*Object Modeling with OMG UML* Tutorial Series

# Introduction to UML: Structural and Use Case Modeling

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## Overview

- Tutorial series
- Quick tour
- Structural modeling
- Use case modeling

## Tutorial Series

- Lecture 1: Introduction to UML: Structural and Use Case Modeling
- Lecture 2: Behavioral Modeling with UML
- Lecture 3: Advanced Modeling with UML

[Note: This version of the tutorial series is based on *OMG UML Specification* v. 1.4, OMG doc# ad/01-02-13, adopted in May 2001.]

## Tutorial Goals

- What you will learn:
  - what the UML is and what is it not
  - UML’s basic constructs, rules and diagram techniques
  - how the UML can model large, complex systems
  - how the UML can specify systems in an implementation-independent manner
- What you will not learn:
  - object methods or processes
  - metamodeling techniques

## Quick Tour

- Why do we model?
- What is the UML?
- Foundation elements
- Unifying concepts
- Language architecture
- Relation to other OMG technologies

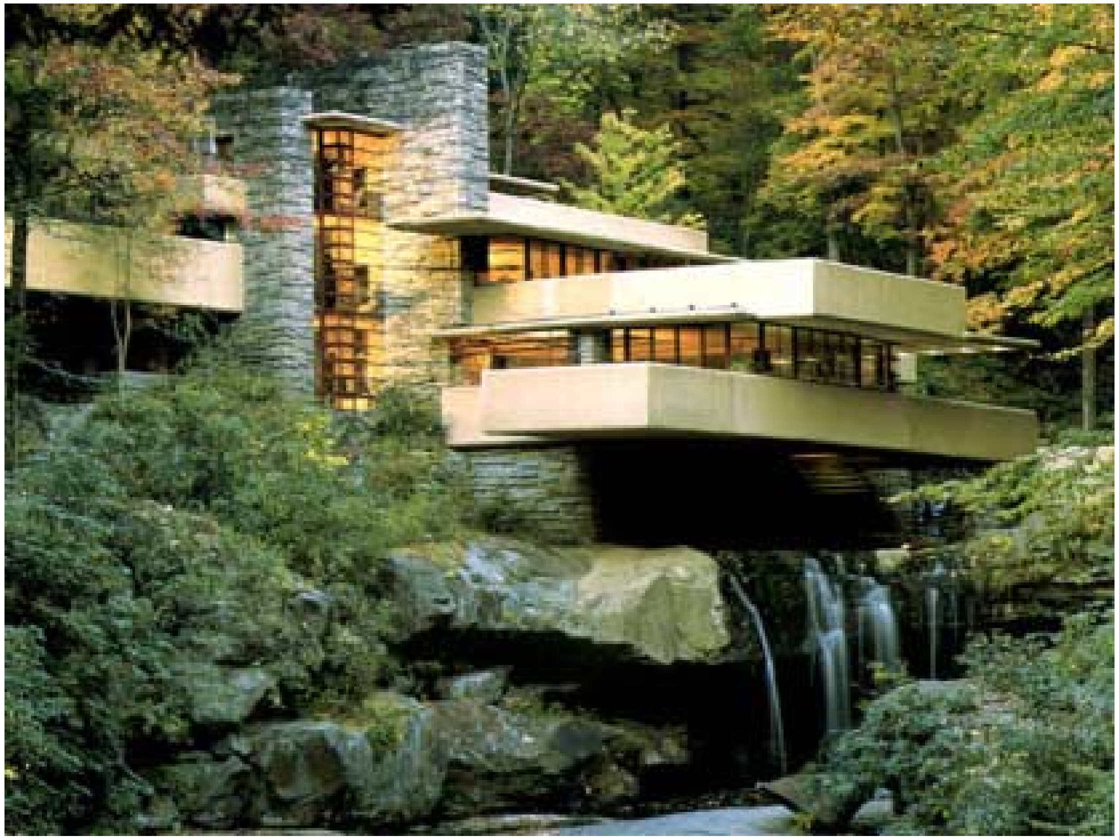
## Why do we model?

- Provide structure for problem solving
- Experiment to explore multiple solutions
- Furnish abstractions to manage complexity
- Reduce time-to-market for business problem solutions
- Decrease development costs
- Manage the risk of mistakes

## The Challenge

Tijuana “shantytown”:
http://www.macalester.edu/~jschatz/residential.html

## The Vision



Fallingwater:
http://www.adelaide.net.au/~jpolias/FLW/Images/FallingWater.jpeg

## Why do we model graphically?

- Graphics reveal data.
  - Edward Tufte
    *The Visual Display of Quantitative Information, 1983*
- 1 bitmap = 1 megaword.
  - Anonymous visual modeler

## Quick Tour

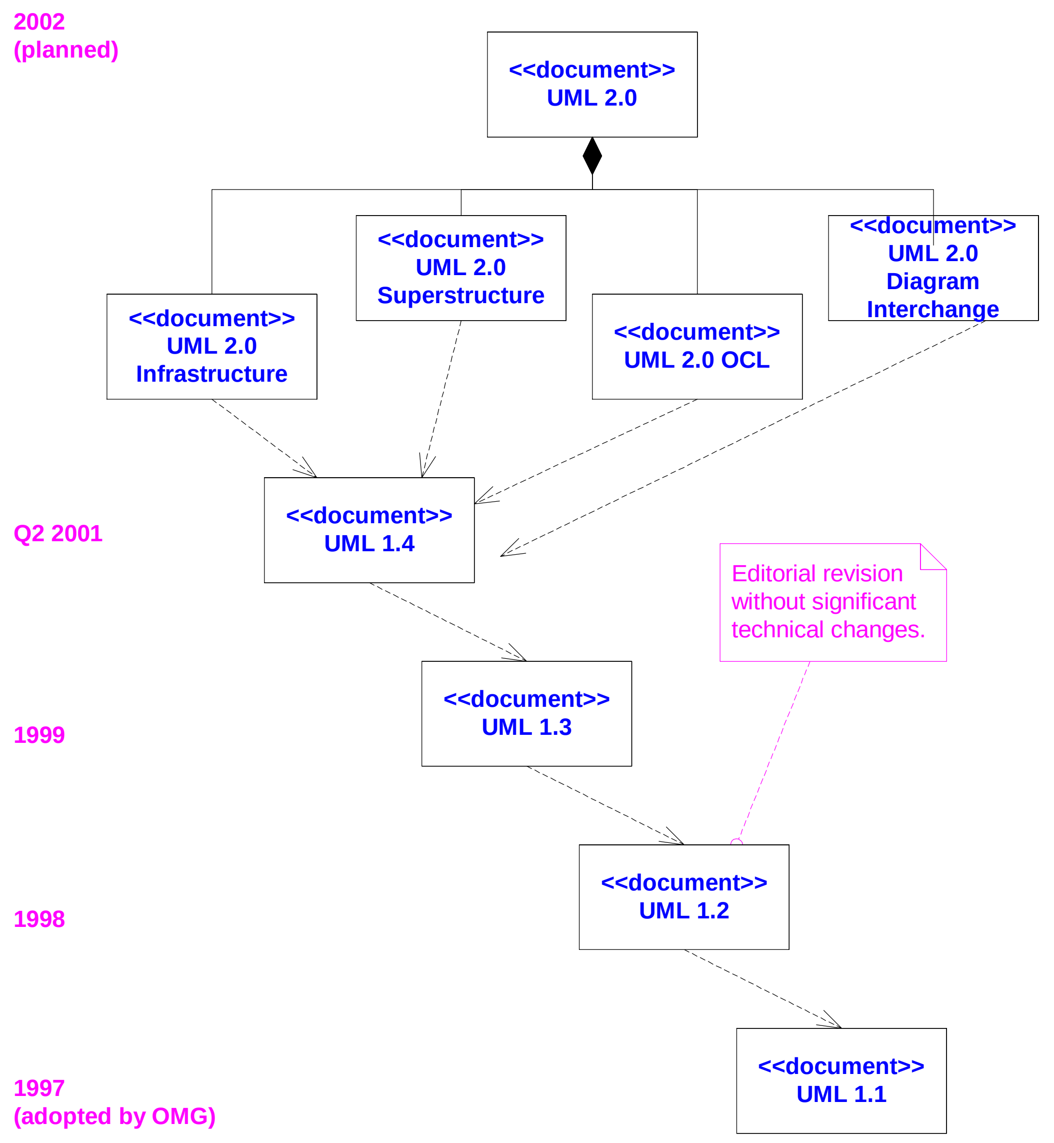
- The UML is a graphical language for
  - specifying
  - visualizing
  - constructing
  - documenting

  the artifacts of software systems
- Added to the list of OMG adopted technologies in November 1997 as UML 1.1
- Most recent minor revision is UML 1.4, adopted in May 2001.
- Next major revision will be UML 2.0, planned to be completed in 2002

# UML Goals

- Define an easy-to-learn but semantically rich visual modeling language
- Unify the Booch, OMT, and Objectory modeling languages
- Include ideas from other modeling languages
- Incorporate industry best practices
- Address contemporary software development issues
  - scale, distribution, concurrency, executability, etc.
- Provide flexibility for applying different processes
- Enable model interchange and define repository interfaces

# OMG UML Evolution



Updated from [Kobryn 01a].

