Software Engineering

Lecture 05: Object-Oriented Analysis

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Outline

Object-Oriented Analysis

- Workflow for object-oriented analysis of systems.
- Modeling: Structural and behavioral
- Overview of supporting UML diagrams

Disclaimer: Today we focus on informal and semi-formal modeling. For a formal approach see the lecture: “Software Design, Modelling, and Analysis in UML”

Object-Oriented Analysis

- After introduction of OOP: need for OOA and OOD
- Purpose: Building OO models of software systems
- No generally accepted methodology; many different approaches: Booch, Rumbaugh (OMT: Object-modeling technique), Coad/Yourdon, Jacobson (OOSE: Object-oriented software engineering), Wirfs-Brock, ...
- Current approaches rely on **UML** (Unified Modeling Language, Booch/Jacobson/Rumbaugh)
- UML supports many kinds of semi-formal modeling techniques
  - **use case diagrams**
  - **class diagrams**
  - **sequence diagrams**
  - **state machine diagrams**
  - **activity diagrams**
  - **...**

The Concept "Model"

(according to Herbert Stachowiak, 1973)

Representation

A model is a representation of an original object.

Abstraction

A model need not encompass all features of the original object.

Pragmatism

A model is always goal-oriented.

- Modeling creates a representation that only encompasses the relevant features for a particular purpose.

Variations of Models

Informal models

- informal syntax, intuitive semantics
- ex: informal drawing on blackboard, colloquial description

Semi-formal models

- formally defined syntax (metamodel), intuitive semantics
- ex: many diagram types of UML

Formal models

- formally defined syntax and semantics
- ex: logical formulae, phrase structure grammars, programs

Obtaining a data model

Ten Steps Towards an OOA Model

Heide Balzert

1. Data analysis: identify classes
2. Identify associations and compositions
3. Identify attributes and operations for each class
4. Construct object life cycle
5. Introduce inheritance
6. Identify internal operations
7. Specify operations
8. Check inheritance
9. Check associations and compositions
10. Decompose in subsystems

Step: Identify Classes

- identify tangible entities: physical objects (airplane), roles (manager), events (request, form), interactions (meeting), locations (office), organizational units (company)
- top-down: scan verbal requirements
    - nouns → objects, attributes
    - verbs → operations

  bottom-up:
    - collect attributes (data) and operations
    - combine into classes
- name of class: concrete noun, singular, describes all objects (no roles)
- classes related via invariable 1:1 associations may be joined

Step: Identify Associations and Compositions

- permanent relations between objects
- scan verbal requirements for verbs
- technical subsidiarity: composition
- communication between objects → association
- determine roles
- snapshot / history required?
- constraints?
- are there attributes / operations for association?
- determine cardinalities

Attributes and Operations by Form Analysis

Upload new Good

Category: Choose One!

Auction off? ● Yes ○ No

Good

name
picture
description
category
status
...

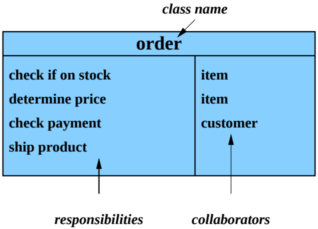
display()
edit()
...

Step: Identify Attributes and Operations

CRC Cards (Wirfs-Brock)

- CRC = Class-Responsibility-Collaboration
- initially, a class is assigned **responsibilities** and **collaborators**
- collaborator is a class cooperating to fulfill responsibilities
- **three-four** responsibilities per card (class); otherwise: split class
- developed iteratively through series of meetings

Example CRC Card



Classes From Use Cases

Use Case: buy product

- Locate product in catalogue
- Browse features of product
- Place product in shopping cart
- Proceed to checkout
- Enter payment info
- Enter shipping info
- Confirm sale

