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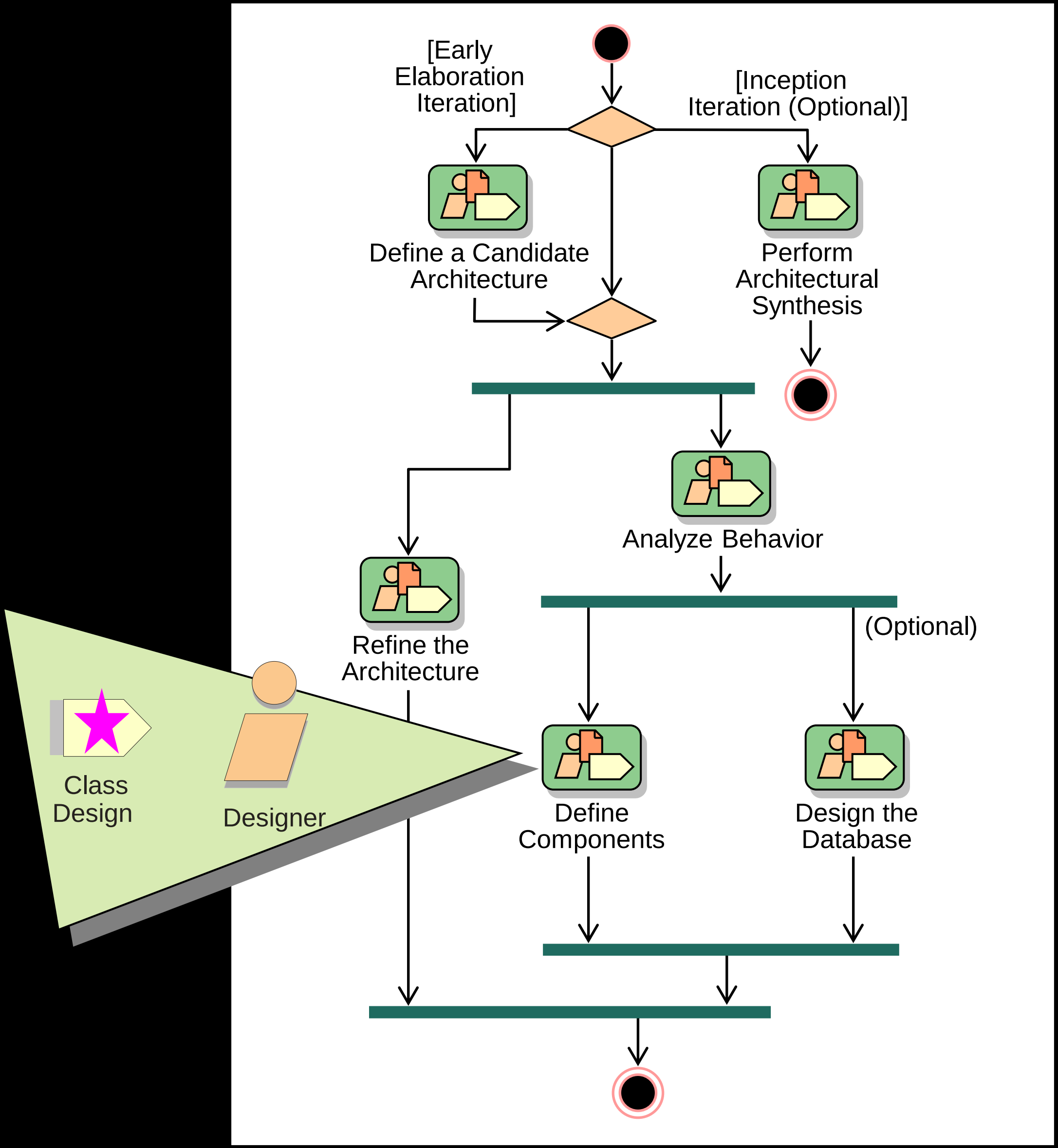
Mastering Object-Oriented Analysis and Design with UML

Module 13: Class Design

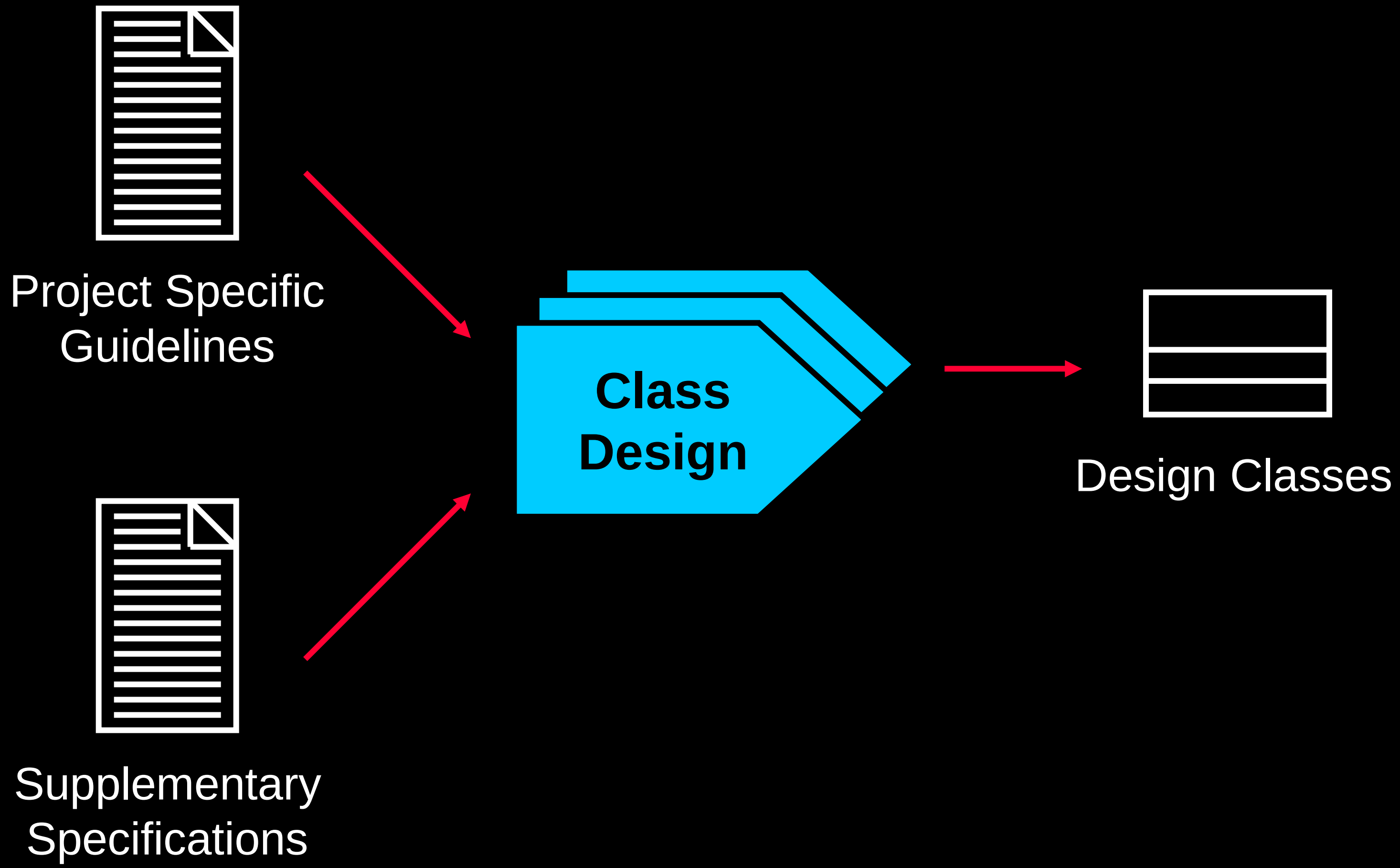
Objectives: Class Design

- Define the purpose of Class Design and where in the lifecycle it is performed
- Identify additional classes and relationships needed to support implementation of the chosen architectural mechanisms
- Identify and analyze state transitions in objects of state-controlled classes
- Refine relationships, operations, and attributes

Class Design in Context

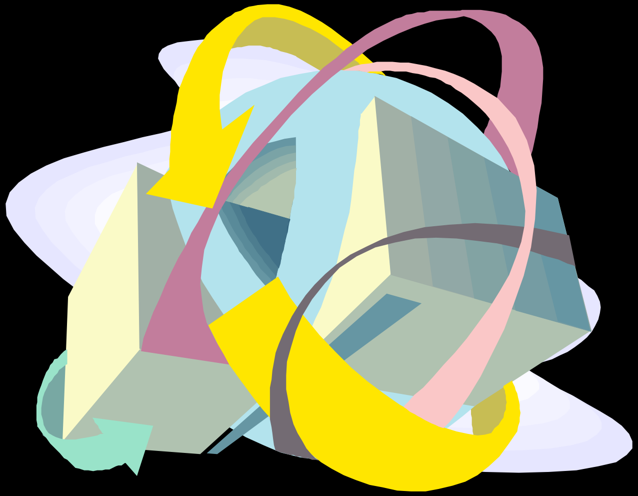

[Early Elaboration Iteration]
[Inception Iteration (Optional)]
Define a Candidate Architecture
Perform Architectural Synthesis
Analyze Behavior
Refine the Architecture
(Optional)
Class Design
Designer
Define Components
Design the Database

Class Design Overview



Class Design Steps

- Create Initial Design Classes
- Define Operations
- Define Methods
- Define States
- Define Attributes
- Define Dependencies
- Define Associations
- Define Generalizations
- Resolve Use-Case Collisions
- Handle Nonfunctional Requirements in General
- Checkpoints



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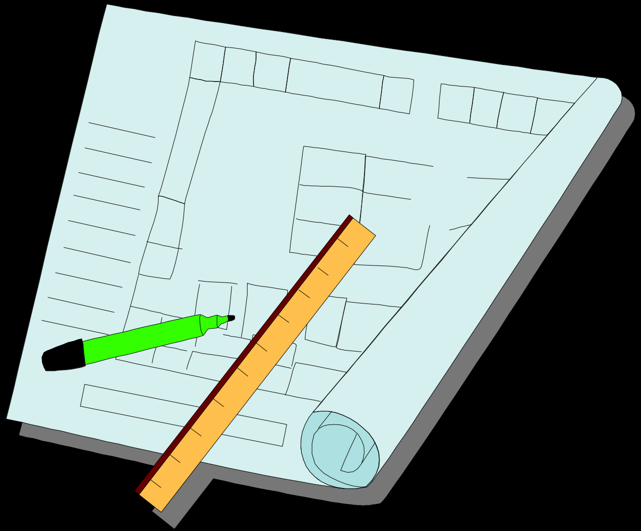
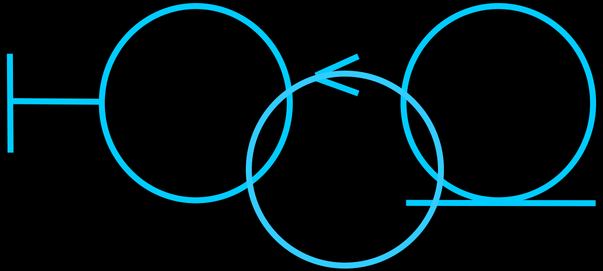
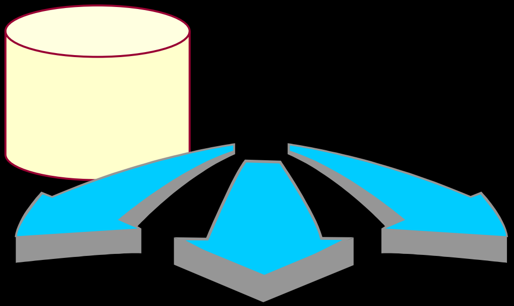


Class Design Considerations

- Class stereotype
  - Boundary
  - Entity
  - Control
- Applicable design patterns
- Architectural mechanisms
  - Persistence
  - Distribution
  - etc.





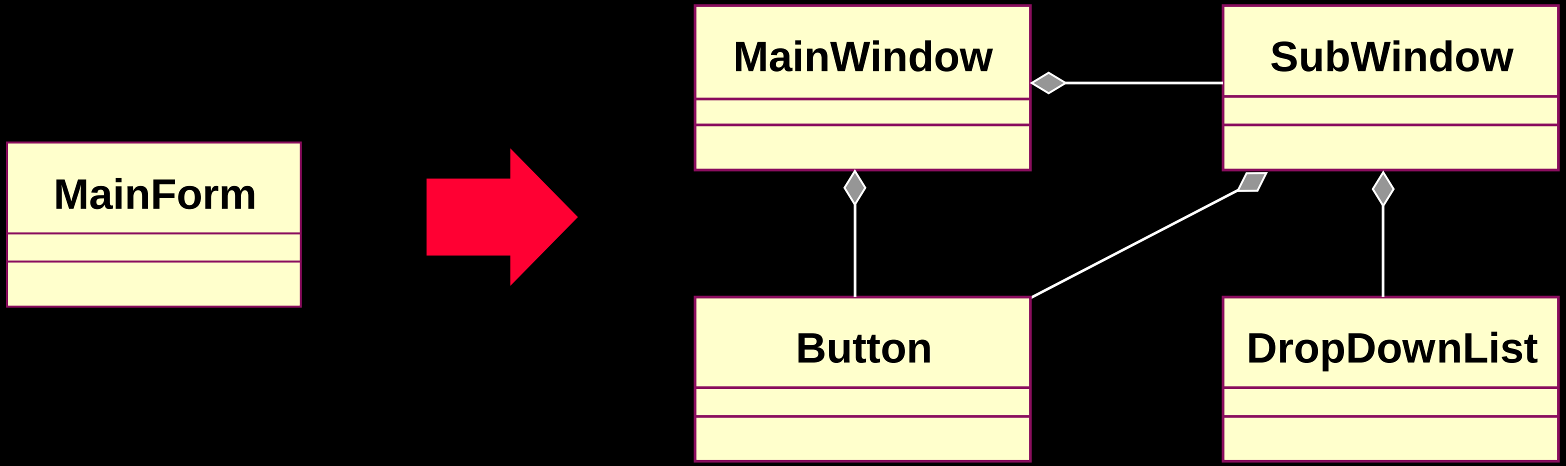
How Many Classes Are Needed?

- Many, simple classes means that each class
  - Encapsulates less of the overall system intelligence
  - Is more reusable
  - Is easier to implement
- A few, complex classes means that each class
  - Encapsulates a large portion of the overall system intelligence
  - Is less likely to be reusable
  - Is more difficult to implement

A class should have a single well-focused purpose. A class should do one thing and do it well!

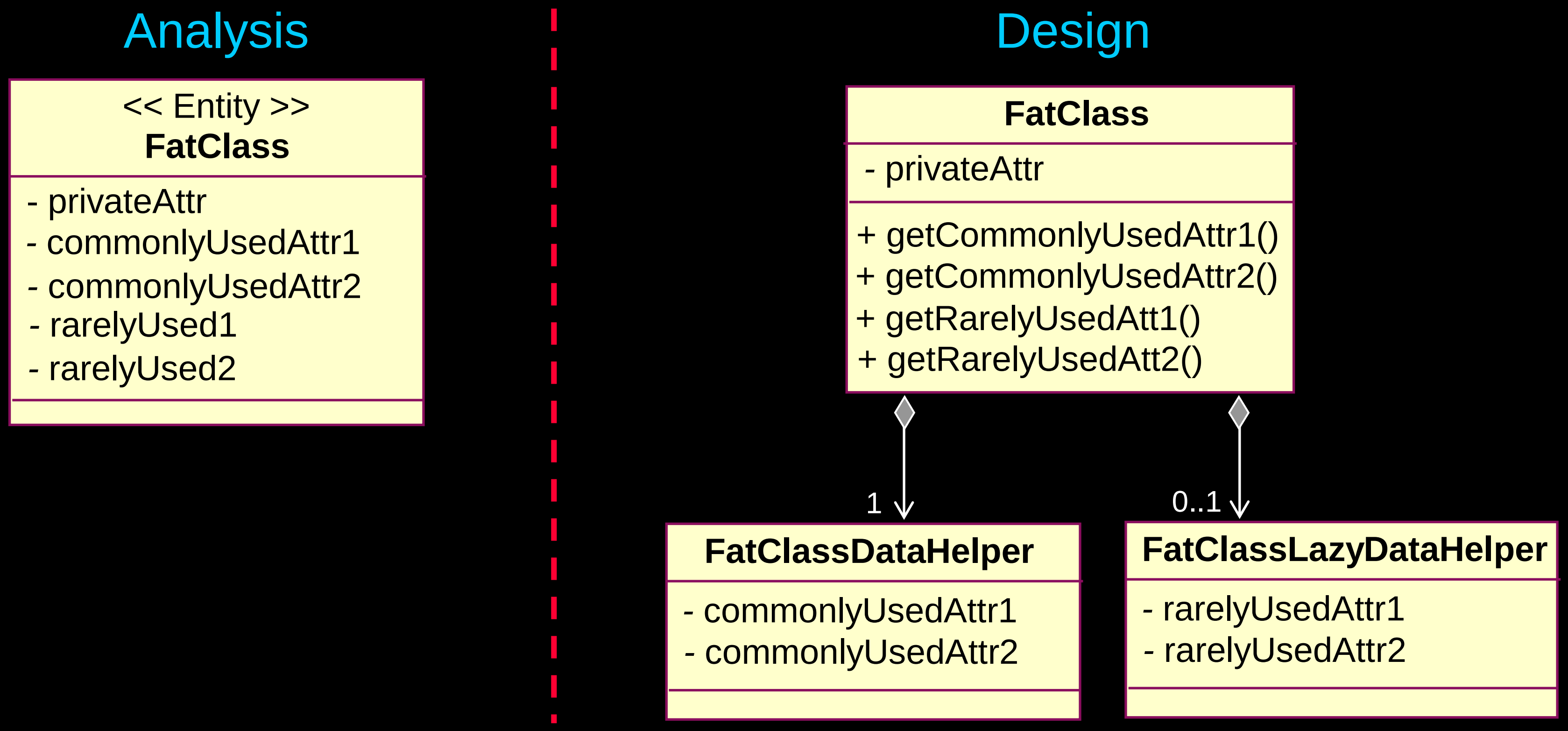
Strategies for Designing Boundary Classes

- User interface (UI) boundary classes
  - What user interface development tools will be used?
  - How much of the interface can be created by the development tool?
- External system interface boundary classes
  - Usually model as subsystem



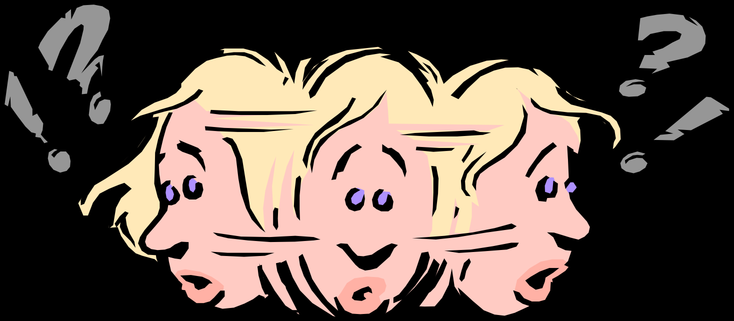
Strategies for Designing Entity Classes

- Entity objects are often passive and persistent
- Performance requirements may force some re-factoring
- See the Identify Persistent Classes step



Strategies for Designing Control Classes

- What happens to Control Classes?
  - Are they really needed?
  - Should they be split?
- How do you decide?
  - Complexity
  - Change probability
  - Distribution and performance
  - Transaction management



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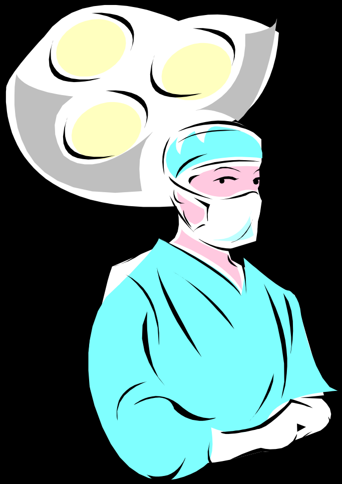
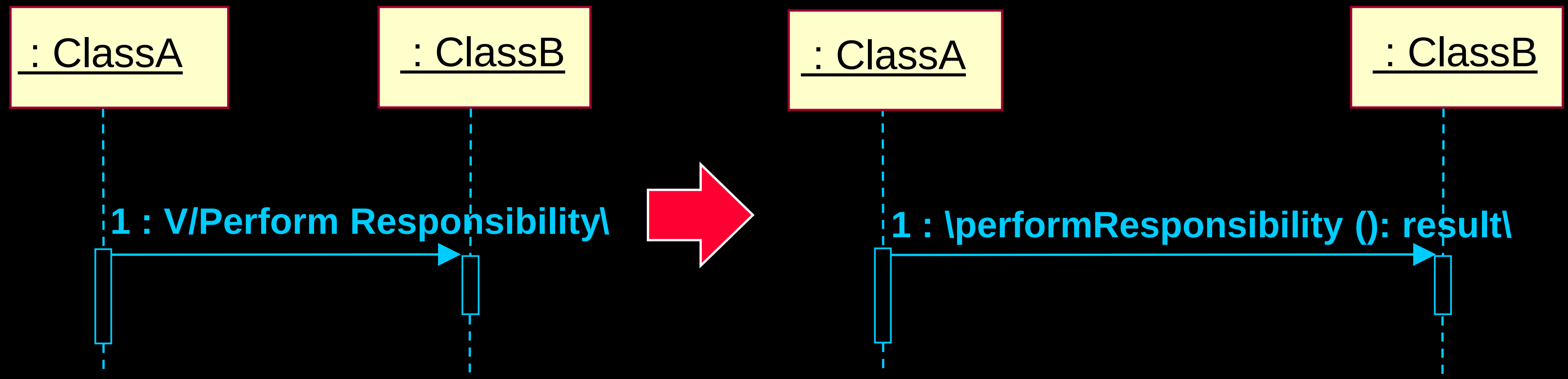


Operations: Where Do You Find Them?

- Messages displayed in interaction diagrams


: ClassA
: ClassB
1 : V/Perform Responsibility\
: ClassA
: ClassB
1 : \performResponsibility (): result\

- Other implementation dependent functionality
  - Manager functions
  - Need for class copies
  - Need to test for equality

Name and Describe the Operations

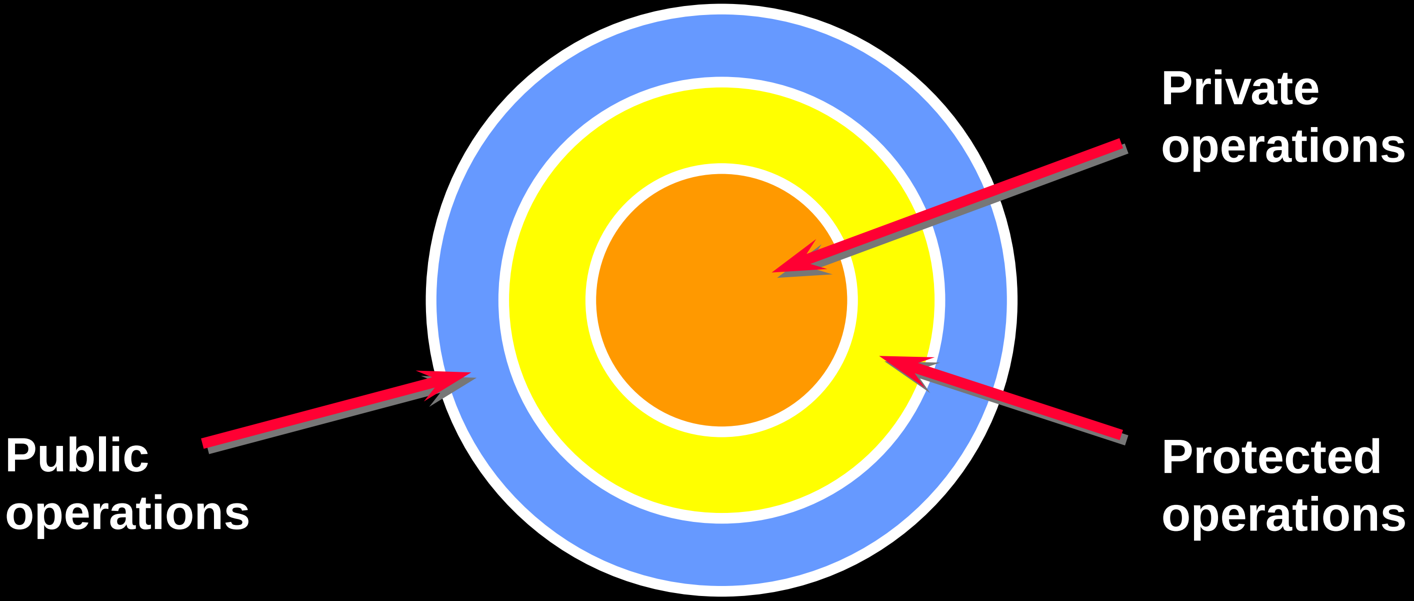
- Create appropriate operation names
  - Indicate the outcome
  - Use client perspective
  - Are consistent across classes
- Define operation signatures
  - operationName([direction]parameter : class,..) : returnType
    - Direction is **in**, **out** or **inout** with the default **in** if absent
- Provide short description, including meaning of all parameters

Guidelines: Designing Operation Signatures

- When designing operation signatures, consider if parameters are:
  - Passed by value or by reference
  - Changed by the operation
  - Optional
  - Set to default values
  - In valid parameter ranges
- The fewer the parameters, the better
- Pass objects instead of “data bits”

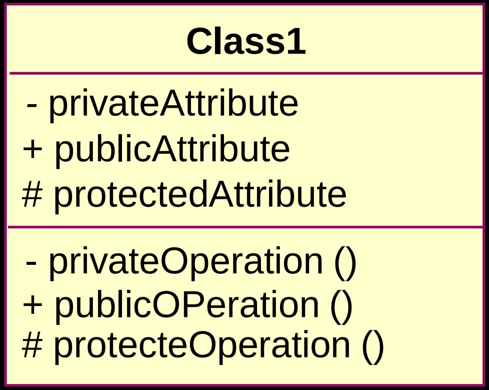
Operation Visibility

- Visibility is used to enforce encapsulation
- May be public, protected, or private



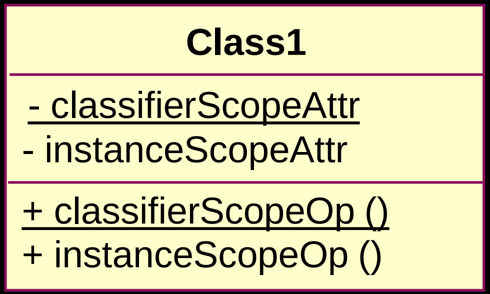
How Is Visibility Noted?

