Object B to ask it to perform a task
    - When done, B may pass a value back to A
    - Sometimes A == B
      - i.e., **an object can send a message to itself**

Objects (III)

- Sometimes **messages can be rerouted**
  - invoking a method defined in class A may in fact invoke an **overridden** version of that method in subclass B
  - a method of class B may in turn invoke messages on its superclass that are then handled by overridden methods from **lower in the hierarchy**
- The fact that messages (**dynamic**) can be rerouted distinguishes them from procedure calls (**static**) in non-OO languages

Objects (IV)

- In response to a message, an object may
  - update its internal state
  - return a value from its internal state
  - perform a calculation based on its state and return the calculated value
  - create a new object (or set of objects)
  - delegate part or all of the task to some other object

- i.e. they can do pretty much anything in response to a message

Objects (V)

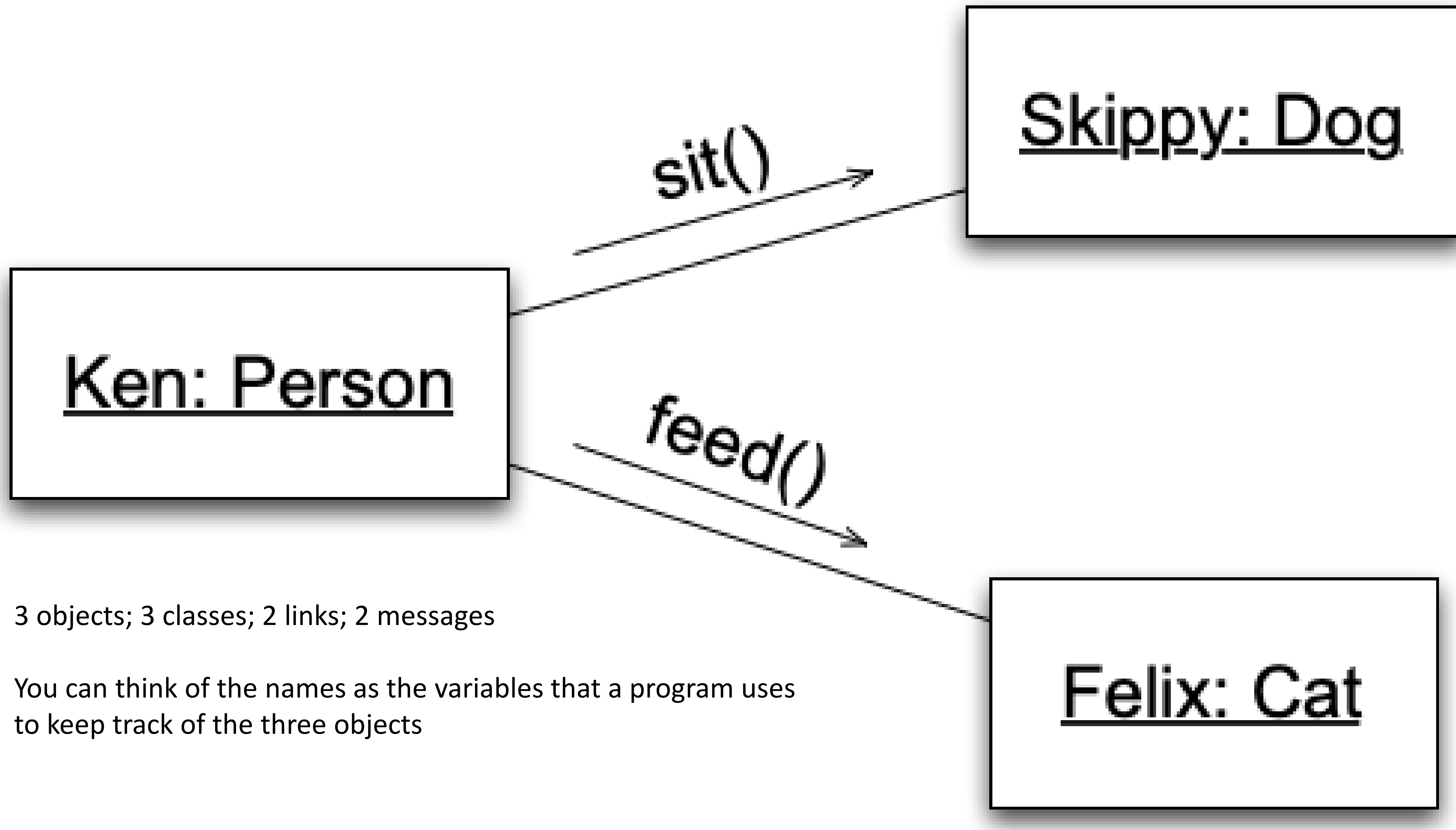
- As a result, objects can be viewed as members of multiple object networks
  - Object networks are also called **collaborations**
- Objects in an collaboration work together to perform a task for their host application

Objects (VI)

- UML notation for Object Diagrams
  - Objects are drawn as rectangles with their names and types (class names) underlined
    - <u>Ken : Person</u>
  - The name of an object is optional. The type is required
    - <u>: Person</u>
  - Note: The colon is not optional.

Objects (VII)

- Objects that *work together* **have lines drawn between them**
  - This connection has many names
    - object reference
    - reference
    - **link**
  - Messages are sent across links
    - Links are instances of associations (see slide 31)



3 objects; 3 classes; 2 links; 2 messages

You can think of the names as the variables that a program uses to keep track of the three objects

Classes (I)

- A **class** is a **blueprint for an object**
  - The blueprint specifies a class's **attributes** and **methods**
    - attributes are **things an object of that class knows**
    - methods are **things an object of that class does**
  - An object is **instantiated** (created) from the description provided by its class
    - Thus, objects are often called **instances**

Classes (II)

- An object of a class **has its own values for the attributes of its class**
  - For instance, two objects of the Person class can have different values for the name attribute
- Objects **share the implementation of a class's methods**
  - and thus behave similarly
    - i.e. Objects A and B of type Person each share the same implementation of the sleep() method

Classes (III)

- Classes can define “class-based” (a.k.a. **static**) attributes and methods
  - A **static attribute** is shared among **all** of a class’s objects
    - That is, all objects of that class can read/write the static attribute
  - A static method is a **method defined on the Class itself**; as such, it does not have to be accessed via an object; you can invoke static methods directly on the class itself
    - In Lecture 2’s Java code: String.format() was an example of a static method

Class Diagrams

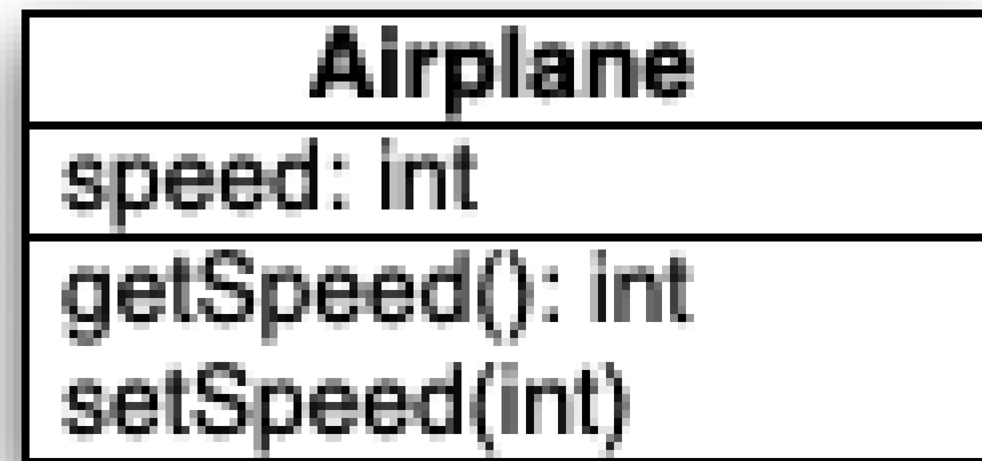
- Classes in UML appear as rectangles with multiple sections
  - The first section contains its name (defines a type)
  - The second section contains the class’s attributes
  - The third section contains the class’s methods

Class Diagrams, 2nd Example

Name

Attributes

Methods



All parts are optional except the class name

A class is represented as a rectangle

This rectangle says that there is a class called Airplane that could potentially have many instances, each with its own speed variable and methods to access it

Airplane in Java

Using Airplane

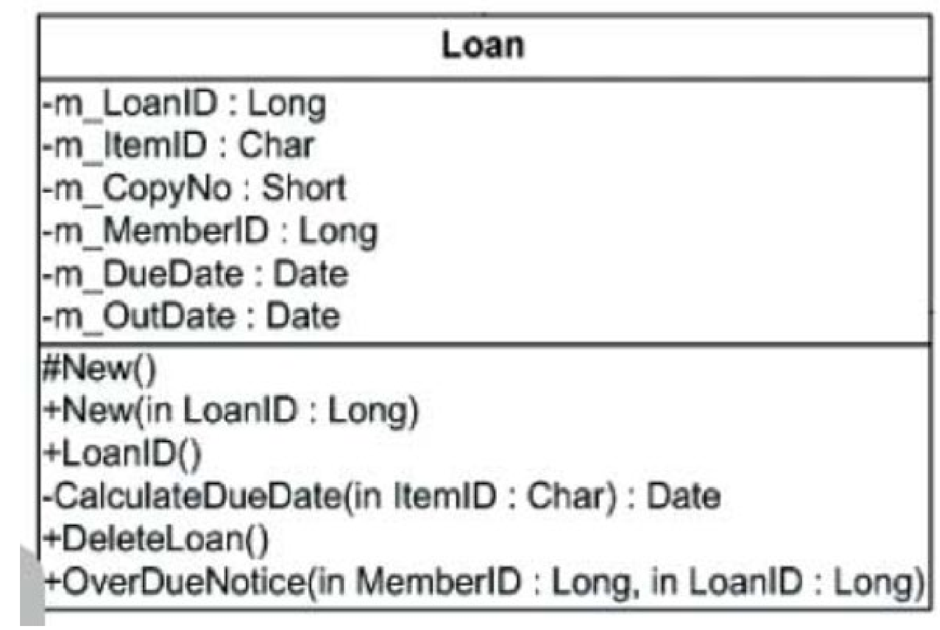
```
Airplane a = new Airplane(5);

a.setSpeed(10);

System.out.println(
   “” + a.getSpeed());
```

```java
public class Airplane {

    private int speed;

    public Airplane(int speed) {
        this.speed = speed;
    }

    public int getSpeed() {
        return speed;
    }

    public void setSpeed(int speed) {
        this.speed = speed;
    }

}
```

Clarification on Class Diagrams and Data/Method Accessibility

You can use UML to notate which accessibility you want each member to have. The three most common types of accessibility available in most object-oriented languages are as follows:

- **Public**—Notated with a plus sign (+). This means all objects can access this data or method.
- **Protected**—Notated with a pound sign (#). This means only this class and all of its subclasses (i.e. derivations) can access this data or method.
- **Private**—Notated with a minus sign (–). This means that only methods of this class can access this data or method.
- There are others – package, derived, static – expect to see variations in this by language!