Notation for Designing Datatypes (F#)

```
type sale =         { cart: shoppingCart;
                      shipment: shipmentInfo;
                      payment: paymentInfo }
and  shoppingCart = { contents: product list }
and  shipmentInfo = { name: string;
                      address: string }
and  paymentInfo =  { accountNr: string;
                      bankingCode: string }
and  product =      { name: string;
                      price: int;
                      features: feature list }
and  feature =      { name: string }
```

- Named record types

Classes from Requirements

A graphics program should draw different geometric shapes in a coordinate system. There are four kinds of shapes:

- *Rectangles given by upper left corner, width, and height*
- *Disks given by center point and radius*
- *Points*
- *Overlays composed of two shapes*

Classes from Requirements

```
type cartPt = { x: int; y: int }
and shape =
     Rectangle of rectangle
   | Disk of disk
   | Point of point
   | Overlay of overlay
and rectangle = { loc: cartPt; width: int; height: int }
and disk = { loc: cartPt; radius: int }
and point = { loc: cartPt }
and overlay = { lower: shape; upper: shape }
```

- Sum type (shape) for alternatives

Classes from Requirements

```
class CartPt{
int x, y;
}
abstract class Shape {}
class Rectangle extends Shape {
cartPt loc;
int width, height;
}
class Disk extends Shape {
cartPt loc;
int radius; }
class Point extends Shape { cartPt loc; }
class overlay extends Shape { Shape upper, lower; }
```

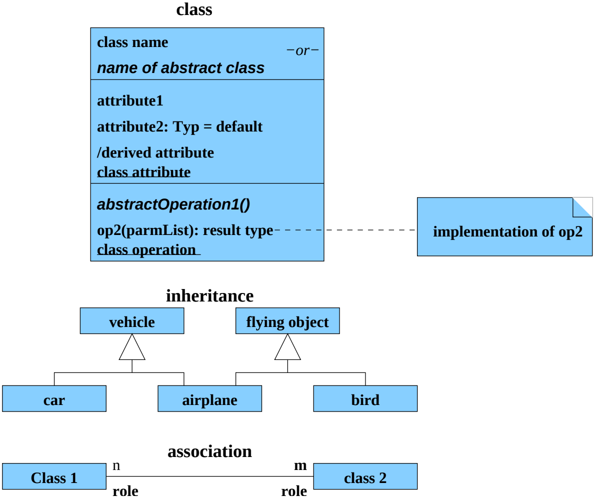
- Use inheritance for alternatives.

Expressing an OO data model

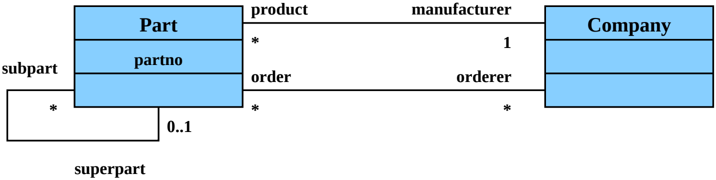
Class Diagram (UML)

- Structural diagram, data-oriented view, cf. ERD
- Representation of **classes** and their **static relationships**
- No information on run-time behavior
- Notation is graph with
  - **nodes**: classes (rectangles)
  - **edges**: various relationships between classes
- May contain interfaces, packages, relationships, as well as instances (objects, links)
- (Only most important modeling elements)
  See `http://www.uml-diagrams.org/` for more

Example Class Diagram



Example Class Diagram



Classes

A class box has compartments for

- Class name
- Attributes (variables, fields)
- Operations (methods)

- only name compartment obligatory
- additional compartments may be defined
- class (static) attributes / operations underlined
- derived (computed) attributes indicated by “/”

Relations Between Classes

Binary Association

- indicates "collaboration" between two classes (possibly reflexive)
- solid line between two classes
- optional:
  - association name
  - decoration with role names
  - navigation indicated by arrows (Design)
  - multiplicities (Design)