- The following symbols are used to specify export control:
  - + Public access
  - # Protected access
  - - Private access

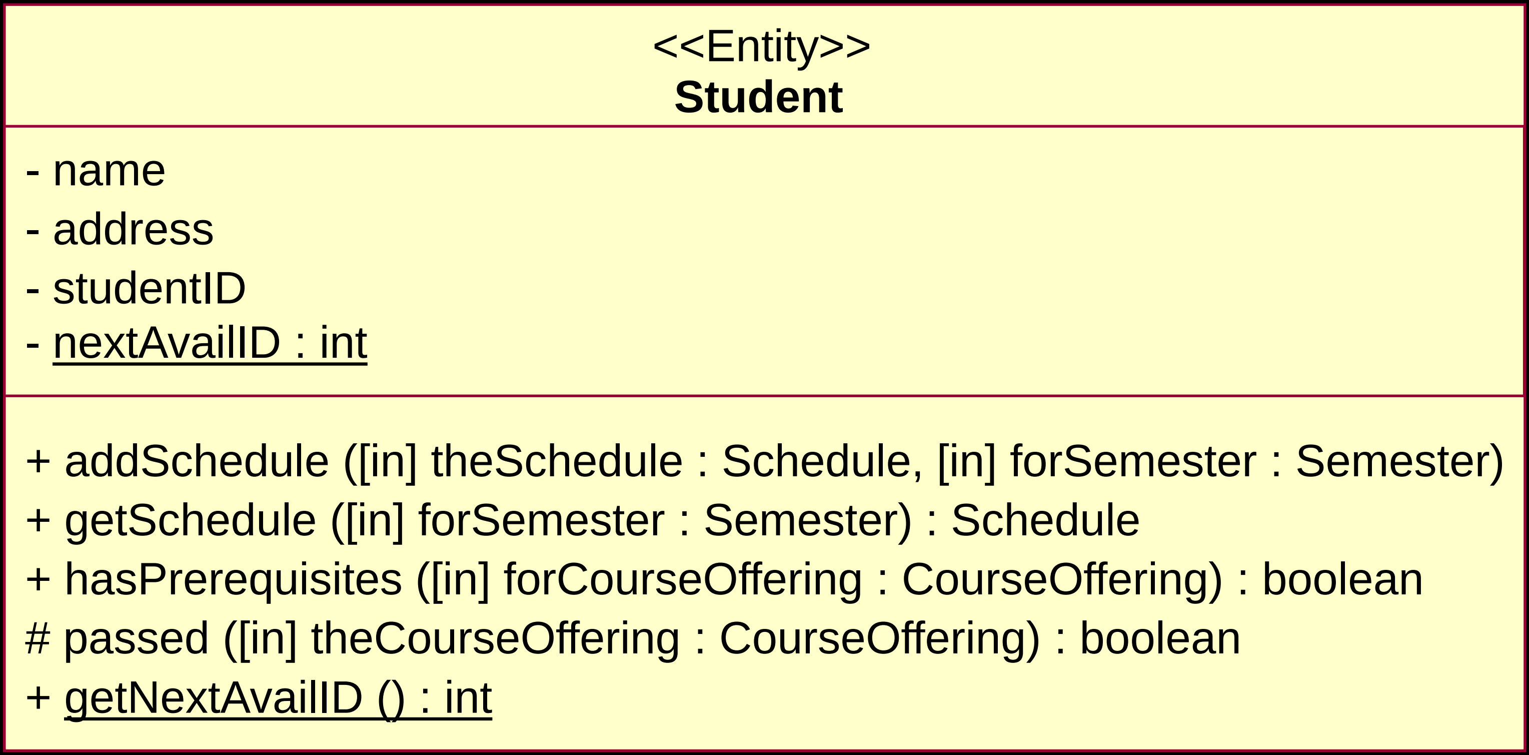


Scope

- Determines number of instances of the attribute/operation
  - Instance: one instance for each class instance
  - Classifier: one instance for all class instances
- Classifier scope is denoted by underlining the attribute/operation name

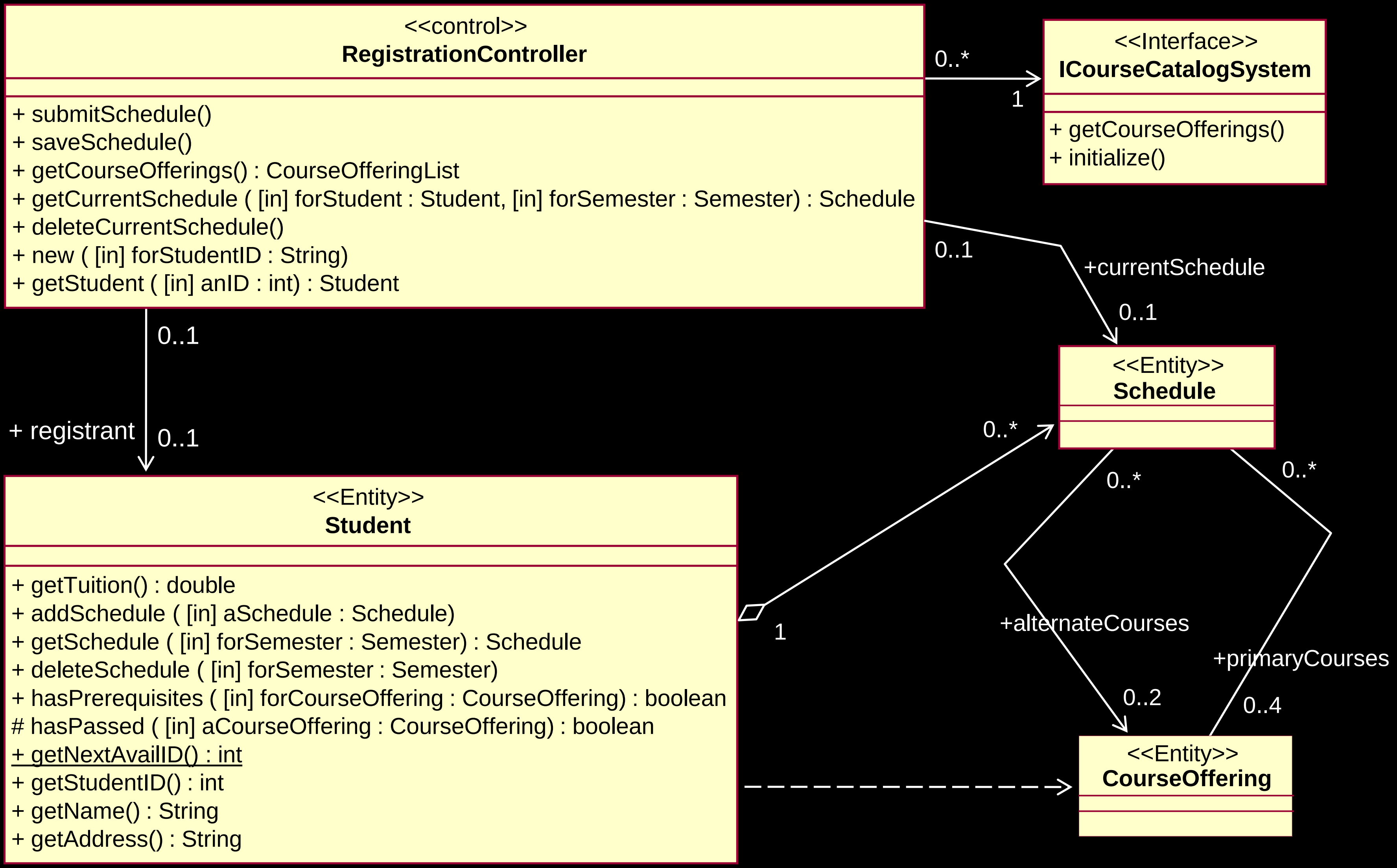


Example: Scope



<<Entity>>
Student
- name
- address
- studentID
- nextAvailID : int
+ addSchedule ([in] theSchedule : Schedule, [in] forSemester : Semester)
+ getSchedule ([in] forSemester : Semester) : Schedule
+ hasPrerequisites ([in] forCourseOffering : CourseOffering) : boolean
# passed ([in] theCourseOffering : CourseOffering) : boolean
+ getNextAvailID () : int

Example: Define Operations



<<control>>
RegistrationController
+ submitSchedule()
+ saveSchedule()
+ getCourseOfferings() : CourseOfferingList
+ getCurrentSchedule ([in] forStudent : Student, [in] forSemester : Semester) : Schedule
+ deleteCurrentSchedule()
+ new ([in] forStudentID : String)
+ getStudent ([in] anID : int) : Student
0..*
1
<<Interface>>
ICourseCatalogSystem
+ getCourseOfferings()
+ initialize()
0..1
+currentSchedule
0..1
<<Entity>>
Schedule
0..1
+ registrant
0..1
<<Entity>>
Student
+ getTuition() : double
+ addSchedule ([in] aSchedule : Schedule)
+ getSchedule ([in] forSemester : Semester) : Schedule
+ deleteSchedule ([in] forSemester : Semester)
+ hasPrerequisites ([in] forCourseOffering : CourseOffering) : boolean
# hasPassed ([in] aCourseOffering : CourseOffering) : boolean
+ getNextAvailID() : int
+ getStudentID() : int
+ getName() : String
+ getAddress() : String
0..*
1
0..*
0..*
+alternateCourses
+primaryCourses
0..2
0..4
<<Entity>>
CourseOffering

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Define Methods

- What is a method?
  - Describes operation implementation
- Purpose
  - Define special aspects of operation implementation
- Things to consider:
  - Special algorithms
  - Other objects and operations to be used
  - How attributes and parameters are to be implemented and used
  - How relationships are to be implemented and used

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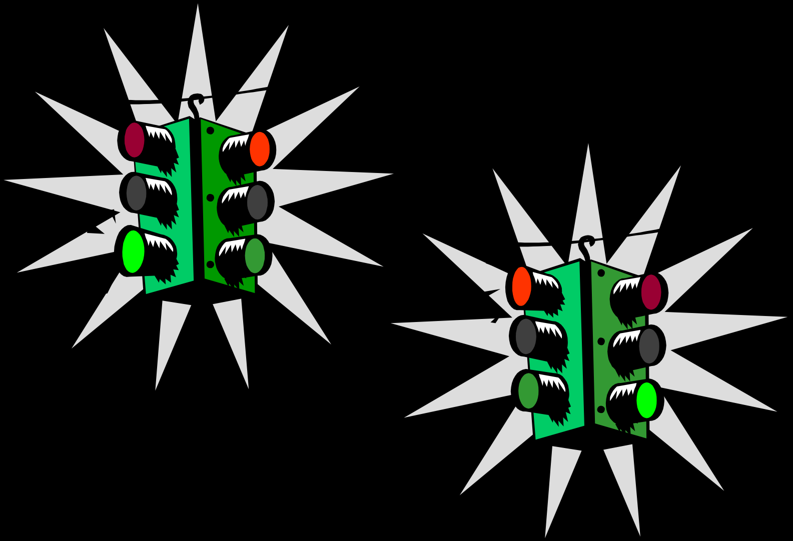
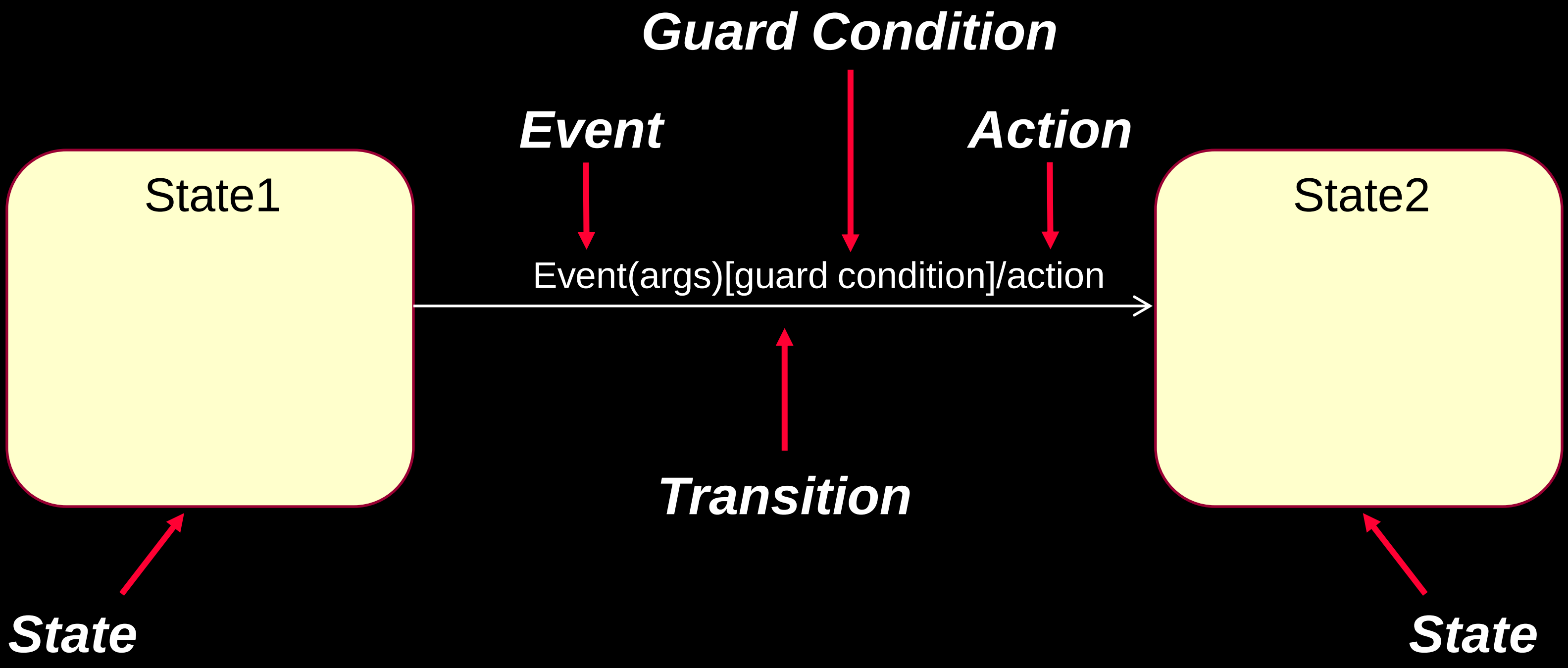


Define States

- Purpose
  - Design how an object’s state affects its behavior
  - Develop statecharts to model this behavior
- Things to consider :
  - Which objects have significant state?
  - How to determine an object’s possible states?
  - How do statecharts map to the rest of the model?

What is a Statechart?

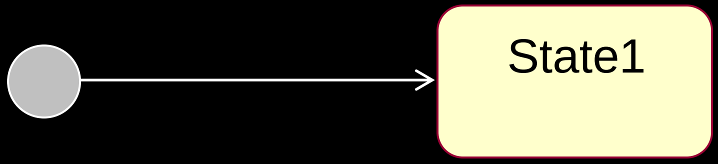
- A directed graph of states (nodes) connected by transitions (directed arcs)
- Describes the life history of a reactive object

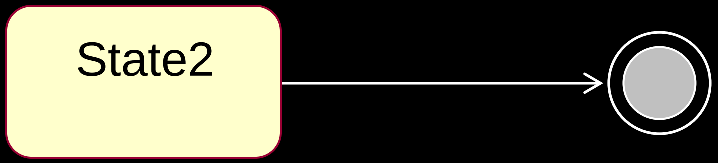


Special States

- Initial state
  - The state entered when an object is created
  - Mandatory
  - Can only have one initial state

- Final state
  - Indicates the object's end of life
  - Optional
  - May have more than one

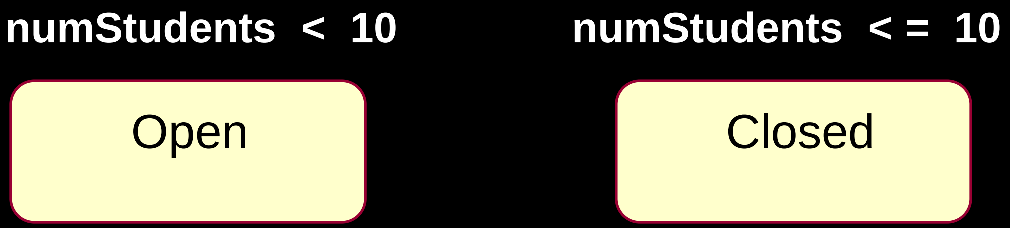




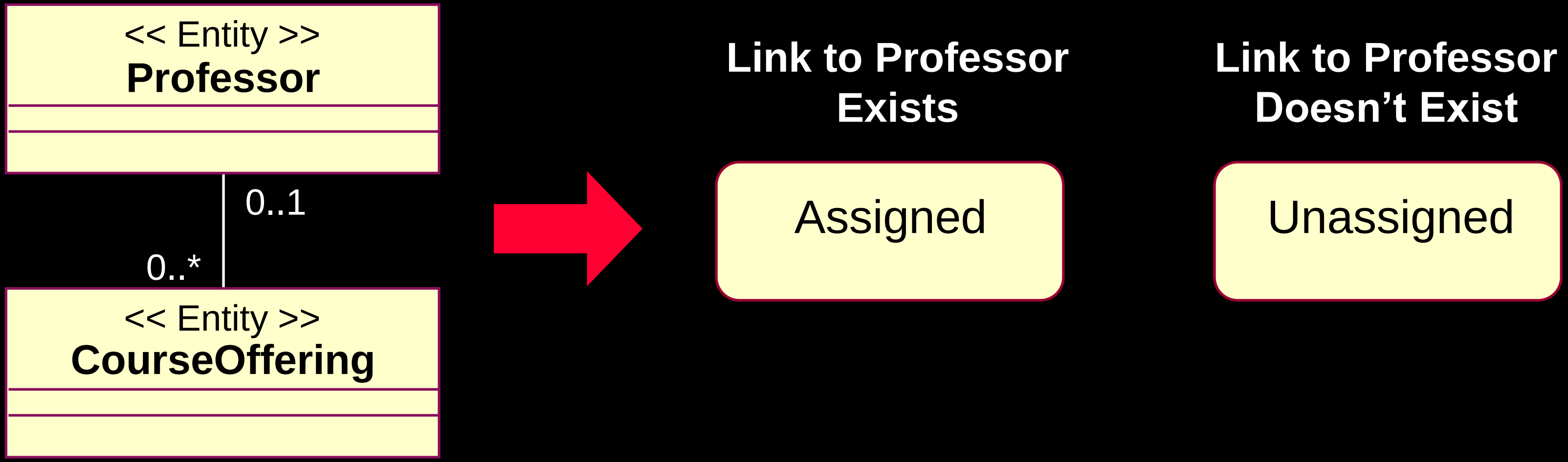
Identify and Define the States

- Significant, dynamic attributes

The maximum number of students per course offering is 10

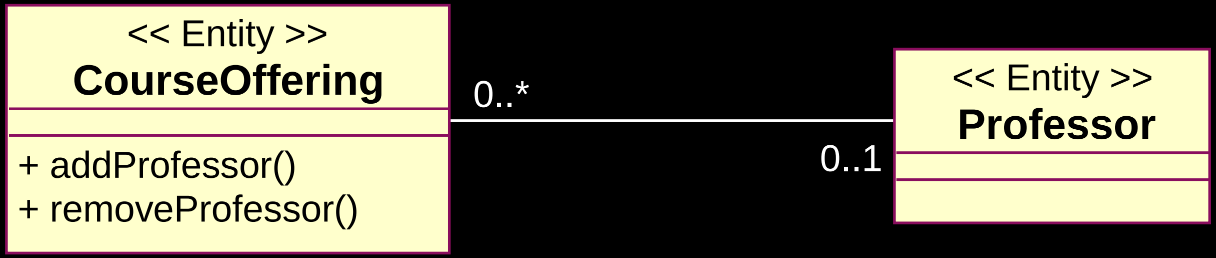


- Existence and non-existence of certain links



Identify the Events

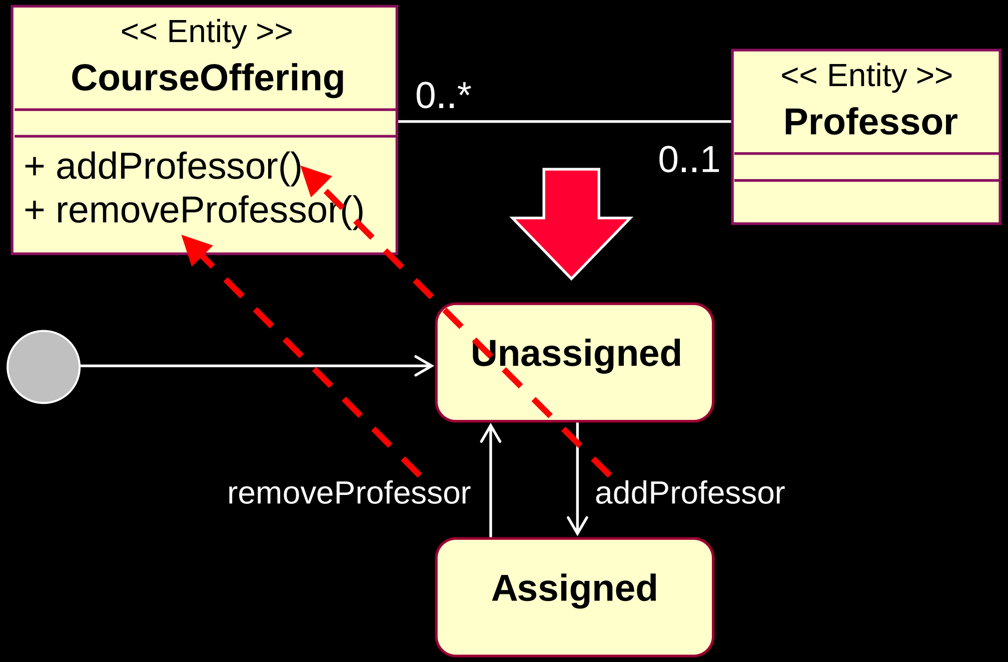
- Look at the class interface operations