http://www2.sys-con.com/itsg/virtualcd/dotnet/archives/0105/clark/index.html

Translation to Code

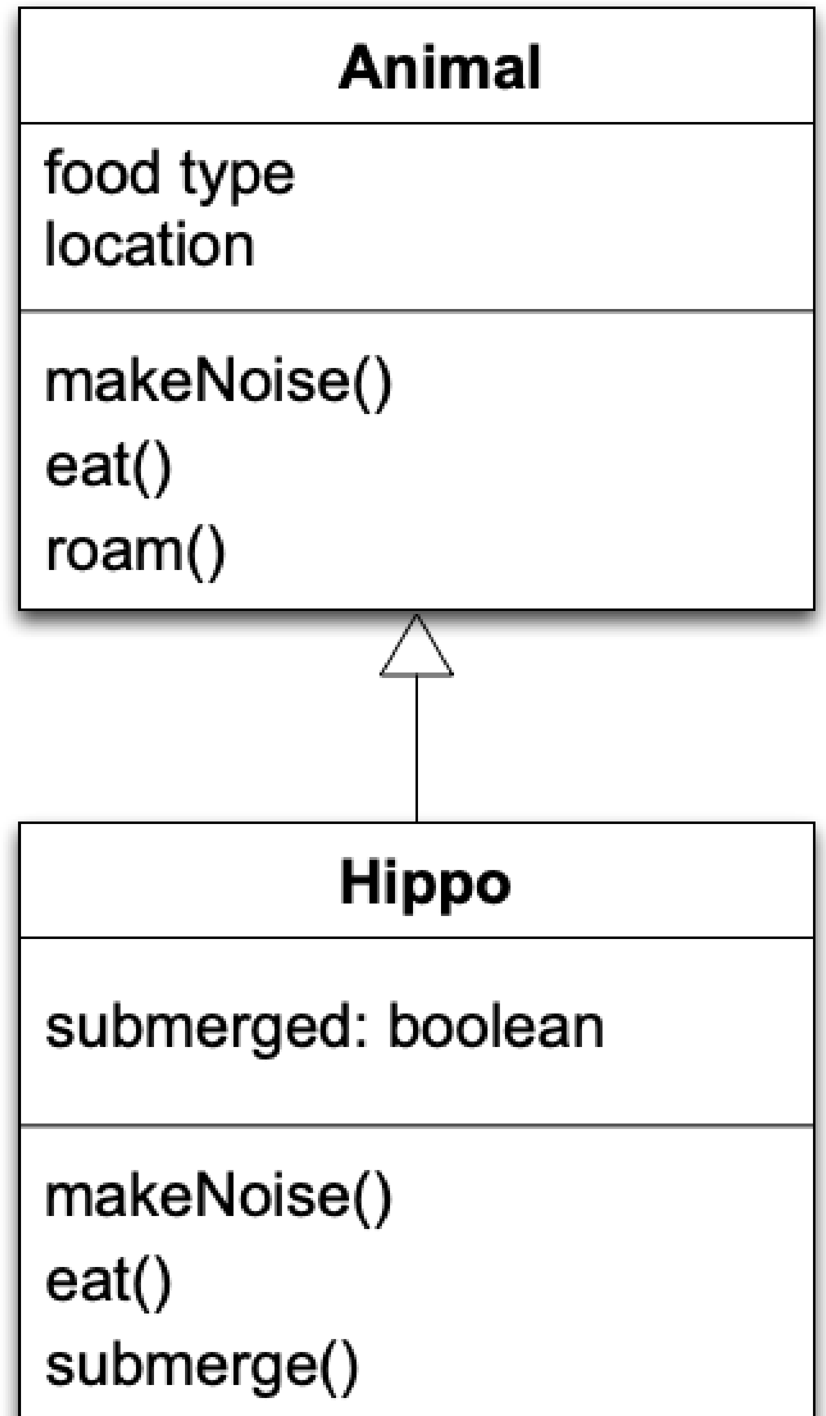
- Class diagrams can be translated into code straightforwardly
  - Define the class with the specified name
  - Define specified attributes (assume private access)
  - Define specified method skeletons (assume public)
- May have to deal with unspecified information
  - Types are optional in class diagrams
  - Class diagrams typically do not specify constructors
    - just the class’s public interface

Relationships Between Classes

- Classes can be related in a variety of ways
  - Inheritance
  - Association
    - Multiplicity
  - Whole-Part (Aggregation and Composition)
  - Qualification
  - Interfaces

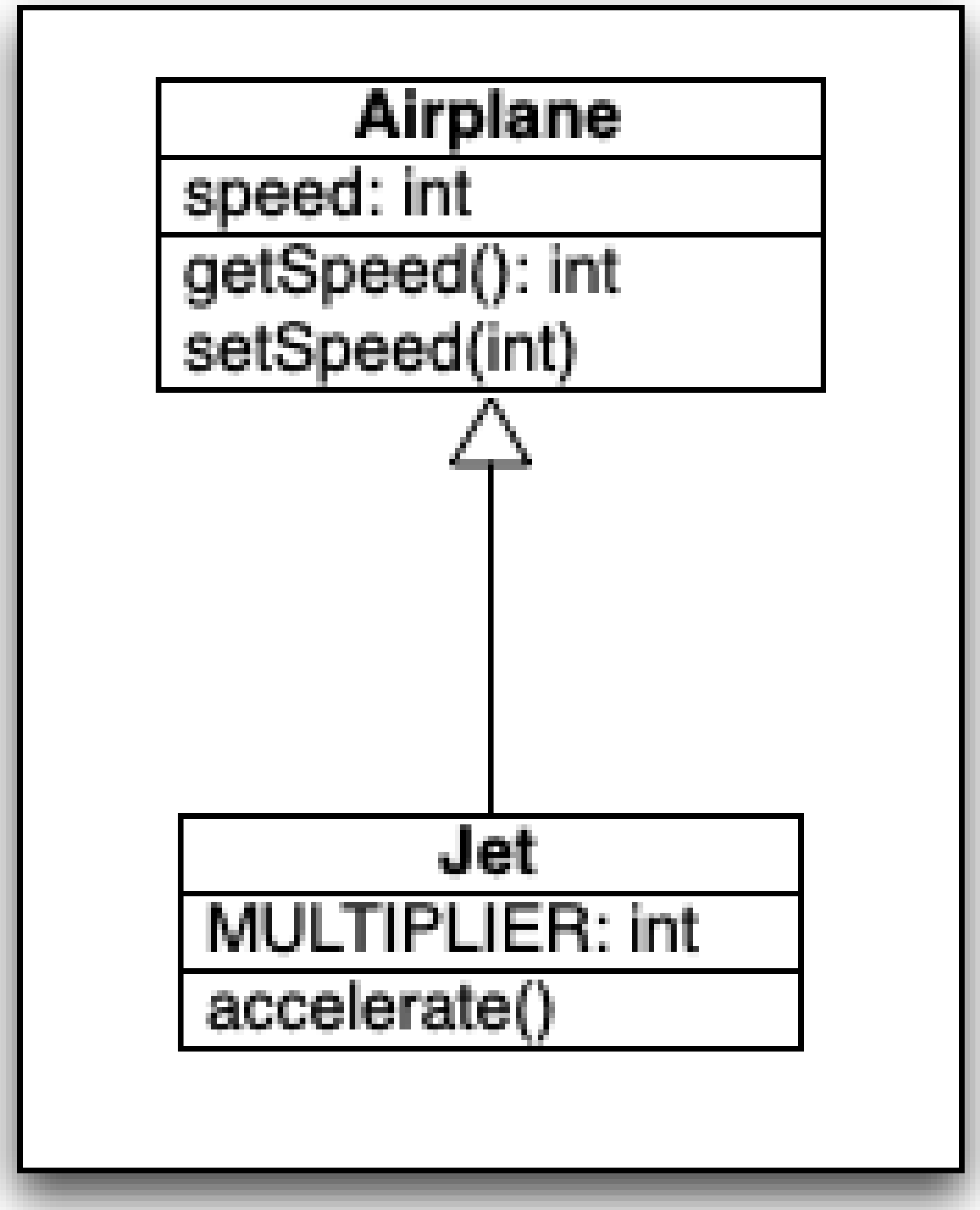
Relationships: Inheritance

- One class can extend another
- UML notation: a white triangle points to the superclass
  - the subclass can add attributes
    - Hippo adds submerged as new state
  - the subclass can add behaviors or override existing ones
    - Hippo is overriding makeNoise() and eat() and adding submerge()



Inheritance

- Inheritance lets you build classes based on other classes and avoid duplicating code
  - Here, Jet builds off the basics that Airplane provides



Inheriting From Airplane (in Java)

```java
public class Jet extends Airplane {

    private static final int MULTIPLIER = 2;

    public Jet(int id, int speed) {
        super(id, speed);
    }

    public void setSpeed(int speed) {
        super.setSpeed(speed * MULTIPLIER);
    }

    public void accelerate() {
        super.setSpeed(getSpeed() * 2);
    }

}
```

Note:

extends keyword indicates inheritance

super() and **super** keyword is used to refer to superclass

No need to define getSpeed() method; its inherited!

setSpeed() method overrides behavior of setSpeed() in Airplane

subclass can define new behaviors, such as accelerate()

Polymorphism: “Many Forms”

- “Being able to refer to different derivations of a class in the same way, …”
  - Implication: both of these are legal statements
    - Airplane plane = new Airplane();
    - Airplane plane = new Jet();
- “...but getting the behavior appropriate to the derived class being referred to”
  - when I invoke setSpeed() on the second plane variable above, I will get Jet’s method, not Airplane’s method

Encapsulation

- Encapsulation lets you
  - hide data and algorithms in one class from the rest of your application
  - limit the ability for other parts of your code to access that information
  - protect information in your objects from being used incorrectly

Encapsulation Example

- The “speed” instance variable is private in Airplane. That means that Jet doesn’t have direct access to it.
  - Nor does any client of Airplane or Jet objects
- Imagine if we changed speed’s visibility to public
- The encapsulation of Jet’s setSpeed() method would be destroyed

```
Airplane

...
public void setSpeed(int speed) {
    this.speed = speed;
}
...

Jet

...
public void setSpeed(int speed) {
    super.setSpeed(speed * MULTIPLIER);
}
...

```

Reminder: Abstraction

- Abstraction is distinct from encapsulation
  - Encapsulation supports abstraction, but so does the design of exposed interfaces and class responsibilities
- It answers the questions
  - What features does a class provide to its users?
  - What services can it perform?
- Abstraction is the MOST IMPORTANT concern in A&D!
  - The choices you make in defining the abstractions of your system will live with you for a LONG time

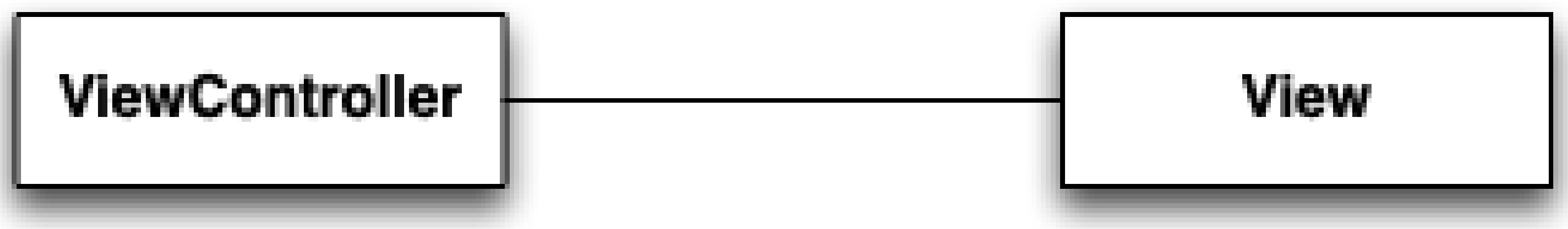
The Difference Illustrated

- The getSpeed() and setSpeed() methods represent Airplane's abstraction
  - Of all the possible things that we can model about airplanes, we choose just to model speed
  - Abstractly, working with speed is the functionality supported by this representation of an Airplane class
- Making the speed attribute private is an example of encapsulation; if we choose to use a linked list to keep track of the history of the airplane's speed, we are free to do so

```java
public class Airplane {

    private int speed;

    public Airplane(int speed) {
        this.speed = speed;
    }

    public int getSpeed() {
        return speed;
    }

    public void setSpeed(int speed) {
        this.speed = speed;
    }

}
```

Relationships: Association

- One class can reference another (a.k.a. association)
  - notation: straight line



- This (particular) notation is a graphical shorthand that each class contains an attribute whose type is the other class