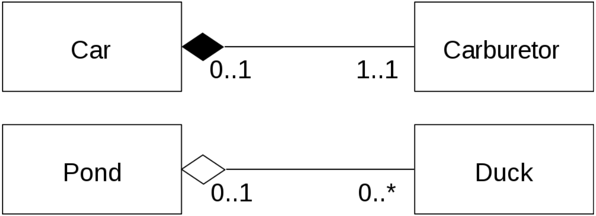
Generalization

- indicates subclass relation
- solid line with open arrow towards super class

Aggregation and Composition

- Aggregation is a particularly strong association: **part-of**
- Notation: edge with rhombus as arrow head
- Composition is yet stronger form of aggregation
- Meaning: object “belongs existentially” to other object
- Object and its components live and die together
- Notation: edge with black rhombus as arrow head

Example



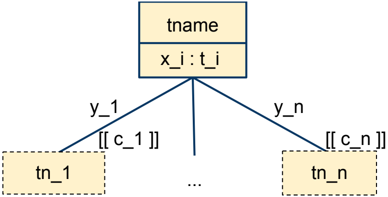
Mapping from F# Types to Class Diagrams

Mapping a type definition

$$[\![\text{type } tdef_1 \text{ and } \ldots \text{ and } tdef_n]\!] = [\![tdef_1]\!] \cup \cdots \cup [\![tdef_n]\!]$$

Mapping a record type

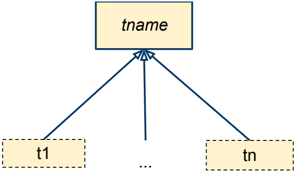
$$[\![\text{tname} = \{x_i : t_i, y_j : \text{tn}_j\ c_j\}]\!] =$$



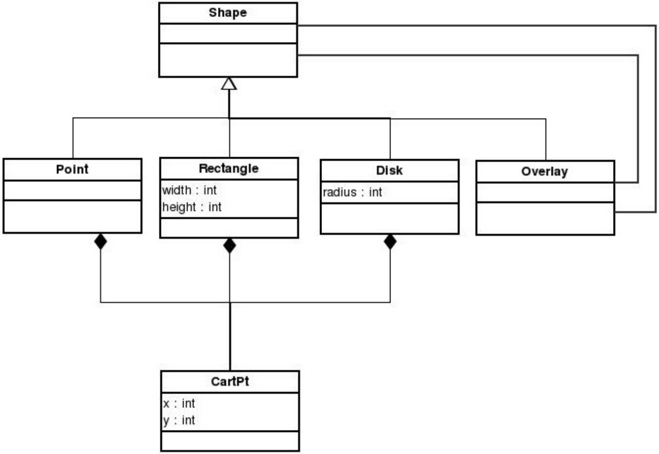
$$\begin{aligned} [\![\text{list}]\!] &= * \\ [\![\text{option}]\!] &= 0, 1 \\ [\![\ ]\!] &= 1 \end{aligned}$$

Mapping a sum type

$$[\![\text{tname} = T_1 \texttt{ of } t_1 \mid \cdots \mid T_n \texttt{ of } t_n]\!] =$$



Applied to Example Code

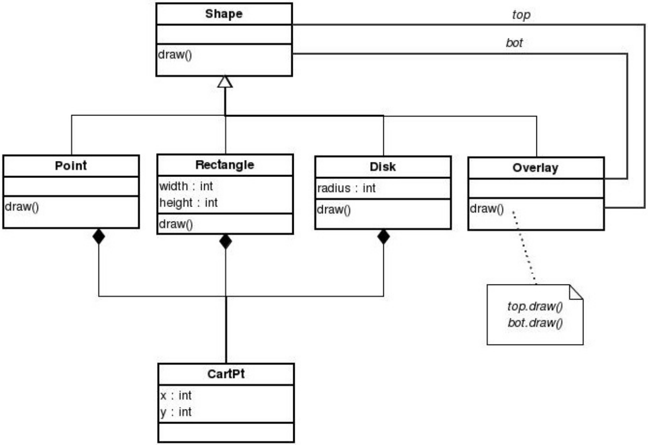


. . . Operations

A graphics program should draw different geometric shapes . . .