Events: addProfessor, removeProfessor

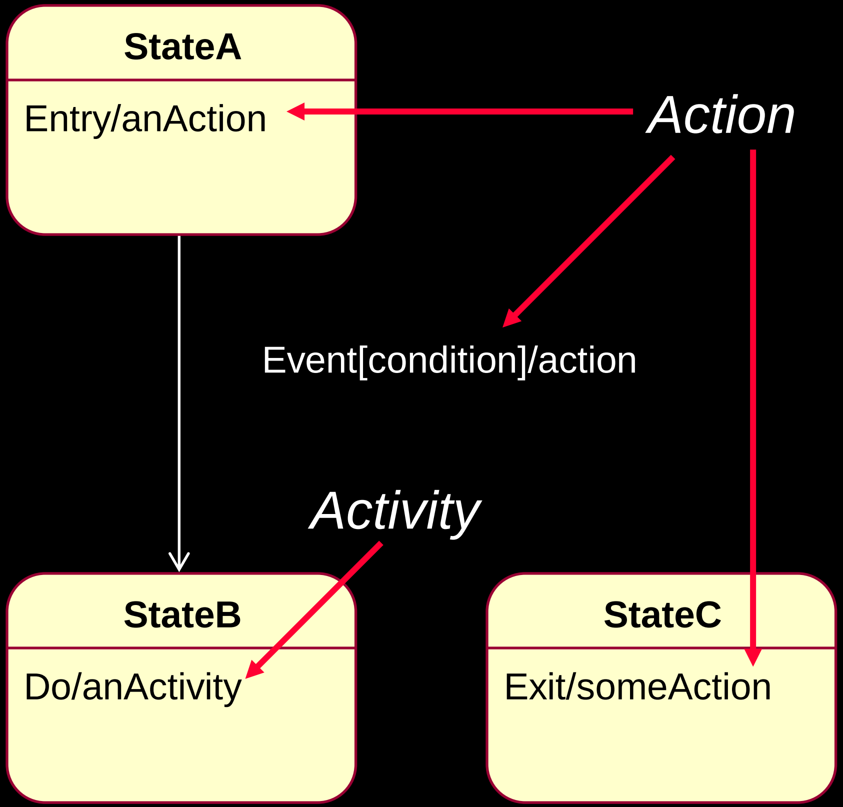
Identify the Transitions

- For each state, determine what events cause transitions to what states, including guard conditions, when needed
- Transitions describe what happens in response to the receipt of an event

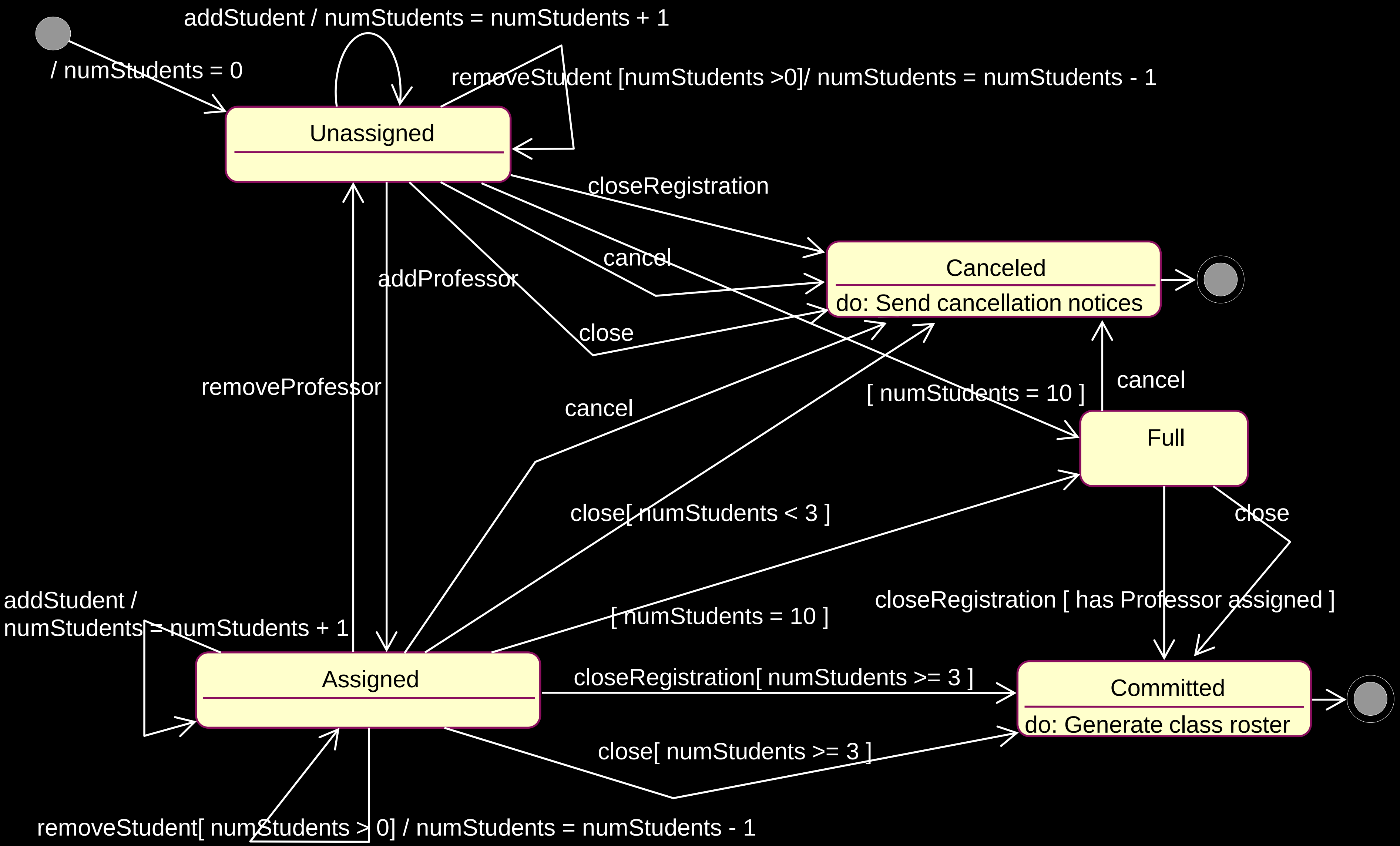


Add Activities and Actions

- Activities
  - Are associated with a state
  - Start when the state is entered
  - Take time to complete
  - Interruptible
- Actions
  - Associated with a transition
  - Take an insignificant amount of time to complete
  - Are non-interruptible

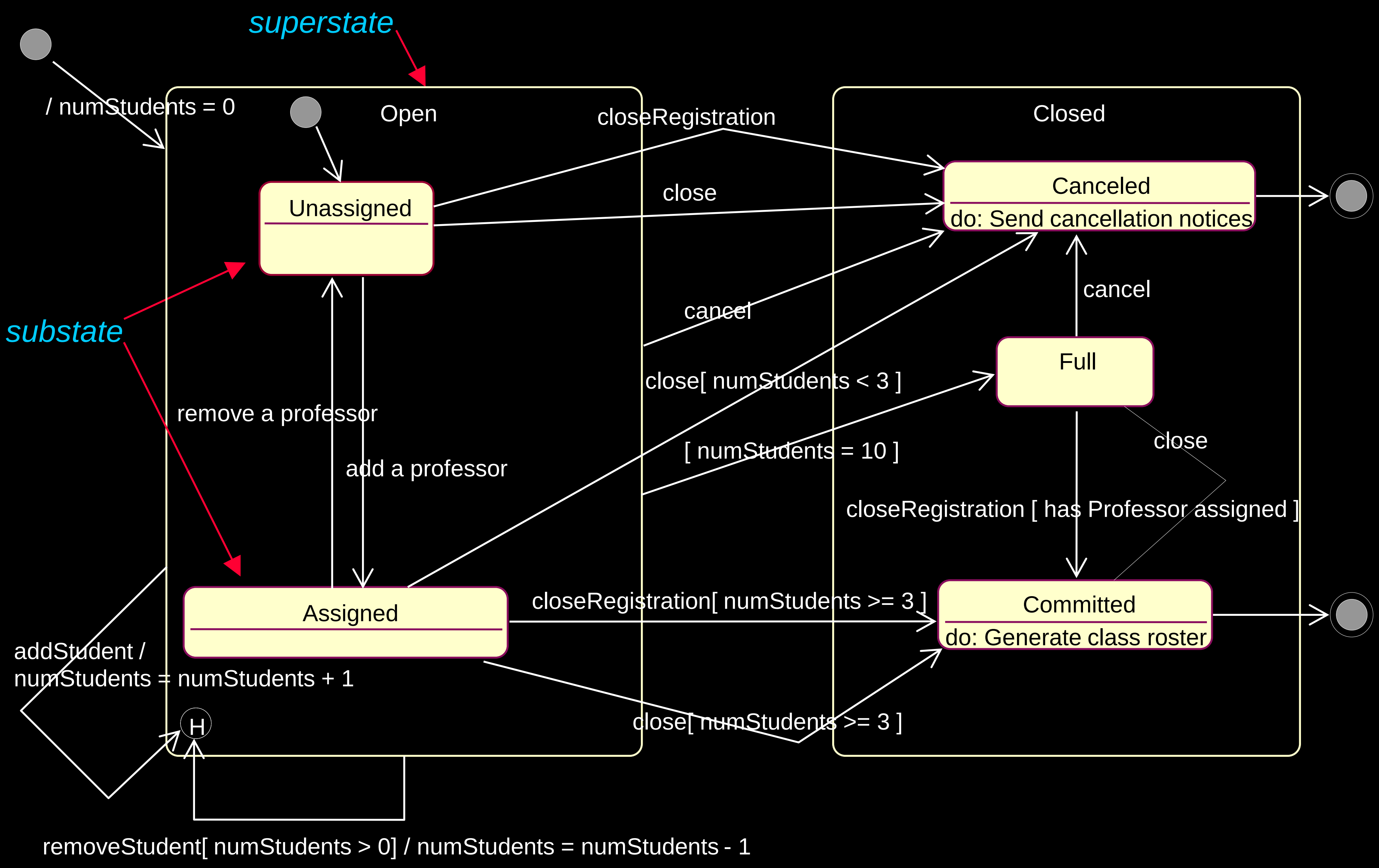


Example: Statechart



addStudent / numStudents = numStudents + 1
/ numStudents = 0
removeStudent [numStudents >0]/ numStudents = numStudents - 1
Unassigned
closeRegistration
cancel
addProfessor
close
Canceled
do: Send cancellation notices
removeProfessor
cancel
[numStudents = 10]
cancel
Full
close[numStudents < 3]
close
addStudent / numStudents = numStudents + 1
closeRegistration [has Professor assigned]
[numStudents = 10]
Assigned
closeRegistration[numStudents >= 3]
Committed
do: Generate class roster
close[numStudents >= 3]
removeStudent[numStudents > 0] / numStudents = numStudents - 1

Example: Statechart with Nested States and History

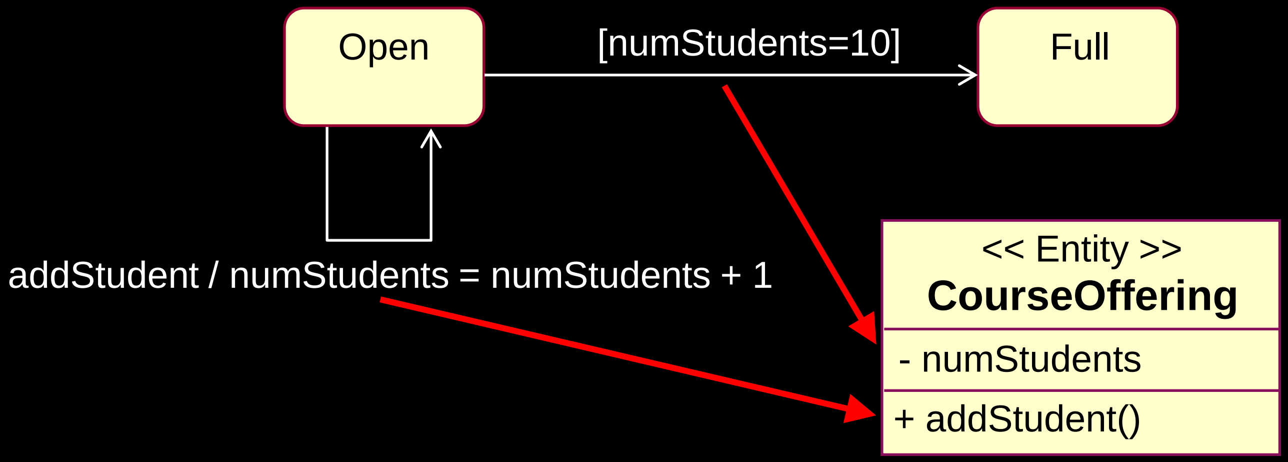

superstate
/ numStudents = 0
Open
closeRegistration
Closed
Unassigned
close
Canceled
do: Send cancellation notices
cancel
substate
cancel
Full
close[numStudents < 3]
remove a professor
[numStudents = 10]
close
add a professor
closeRegistration [has Professor assigned]
closeRegistration[numStudents >= 3]
Assigned
Committed
do: Generate class roster
addStudent /
numStudents = numStudents + 1
H
close[numStudents >= 3]
removeStudent[numStudents > 0] / numStudents = numStudents - 1

Which Objects Have Significant State?

- Objects whose role is clarified by state transitions
- Complex use cases that are state-controlled
- It is not necessary to model objects such as:
  - Objects with straightforward mapping to implementation
  - Objects that are not state-controlled
  - Objects with only one computational state

How Do Statecharts Map to the Rest of the Model?

- Events may map to operations
- Methods should be updated with state-specific information
- States are often represented using attributes
  - This serves as input into the "*Define Attributes*" step



(Stay tuned for derived attributes)

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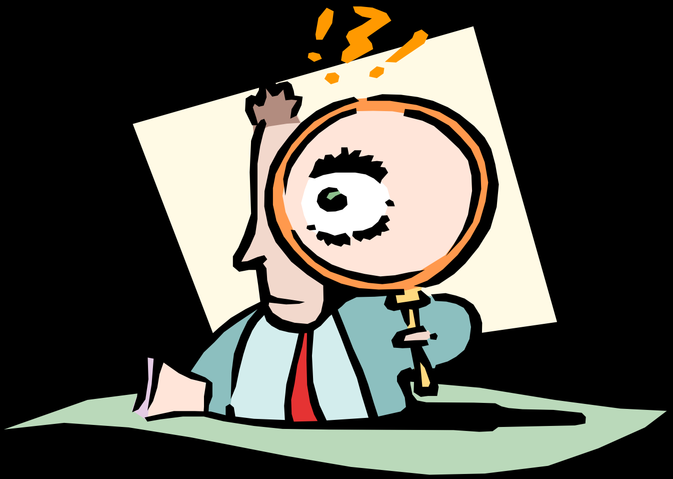
Attributes: How Do You Find Them?

- Examine method descriptions
- Examine states
- Examine any information the class itself needs to maintain



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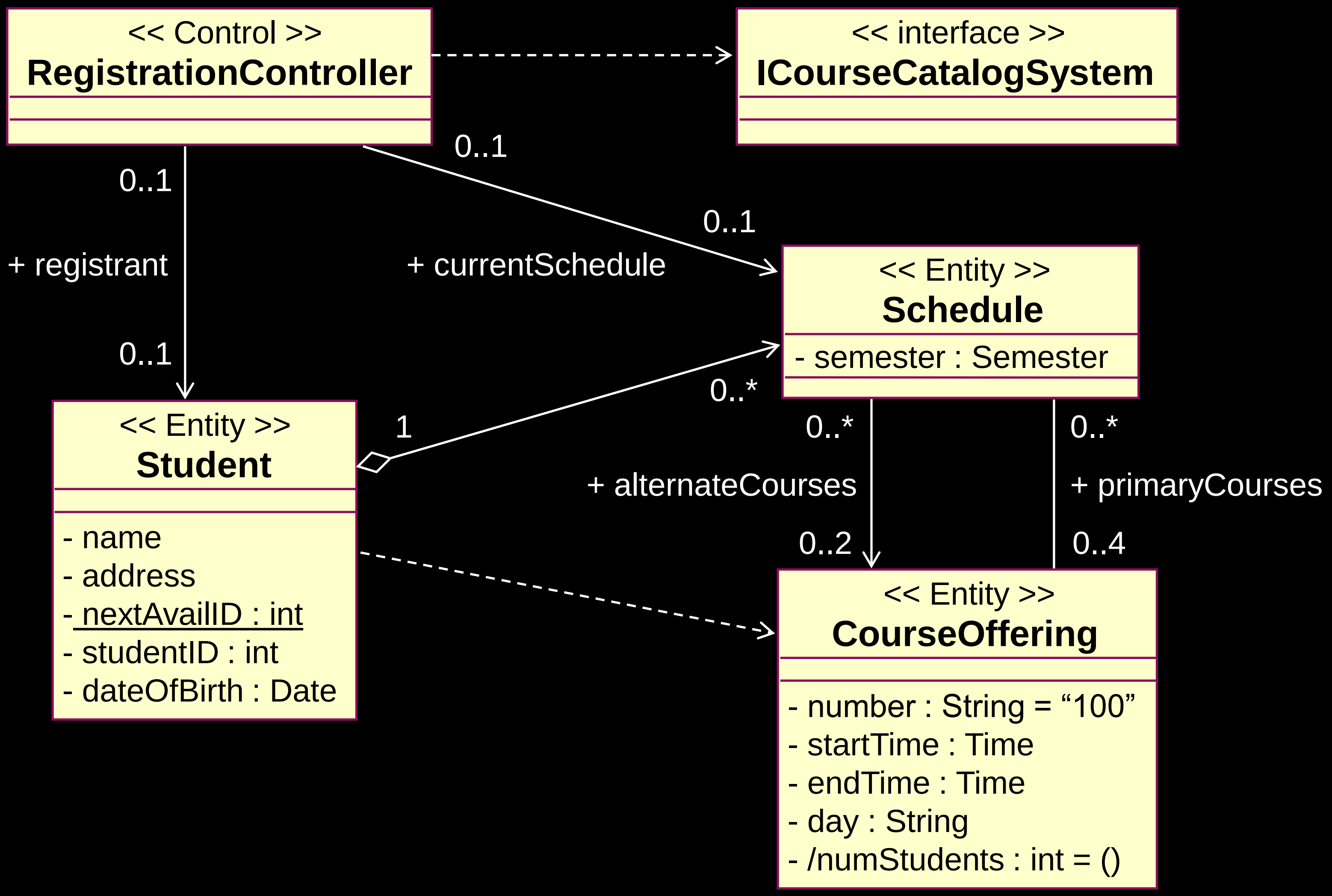
Attribute Representations

- Specify name, type, and optional default value
  - attributeName : Type = Default
- Follow naming conventions of implementation language and project
- Type should be an elementary data type in implementation language
  - Built-in data type, user-defined data type, or user-defined class
- Specify visibility
  - Public: +
  - Private: -
  - Protected: #

Derived Attributes

- What is a derived attribute?
  - An attribute whose value may be calculated based on the value of other attribute(s)
- When do you use it?
  - When there is not enough time to re-calculate the value every time it is needed
  - When you must trade-off runtime performance versus memory required

Example: Define Attributes



Exercise 1: Class Design

- Given the following:
  - The architectural layers, their packages, and their dependencies
  - Design classes for a particular use case

(continued)

Exercise 1: Class Design (cont.)

- Identify the following:
  - Attributes, operations, and their complete attribute signatures
  - Attribute and operation scope and visibility
  - Any additional relationships and/or classes to support the defined attributes and attribute signatures
  - Class(es) with significant state-controlled behavior
  - The important states and transitions for the identified class

(continued)

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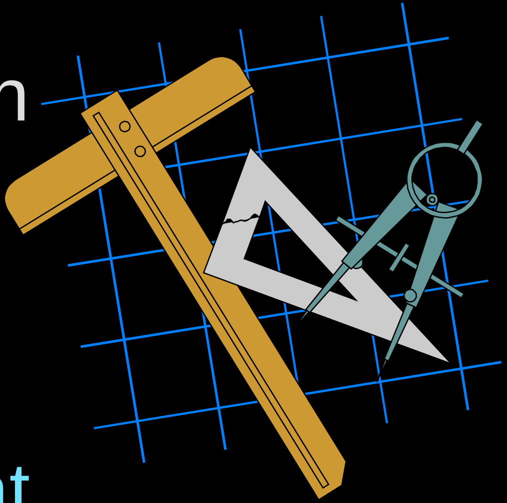
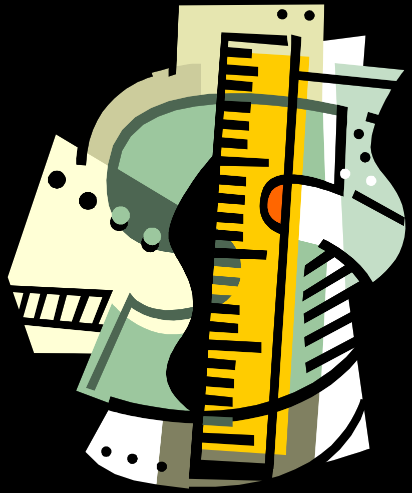
Exercise 1: Class Design

- Produce the following:
  - Design Use-Case Realization
    - Statechart for one of the classes that exhibits state-controlled behavior
    - Class diagram (VOPC) that includes all operations, operation signatures, attributes, and attribute signatures



Exercise 1: Review

- Compare your results
  - Is the name of each operation descriptive and understandable? Does the name of the operation indicate its outcome?
  - Does each attribute represent a single conceptual thing? Is the name of each attribute descriptive and does it correctly convey the information it stores?
  - Is the state machine understandable? Do state names and transitions reflect the context of the domain of the system? Does the state machine contain any superfluous states or transitions?


Payroll System

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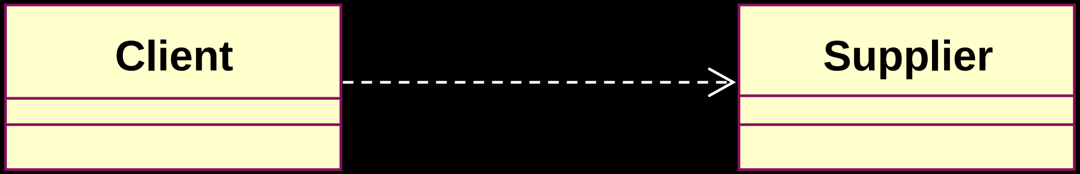
Define Dependency

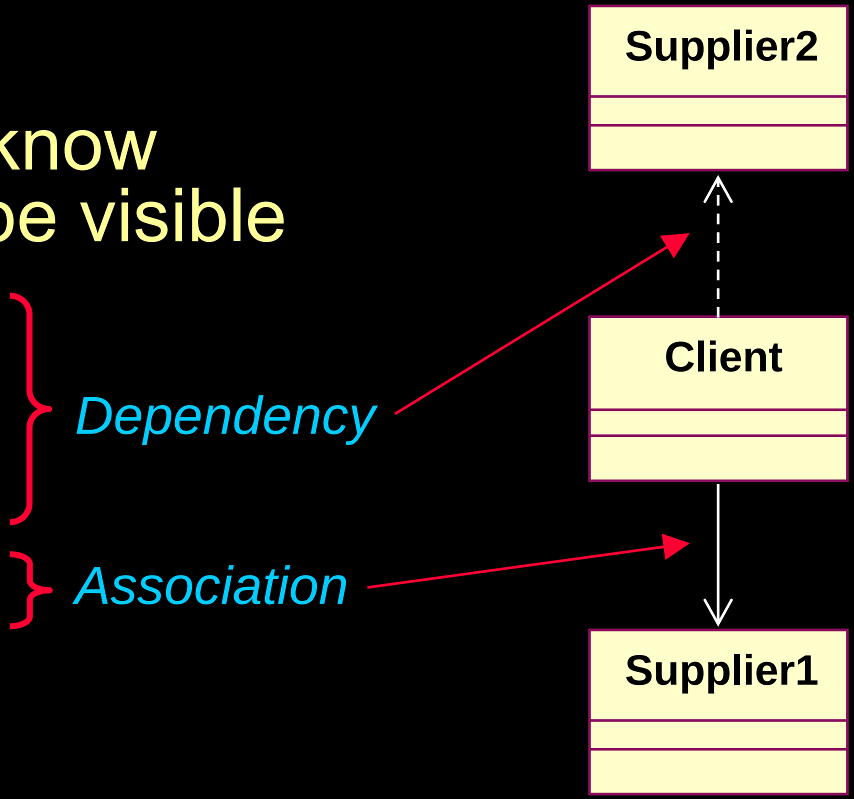
- What Is a Dependency?
  - A relationship between two objects



- Purpose
  - Determine where structural relationships are NOT required
- Things to look for :
  - What causes the supplier to be visible to the client

Dependencies vs. Associations

- Associations are structural relationships
- Dependencies are non-structural relationships
- In order for objects to "know each other" they must be visible
  - Local variable reference
  - Parameter reference
  - Global reference
  - Field reference



Associations vs. Dependencies in Collaborations

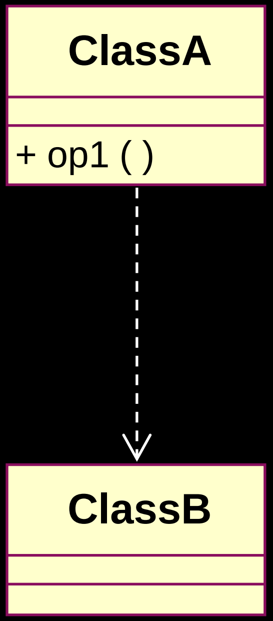
- An instance of an association is a link
  - All links become associations unless they have global, local, or parameter visibility
  - Relationships are context-dependent
- Dependencies are transient links with:
  - A limited duration
  - A context-independent relationship
  - A summary relationship

A dependency is a secondary type of relationship in that it doesn't tell you much about the relationship. For details you need to consult the collaborations.