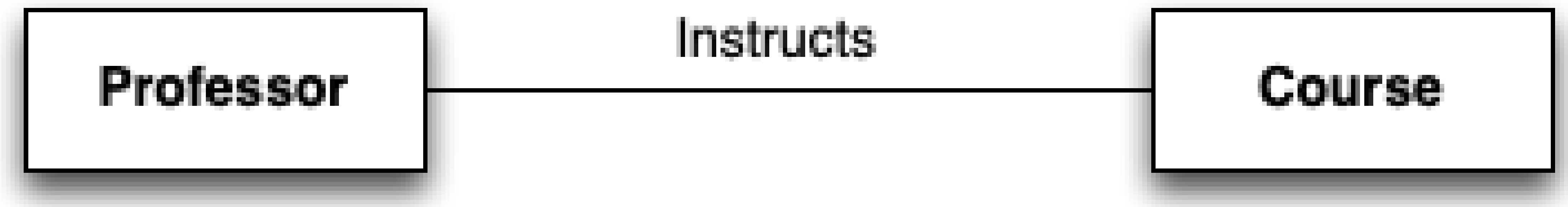
Roles

- Roles can be assigned to the classes that take part in an association

- Here, a simplified model of a lawsuit might have a lawsuit object that has relationships to two people, one person playing the role of the defendant and the other playing the role of the plaintiff
  - Typically, this is implemented via "plaintiff" and "defendant" instance variables inside of the Lawsuit class

Labels

- Associations can also be labelled in order to convey semantic meaning to the readers of the UML diagram

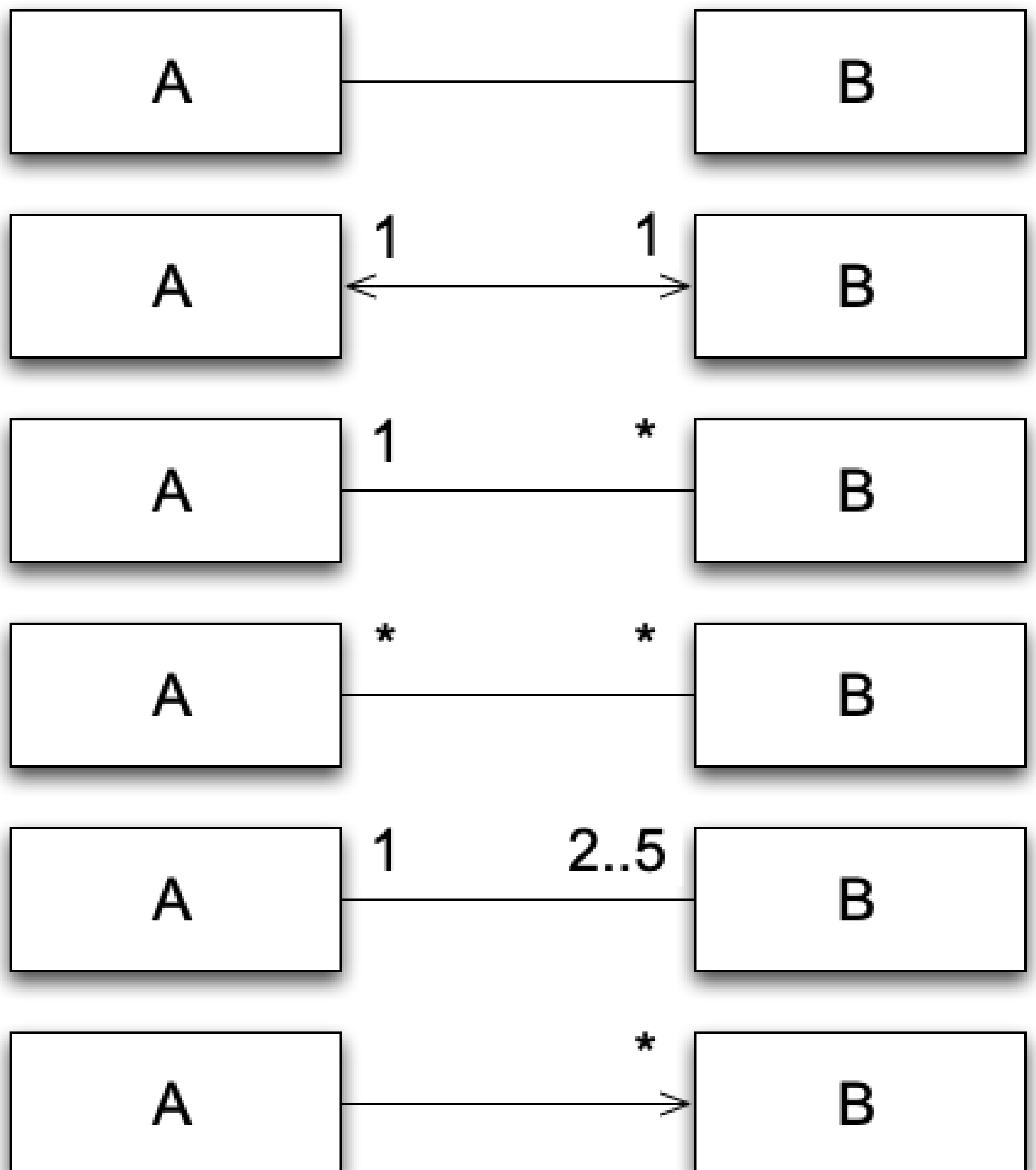


- In addition to roles and labels, associations can also have multiplicity annotations
  - Multiplicity indicates how many instances of a class participate in an association

Multiplicity

- Associations can indicate the number of instances involved in the relationship
  - this is known as multiplicity
- An association with no markings is “one to one”
- An association can also indicate directionality
  - if so, it indicates that the “knowledge” of the relationship is not bidirectional
- Examples on next slide

Multiplicity Examples



One B with each A; one A with each B

Same as above

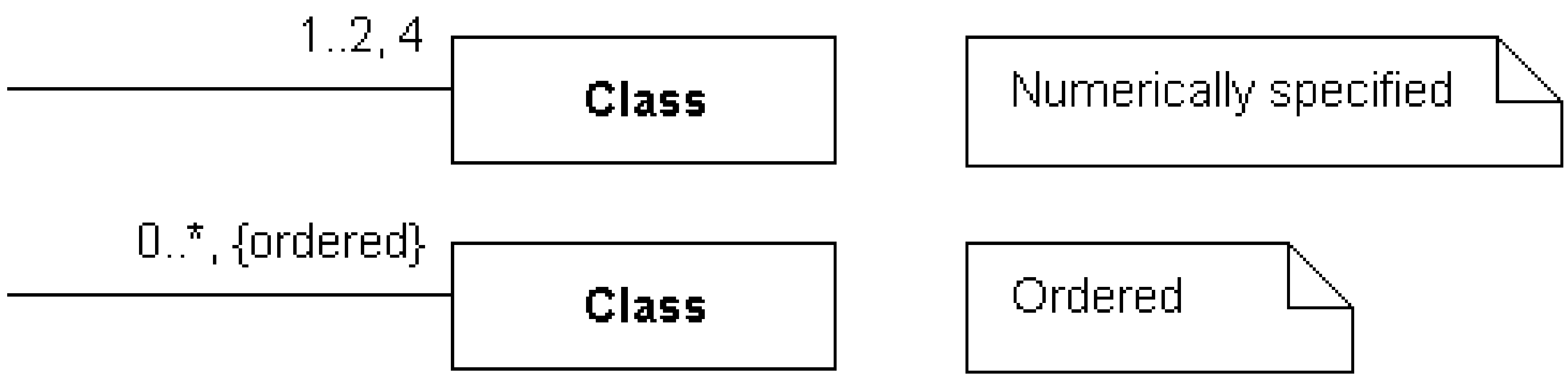
Zero or more Bs with each A; one A with each B

Zero or more Bs with each A; ditto As with each B

Two to Five Bs with each A; one A with each B

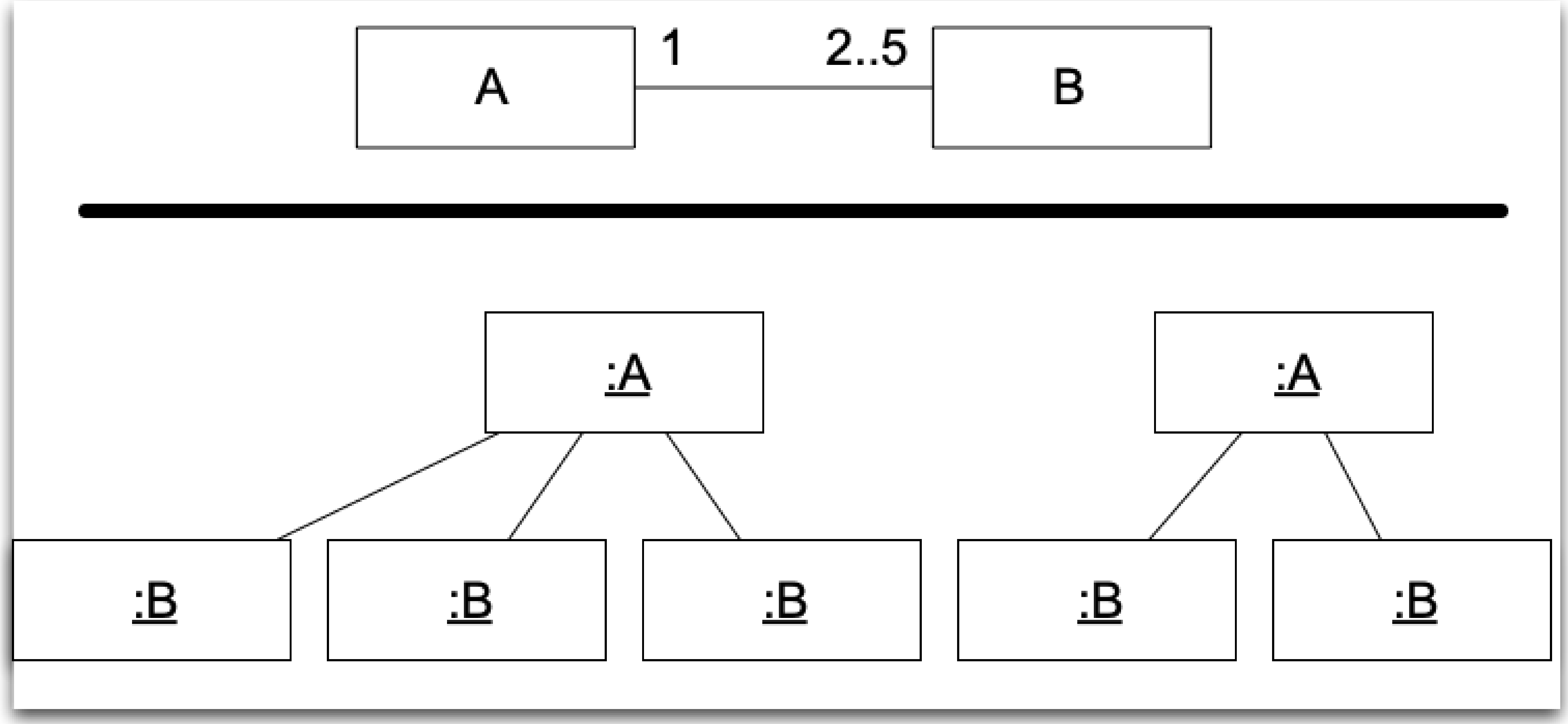
Zero or more Bs with each A; B knows nothing about A