- Each class should have a draw() operation
- Shape should also have draw() operation
- Discovered the “Composite Pattern”!

Example Code with Draw Method



Example Code with Draw Method

```
class CartPt{
int x, y;
}
abstract class Shape {public void draw();}
class Rectangle extends Shape {
cartPt loc;
int width, height;
}
class Disk extends Shape {
cartPt loc;
int radius; }
class Point extends Shape { cartPt loc; }
class overlay extends Shape { Shape upper, lower; }
```

Step: Construct Object Life Cycle

Object Life Cycle

- Object creation
- Initialization
- . . .
- Finalization
- Object destruction

Life Cycle — Type State

- certain operations can only be executed in particular state
- operation $\widehat{=}$ event that triggers a state change

Modeling Behavior with Finite State Machines (FSM)

- Basis: deterministic finite automaton (FSA) accepts a language $\subseteq \Sigma^*$
  $A = (Q, \Sigma, \delta, q_0, F)$ where

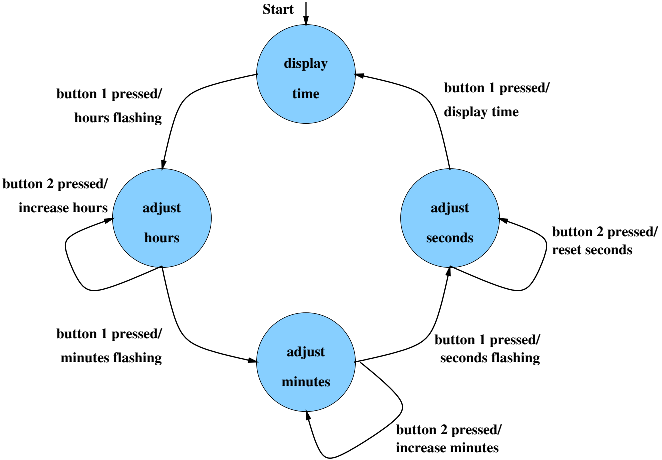
  Q: finite set of states
  Σ: finite input alphabet
  δ: $Q \times \Sigma \longrightarrow Q$ transition function
  q_0 $\in Q$ initial state
  F $\subseteq Q$ set of final states

- **FSA with output** specifies a translation $\Sigma^* \to \Delta^*$
  - $M = (Q, \Sigma, \Delta, \delta, \lambda, q_0)$
  - replace final states F by output alphabet Δ and output function λ
  - **Mealy-automaton:** $\lambda : Q \times \Sigma \longrightarrow \Delta$
    edge from q to $\delta(q, a)$ additionally carries $\lambda(q, a)$
  - **Moore-automaton:** $\lambda : Q \longrightarrow \Delta$
    state q labeled with $\lambda(q)$
- Mealy and Moore automata are equivalent regarding the translation

Graphical Representation of FSM

- **nodes:** states of the automaton (circles or rectangles)
- arrow pointing to q_0
- final states indicated by double circle
- **edges:** if $\delta(q, a) = q'$ then **transition** labeled a from q to q'
- **output:** if $\lambda(q, a) = o$ then transition from q to q' labeled with a/o

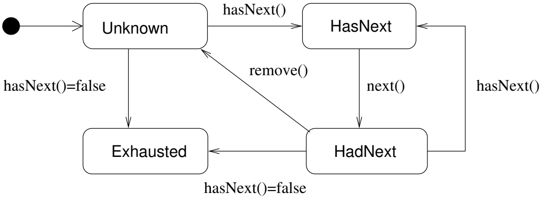
Example: Digital Clock as a Mealy-automaton