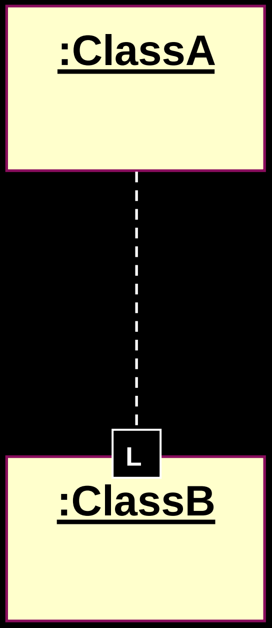
Local Variable Visibility

- The op1() operation contains a local variable of type ClassB

Class Diagram

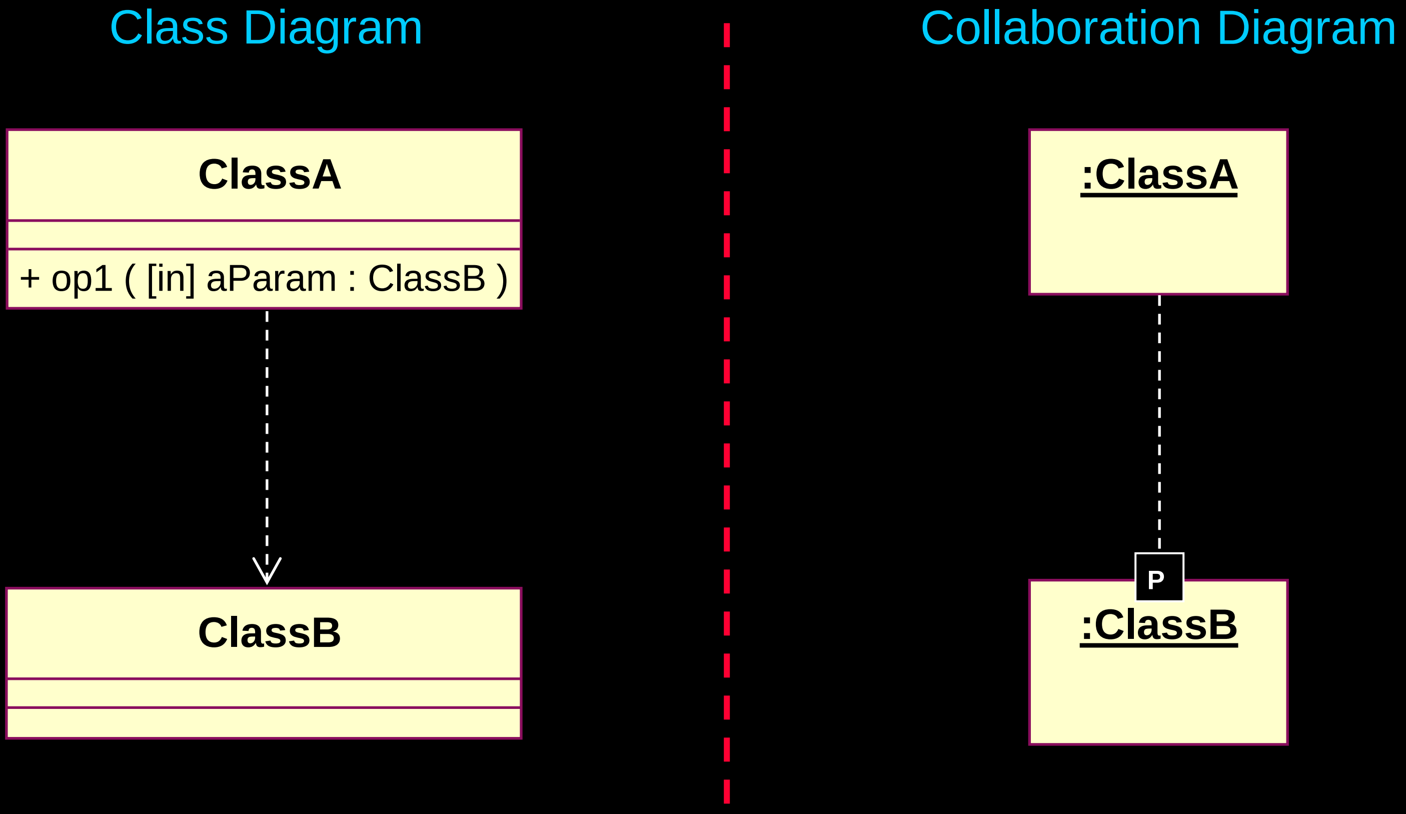


Collaboration Diagram



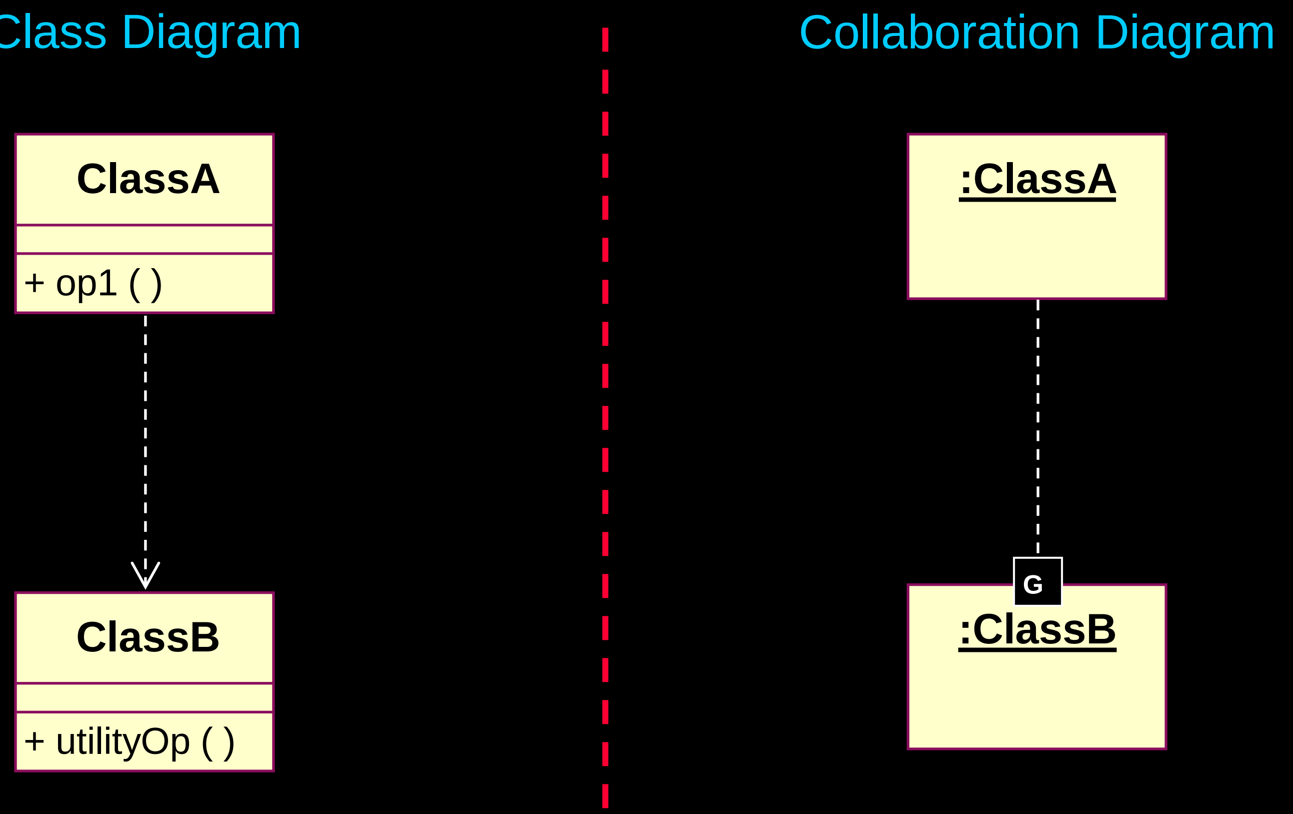
Parameter Visibility

- The ClassB instance is passed to the ClassA instance



Global Visibility

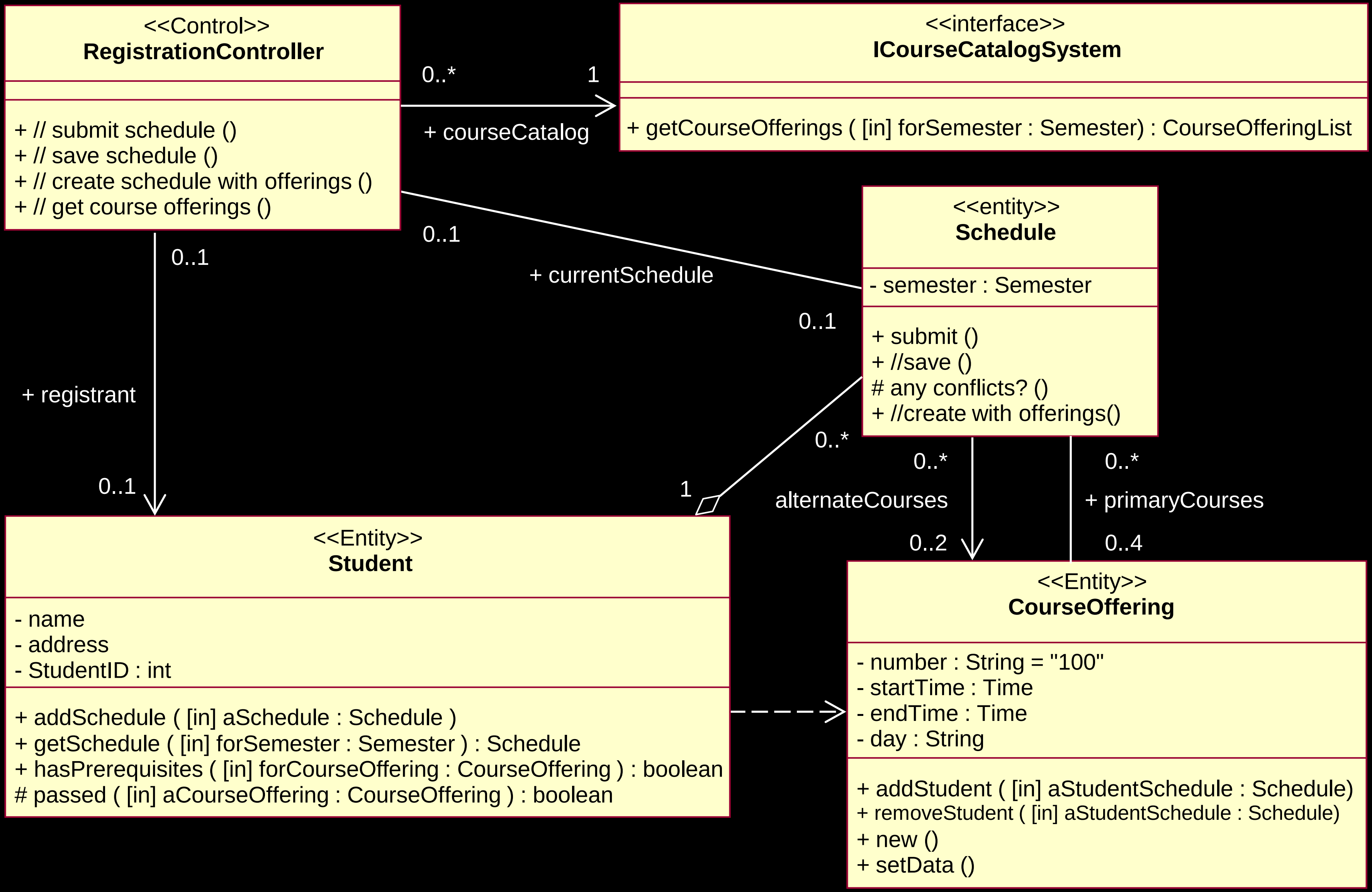
- The ClassUtility instance is visible because it is global



Identifying Dependencies: Considerations

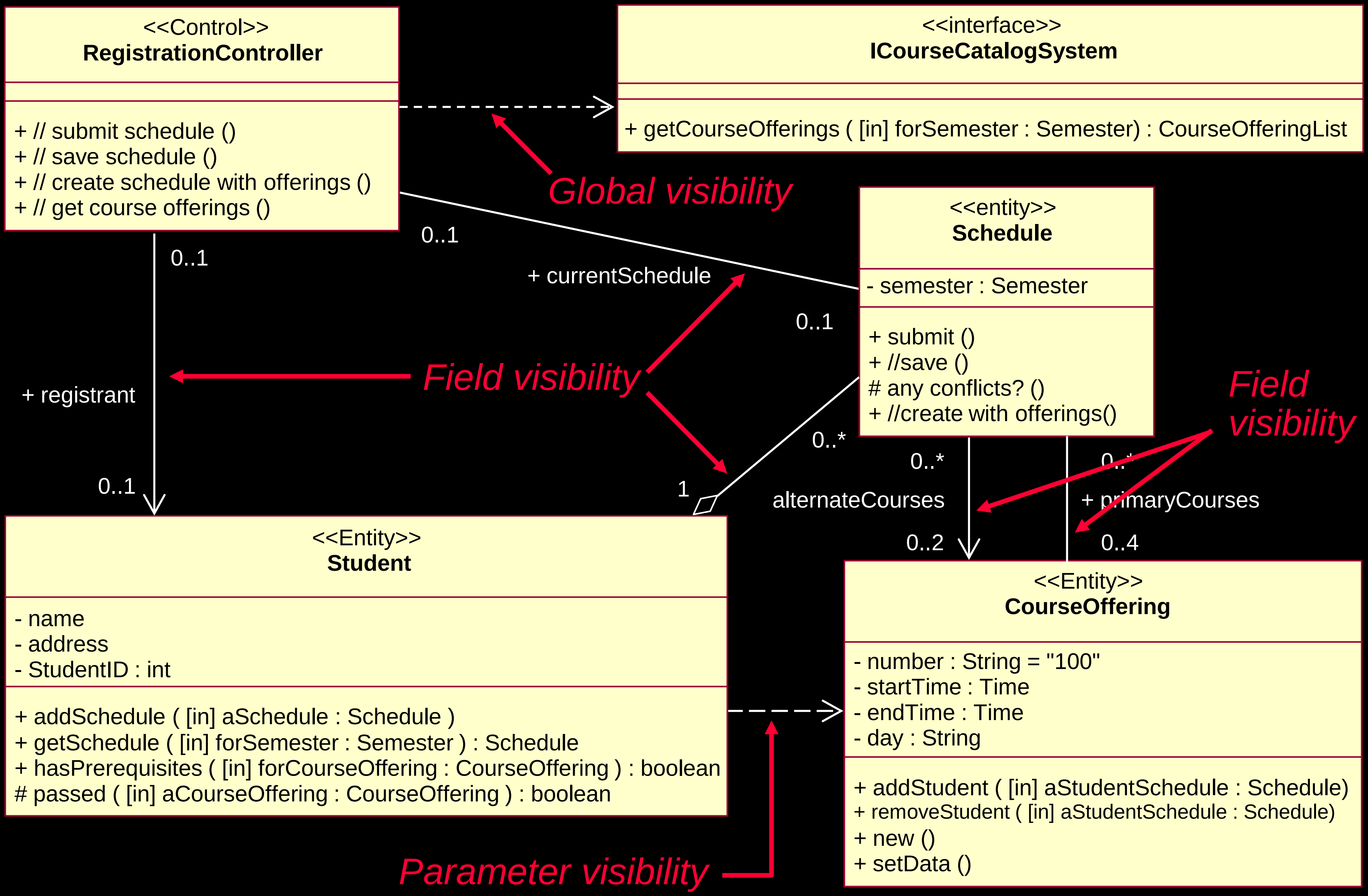
- Permanent relationships — Association (field visibility)
- Transient relationships — Dependency
  - Multiple objects share the same instance
    - Pass instance as a parameter (parameter visibility)
    - Make instance a managed global (global visibility)
  - Multiple objects don't share the same instance (local visibility)
- How long does it take to create/destroy?
  - Expensive? Use field, parameter, or global visibility
  - Strive for the lightest relationships possible

Example: Define Dependencies (before)



<<Control>>
RegistrationController
+ // submit schedule ()
+ // save schedule ()
+ // create schedule with offerings ()
+ // get course offerings ()
0..*
1
+ courseCatalog
<<interface>>
ICourseCatalogSystem
+ getCourseOfferings ([in] forSemester : Semester) : CourseOfferingList
0..1
+ currentSchedule
0..1
<<entity>>
Schedule
- semester : Semester
+ submit ()
+ //save ()
# any conflicts? ()
+ //create with offerings()
0..1
+ registrant
0..1
0..*
1
0..*
alternateCourses
0..2
0..*
+ primaryCourses
0..4
<<Entity>>
Student
- name
- address
- StudentID : int
+ addSchedule ([in] aSchedule : Schedule)
+ getSchedule ([in] forSemester : Semester) : Schedule
+ hasPrerequisites ([in] forCourseOffering : CourseOffering) : boolean
# passed ([in] aCourseOffering : CourseOffering) : boolean
<<Entity>>
CourseOffering
- number : String = "100"
- startTime : Time
- endTime : Time
- day : String
+ addStudent ([in] aStudentSchedule : Schedule)
+ removeStudent ([in] aStudentSchedule : Schedule)
+ new ()
+ setData ()

Example: Define Dependencies (after)



<<Control>>
RegistrationController
+ // submit schedule ()
+ // save schedule ()
+ // create schedule with offerings ()
+ // get course offerings ()
<<interface>>
ICourseCatalogSystem
+ getCourseOfferings ([in] forSemester : Semester) : CourseOfferingList
Global visibility
<<entity>>
Schedule
- semester : Semester
+ submit ()
+ //save ()
# any conflicts? ()
+ //create with offerings()
0..1
0..1
+ currentSchedule
0..1
+ registrant
Field visibility
Field visibility
0..*
0..*
0..*
alternateCourses
+ primaryCourses
0..1
1
0..2
0..4
<<Entity>>
Student
- name
- address
- StudentID : int
+ addSchedule ([in] aSchedule : Schedule)
+ getSchedule ([in] forSemester : Semester) : Schedule
+ hasPrerequisites ([in] forCourseOffering : CourseOffering) : boolean
# passed ([in] aCourseOffering : CourseOffering) : boolean
<<Entity>>
CourseOffering
- number : String = "100"
- startTime : Time
- endTime : Time
- day : String
+ addStudent ([in] aStudentSchedule : Schedule)
+ removeStudent ([in] aStudentSchedule : Schedule)
+ new ()
+ setData ()
Parameter visibility

Class Design Steps

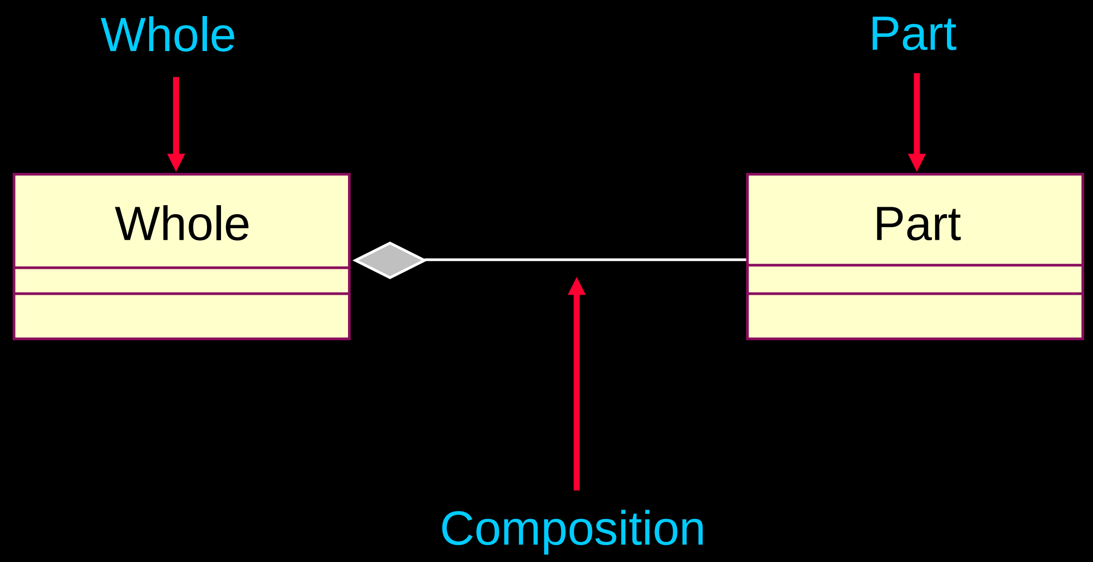
- Create Initial Design Classes
- Define Operations
- Define Methods
- Define States
- Define Attributes
- Define Dependencies
- ★ Define Associations
- Define Generalizations
- Resolve Use-Case Collisions
- Handle Non-Functional Requirements in General
- Checkpoints

Define Associations

- Purpose
  - Refine remaining associations
- Things to look for :
  - Association vs. Aggregation
  - Aggregation vs. Composition
  - Attribute vs. Association
  - Navigability
  - Association class design
  - Multiplicity design

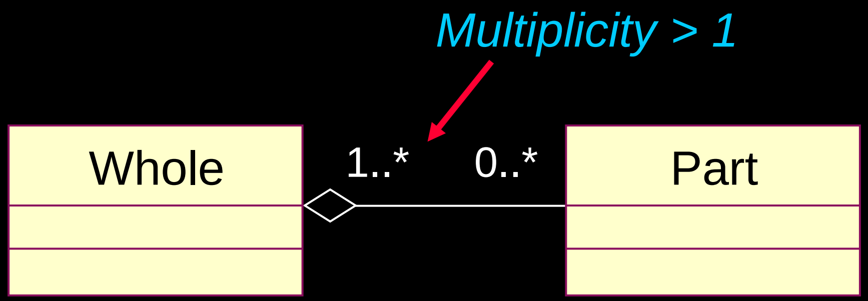
What Is Composition?