Clarification on Multiplicity Notation

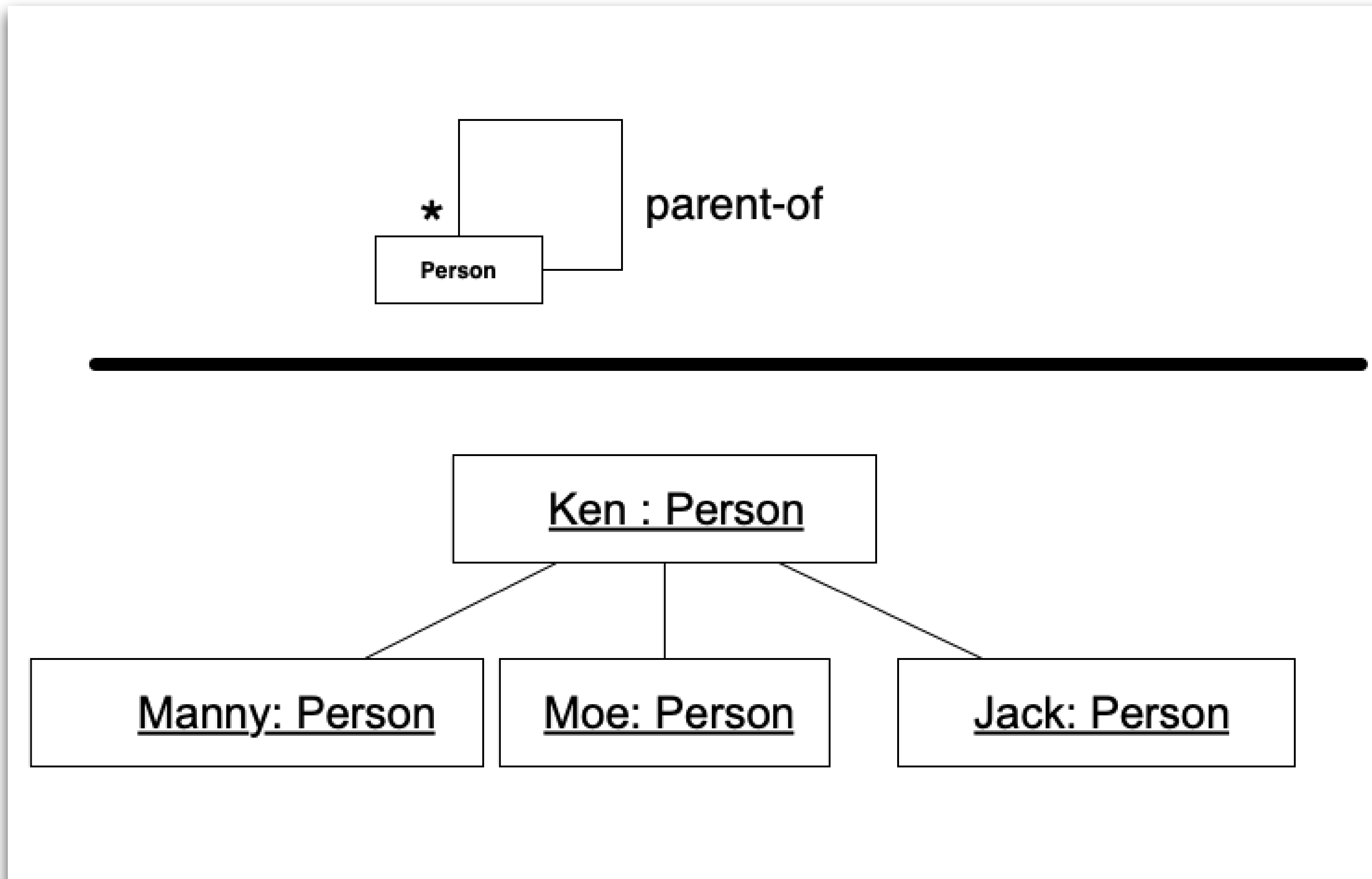


- The first example calls for 1, 2, or 4 instances of Class, not 0, 3, or more than 4
- The second one shows an added keyword indicating the instances have an order that is maintained

Multiplicity Example



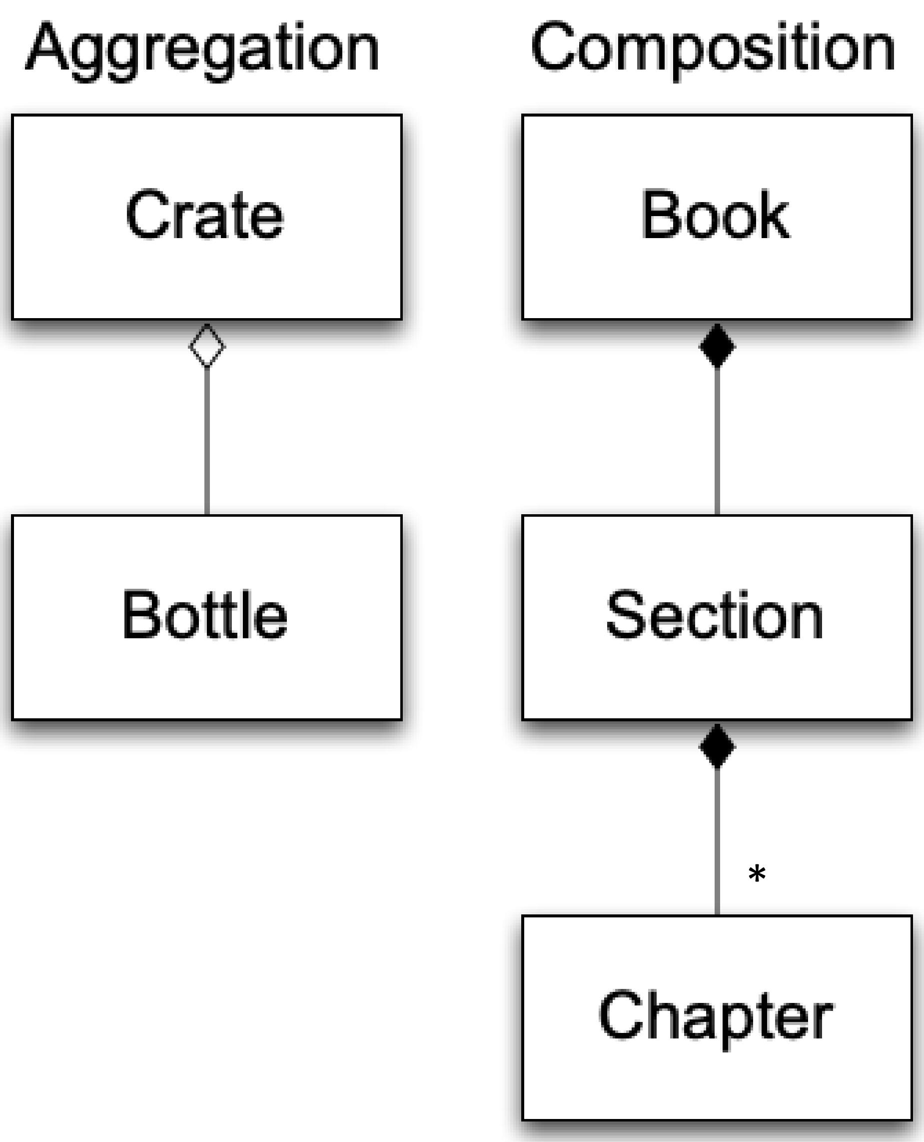
Self Association



Relationships: whole-part

- Associations can also convey semantic information about themselves
  - In particular, **aggregations** indicate that **one object contains a set of other objects**
    - think of it as a whole-part relationship between
      - a class representing a group of components
      - a class representing the components
  - Notation: aggregation is indicated with a **white diamond attached to the class playing the container role**

Example: Aggregation



Composition will be defined on the next slide

Note: multiplicity annotations for aggregation/composition is tricky

Some authors assume “one to many” when the diamond is present; others assume “one to one” and then add multiplicity indicators to the other end. For clarity, multiplicity could be declared at both ends.

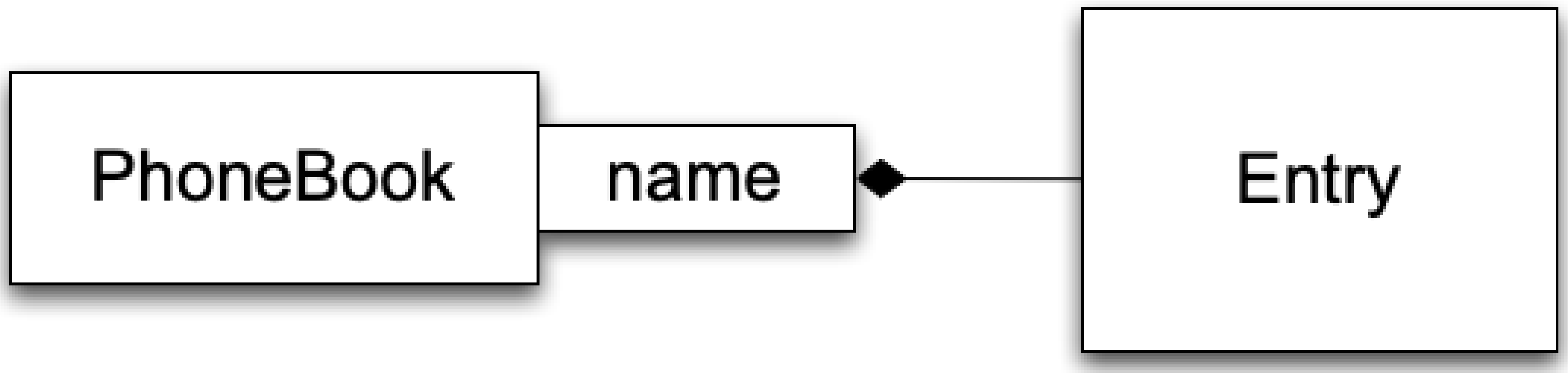
Semantics of Aggregation

- Aggregation relationships are **transitive**
  - if A contains B and B contains C, then A contains C
- Aggregation relationships are **asymmetric**
  - If A contains B, then B does not contain A
- A variant of aggregation is **composition** which adds the property of **existence dependency**
  - if A composes B, then if A is deleted, B is deleted
- Composition relationships are shown with a black diamond attached to the composing class

Relationships: Qualification

- An association can be **qualified** with information that indicates **how objects on the other end** of the association **are found**
  - This allows a designer to indicate that the association **requires a query mechanism of some sort**
    - e.g., an association between a phonebook and its entries might be qualified with a name
  - Notation: a qualification is indicated with a rectangle attached to the end of an association indicating the attributes used in the query

Qualification Example



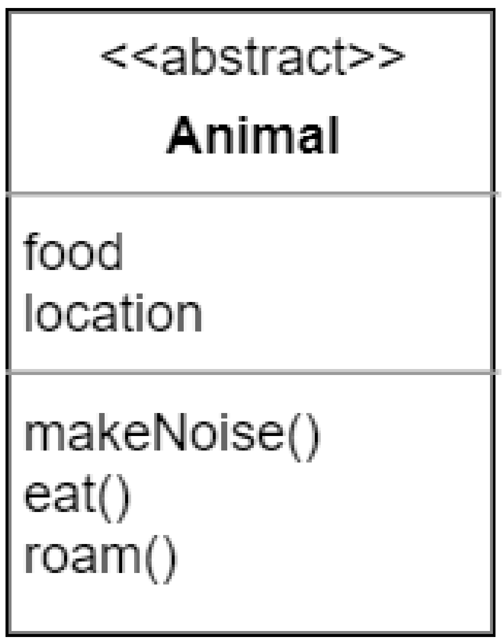
"With a Phonebook, there may be Entries for each instance of name."