## OMG UML Contributors

- Aonix
- Colorado State University
- Computer Associates
- Concept Five
- Data Access
- EDS
- Enea Data
- Hewlett-Packard
- IBM
- I-Logix
- InLine Software
- Intellicorp
- Kabira Technologies
- Klasse Objecten
- Lockheed Martin
- Microsoft
- ObjecTime
- Oracle
- Ptech
- OAO Technology Solutions
- Rational Software
- Reich
- SAP
- Softeam
- Sterling Software
- Sun
- Taskon
- Telelogic
- Unisys
- …

## OMG UML 1.4 Specification

- UML Summary
- UML Semantics
- UML Notation Guide
- UML Example Profiles
  - Software Development Processes
  - Business Modeling
- Model Interchange
  - Model Interchange Using XMI
  - Model Interchange Using CORBA IDL
- Object Constraint Language

## Tutorial Focus: the Language

- language = syntax + semantics
  - syntax = rules by which language elements (e.g., words) are assembled into expressions (e.g., phrases, clauses)
  - semantics = rules by which syntactic expressions are assigned meanings
- *UML Notation Guide* – defines UML’s graphic syntax
- *UML Semantics* – defines UML’s semantics

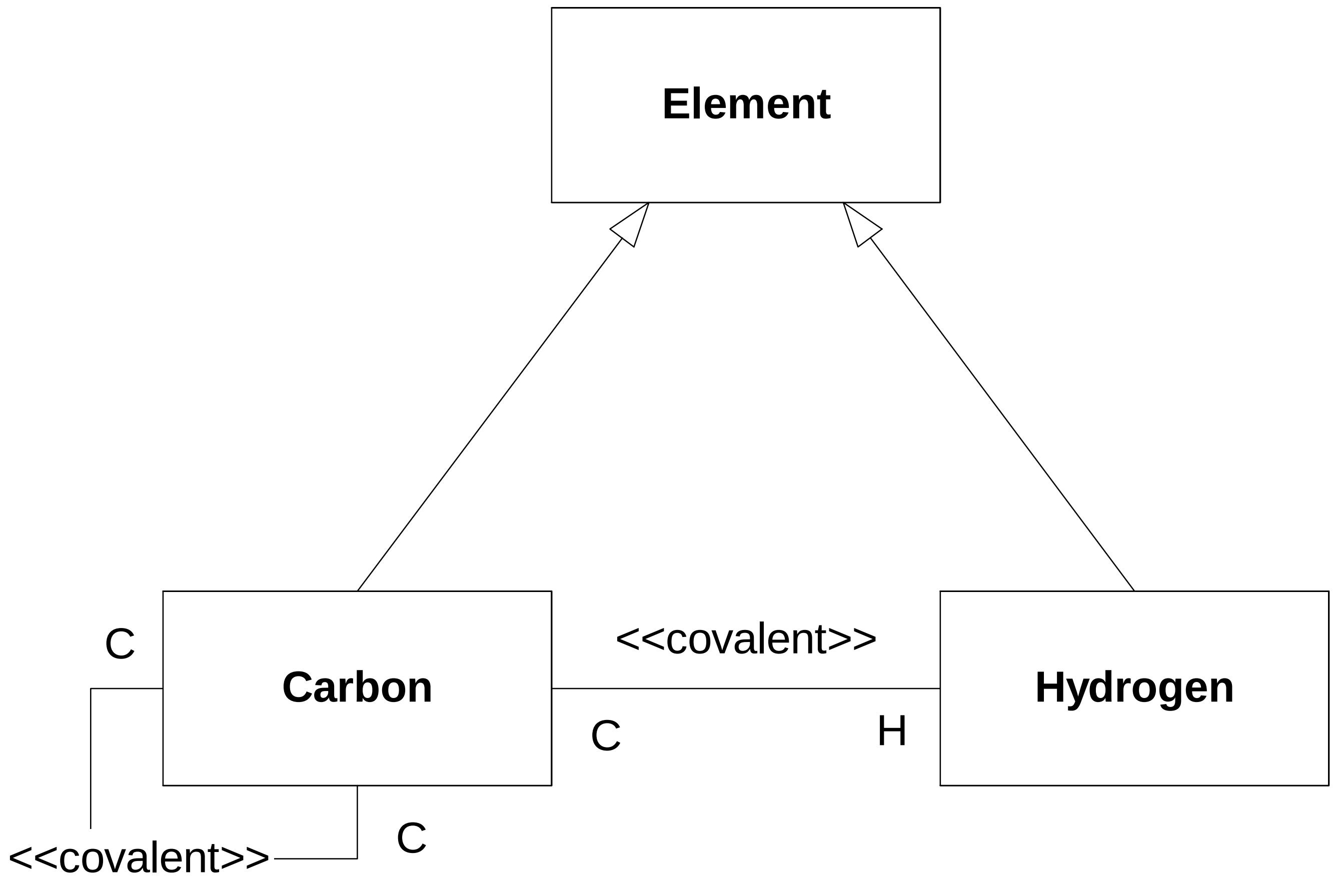
## Foundation Concepts

- Building blocks
- Well-formedness rules

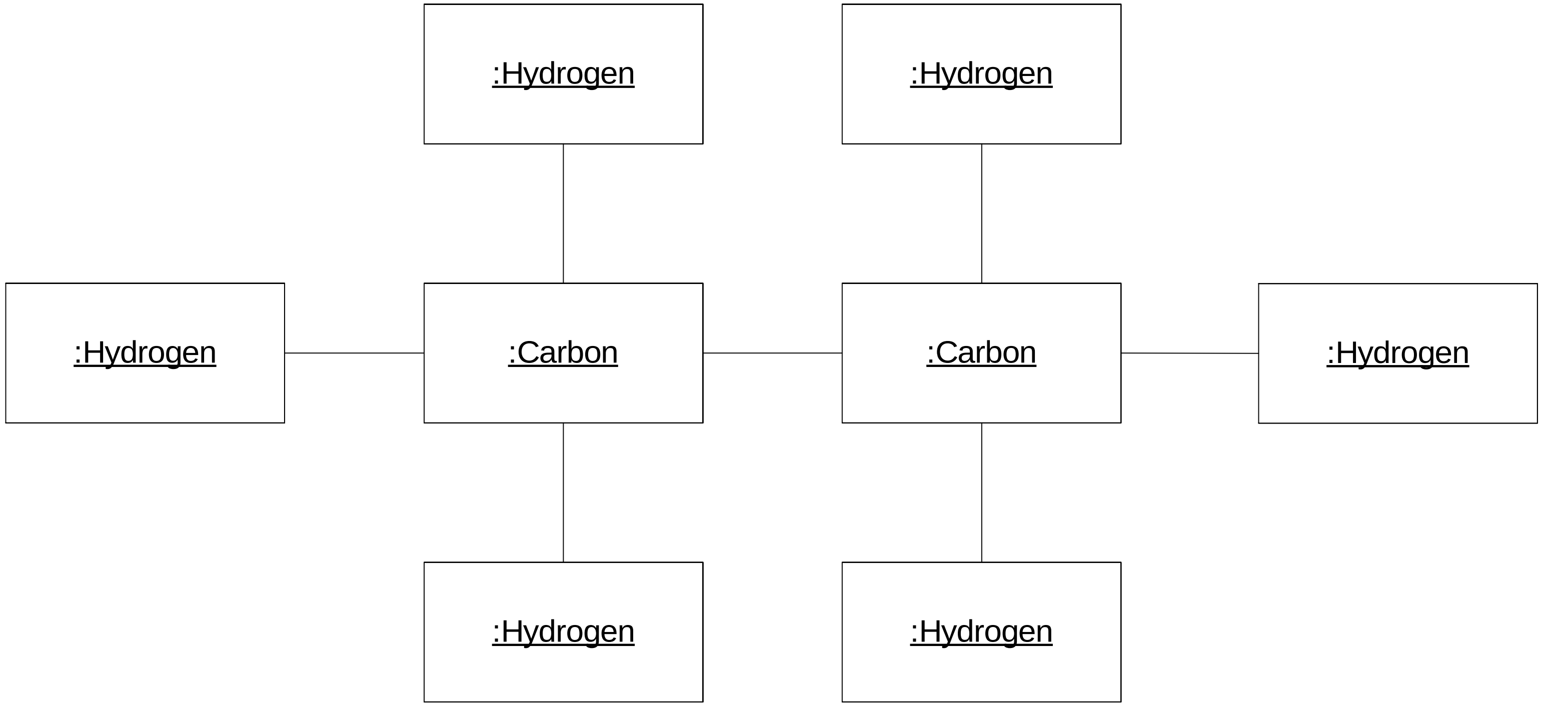
## Building Blocks

- The basic building blocks of UML are:
  - model elements (classes, interfaces, components, use cases, etc.)
  - relationships (associations, generalization, dependencies, etc.)
  - diagrams (class diagrams, use case diagrams, interaction diagrams, etc.)
- Simple building blocks are used to create large, complex structures
  - cf. elements, bonds and molecules in chemistry
  - cf. components, connectors and circuit boards in hardware

# Diagram: Classifier View



## Diagram: Instance View



## Well-Formedness Rules

- Well-formed: indicates that a model or model fragment adheres to all semantic and syntactic rules that apply to it.
- UML specifies rules for:
  - naming
  - scoping
  - visibility
  - integrity
  - execution (limited)
- However, during iterative, incremental development it is expected that models will be incomplete and inconsistent.

## Well-Formedness Rules (cont’d)

- Example of semantic rule: Class [1]
  - ***English:*** If a Class is concrete, all the Operations of the Class should have a realizing Method in the full descriptor.
  - ***OCL:*** **not** self.isAbstract **implies**
    self.allOperations->
    forAll (op | self.allMethods->
    exists (m | m.specification-> includes(op)))

## Well-Formedness Rules (cont'd)

- Example of syntactic rules: Class
  - ***Basic Notation:*** A class is drawn as a solid-outline rectangle with three compartments separated by horizontal lines.
  - ***Presentation Option:*** Either or both of the attribute and operation compartments may be suppressed.
- Example of syntactic guideline: Class
  - ***Style Guideline:*** Begin class names with an uppercase letter.

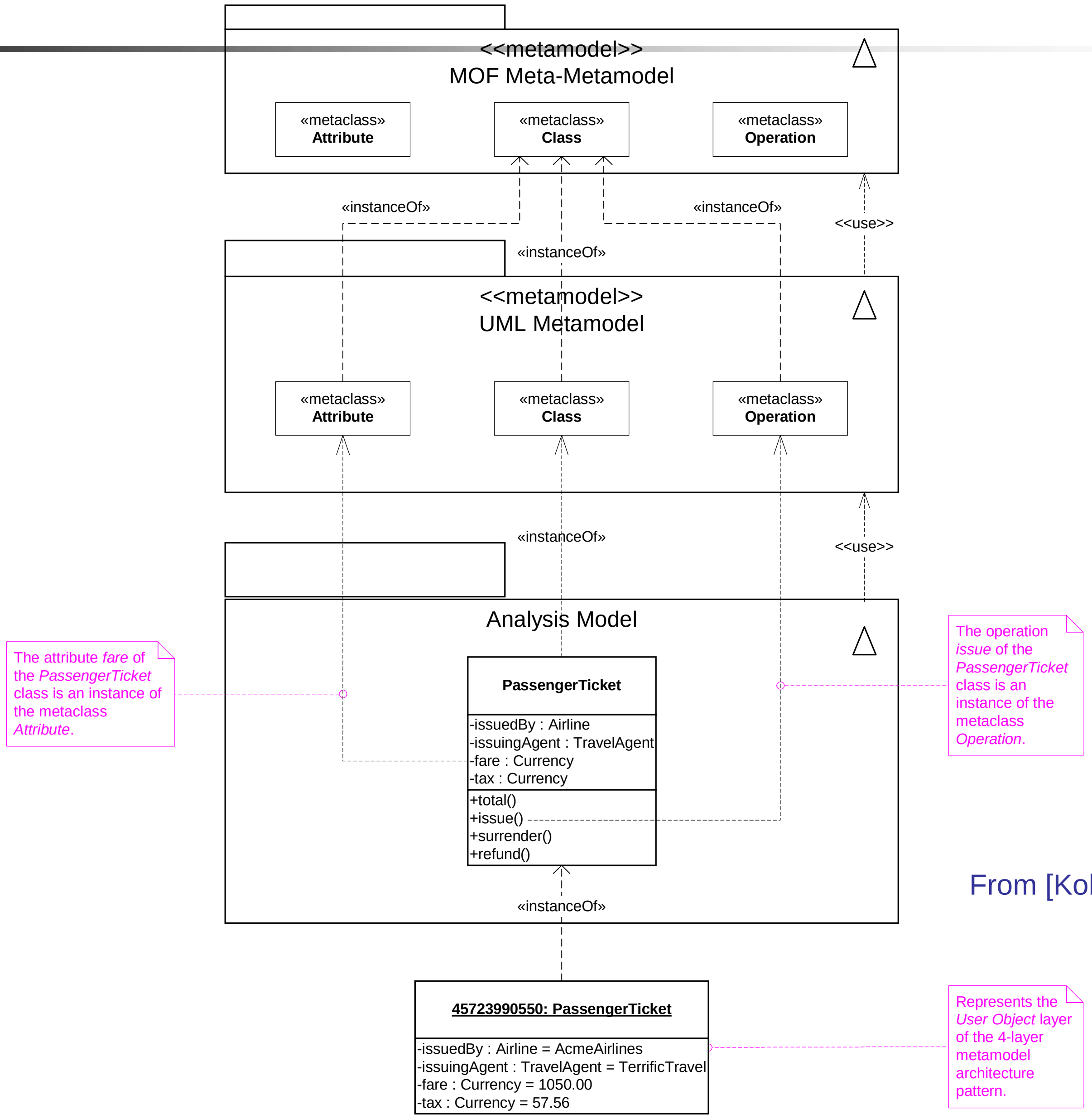
## Unifying Concepts

- classifier-instance dichotomy
  - e.g., an object is an instance of a class OR a class is the classifier of an object
- specification-realization dichotomy
  - e.g., an interface is a specification of a class OR
    a class is a realization of an interface
- analysis-time vs. design-time vs. run-time
  - modeling phases ("process creep")
  - usage guidelines suggested, not enforced