- A form of aggregation with strong ownership and coincident lifetimes
  - The parts cannot survive the whole/aggregate

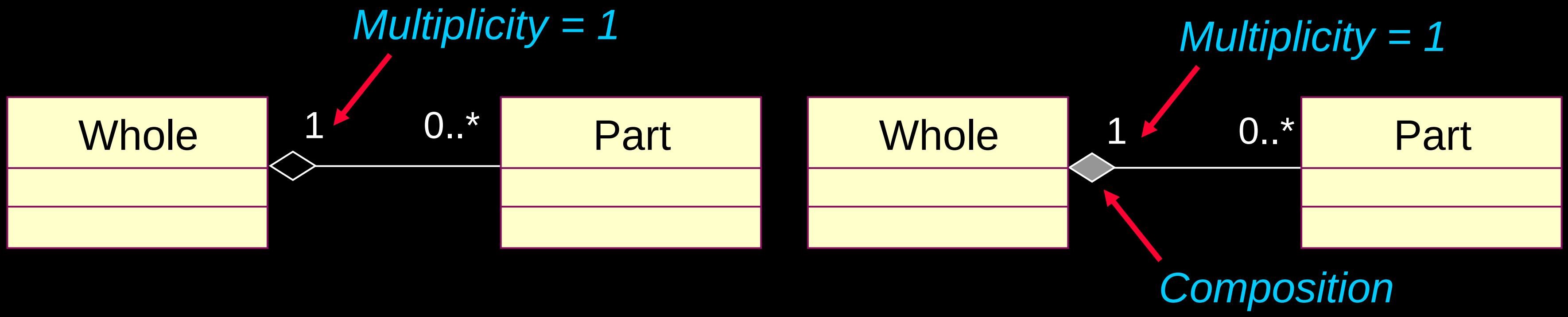


Aggregation: Shared vs. Non-shared

- Shared Aggregation



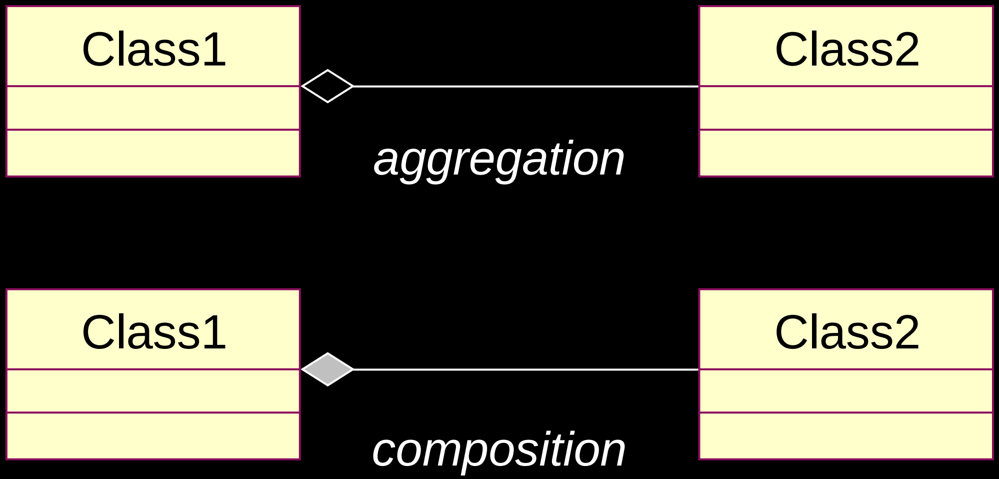
- Non-shared Aggregation



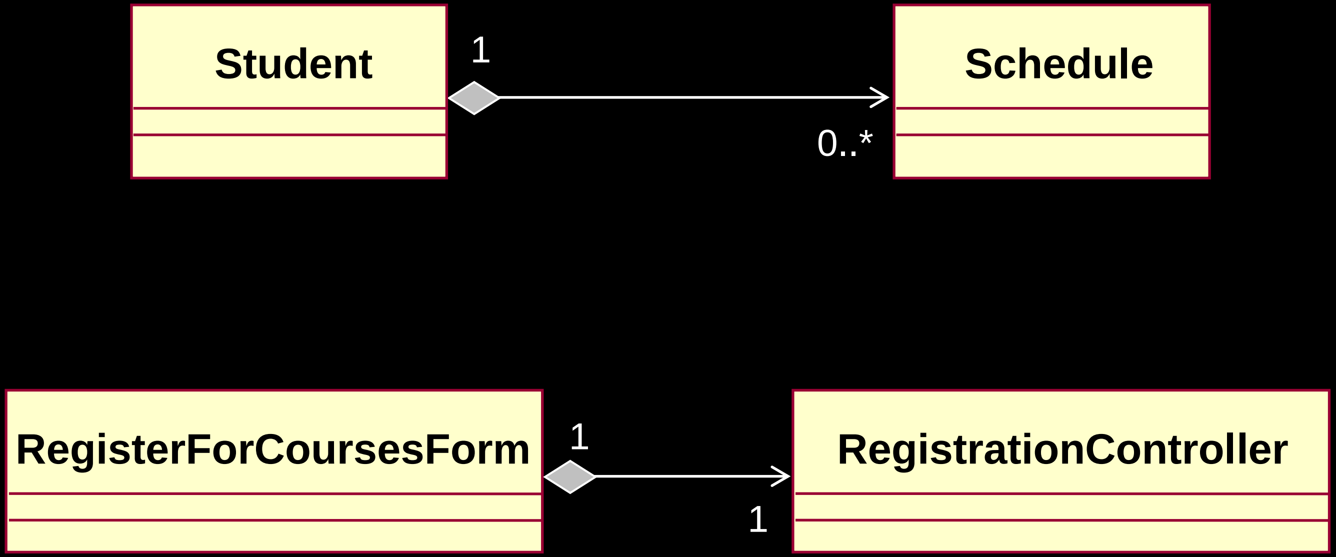
By definition, composition is non-shared aggregation

Aggregation or Composition?

- Consideration
  - Lifetimes of Class1 and Class2



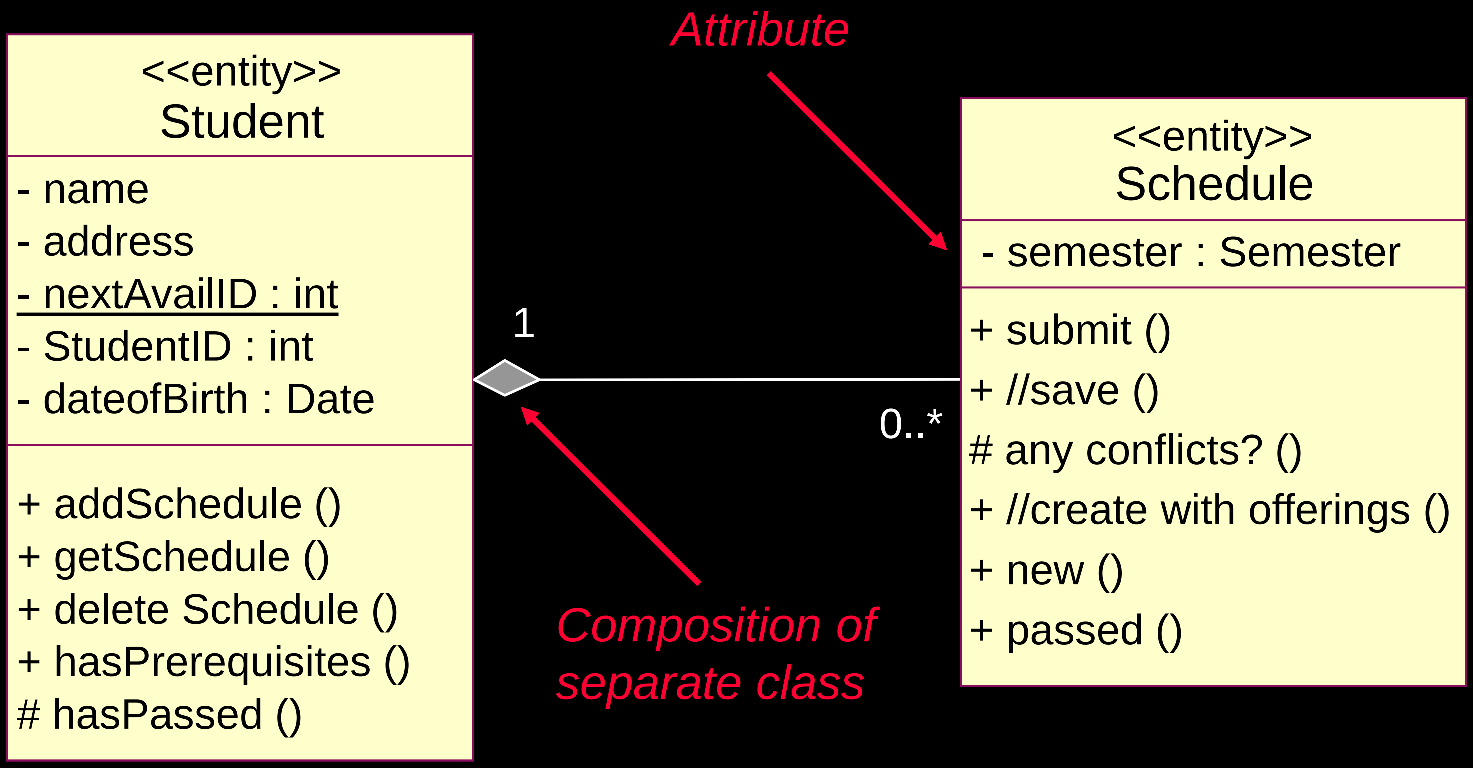
Example: Composition



Attributes Vs Composition

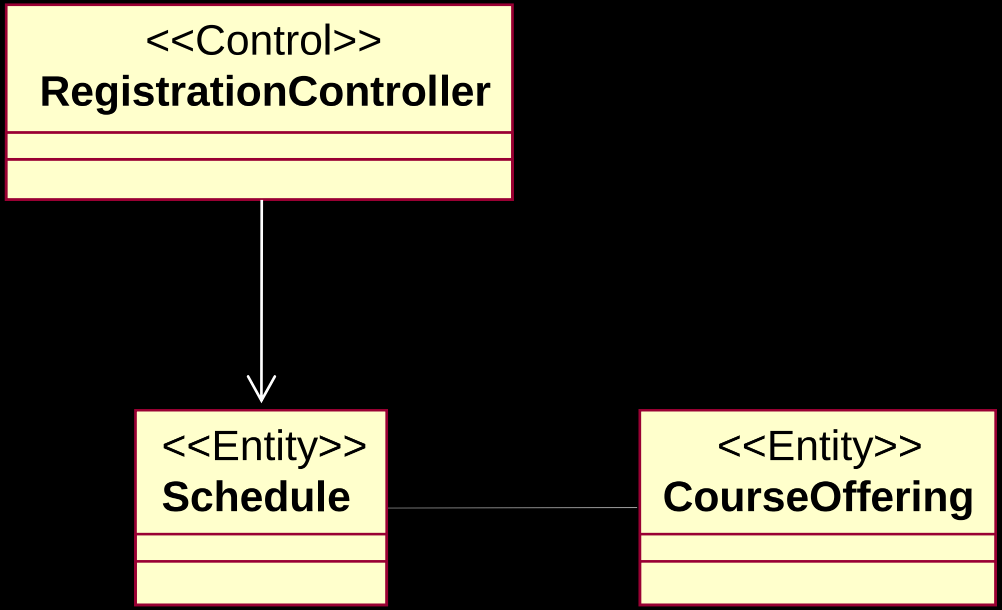
- Use composition when
  - Properties need independent identities
  - Multiple classes have the same properties
  - Properties have a complex structure and properties of their own
  - Properties have complex behavior of their own
  - Properties have relationships of their own
- Otherwise use attributes

Example: Attributes vs. Composition



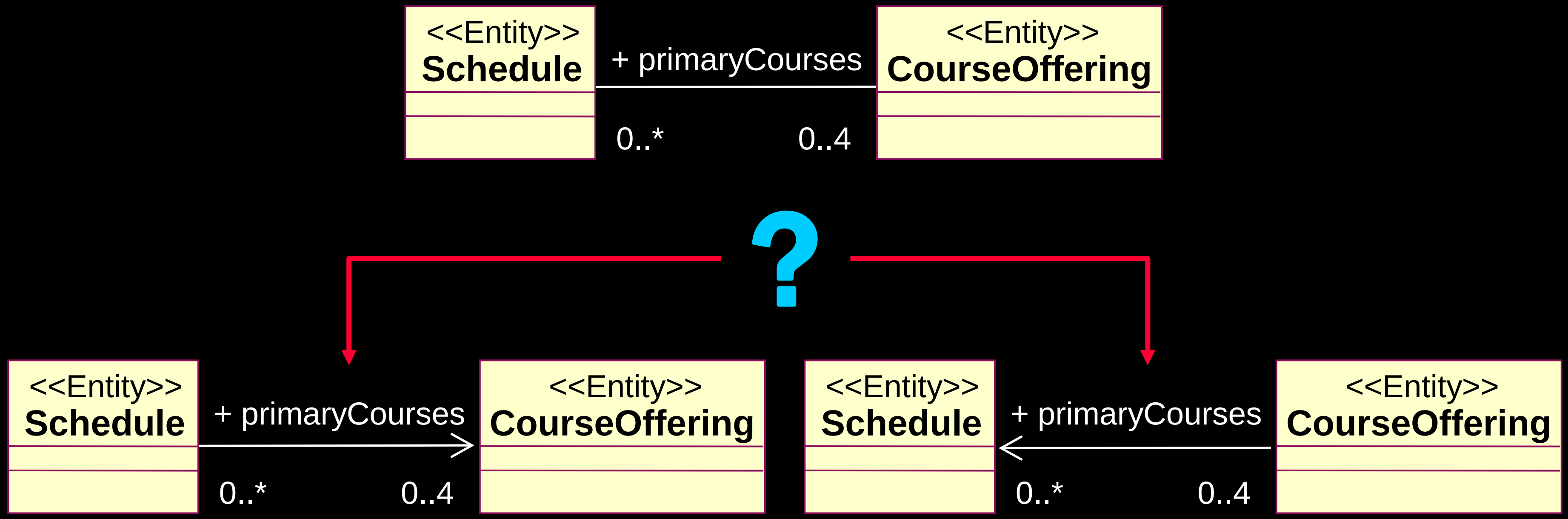
Review: What Is Navigability?

- Indicates that it is possible to navigate from a associating class to the target class using the association



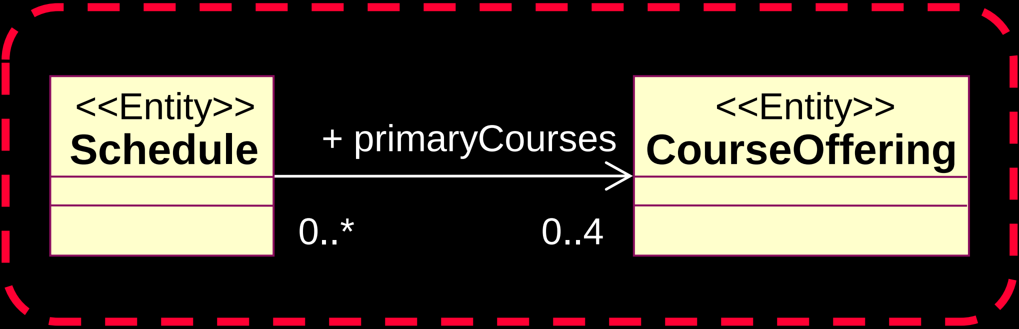
Navigability: Which Directions Are Really Needed?

- Explore interaction diagrams
- Even when both directions seem required, one may work
  - Navigability in one direction is infrequent
  - Number of instances of one class is small

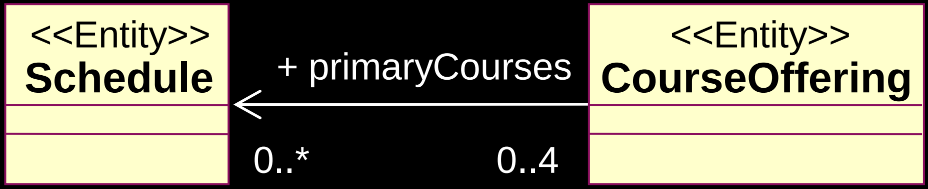


Example: Navigability Refinement

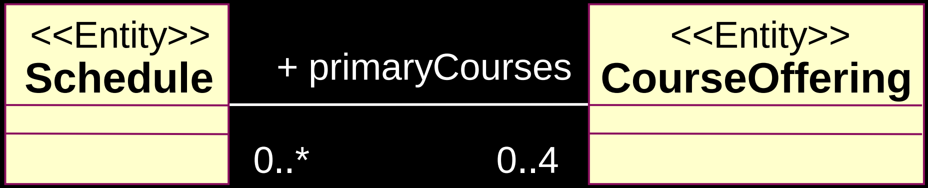
- Total number of Schedules is small, or
- Never need a list of the Schedules on which the CourseOffering appears



- Total number of CourseOfferings is small, or
- Never need a list of CourseOfferings on a Schedule

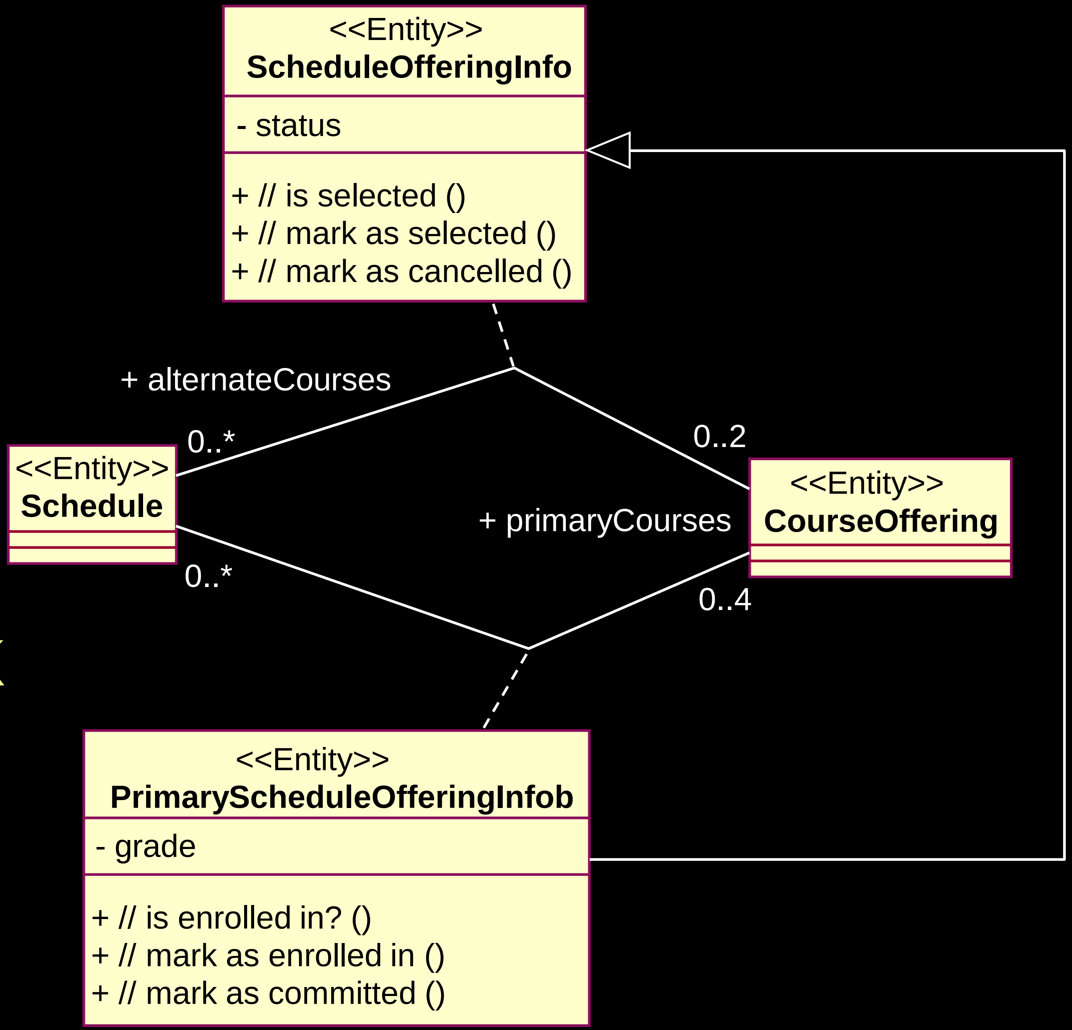


- Total number of CourseOfferings and Schedules are not small
- Must be able to navigate in both directions

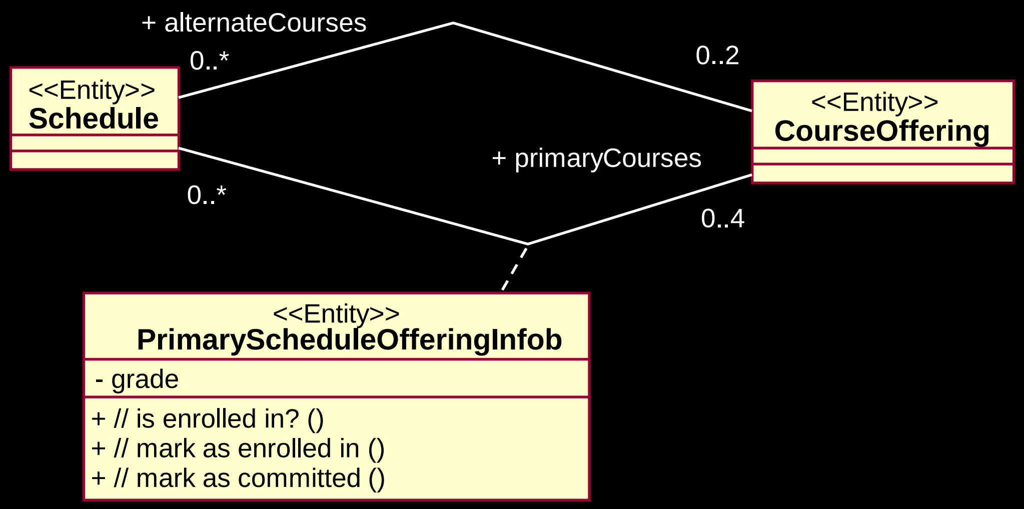


Association Class

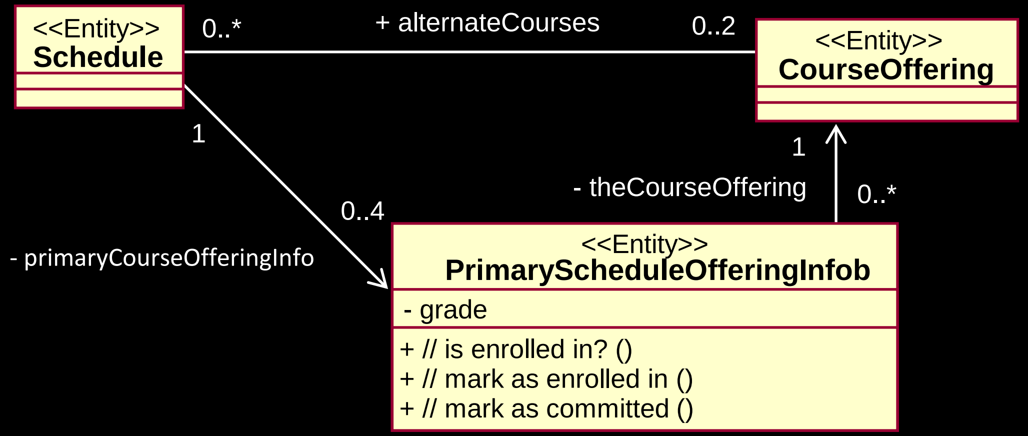
- A class is "attached" to an association
- Contains properties of a relationship
- Has one instance per link



Example: Association Class Design

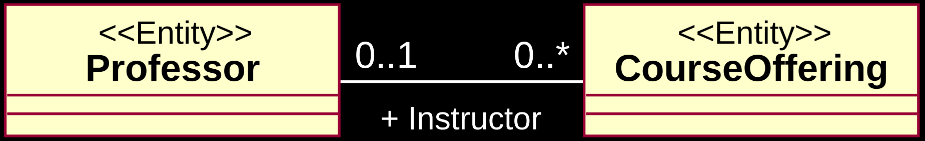


Design Decisions



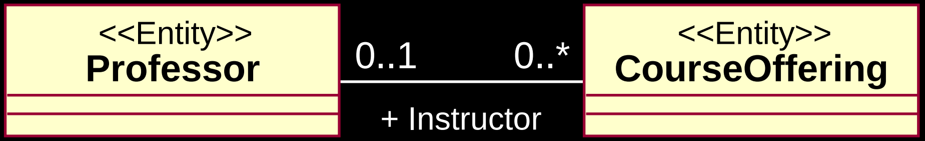
Multiplicity Design

- Multiplicity = 1, or Multiplicity = 0..1
  - May be implemented directly as a simple value or pointer
  - No further "design" is required

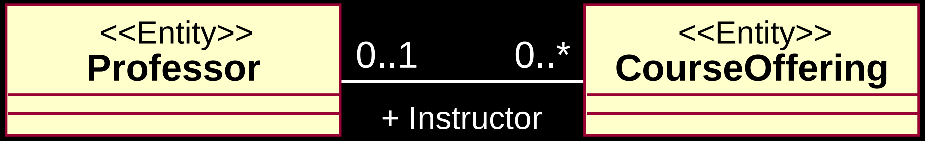


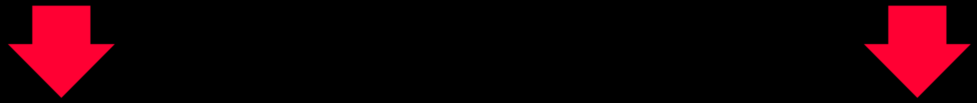
- Multiplicity > 1
  - Cannot use a simple value or pointer
  - Further "design" may be required