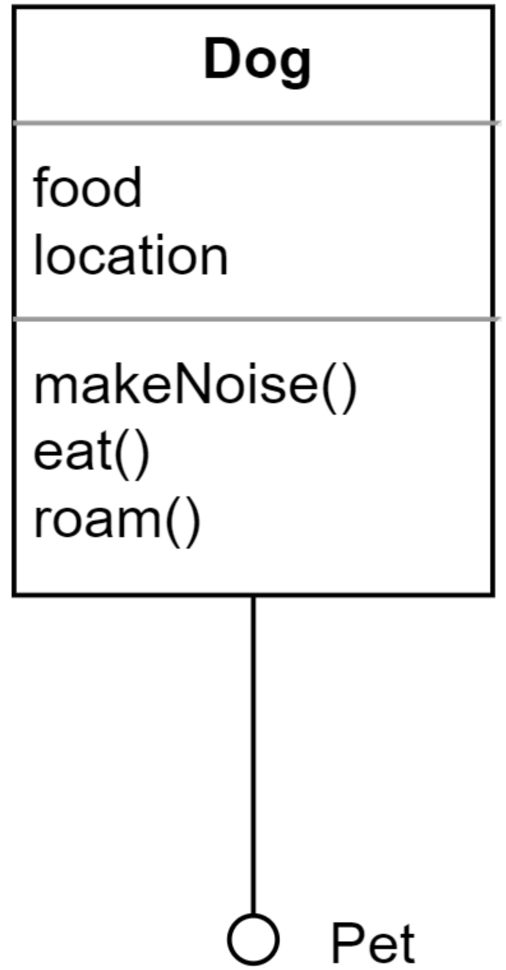
Qualification is **not used very often** – it's a UML equivalent of programming constructs like associative arrays, maps, and dictionaries; the same information can be conveyed via a note or a use case that accompanies the class diagram

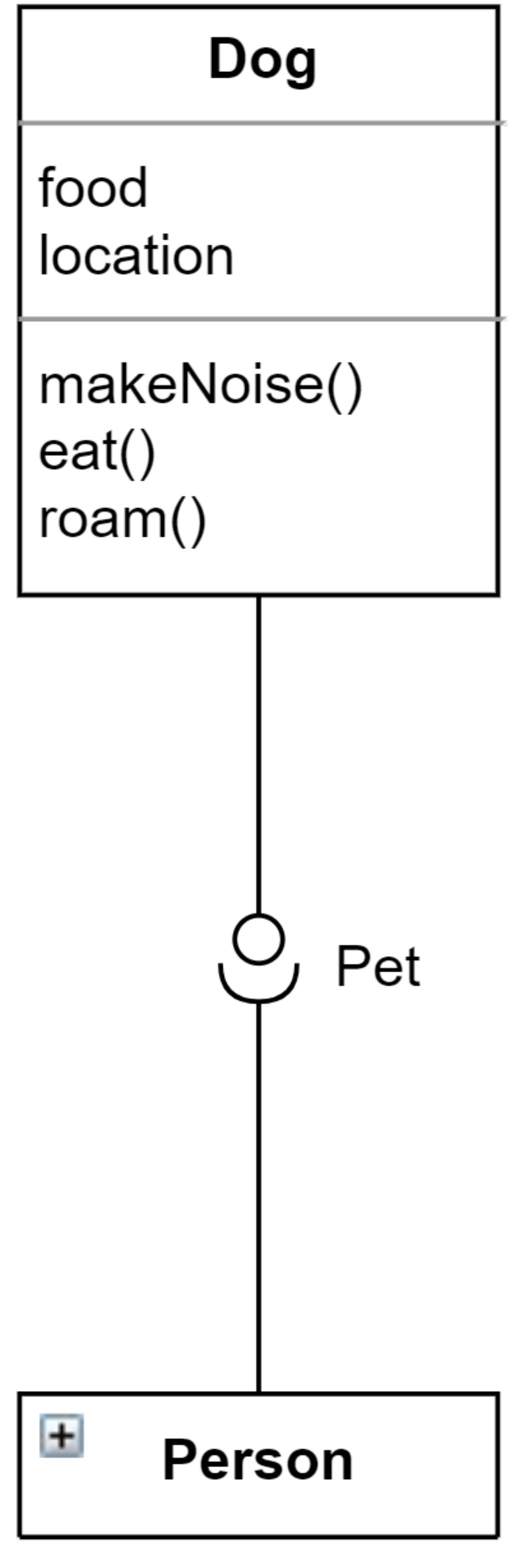
Relationships: Abstract Classes & Interfaces

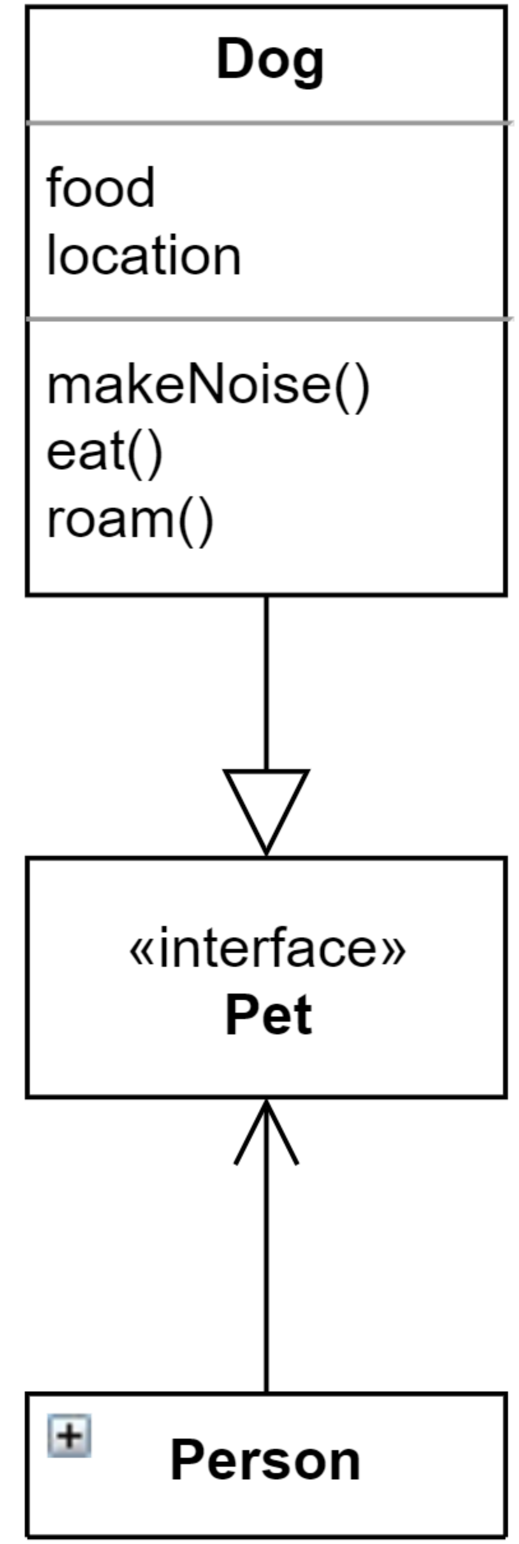
- **Abstract classes** are treated much the same as classes, with an annotation that they are abstract
- A class can indicate that it **implements an interface**
  - An interface is a type of class definition in which (usually) only method signatures are defined
- A class implementing an interface provides method bodies for each defined method signature in that interface
  - This allows a class to play different roles, with each role providing a different set of services
    - These roles are then independent of the class's inheritance relationships

Examples









- Animal is an abstract class, which just includes the <<abstract>> keyword
- Interface Pet is realized or implemented by Dog
- Interface Pet is used or required by Person
- Other classes can access a class via its interface
- This is indicated via a “ball and socket” notation or a class box labeled as an “<<interface>>”

Class Summary

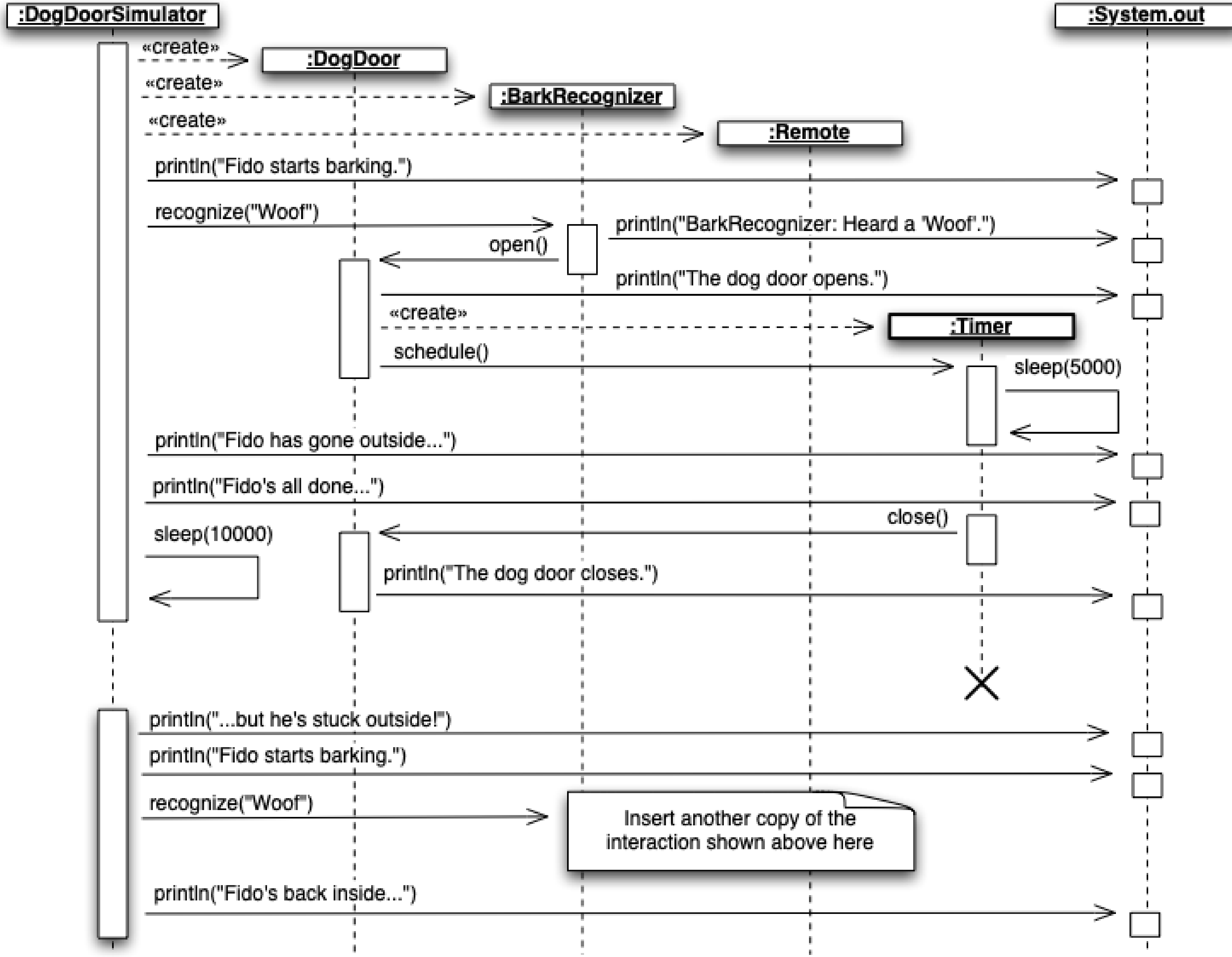
- Classes are blue prints used to create objects
- Classes can participate in multiple types of relationships
  - inheritance, association (with multiplicity), aggregation/composition, qualification, interfaces

Sequence Diagrams (I)