Drawback: FSMs get too big → structuring required → UML state machine diagram

Example: Java Iterator — State Machine Diagram

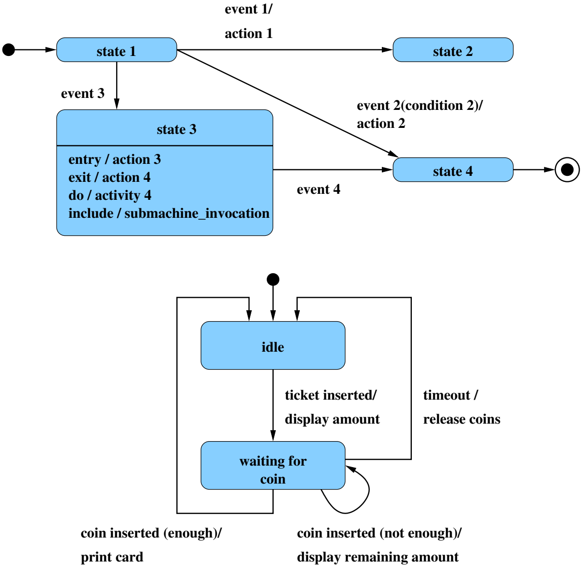
```
interface Iterator<E> {
  /** Returns true if the iteration has more elements. */
  public boolean hasNext();
  /** Returns the next element in the iteration. */
  public E next();
  /** Removes from the underlying collection the last element
      returned by the iterator (optional operation). */
  public void remove();
}
```



State Machine Diagram (UML)

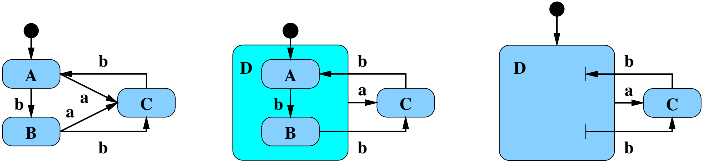
- behavioral diagram derived from David Harel's Statecharts
- hybrid automata ("Moore + Mealy")
- each state may have
  - **entry action:** executed on entry to state
    $\cong$ labeling all incoming edges
  - **exit action:** executed on exit of state
    $\cong$ labeling all outgoing edges
  - **do activity:**
    executed while in state
- composite states
- states with history
- concurrent states
- optional: conditional state transitions

Example: State Machine Diagram



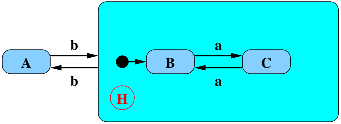
Composite States

- states can be grouped into a composite state with designated start node (→ hierarchy)
- edges may start and end at any level
- transition from a composite state $\cong$ set of transitions with identical labels from all members of the composite state
- transition to a composite state leads to its initial state
- transitions may be “stubbed”



States with History

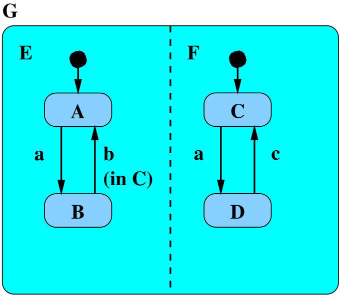
- composite state with history — marked **(H)** — remembers the internal state on exit and resumes in that internal state on the next entry



- the history state indicator may be target of transitions from the outside and it may indicate a default “previous state”
- “deep history” **(H*)** remembers nested state

Concurrent States

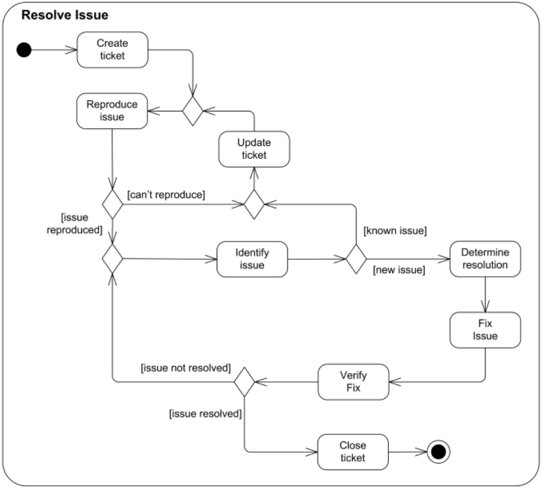
- composite state may contain **concurrent state regions** (separated by dashed lines)
- all components execute concurrently
- transitions may depend on state of another component (synchronisation)
- explicit synchronization points
- concurrent transitions



sequence of states on input `abcb`:
(A, C), (B, D), (B, D), (B, C), (A, C)