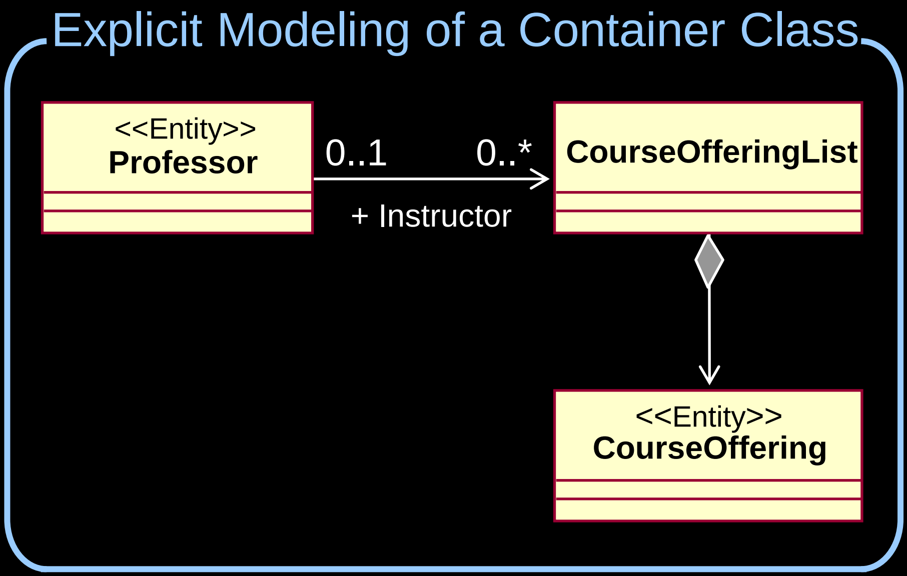
Needs a container for CourseOfferings

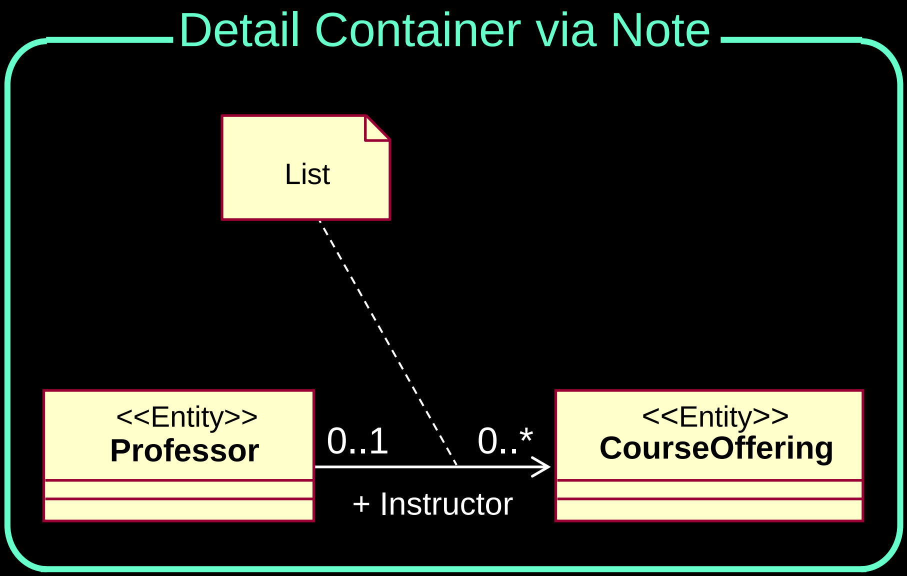


Multiplicity Design Options



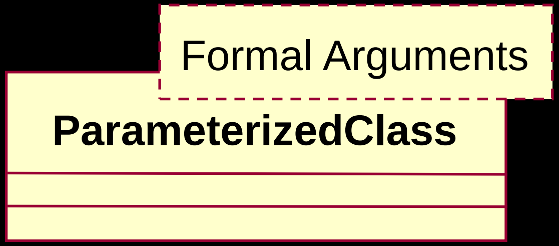


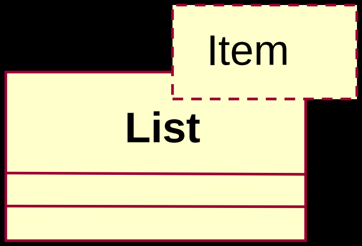




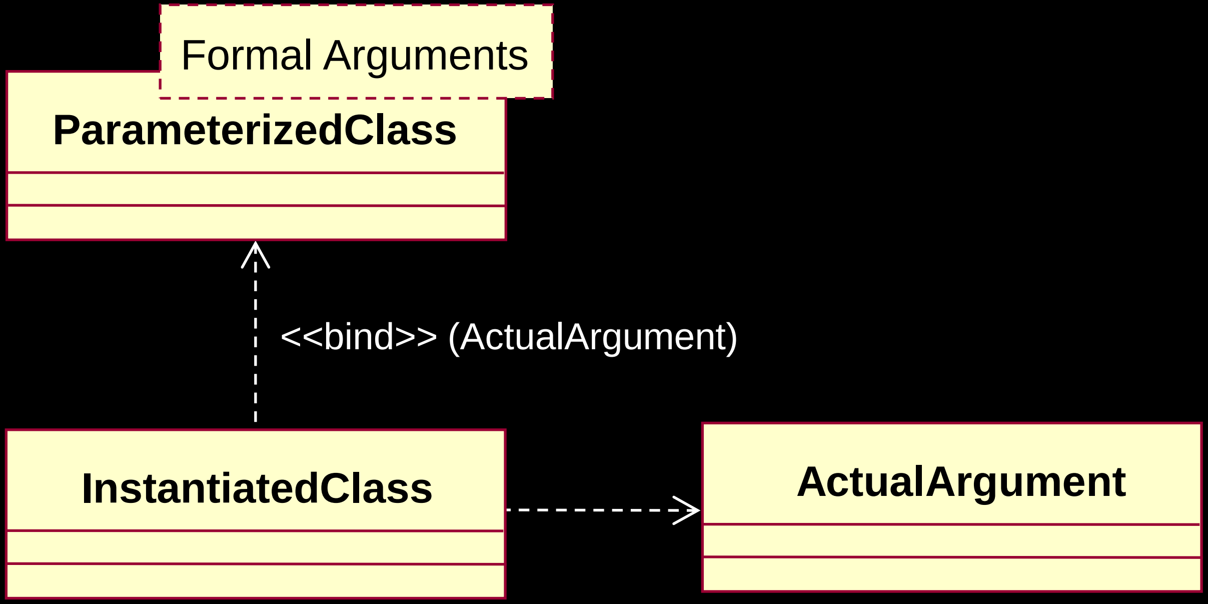
What is a Parameterized Class (template)?

- A class definition that defines other classes
- Often used for container classes
  - Some common container classes:
    - Sets, lists, dictionaries, stacks, queues



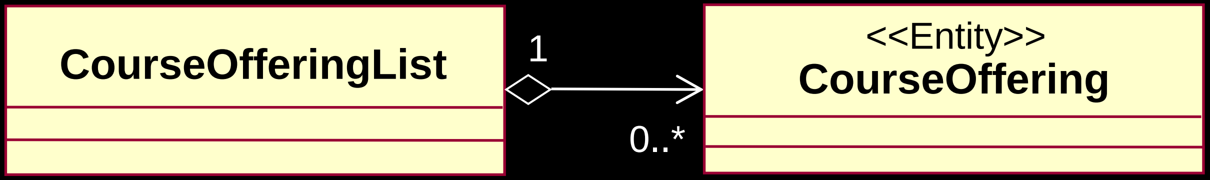


Instantiating a Parameterized Class

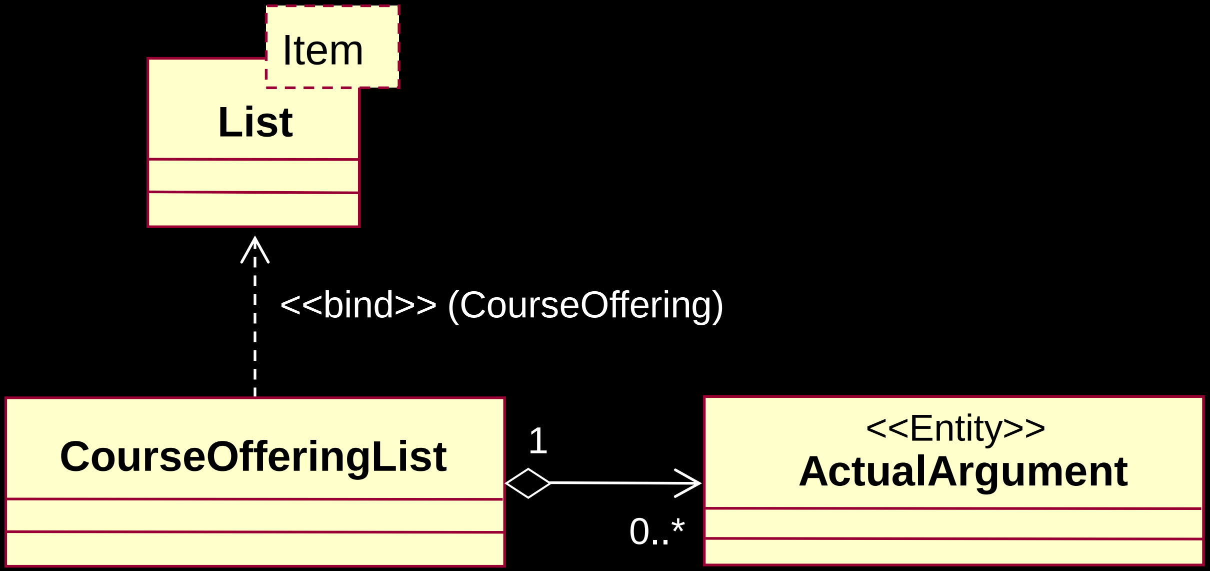


Example: Instantiating a Parameterized Class

Before

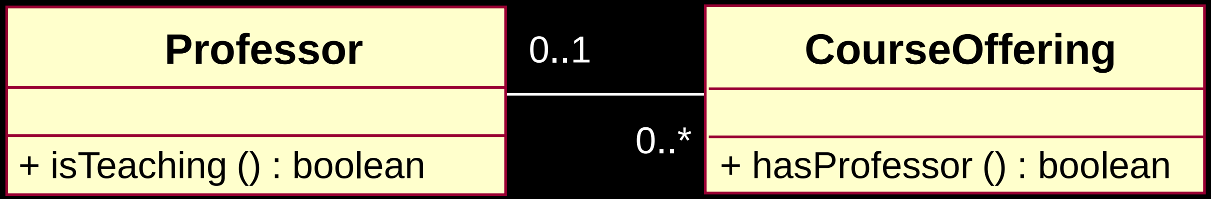


After



Multiplicity Design: Optionality

- If a link is optional, make sure to include an operation to test for the existence of the link



Class Design Steps

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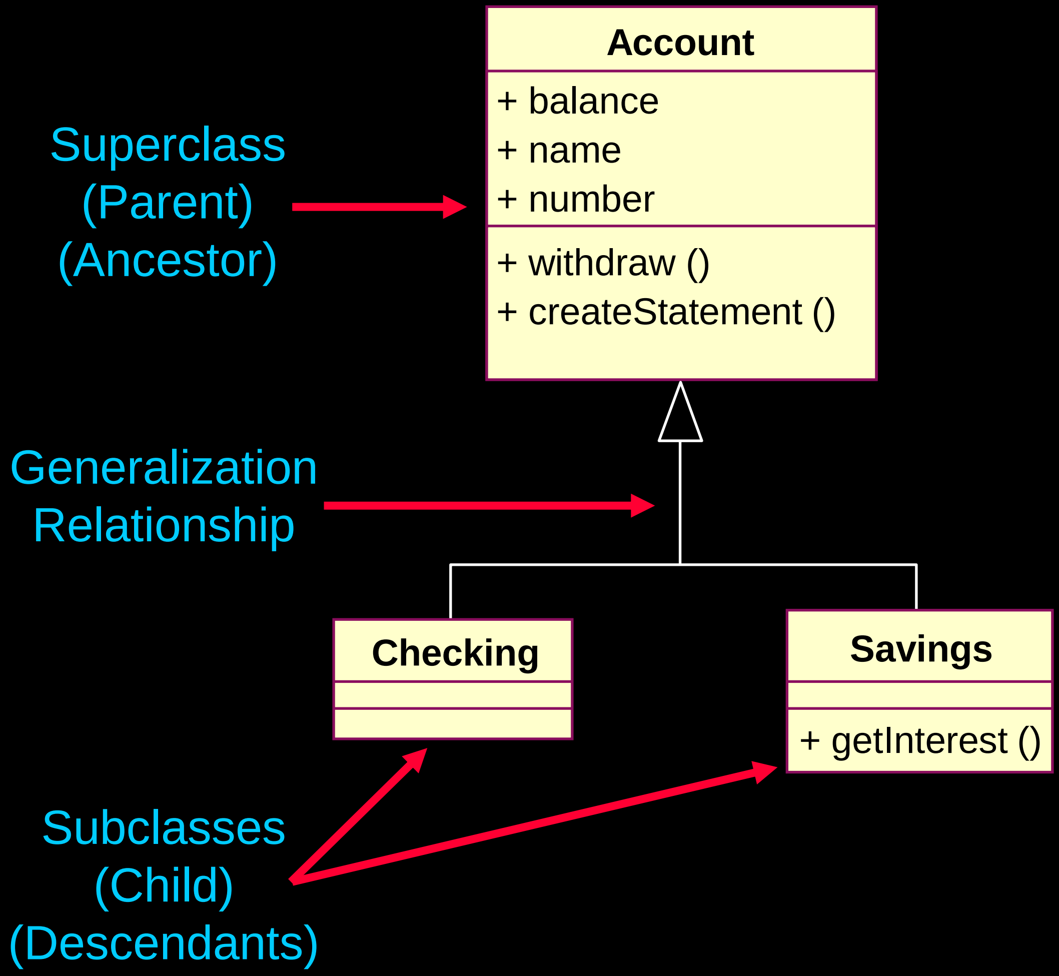
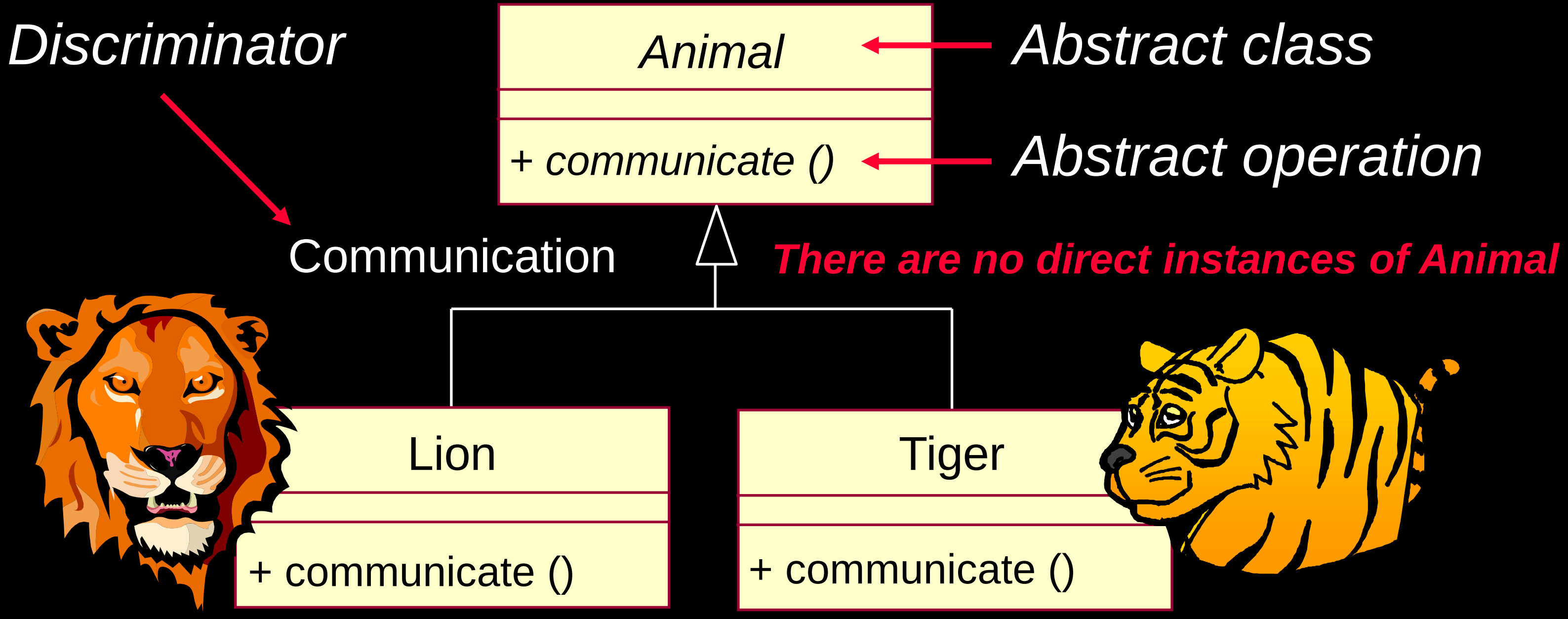
Review: Generalization

- One class shares the structure and/or behavior of one or more classes
- "Is a kind of" relationship
- In Analysis, use sparingly



Abstract and Concrete Classes

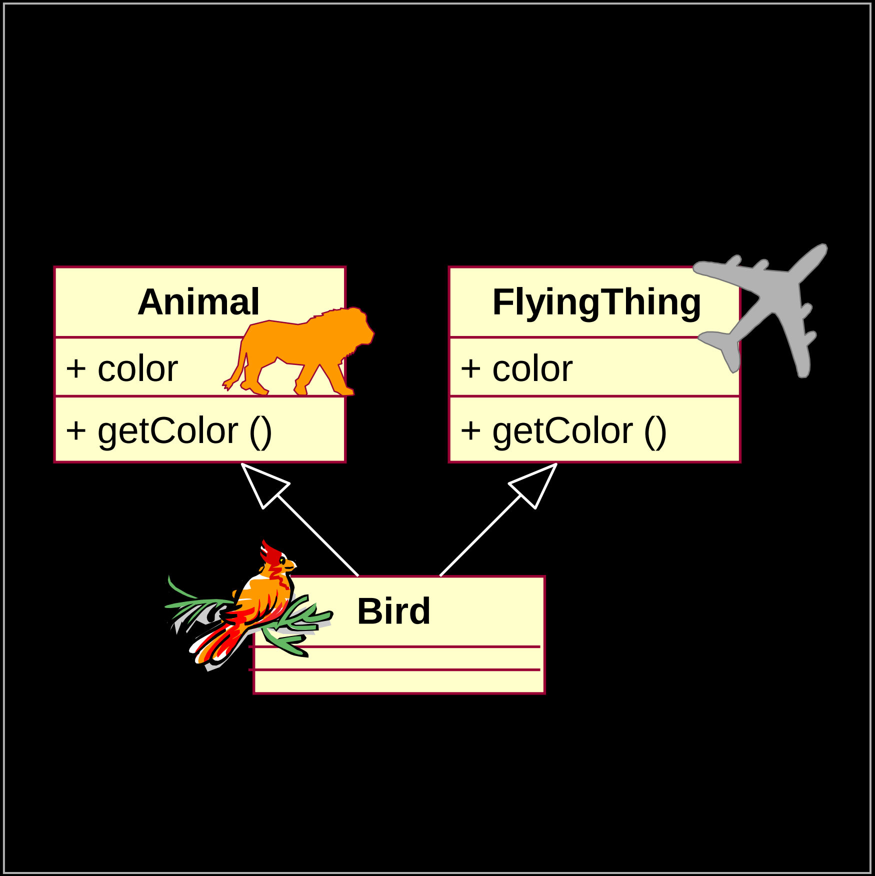
- Abstract classes cannot have any objects
- Concrete classes can have objects