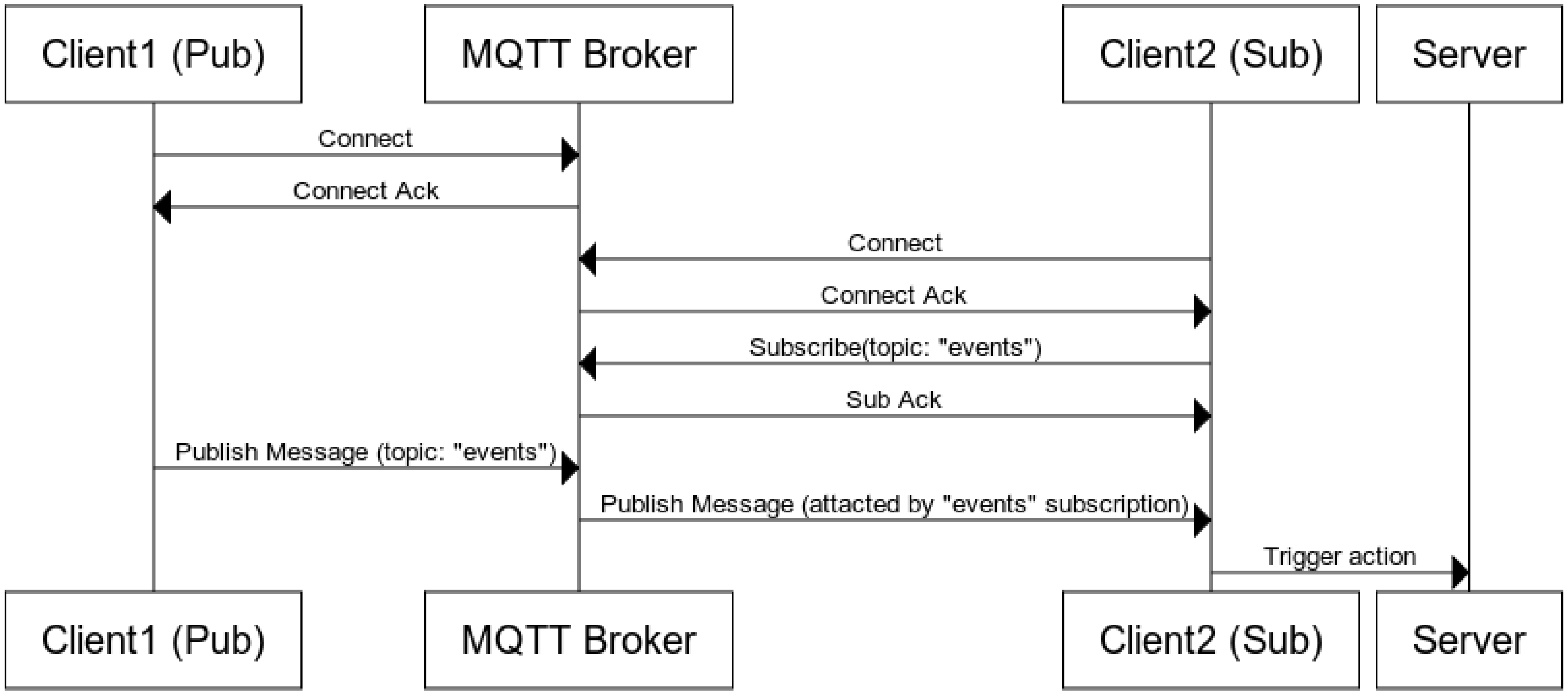
- Sequence diagrams show interactions between objects – not only how they communicate but in what order over time
- Objects are shown across the top of the diagram
  - Objects at the top of the diagram existed when the scenario begins
    - All other objects are created during the execution of the scenario
- Each object has a vertical dashed line known as its lifeline
  - When an object is active, the lifeline has a rectangle placed above its lifeline
  - If an object dies during the scenario, its lifeline terminates with an “X”

Sequence Diagrams (II)

- Messages between objects are shown with lines pointing at the object receiving the message
  - The line is labeled with the method being called and (optionally) its parameters
- All UML diagrams can be annotated with “notes”
- Sequence diagrams can be useful, but they are also labor intensive
- Often needed to understand embedded system interactions that are timing dependent


:DogDoorSimulator
:System.out
«create»
:DogDoor
«create»
:BarkRecognizer
«create»
:Remote
println("Fido starts barking.")
recognize("Woof")
println("BarkRecognizer: Heard a 'Woof'.")
open()
println("The dog door opens.")
«create»
:Timer
schedule()
sleep(5000)
println("Fido has gone outside...")
println("Fido's all done...")
close()
sleep(10000)
println("The dog door closes.")
println("...but he's stuck outside!")
println("Fido starts barking.")
recognize("Woof")
Insert another copy of the interaction shown above here
println("Fido's back inside...")

Another example: MQTT Broker

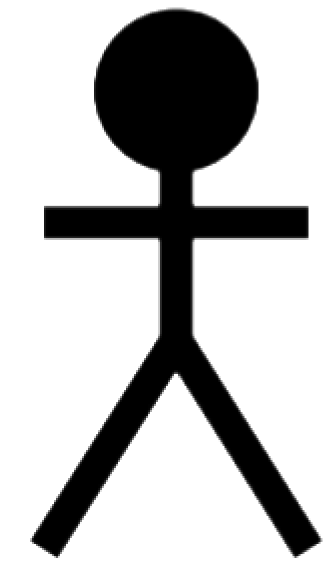


- My experience: often needed to understand embedded and/or connected system interactions that may have timing dependencies
- From an article on Node.JS publishing events to an MQTT broker
  - https://stackoverflow.com/questions/32538535/node-and-mqtt-do-something-on-message

User Perspective and Use Cases

- In analysis, as much as possible, we want to write our artifacts from the standpoint of a user
  - We will make frequent and consistent use of domain-related vocabulary and concepts
  - We will talk about the software system as a “black box”
  - We can describe its inputs and its expected outputs but we try to avoid discussing how the system will process or produce this information
- In UX oriented workflows, understanding the user and their tasks are key
  - A typical UX development process might include
    - Analysis and Planning
    - User and Task Research (<- Use cases)
    - Interface and Interaction Design
    - Verification and Validation
- Use cases help maintain the user perspective
  - We identify the different types of users for our system – “who”
  - We then develop tasks for each of the different types of user – “what”
- Use cases are used to capture functional requirements
    - They can be annotated to also describe non-functional requirements but typically the focus is on functional requirements only

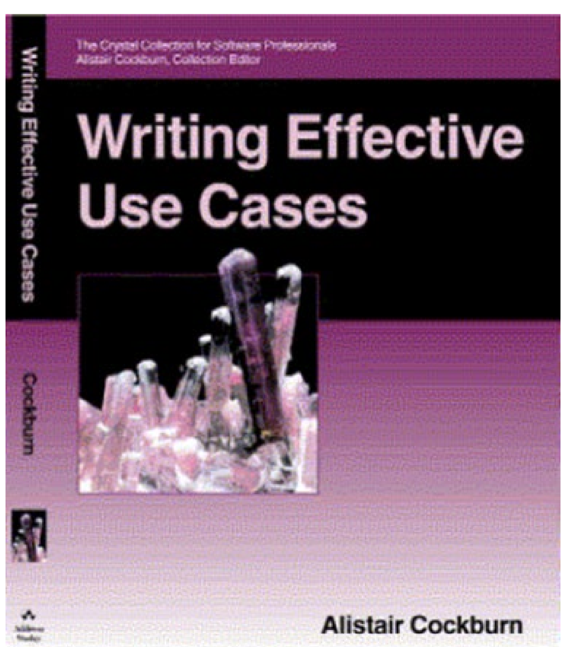
Actors



- More formally, a user is represented by an actor
  - Each use case can have one or more actors involved
    - An actor can be either a human user or a software system
- Actors have two defining characteristics
  - They are external to the system under design
  - They take initiative and interact with our system
  - During a use case, they have a goal they are trying to achieve
- Each use case describes a task or tasks for a particular actor
  - The description typically includes one “success” case and a number of extensions that document “exceptional” conditions

Text-based Use Cases

- From a presentation by Alistair Cockburn, author of Writing Effective Use Cases
  - Presentation is: Agile Use Cases
  - https://canvas.colorado.edu/files/43695114/download?download_frd=1
  - What is and isn't a use case good for:



Good use cases

are	aren't
Text	UML use case diagrams
No GUI	describing the GUI
No data formats	describing data formats
3 - 9 steps in main scenario	multiple-page main scenario
Easy to read	complicated to read
At user's goal level	at program-feature level
Record of decisions made	tutorial on the domain