## Language Architecture

- Metamodel architecture
- Package structure

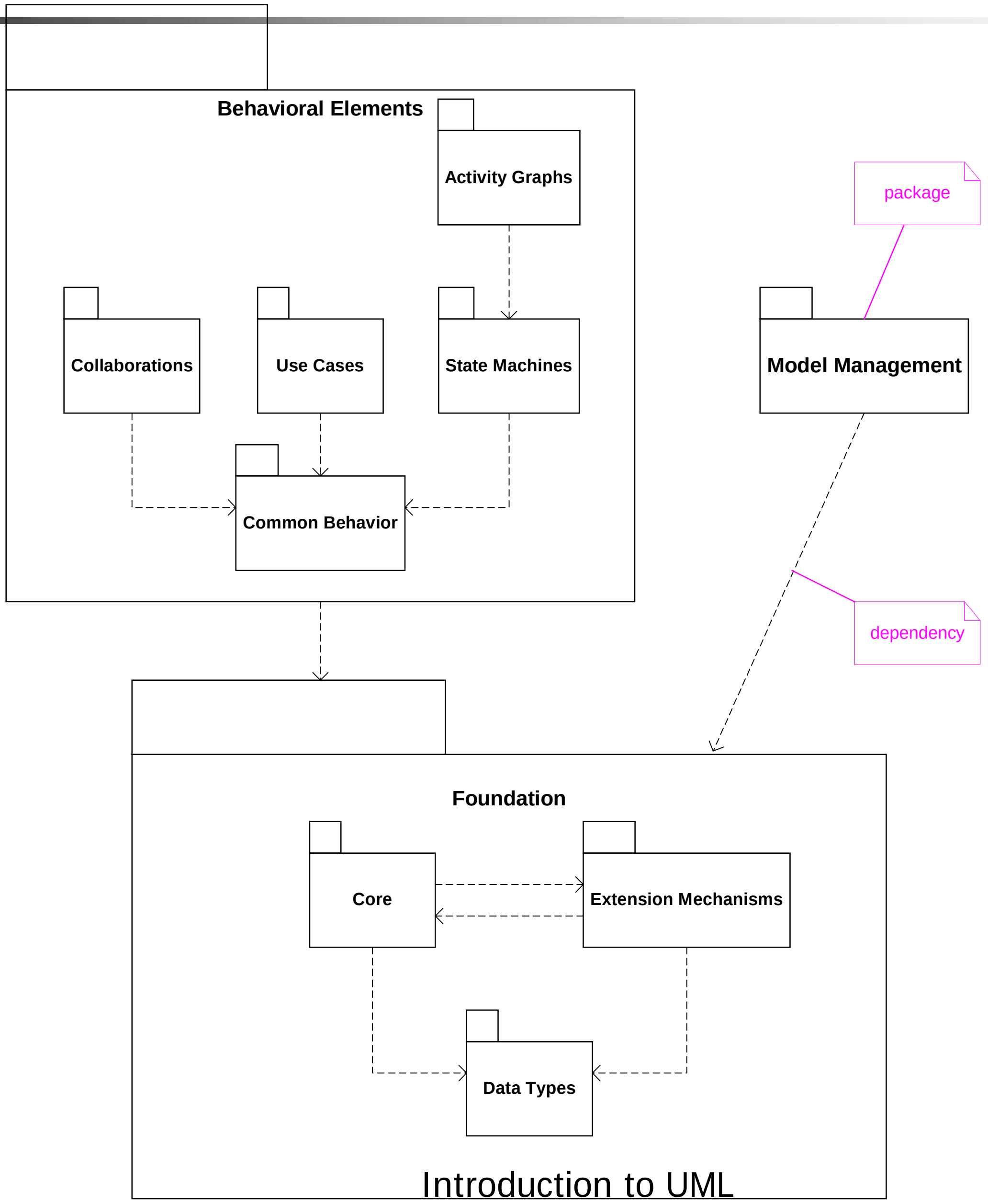
## Metamodel Architecture



<<metamodel>>
MOF Meta-Metamodel
«metaclass» Attribute
«metaclass» Class
«metaclass» Operation
«instanceOf»
«instanceOf»
«instanceOf»
<<use>>
<<metamodel>>
UML Metamodel
«metaclass» Attribute
«metaclass» Class
«metaclass» Operation
«instanceOf»
<<use>>
Analysis Model
PassengerTicket
-issuedBy : Airline
-issuingAgent : TravelAgent
-fare : Currency
-tax : Currency
+total()
+issue()
+surrender()
+refund()
«instanceOf»
45723990550: PassengerTicket
-issuedBy : Airline = AcmeAirlines
-issuingAgent : TravelAgent = TerrificTravel
-fare : Currency = 1050.00
-tax : Currency = 57.56
The attribute *fare* of the *PassengerTicket* class is an instance of the metaclass *Attribute*.
The operation *issue* of the *PassengerTicket* class is an instance of the metaclass *Operation*.
Represents the *User Object* layer of the 4-layer metamodel architecture pattern.

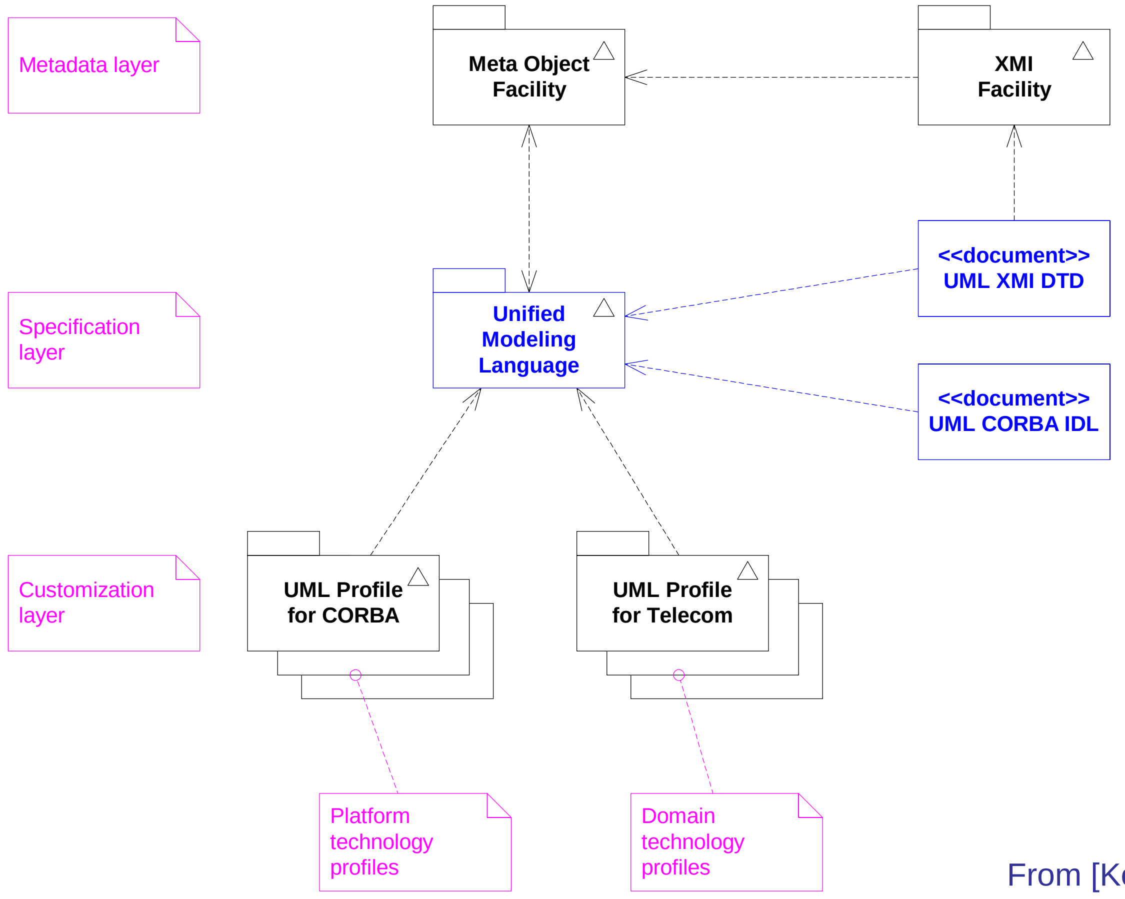
From [Kobryn 01b].

# UML Metamodel Layer



From [Kobryn 01b].

## Relationships to Other Modeling Technologies



From [Kobryn 01b].

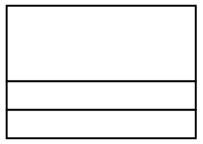
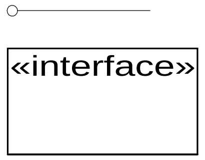
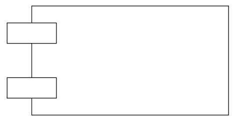
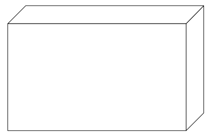
## Structural Modeling

- What is structural modeling?
- Core concepts
- Diagram tour
- When to model structure
- Modeling tips
- Example: Interface-based design

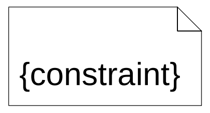
## What is structural modeling?

- Structural model: a view of an system that emphasizes the structure of the objects, including their classifiers, relationships, attributes and operations.

## *Structural Modeling:* Core Elements

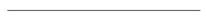
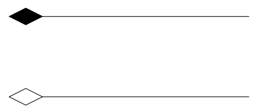
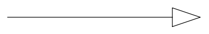
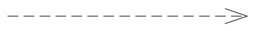
| **Construct** | **Description** | **Syntax** |
|---|---|---|
| **class** | a description of a set of objects that share the same attributes, operations, methods, relationships and semantics. |  |
| **interface** | a named set of operations that characterize the behavior of an element. |  |
| **component** | a modular, replaceable and significant part of a system that packages implementation and exposes a set of interfaces. |  |
| **node** | a run-time physical object that represents a computational resource. |  |

## *Structural Modeling:* Core Elements (cont'd)

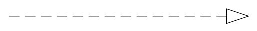
| Construct | Description | Syntax |
|---|---|---|
| **constraint**[1] | a semantic condition or restriction. |  |

[1] An extension mechanism useful for specifying structural elements.