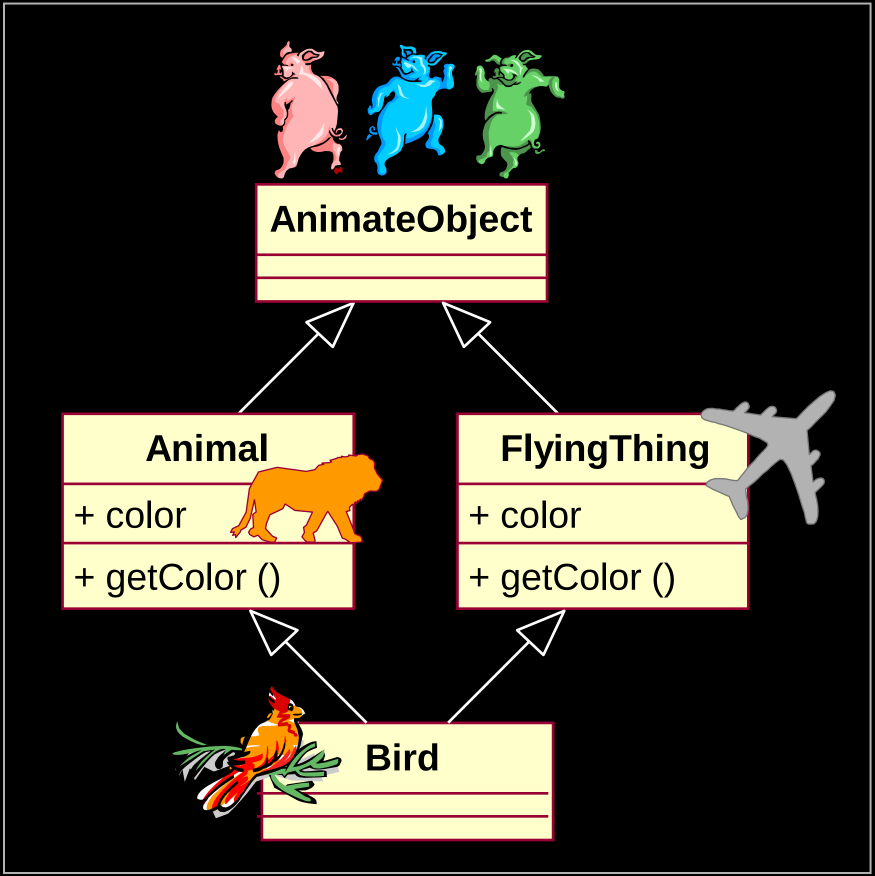
All objects are either lions or tigers

Multiple Inheritance: Problems

Name clashes on attributes or operations



Repeated inheritance

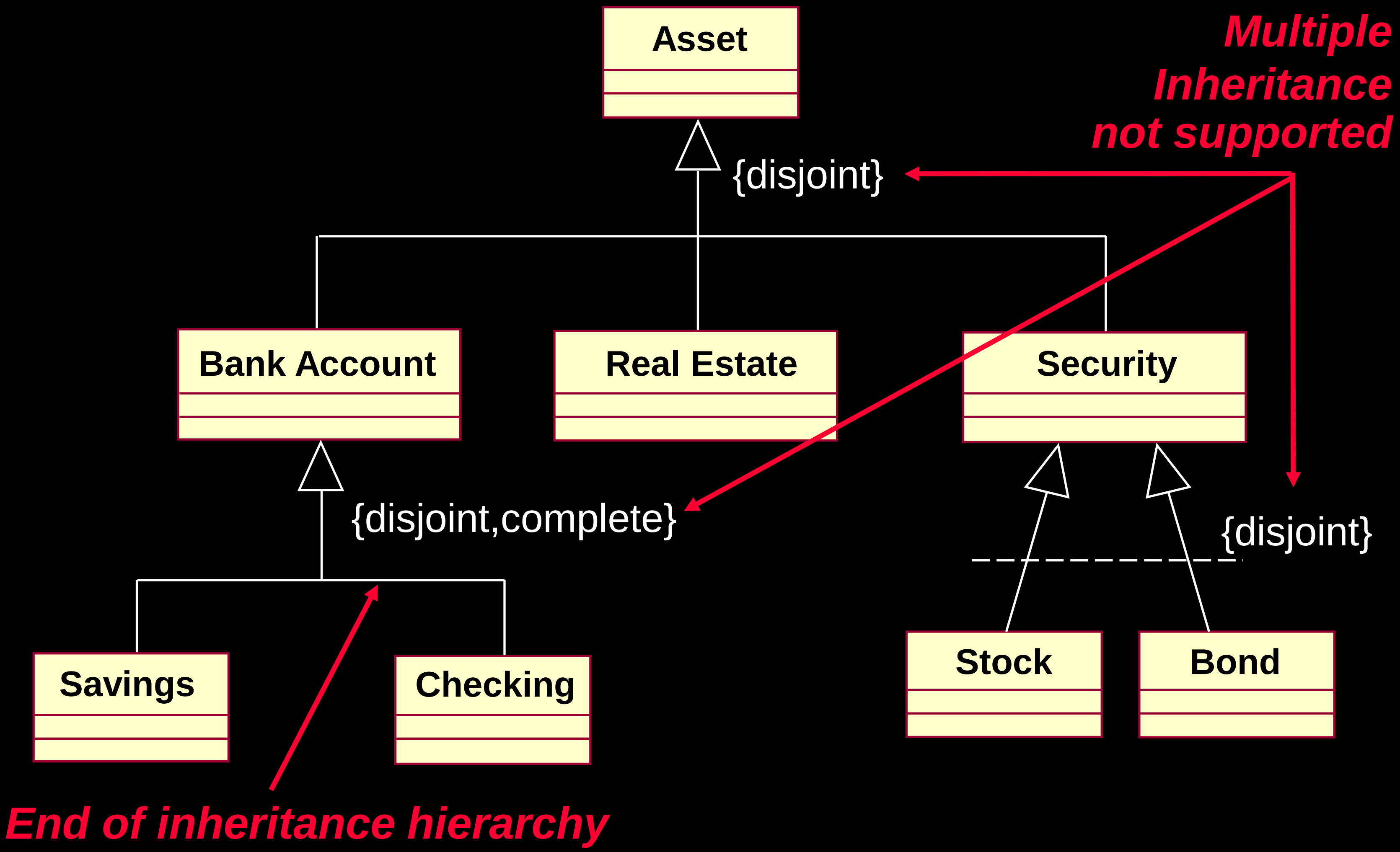


Resolution of these problems is implementation-dependent

Generalization Constraints

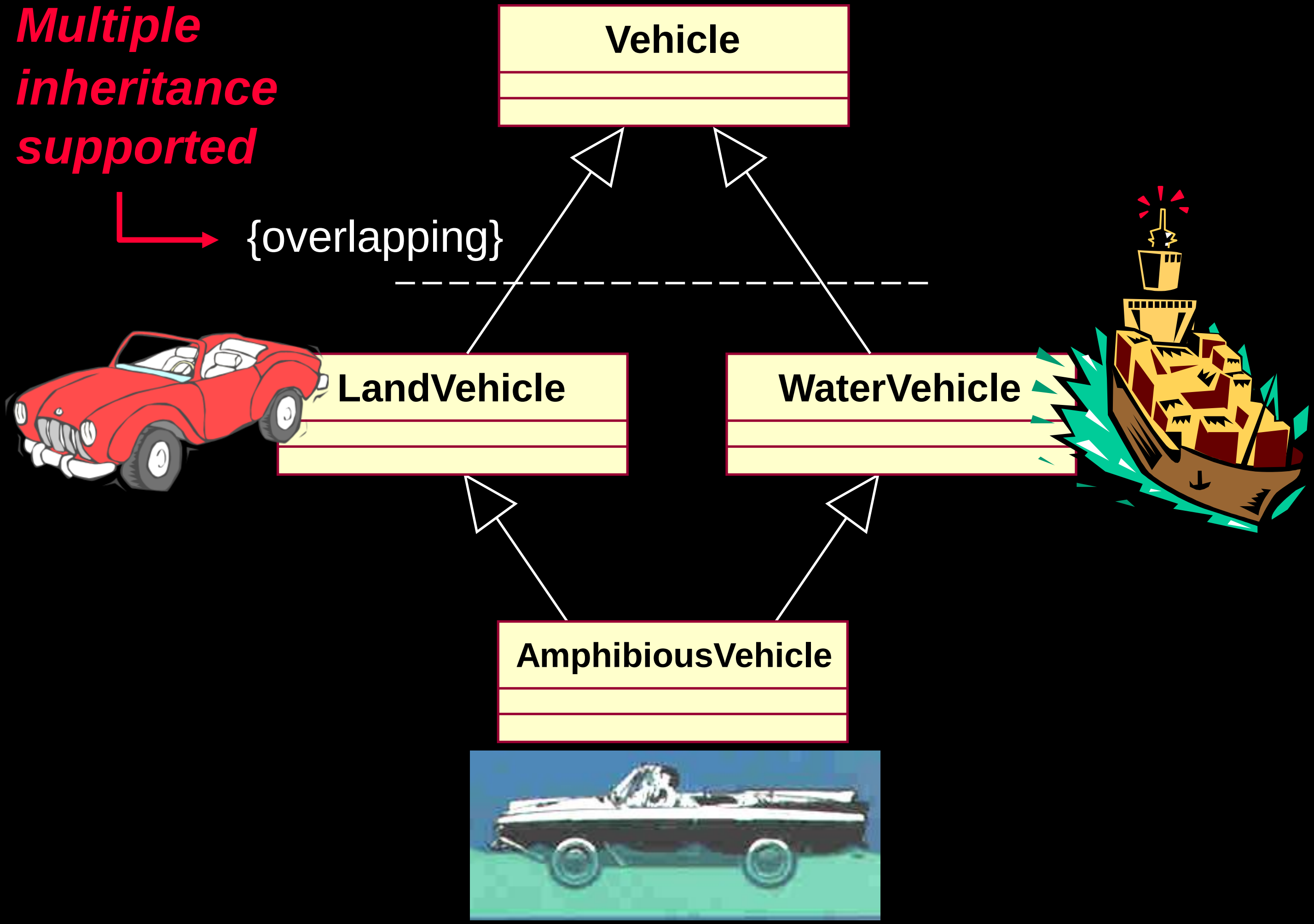
- Complete
  - End of the inheritance tree
- Incomplete
  - Inheritance tree may be extended
- Disjoint
  - Subclasses mutually exclusive
  - Doesn’t support multiple inheritance
- Overlapping
  - Subclasses are not mutually exclusive
  - Supports multiple inheritance

Example: Generalization Constraints



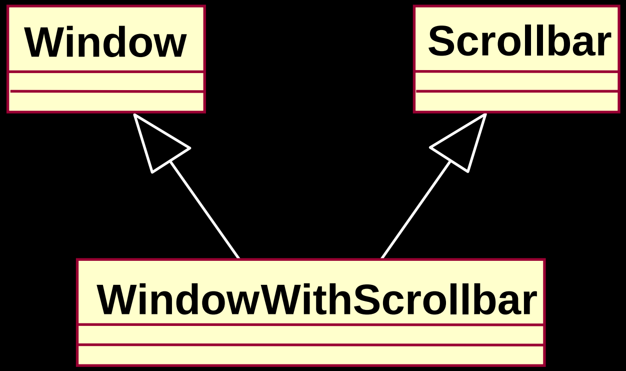
Example: Generalization Constraints (cont.)

Multiple inheritance supported



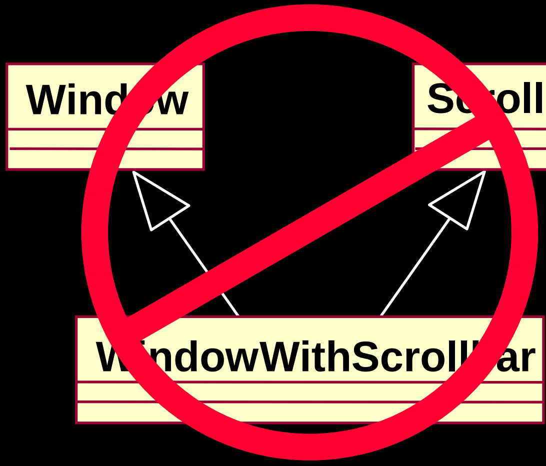
Generalization vs. Aggregation

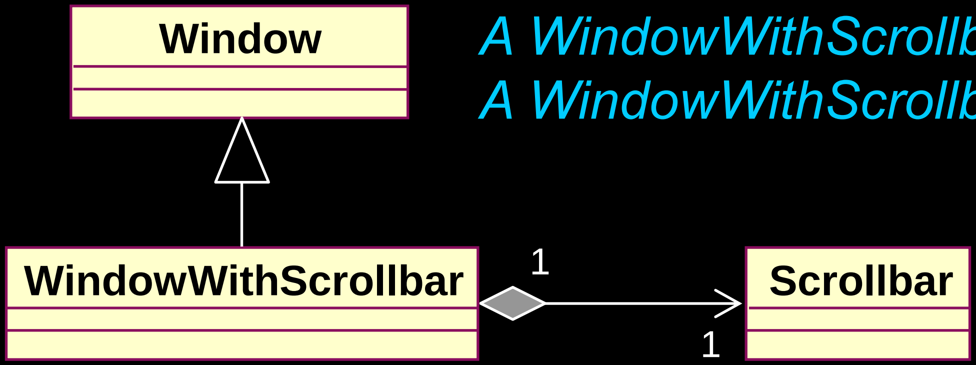
- Generalization and aggregation are often confused
  - Generalization represents an “is a” or “kind-of” relationship
  - Aggregation represents a “part-of” relationship



Is this correct?

Generalization vs. Aggregation

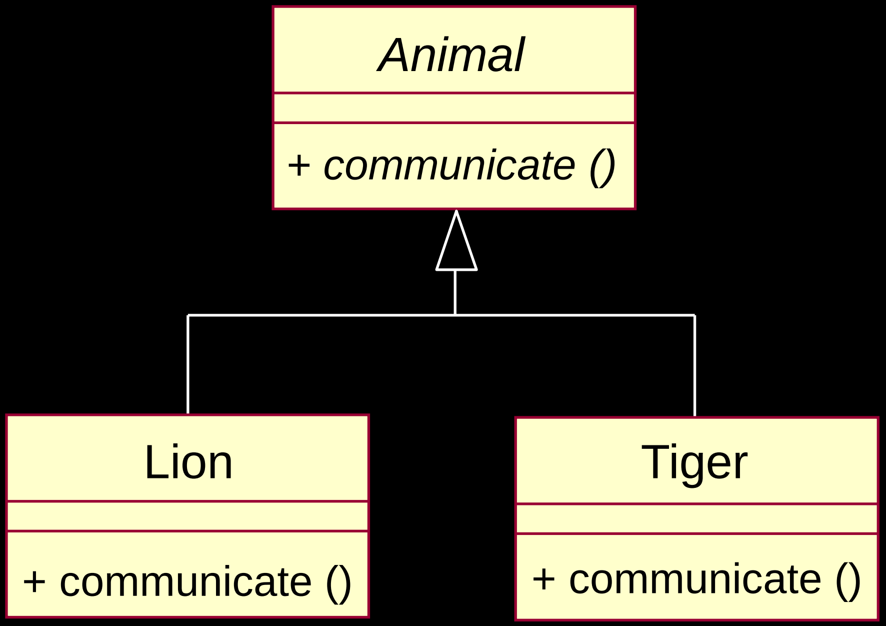


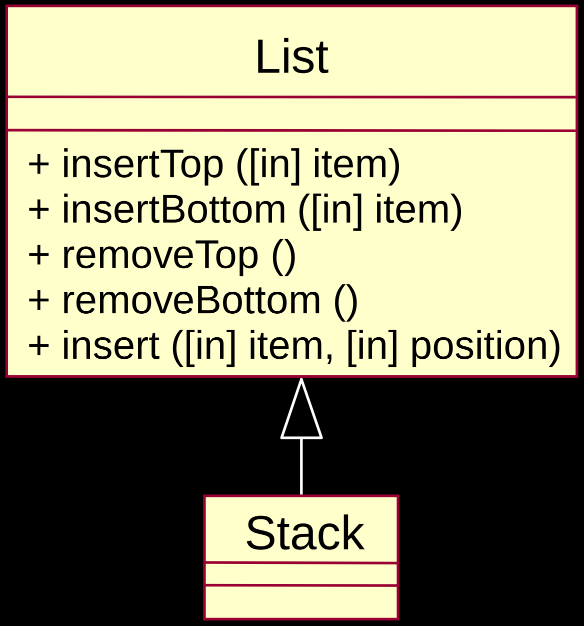


A WindowWithScrollbar "is a" Window
A WindowWithScrollbar "contains a" Scrollbar

Generalization: Share Common Properties and Behavior

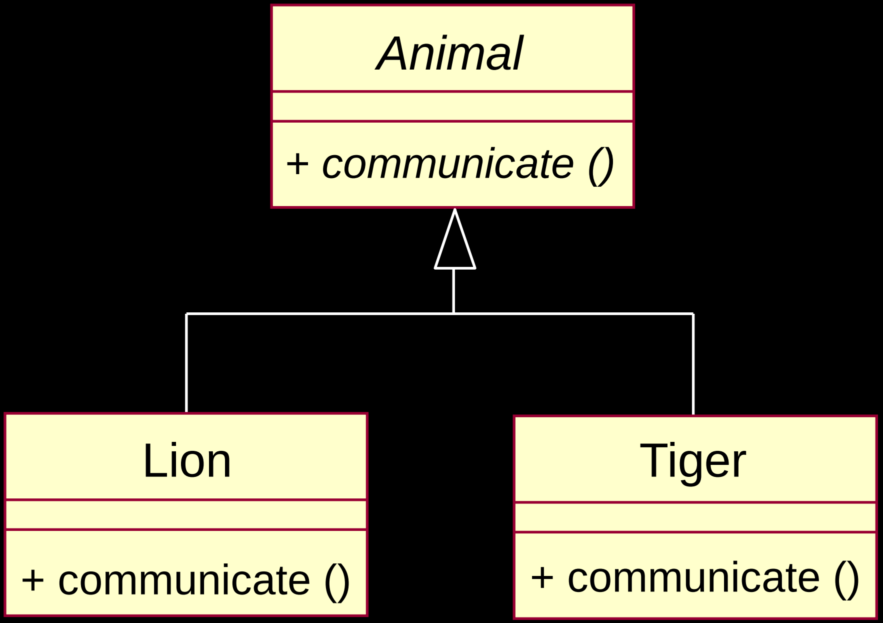
- Follows the "is a" style of programming
- Class substitutability

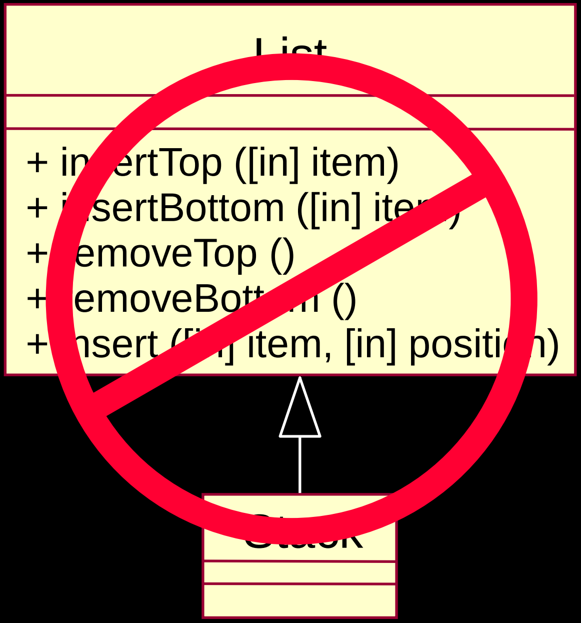




Do these classes follow the "is a" style of programming?

Generalization: Share Common Properties and Behavior (cont.)

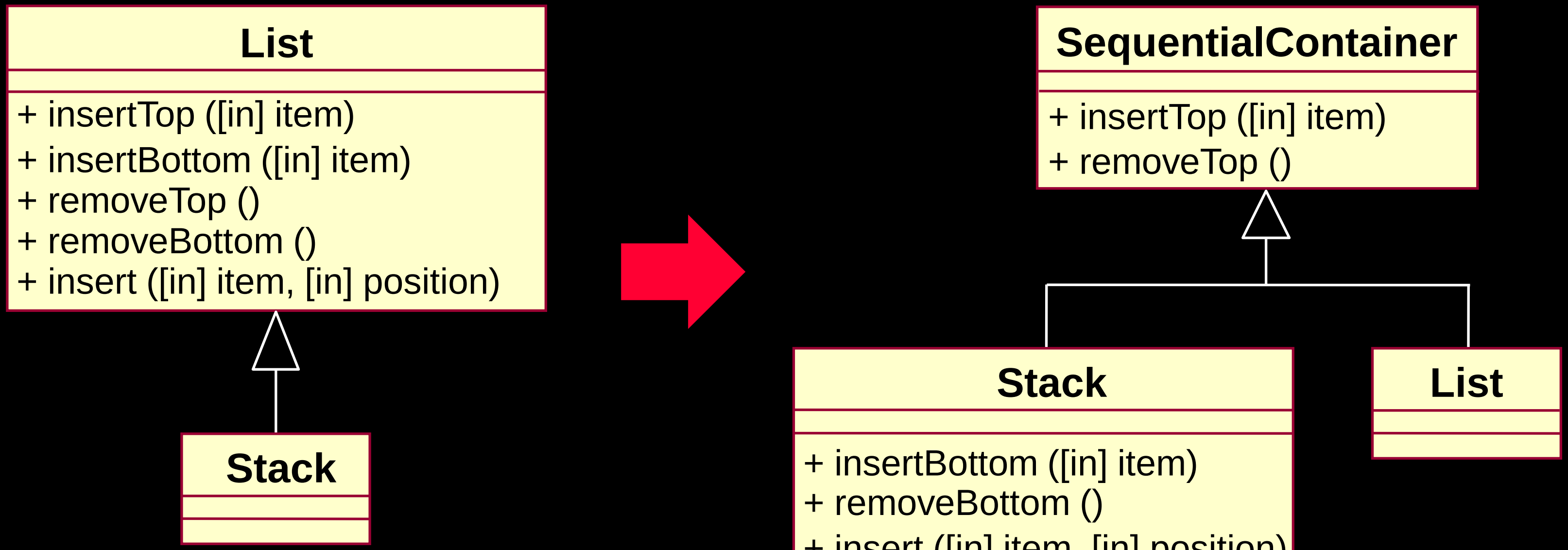




Rational
the software development company

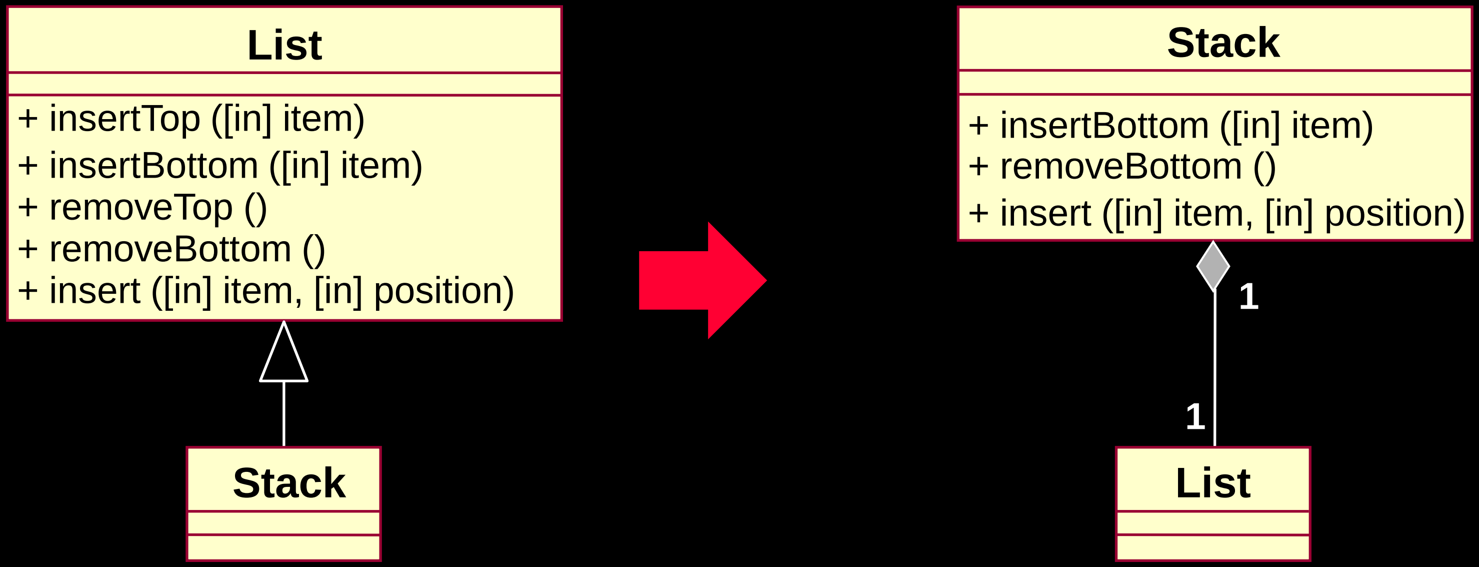
Generalization: Share Implementation: Factoring

- Supports the reuse of the implementation of another class
- Cannot be used if the class you want to “reuse” cannot be changed



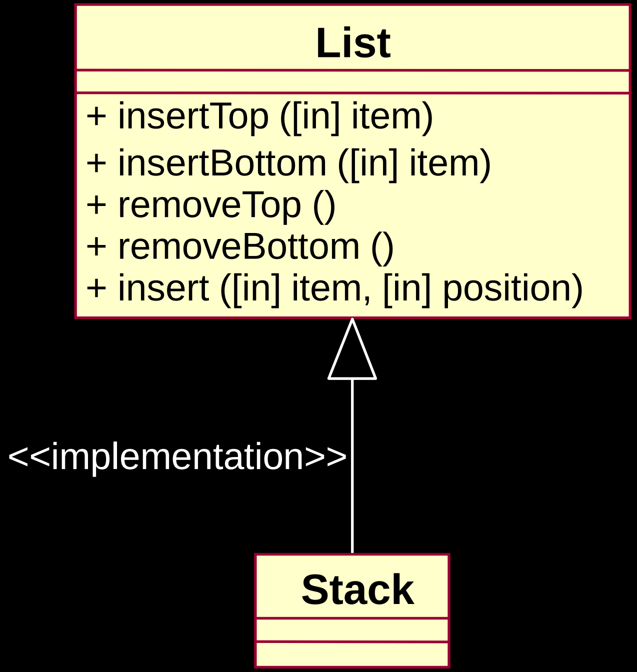
Generalization Alternative: Share Implementation: Delegation

- Supports the reuse of the implementation of another class
- Can be used if the class you want to "reuse" cannot be changed


List
+ insertTop ([in] item)
+ insertBottom ([in] item)
+ removeTop ()
+ removeBottom ()
+ insert ([in] item, [in] position)
Stack
Stack
+ insertBottom ([in] item)
+ removeBottom ()
+ insert ([in] item, [in] position)
1
1
List