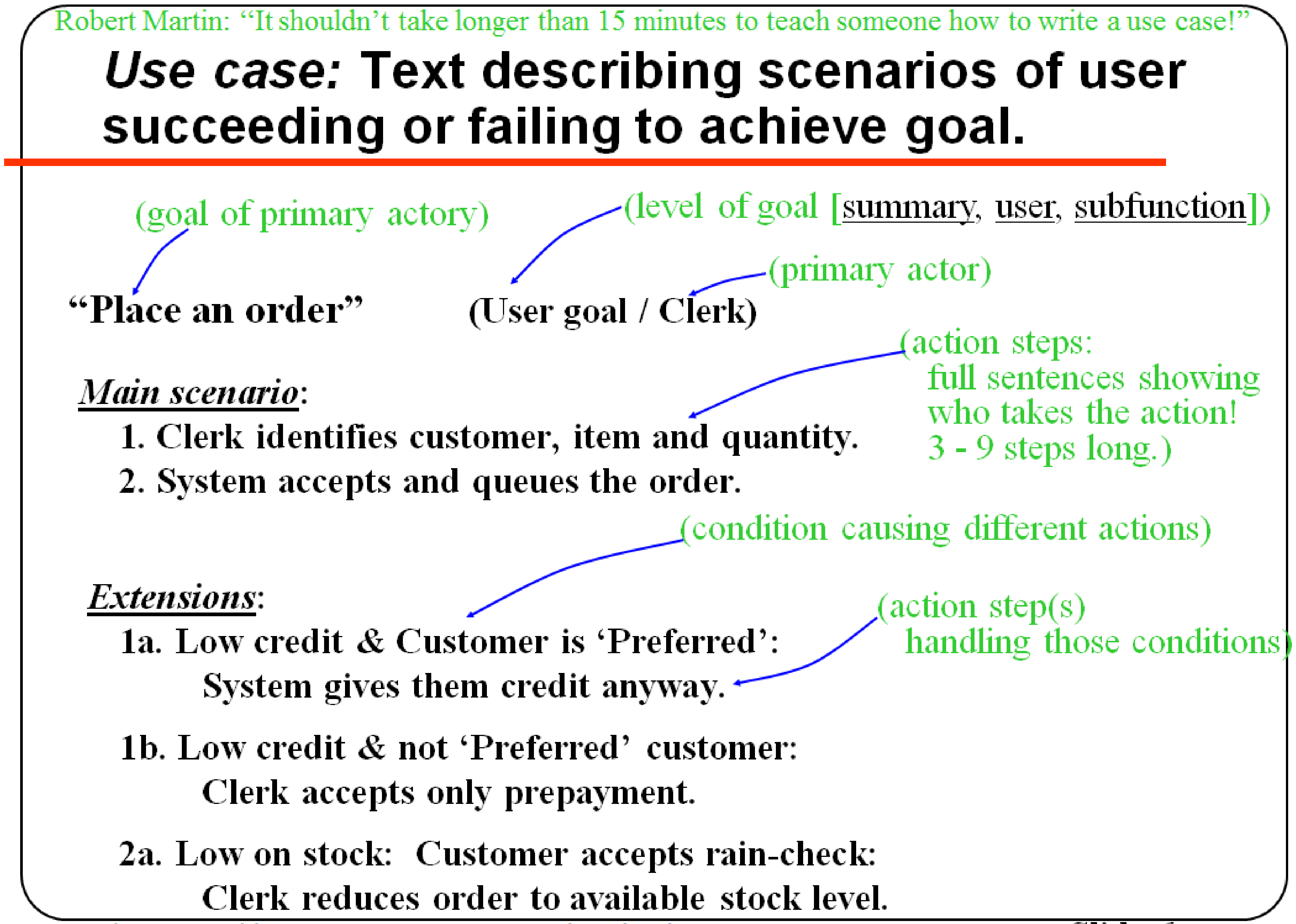
Use cases *can be* written --

all up front --or-- just-in-time

each to completion --or-- in (usable) increments

Text-based Use Cases

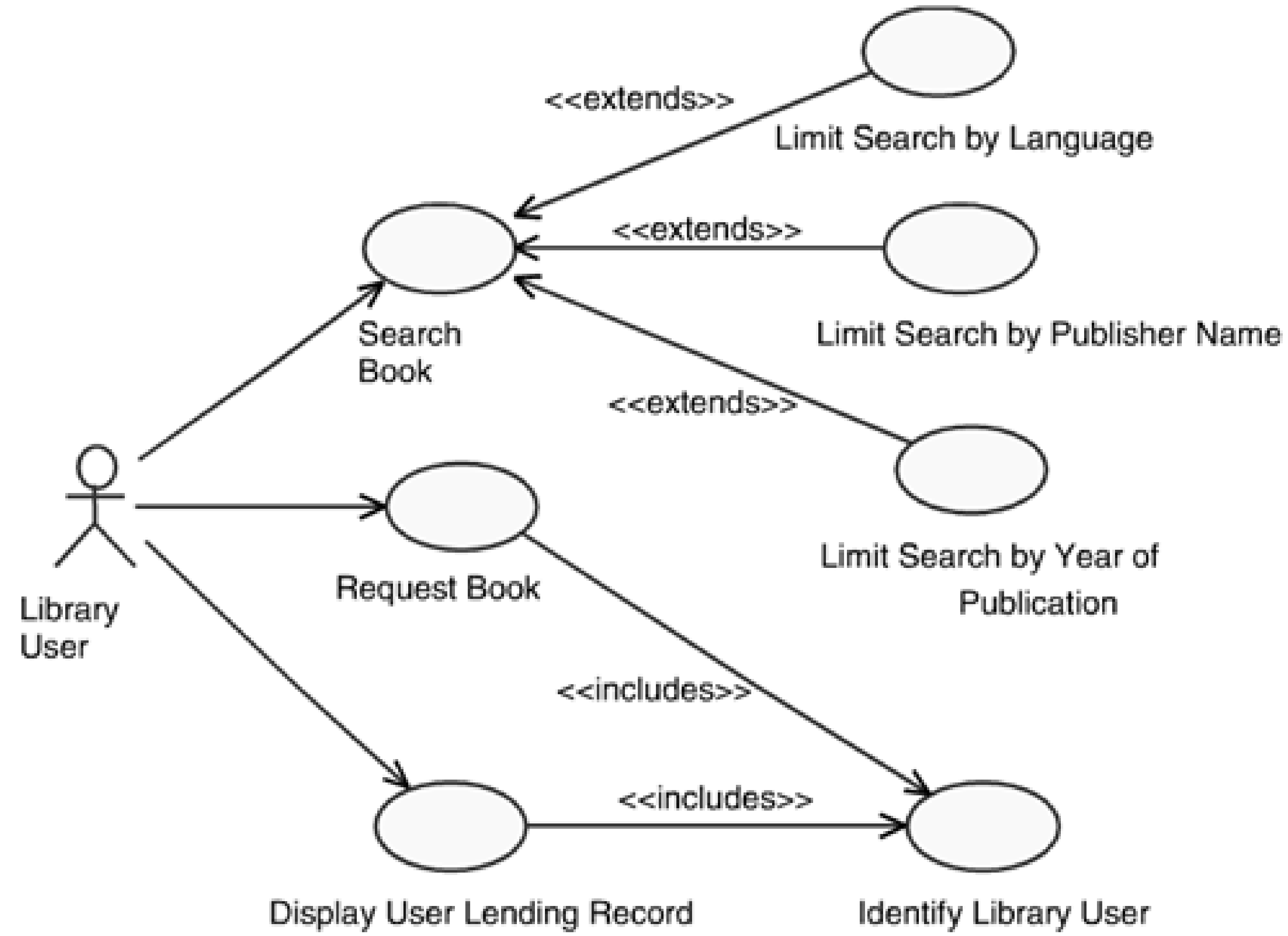
- Four benefits:
  - Short summary of system goals
  - Main success scenario (system responsibility)
  - Extension conditions (things to watch for or consider)
  - Extension handling (decisions on policy)
- From a presentation by Alistair Cockburn
  - Agile Use Cases
  - http://alistair.cockburn.us/get/2231



- Use Cases contain scenarios
  - A complete path through a use case from the first step to the last is called a **scenario** 57
  - Some use cases have multiple scenarios but a single user goal
    - All paths try to achieve victory

UML Use Cases – Best Practices

- Always design use cases from the actor's point of view
- Model the entire flow of a given operation
- For most systems, use cases should number in the tens, not hundreds
- <include> cases: not optional, base use case not complete without it, not conditional, and doesn't change the base use case behavior
- <extend> cases: Can be optional, not part of base use case, can be conditional or change behavior



WAVE Test for Use Cases (from Maksimchuk)
W: Use case describes WHAT to do, not how
A: ACTOR'S point of view
V: Has VALUE for actor
E: Use case models ENTIRE scenario

What are Activity & State Diagrams?

- They represent alternate ways to record/capture design information about your system
- They can help you identify new classes and methods
- They are typically used after use case creation: for instance, create an activity diagram for a given use case scenario
- For each activity in the diagram, (you might) follow-on and draw a sequence diagram
  - Add a class for each object in the sequence diagrams to your class diagram, add methods in sequence diagrams to relevant classes
  - Remember – sequence diagrams may not needed for simple logic

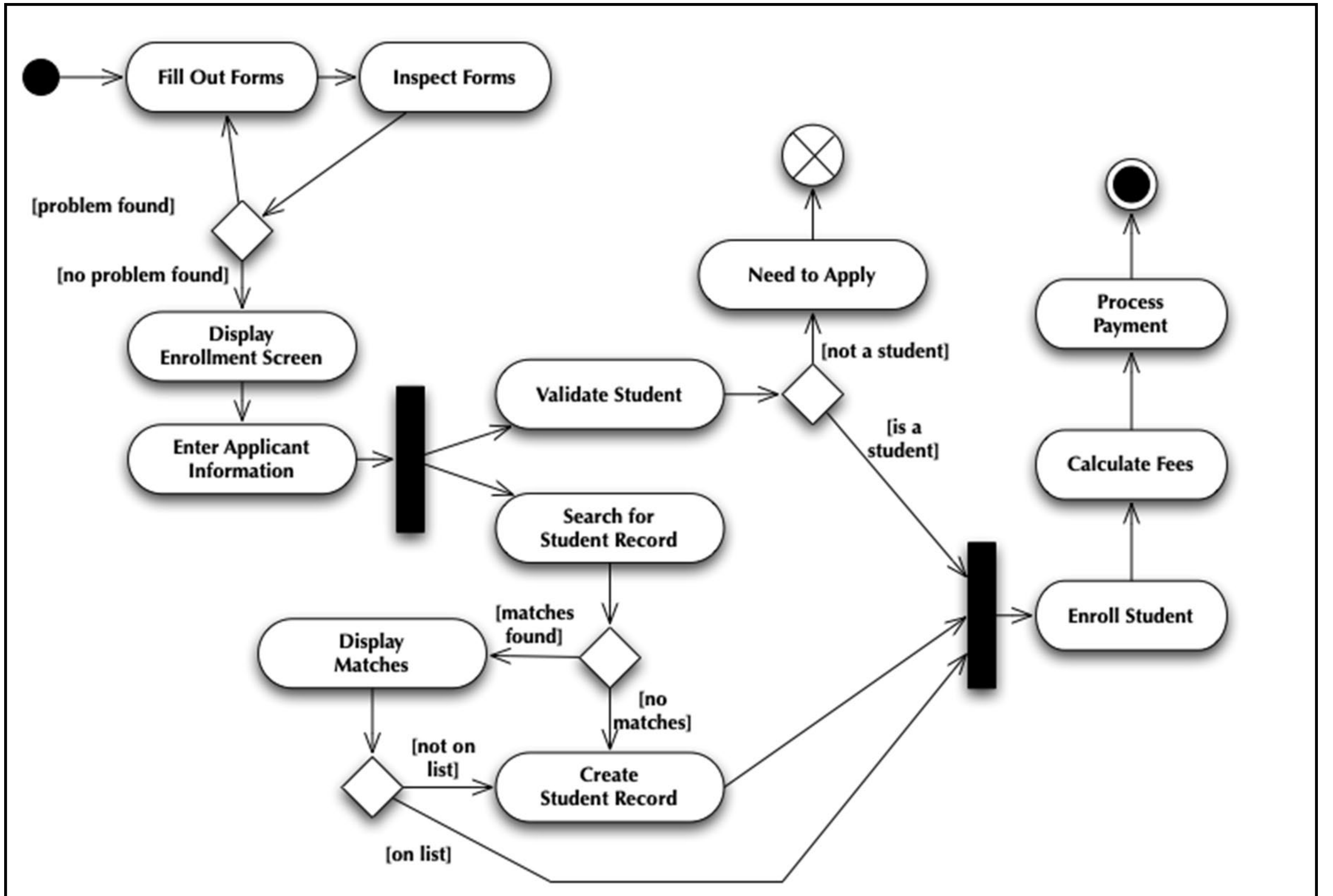
What are Activity & State Diagrams?

- Activity Diagram
  - Think “Super Flow Chart”
  - Able to model complex, parallel processes with multiple ending conditions
- State Diagram
  - Shows the major states of an object or system
  - partition an object’s behavior into various categories (initializing, acquiring info, performing calcs, …)
  - documents these states and the transitions between them (transitions typically map to method calls)

Activity Diagrams

Notation

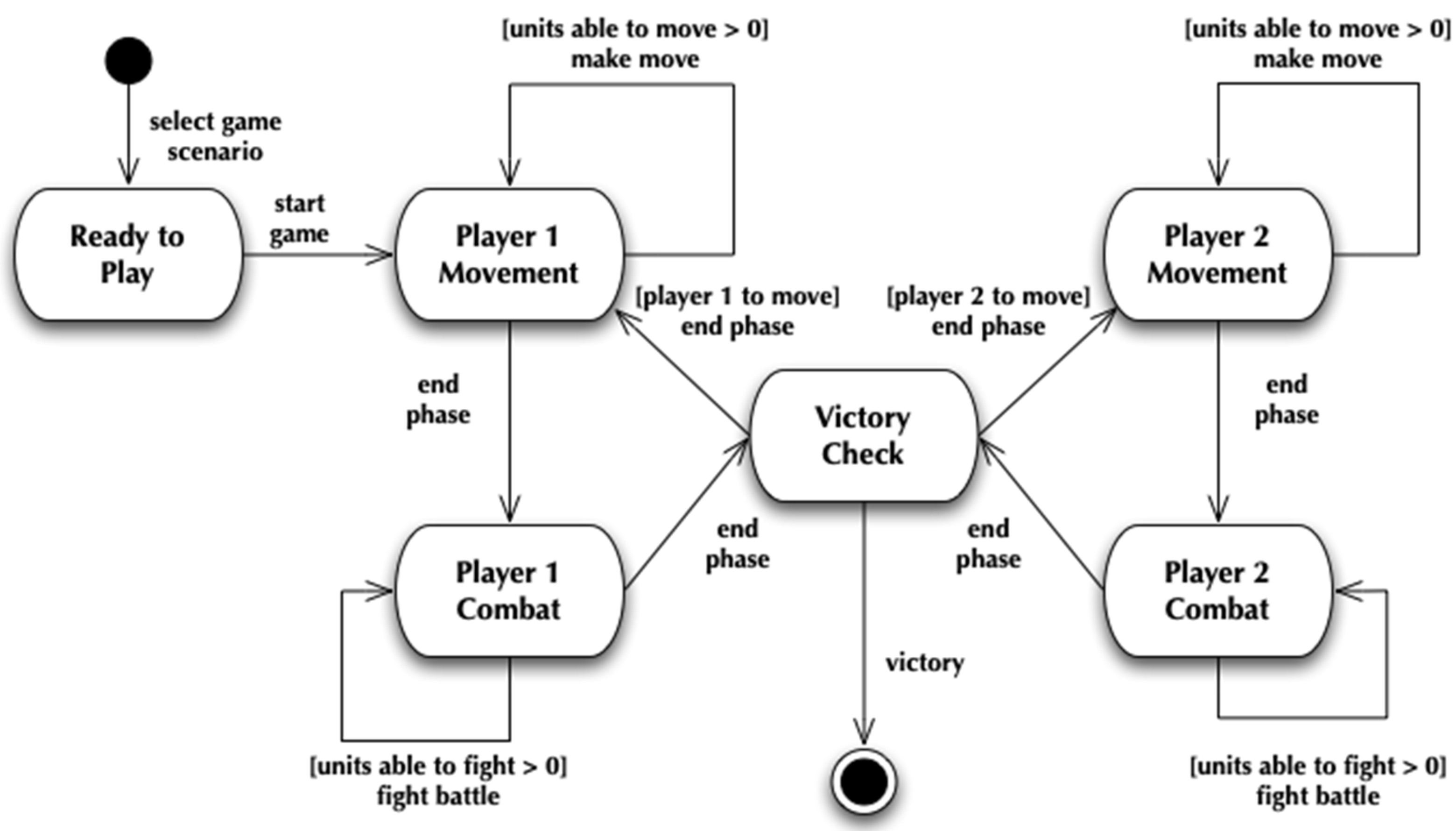
- Initial Node (circle)/Final Node (circle in circle)/Early Termination Node (circle with x through it)
- Activity: Rounded Rectangle indication an action of some sort either by a system or by a user
- Flow: directed lines between activities and/or other constructs. Flows can be annotated with guards "[student on list]" that restrict its use
- Fork/Join: Black bars that indicate activities that happen in parallel
- Decision/Merge: Diamonds used to indicate conditional logic.