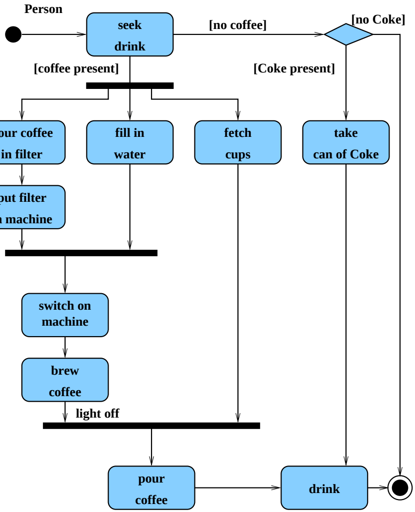
Alternative: Activity Diagram

- Behavioral diagram, which emphasizes flow of control



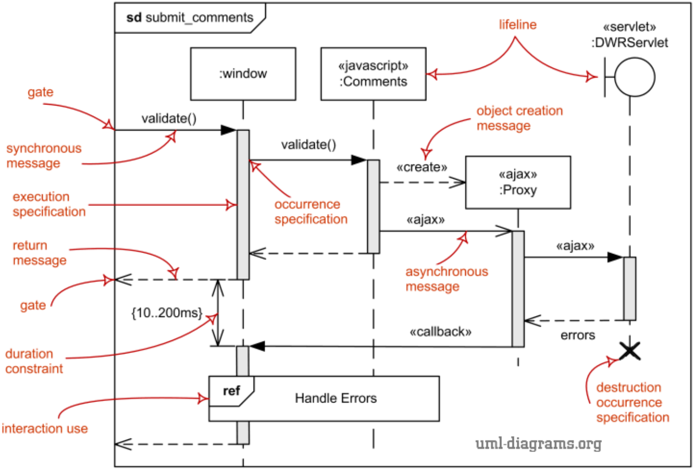
`http://www.uml-diagrams.org/examples/activity-examples-resolve-issue.png`

Activity Diagram with Synchronization



Alternative: Sequence Diagram

- behavioral diagram describing interaction between group of objects
- → communication protocols



`http://www.uml-diagrams.org/examples/sequence-diagram-overview.png`

Alternative: Object and Collaboration Diagrams (UML)

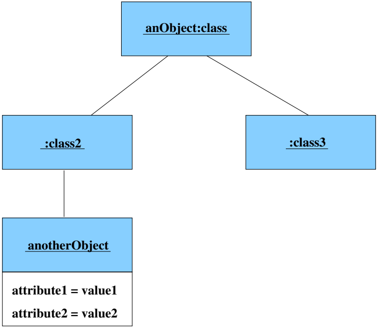
Object Diagram (structural)

- notation for **objects** and their **links**
- UML notation:
  - **nodes**: objects (rectangles), labeled with **object name:type**
  - **edges**: links between objects
    "objects that know each other"