Implementation Inheritance

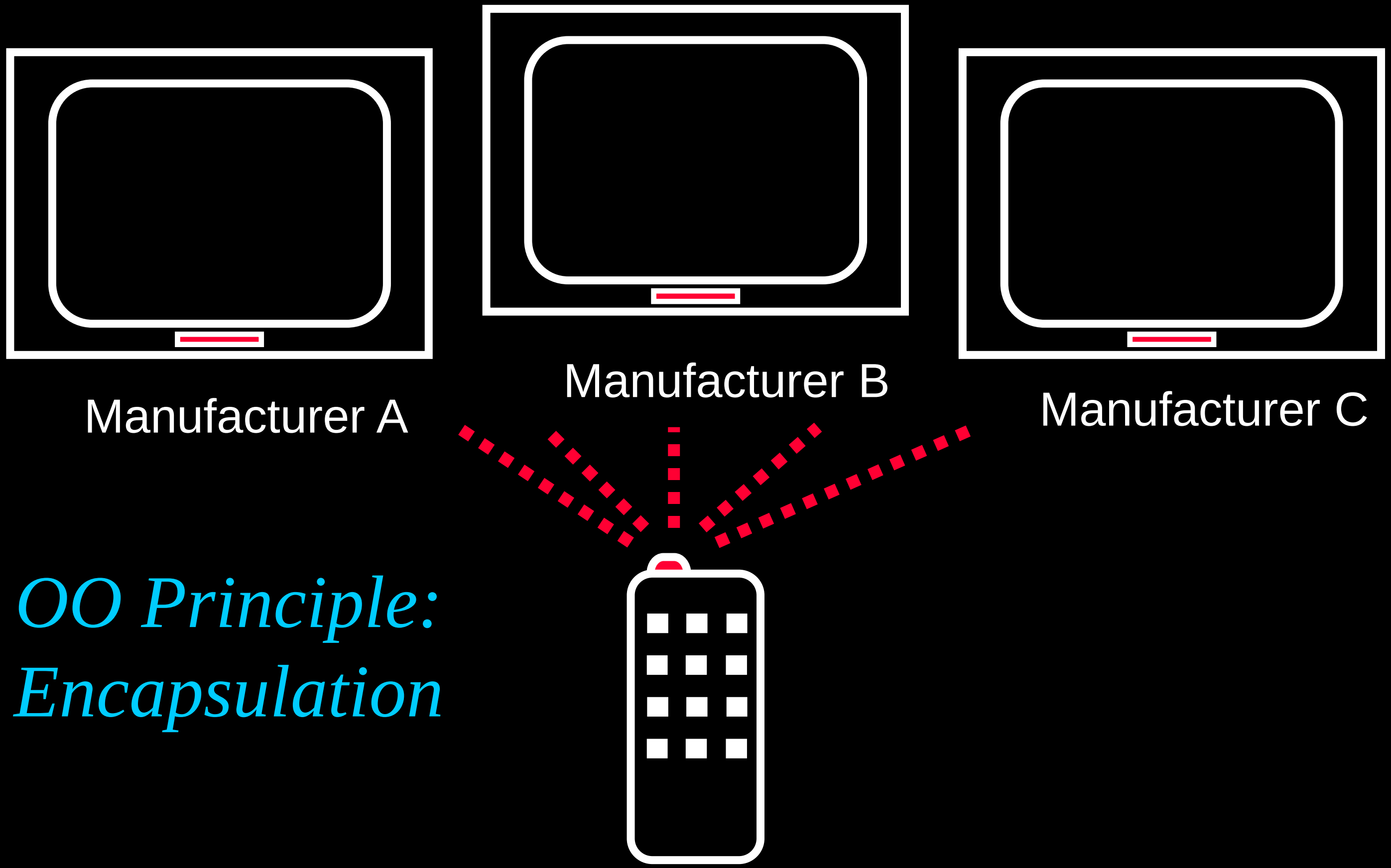
- Ancestor public operations, attributes, and relationships are NOT visible to clients of descendent class instances
- Descendent class must define all access to ancestor operations, attributes, and relationships



push() and pop() can access methods of List but instances of Stack cannot

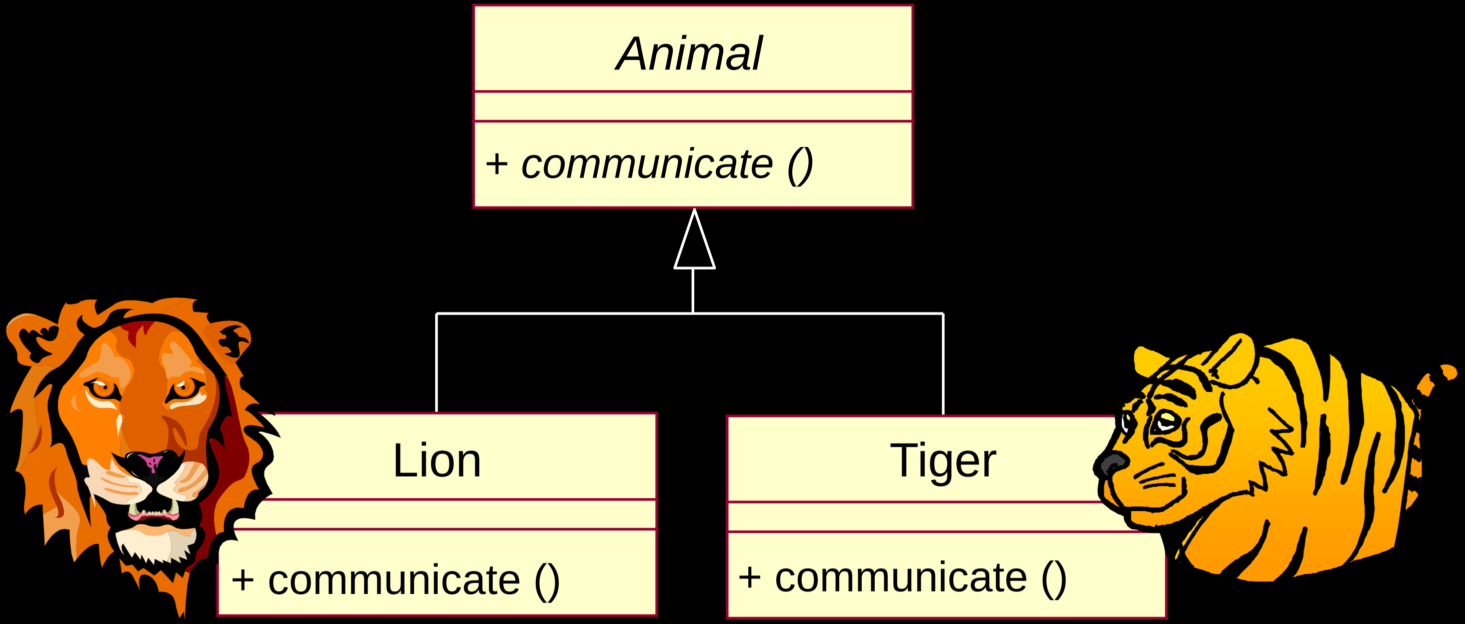
Review: What Is Polymorphism?

- The ability to hide many different implementations behind a single interface



OO Principle: Encapsulation

Generalization: Implement Polymorphism



Without Polymorphism

```
if animal = “Lion” then
        Lion communicate
else if animal = “Tiger” then
        Tiger communicate
end
```

With Polymorphism

Animal communicate

Polymorphism: Use of Interfaces vs. Generalization

- Interfaces support implementation-independent representation of polymorphism
  - Realization relationships can cross generalization hierarchies
- Interfaces are pure specifications, no behavior
  - Abstract base class may define attributes and associations
- Interfaces are totally independent of inheritance
  - Generalization is used to re-use implementations
  - Interfaces are used to re-use behavioral specifications
- Generalization provides a way to implement polymorphism

Polymorphism via Generalization Design Decisions

- Provide interface only to descendant classes?
  - Design ancestor as an abstract class
  - All methods are provided by descendent classes
- Provide interface and default behavior to descendent classes?
  - Design ancestor as a concrete class with a default method
  - Allow polymorphic operations
- Provide interface and mandatory behavior to descendent classes?
  - Design ancestor as a concrete class
  - Do not allow polymorphic operations

What Is Metamorphosis?

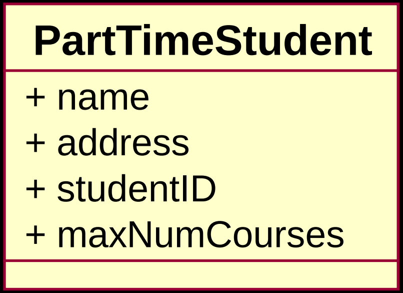
- Metamorphosis
  - 1. A change in form, structure, or function; specifically the physical change undergone by some animals, as of the tadpole to the frog.
  - 2. Any marked change, as in character, appearance, or condition.

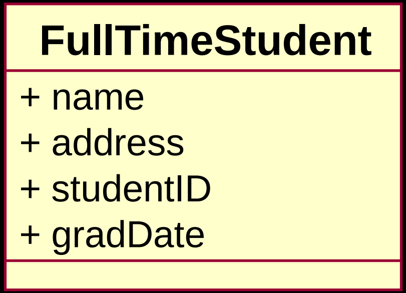
~ Webster's New World Dictionary, Simon & Schuster, Inc., 1979

Metamorphosis exists in the real world.
How should it be modeled?

Example: Metamorphosis

- In the university, there are full-time students and part-time students
  - Full-time students have an expected graduation date but part-time students do not
  - Part-time students may take a maximum of three courses but there is no maximum for full-time students

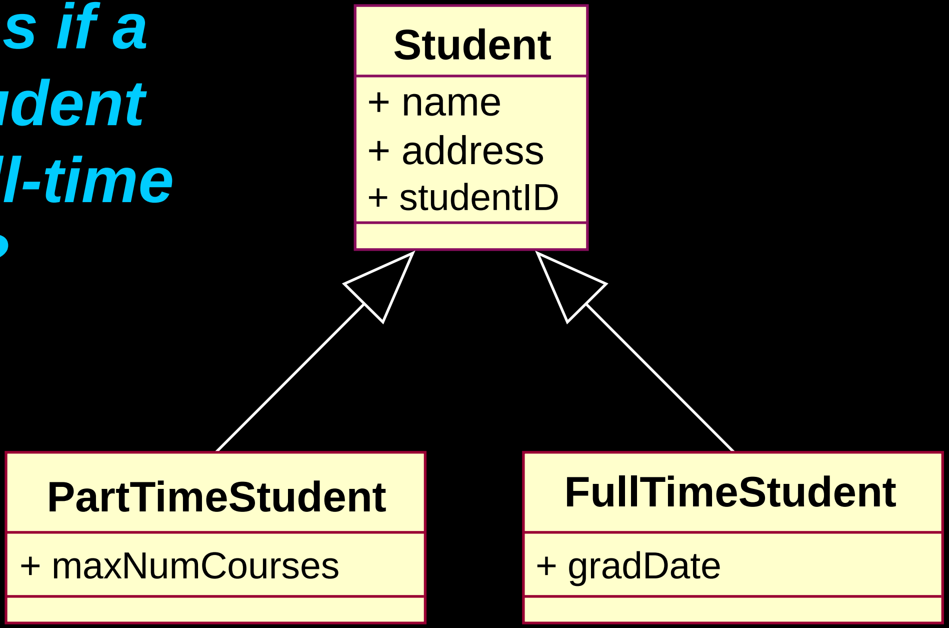




Modeling Metamorphosis: One Approach

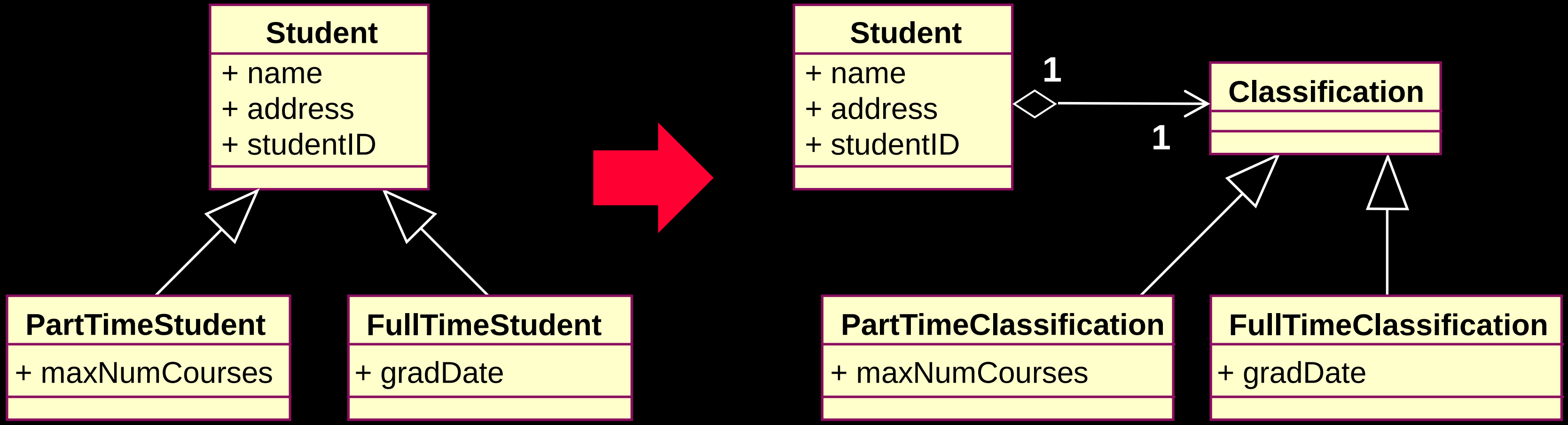
- A generalization relationship may be created

What happens if a part-time student becomes a full-time student?



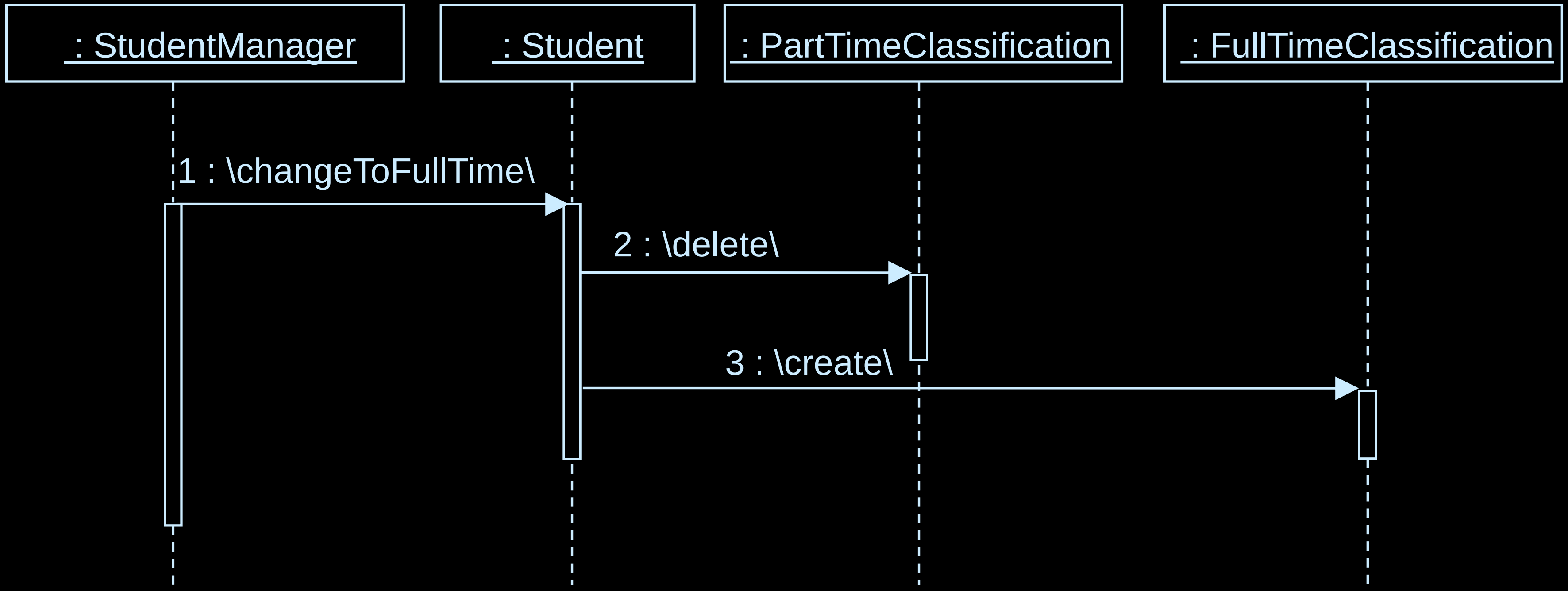
Modeling Metamorphosis: Another Approach

- Inheritance may be used to model common structure, behavior, and/or relationships to the “changing” parts



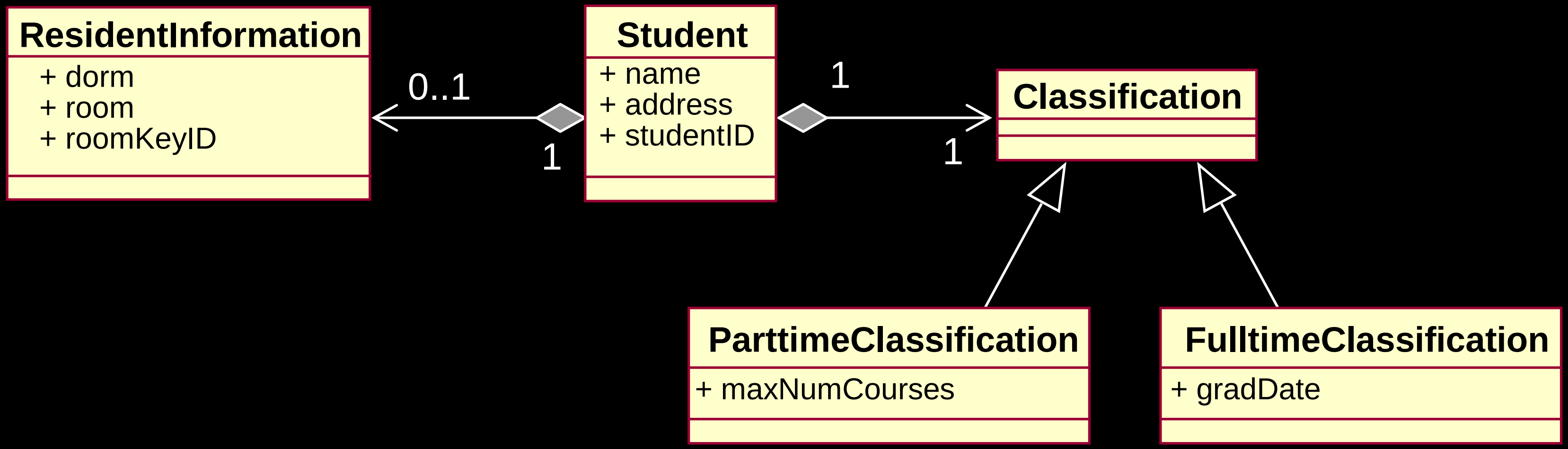
Modeling Metamorphosis: Another Approach (cont.)

- Metamorphosis is accomplished by the object "talking" to the changing parts



Metamorphosis and Flexibility

- This technique also adds to the flexibility of the model



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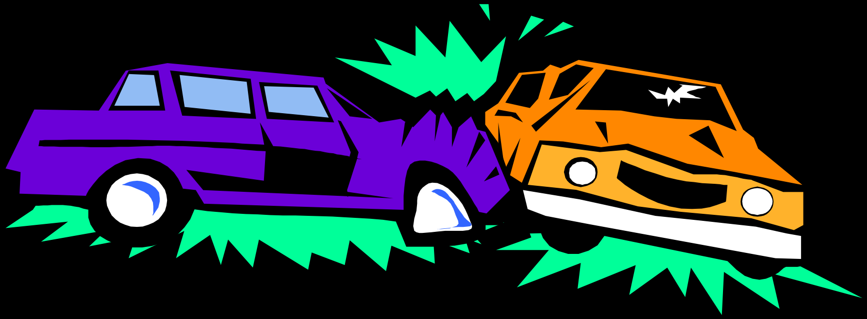
- Handle Non-Functional Requirements in General
- Checkpoints



Resolve Use-Case Collisions

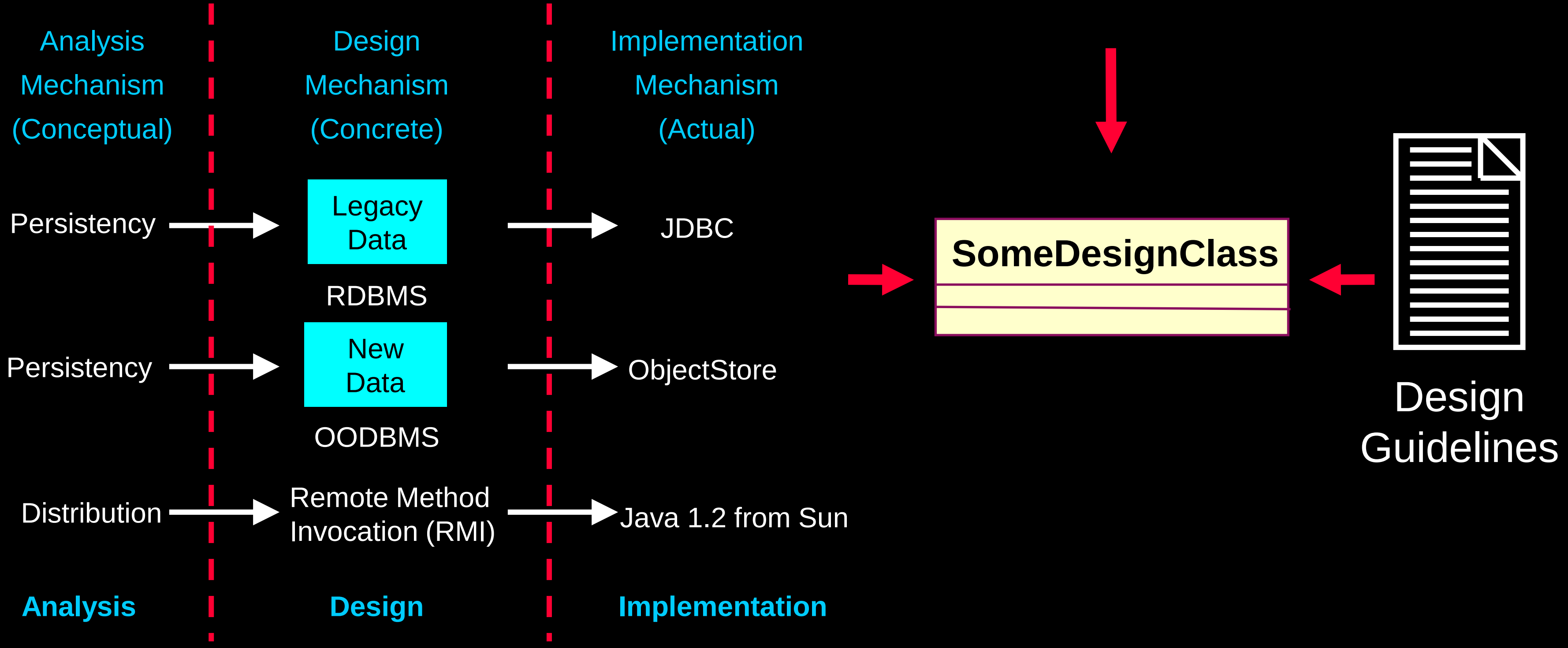
- Multiple use cases may simultaneously access design objects
- Options
  - Use synchronous messaging => first-come first-serve order processing
  - Identify operations (or code) to protect
  - Apply access control mechanisms
    - Message queuing
    - Semaphores (or “tokens”)
    - Other locking mechanism
- Resolution is highly dependent on implementation environment

Class Design Steps

- Create Initial Design Classes
- Define Operations
- Define Methods
- Define States
- Define Attributes
- Define Dependencies
- Define Associations
- Define Generalizations
- Resolve Use-Case Collisions
- ★ Handle Non-Functional Requirements in General
- Checkpoints

Handle Non-Functional Requirements in General

Analysis Class	Analysis Mechanism(s)
Student	Persistency, Security
Schedule	Persistency, Security
CourseOffering	Persistency, Legacy Interface
Course	Persistency, Legacy Interface
RegistrationController	Distribution



Class Design Steps

- Create Initial Design Classes
- Define Operations
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Checkpoints: Classes

- Clear class names
- One well-defined abstraction
- Functionally coupled attributes/behavior
- Generalizations were made.
- All class requirements were addressed
- Demands are consistent with statecharts.
- Complete class instance life cycle is described.
- The class has the required behavior.

Checkpoints: Operations

- Operations are easily understood
- State description is correct
- Required behavior is offered
- Parameters are defined correctly
- Messages are completely assigned operations
- Implementation specifications are correct
- Signatures conform to standards
- All operations are needed by Use-Case Realizations

Checkpoints: Attributes

- A single concept
- Descriptive names
- All attributes are needed by Use-Case Realizations

Checkpoints: Relationships

- Descriptive role names
- Correct multiplicities

Review: Class Design

- What is the purpose of Class Design?
- In what ways are classes refined?
- Are statecharts created for every class?
- What are the major components of a statechart? Provide a brief description of each.
- What kind of relationship refinements occur?
- What is the difference between an association and a dependency?
- What is done with operations and attributes?

Exercise 2: Class Design

- Given the following:
  - The Use-Case Realization for a use case and/or the detailed design of a subsystem
  - The design of all participating design elements

(continued)

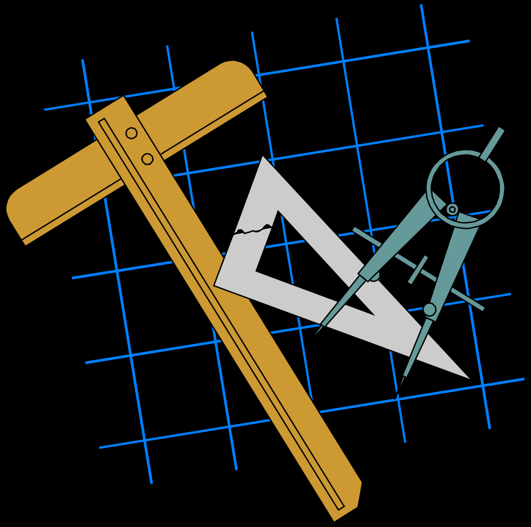
Exercise 2: Class Design (cont.)

- Identify the following:
  - The required navigability for each relationship
  - Any additional classes to support the relationship design
  - Any associations refined into dependencies
  - Any associations refined into aggregations or compositions
  - Any refinements to multiplicity
  - Any refinements to existing generalizations
  - Any new applications of generalization
    - Make sure any metamorphosis is considered

(continued)

Exercise 2: Class Design (cont.)

- Produce the following:
  - An updated VOPC, including the relationship refinements (generalization, dependency, association)



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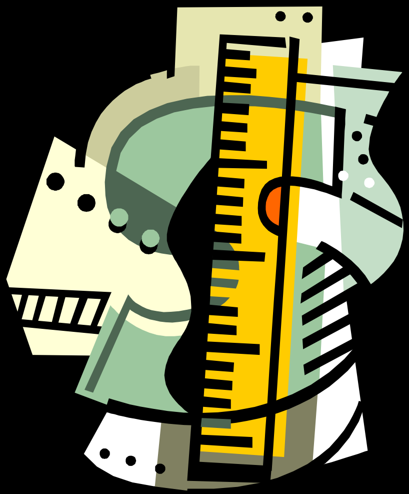
Exercise 2: Review

- Compare your results
  - Do your dependencies represent context independent relationships?
  - Are the multiplicities on the relationships correct?
  - Does the inheritance structure capture common design abstractions, and not implementation considerations?
  - Is the obvious commonality reflected in the inheritance hierarchy?



Payroll System