## *Structural Modeling:* Core Relationships

| Construct | Description | Syntax |
|---|---|---|
| **association** | a relationship between two or more classifiers that involves connections among their instances. |  |
| **aggregation** | A special form of association that specifies a whole-part relationship between the aggregate (whole) and the component part. |  |
| **generalization** | a taxonomic relationship between a more general and a more specific element. |  |
| **dependency** | a relationship between two modeling elements, in which a change to one modeling element (the independent element) will affect the other modeling element (the dependent element). |  |

## *Structural Modeling:* Core Relationships (cont'd)

| **Construct** | **Description** | **Syntax** |
|---|---|---|
| **realization** | a relationship between a specification and its implementation. |  |

## Structural Diagram Tour

- Show the static structure of the model
  - the entities that exist (e.g., classes, interfaces, components, nodes)
  - internal structure
  - relationship to other entities
- Do not show
  - temporal information
- Kinds
  - static structural diagrams
    - class diagram
    - object diagram
  - implementation diagrams
    - component diagram
    - deployment diagram

## Static Structural Diagrams

- Shows a graph of classifier elements connected by static relationships.
- kinds
  - class diagram: classifier view
  - object diagram: instance view

# Classes

***Window***

***Window***

size: Area
visibility: Boolean

*display ()*
*hide ()*

***Window***
{abstract,
author=Joe,
status=tested}

+size: Area = (100,100)
#visibility: Boolean = true
+default-size: Rectangle
#maximum-size: Rectangle
-xptr: XWindow*

+*display ()*
+*hide ()*
+*create ()*
-attachXWindow(xwin:Xwindow*)

Fig. 3-20, *UML Notation Guide*

## Classes: compartments with names

**Reservation**

**operations**

guarantee()
cancel ()
change (newDate: Date)