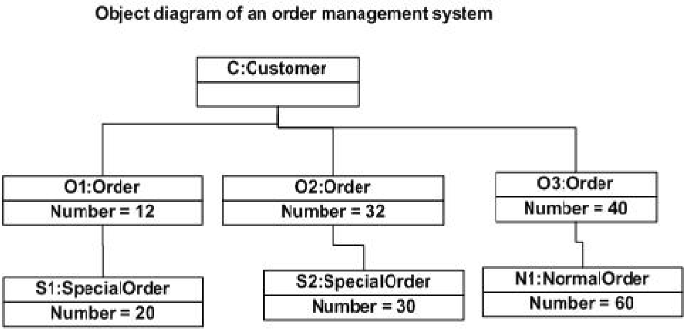
Properties of object diagrams

- snapshot of a system state
- configuration of a specific group of objects

Example: Object Diagram



Example: Object Diagram

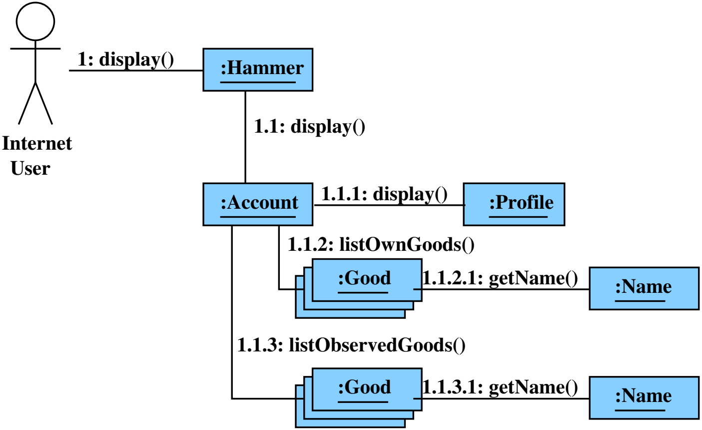


Collaboration diagrams (behavioral)

Collaboration diagram = object diagram + behavior

- objects → **object roles**
- object notation stands for "any object of that class"
- object roles and links may be labeled with constraints
  - {new}
  - {transient}
  - {destroyed}
- labeling links with numbered operations
- numbering implies sequence of execution

Example: Collaboration Diagram



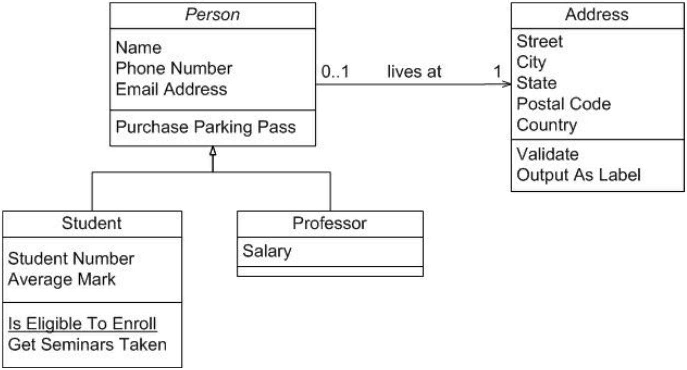
Step: Introduce Inheritance

- Use sparingly!
- Use inheritance for abstracting common patterns:
  Collect common attributes and operations in abstract superclass
- Alternative: collect in separate class and use composition

Inheritance is a good choice when:

- Your inheritance hierarchy represents an "is-a" relationship and not a "has-a" relationship.
- You can reuse code from the base classes.
- You need to apply the same class and methods to different data types.
- The class hierarchy is reasonably shallow, and other developers are not likely to add many more levels.
- You want to make global changes to derived classes by changing a base class.

Inheritance: Example



Final Step: Specify Operations

- Data-driven development: [Jackson]
  Derive structure of operation from data it operates on
- Test-driven development: [Beck]
  Specify a set of meaningful test cases
- Design by contract: [Meyer]
  - Define class invariants
  - Specify operations by pre- and postconditions
- Pseudocode Programming Process (PPP): [McConnell]
  - Start with high-level pseudocode
  - Refine pseudocode until implementation obvious

Summary

- Workflow for object-oriented analysis.
- There are structural models: Class diagrams, object diagrams
- There are behavioral models: State machines, sequence and activity diagrams, collaboration diagrams, etc.

There are **many** alternatives for modeling a software system. Choose the one that fits the particular problem.