Example adapted from <http://www.agilemodeling.com/artifacts/activityDiagram.htm>. Copyright © 2003-2006 Scott W. Ambler

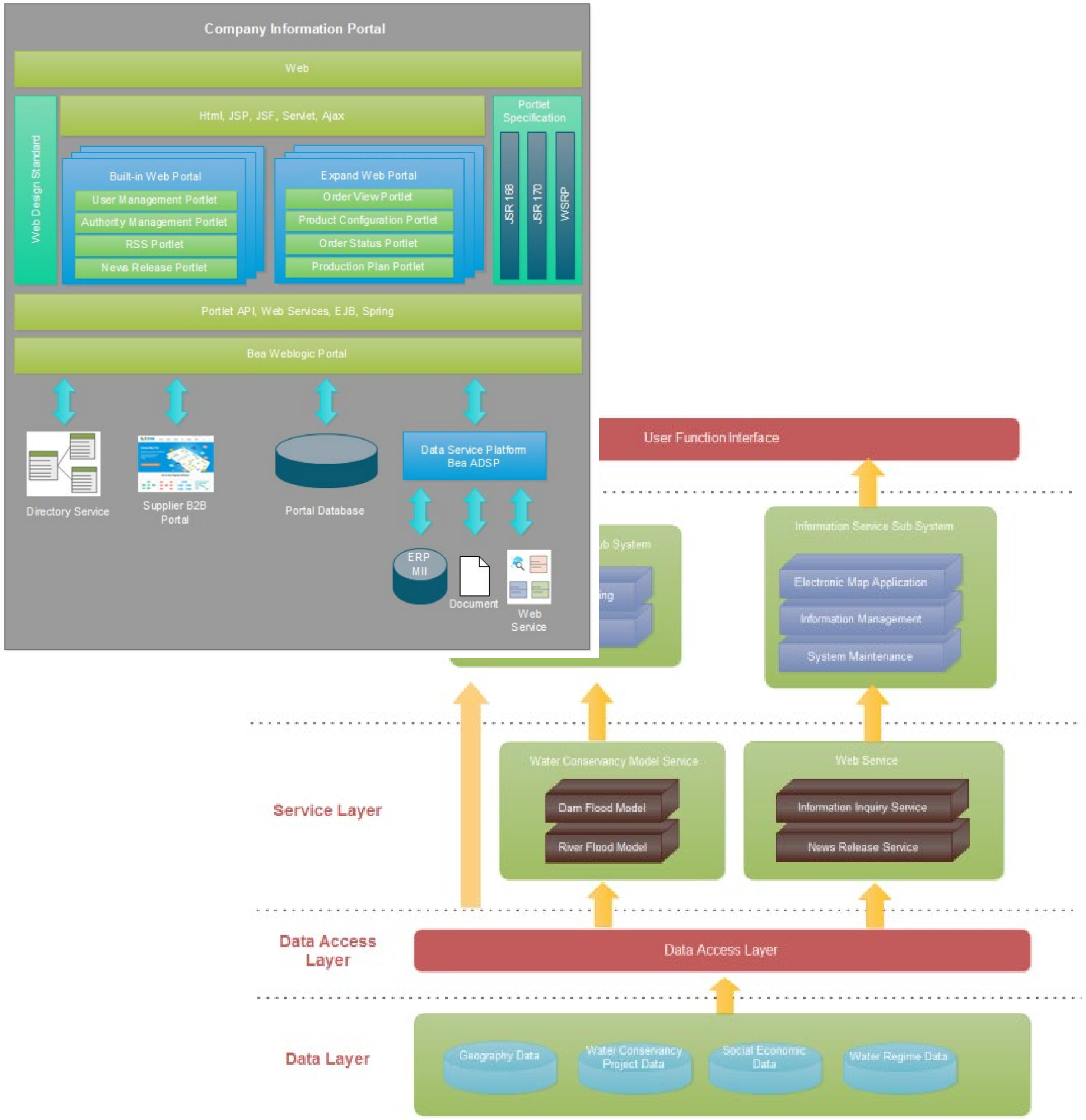
State Diagrams

- Each state appears as a rounded rectangle
- Arrows indicate state transitions
    - Each transition has a name that indicates what triggers the transition (often times, this name corresponds to a method name)
    - Each transition may optionally have a guard that indicates a condition that must be true before the transition can be followed
- A state diagram also has a start state and an end state



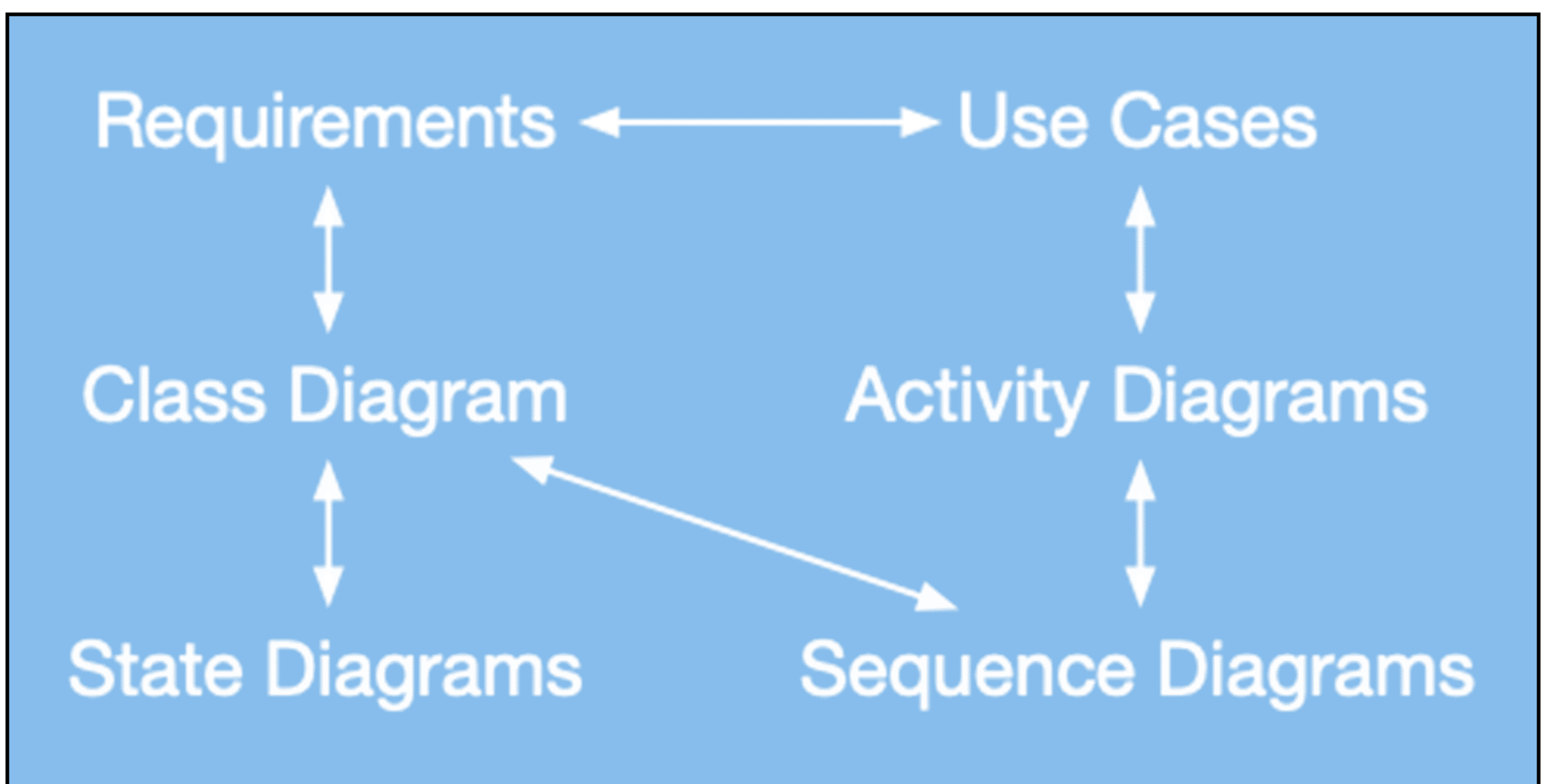
Architecture Diagram (not UML)

- A common diagramming style to present a high-level view of a system is an architecture diagram
- This is usually produced as a layered image of the internal major sub-systems of an application, external elements, and communication connections
- aka “Boxes and Arrows”
- Typical examples at https://www.edrawsoft.com/architecture-diagram.php
- The closest UML diagrams would be Component and Deployment diagrams



Iterative UML-based Development Process

- Once you have written requirements and use cases to fulfill them
  - and you've reviewed the use cases with clients to determine the various alternate paths
  - You're ready to start creating class diagrams, activity diagrams, state diagrams and sequence diagrams using information in the use cases as inspiration
  - Details are developed in iterative change and review
- Relationships between OO A&D Software Artifacts



Summary

- You should feel comfortable building the following UML diagrams
  - Class
    - inheritance
    - association (with multiplicity)
    - aggregation/composition
    - qualification
    - Interfaces and abstract classes
  - Use Case
  - Sequence
  - Activity
  - State
- You'll be making UML diagrams for project designs and possibly on exams, you'll certainly need to know how to read the diagrams

Next Steps

- Latest
  - All office hours for myself and the staff are posted on Canvas and Piazza
  - All class assignments and dates are loaded on Canvas
  - Examples of graduate and semester projects posted…
- Assignments
  - The next participation discussion topic is up on Piazza (about testing), please respond – don't get too far behind on these!
  - Project 2, the first team programming project: Part 1 due 2/2, Part 2 due 2/9
  - Quiz 2 up this weekend, due Thur 2/3
  - The first part of the Graduate Project, the Proposal, was reviewed and is due on 2/4
    - Don't forget to post your topics in the Google Doc that's linked in the project directions
- Stay Engaged
  - Make sure you sign up for Piazza and Canvas notifications
  - Make sure you can access the Head First Design Patterns textbook – no readings yet
  - Consider the tutorials/sources for Git, Java, Python if you need them
- Coming up
  - Next up: Tools - Python, TDD, and on to Patterns
- Please come find us for any help you need or questions you have!