**responsibilities**

bill no-shows
match to available rooms

**exceptions**

invalid credit card

Fig. 3-23, *UML Notation Guide*

# Classes: method body

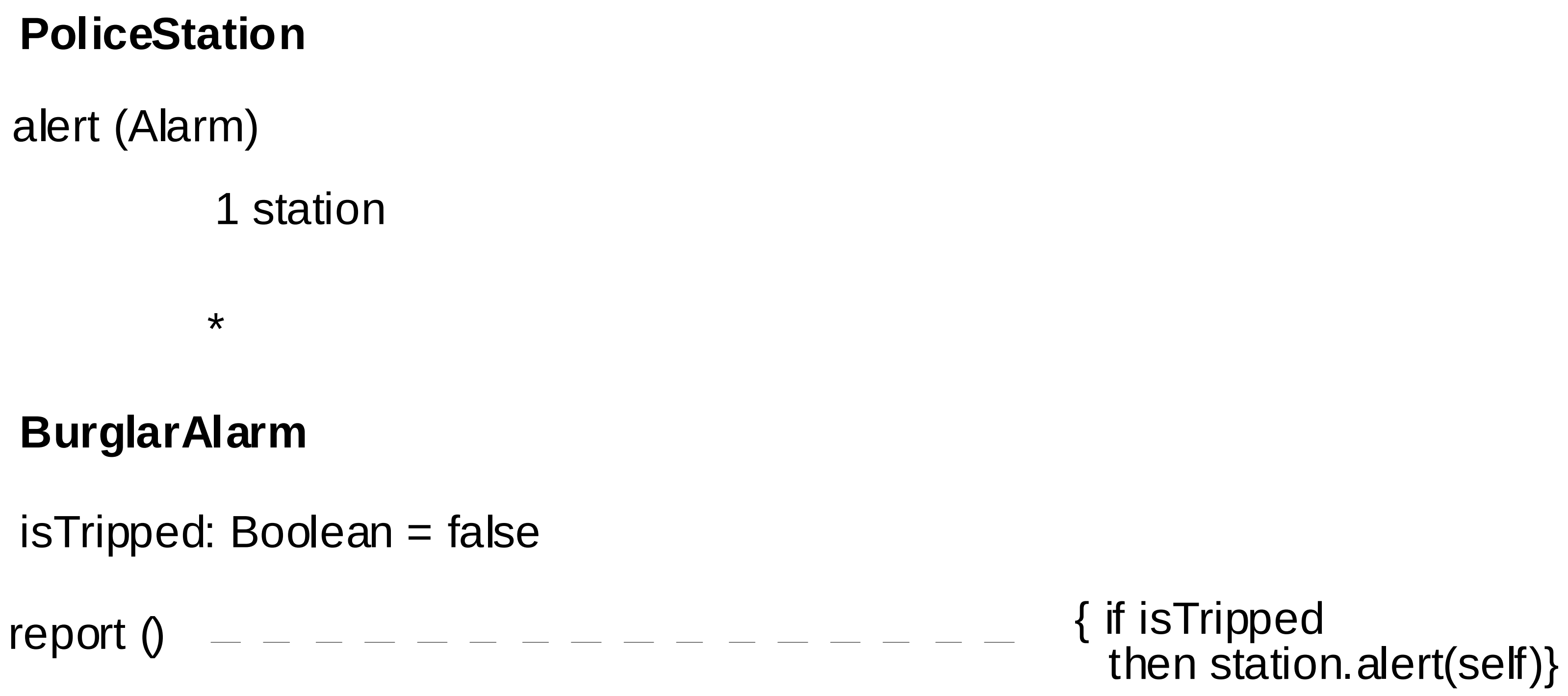


Fig. 3-24, *UML Notation Guide*

# Types and Implementation Classes

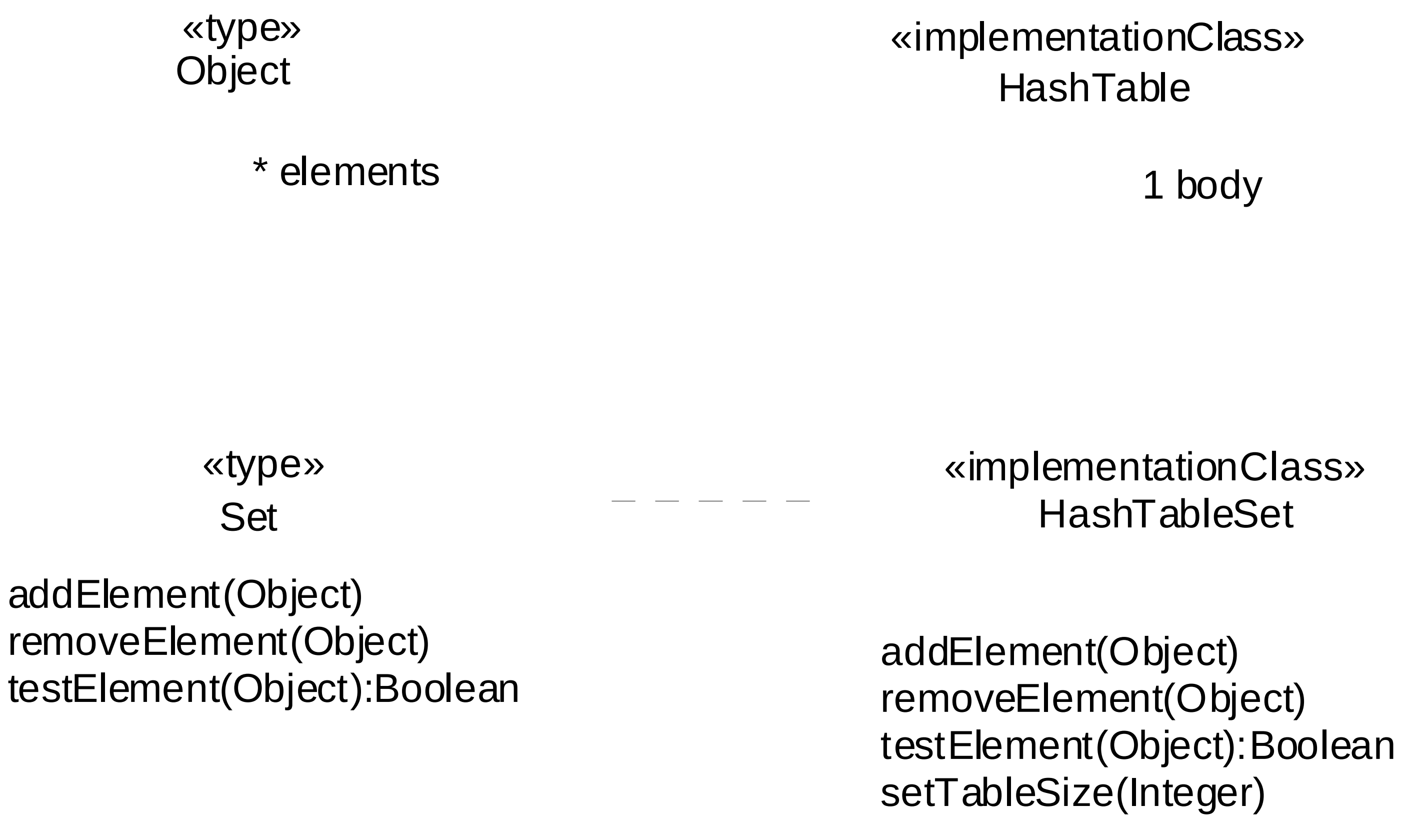


Fig. 3-27, *UML Notation Guide*

# Interfaces: Shorthand Notation

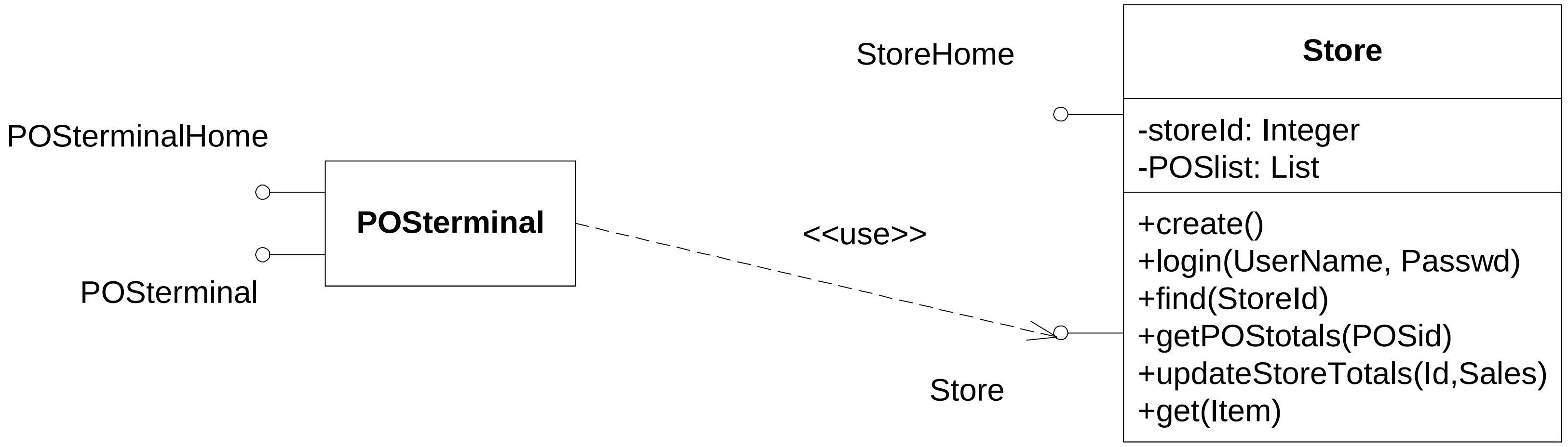


Fig. 3-29, *UML Notation Guide*

# Interfaces: Longhand Notation

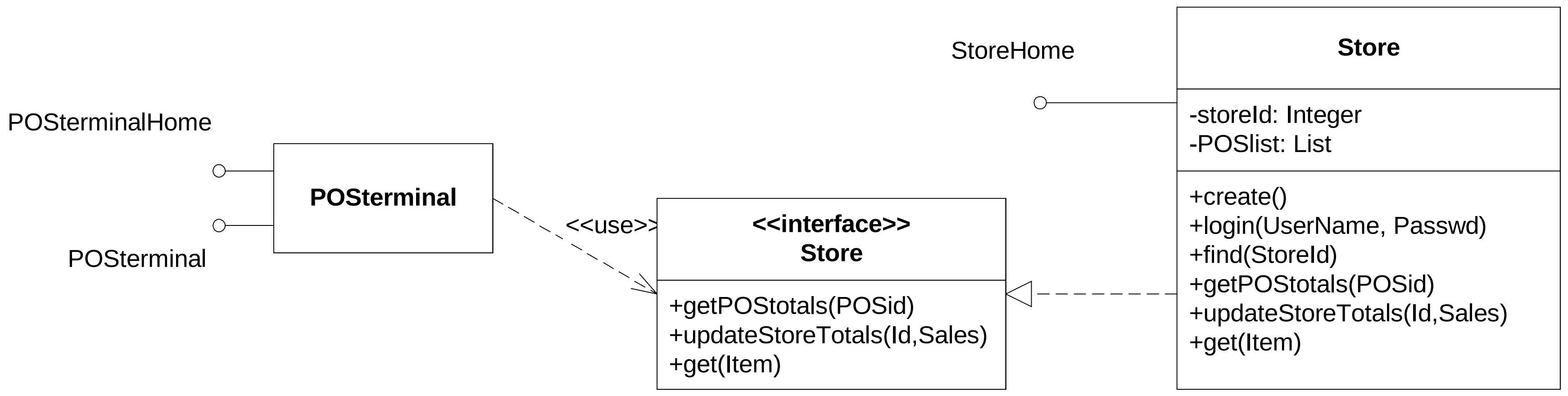


Fig. 3-29, *UML Notation Guide*

# Associations

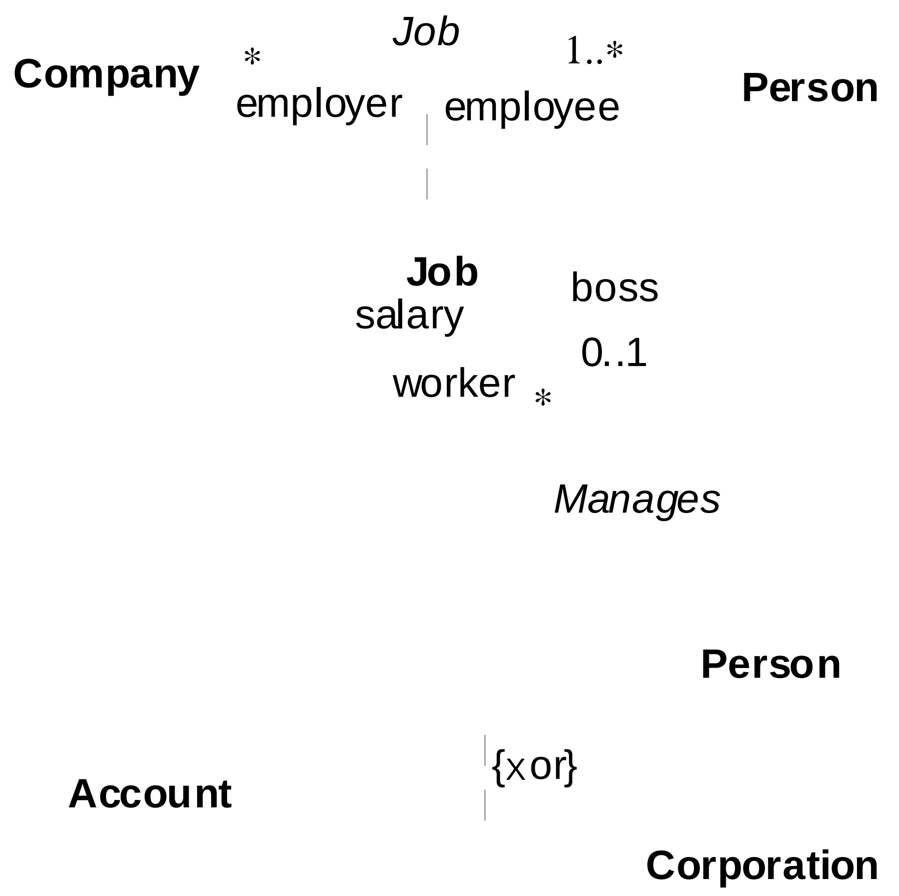


Fig. 3-40, *UML Notation Guide*

# Association Ends

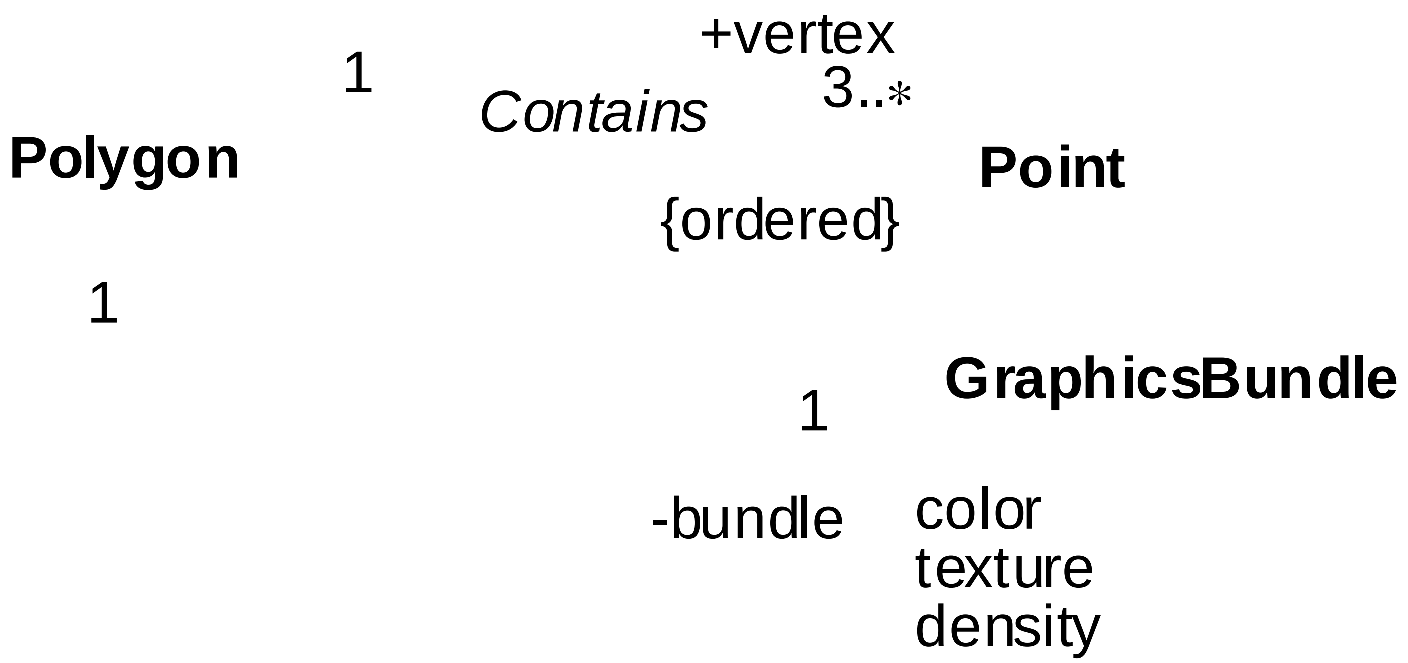


Fig. 3-41, *UML Notation Guide*

# Ternary Associations

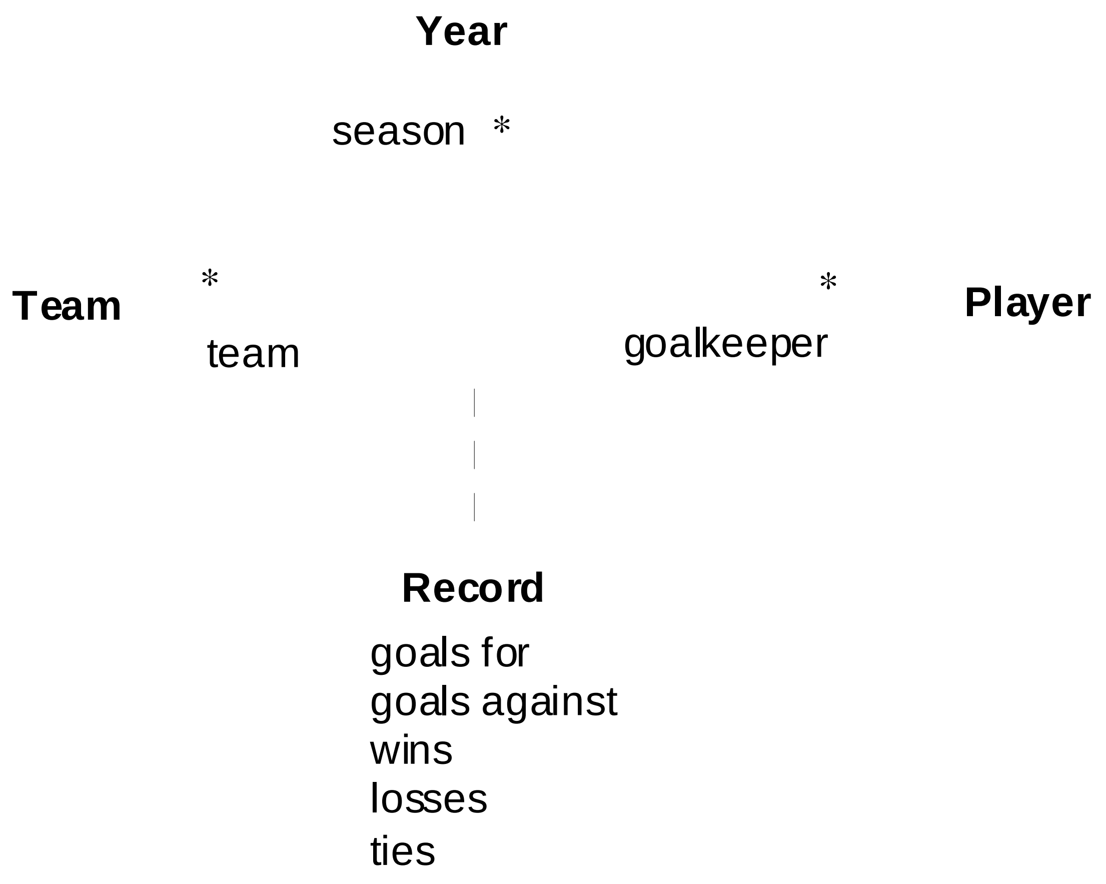


Fig. 3-44, *UML Notation Guide*

# Composition

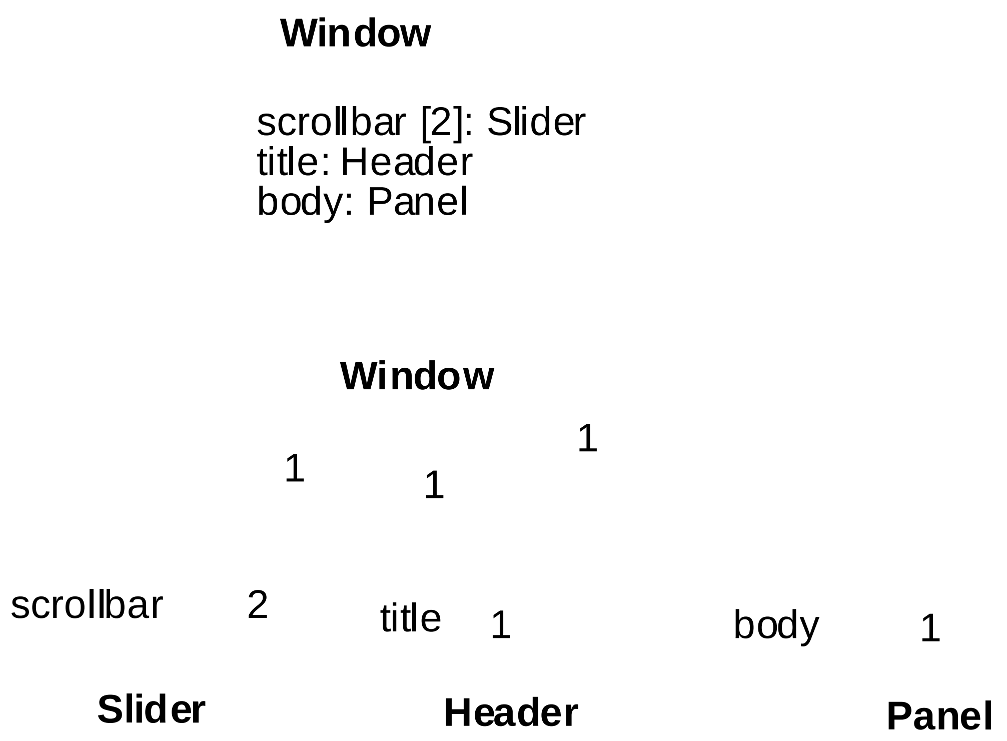


Fig. 3-45, *UML Notation Guide*

# Composition (cont'd)

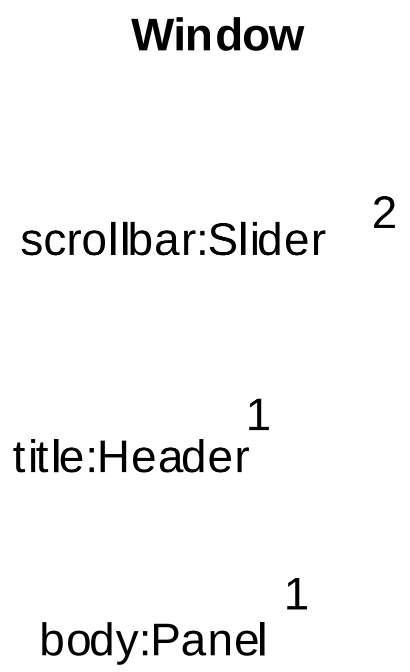


Fig. 3-45, *UML Notation Guide*

## Generalization

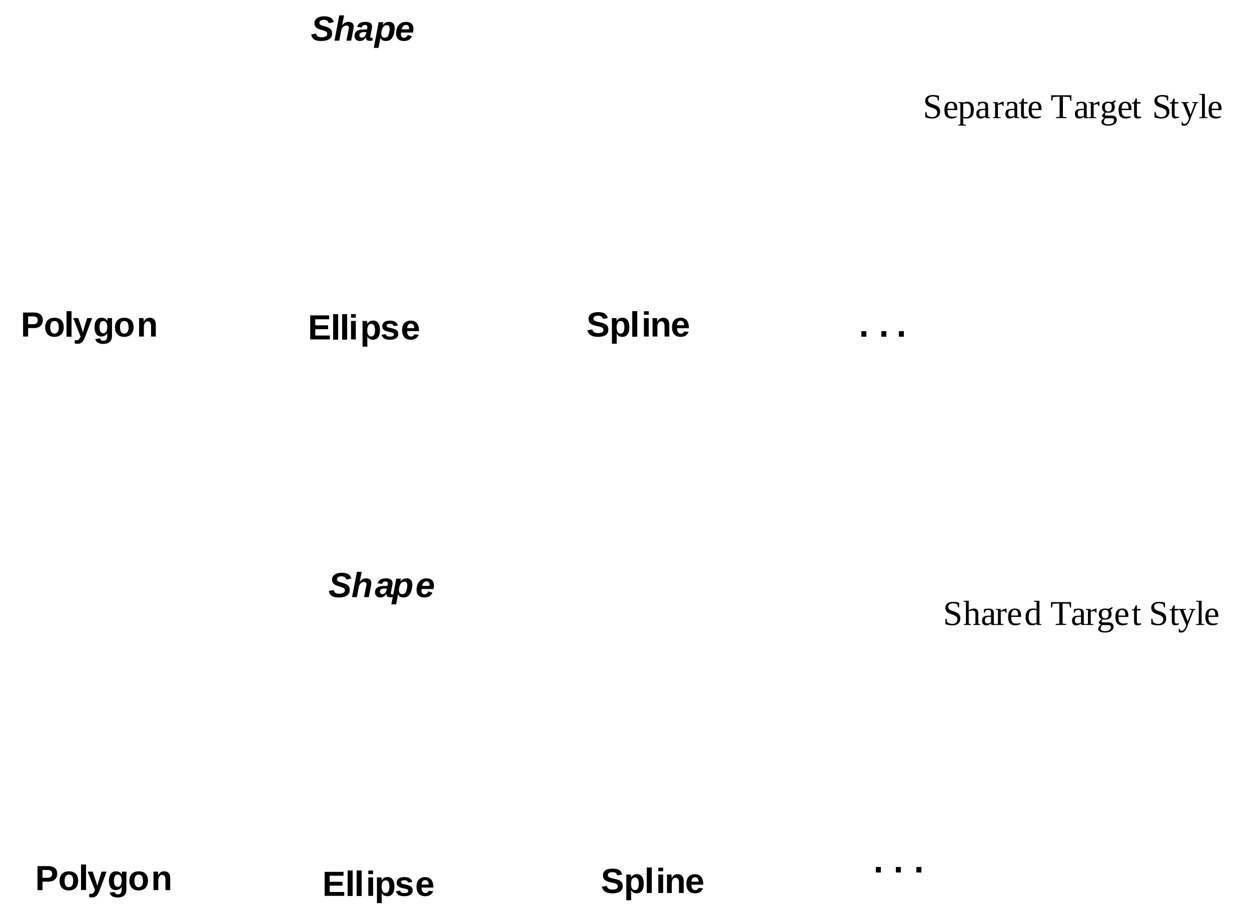


Fig. 3-47, *UML Notation Guide*

# Generalization

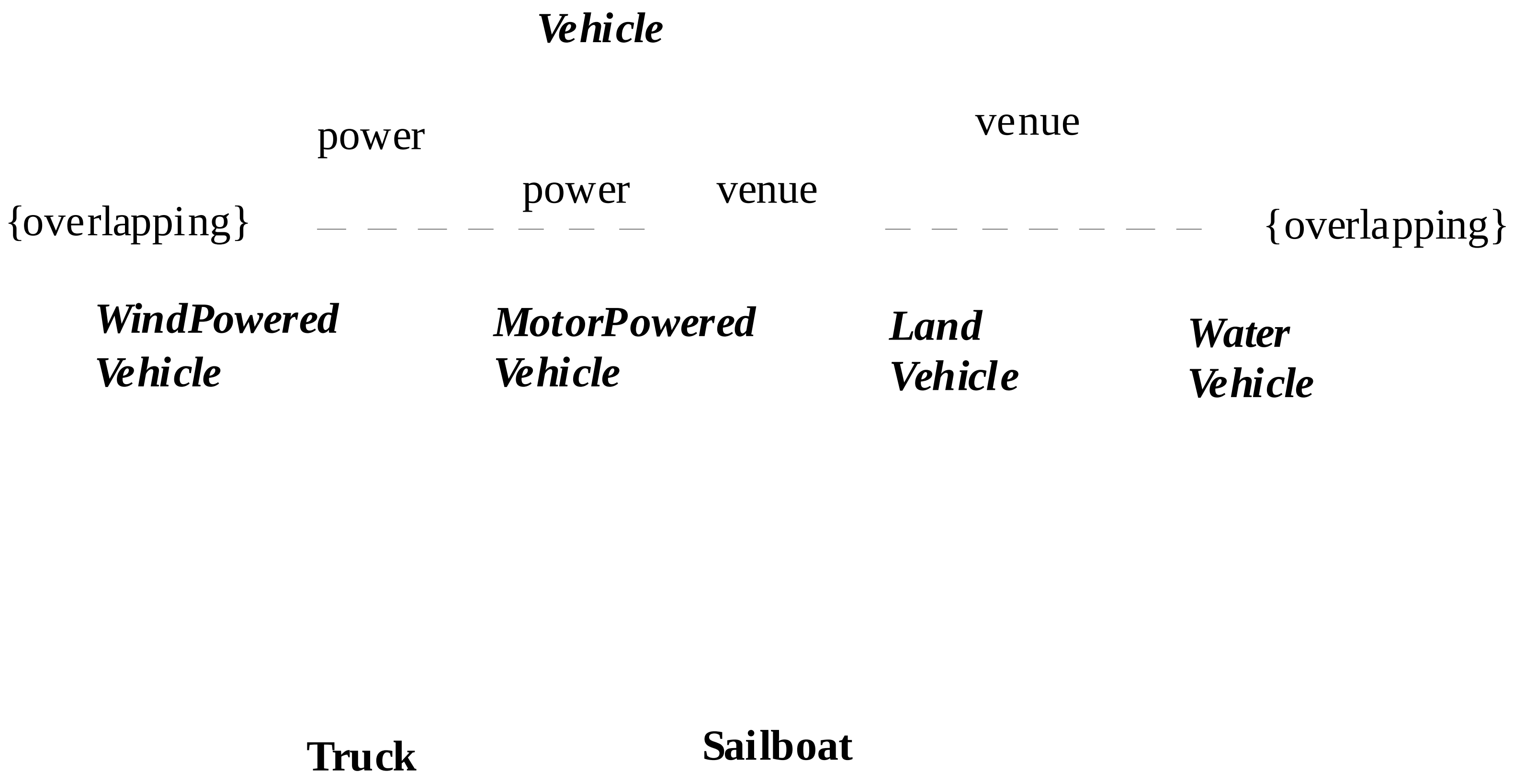


Fig. 3-48, *UML Notation Guide*

# Dependencies

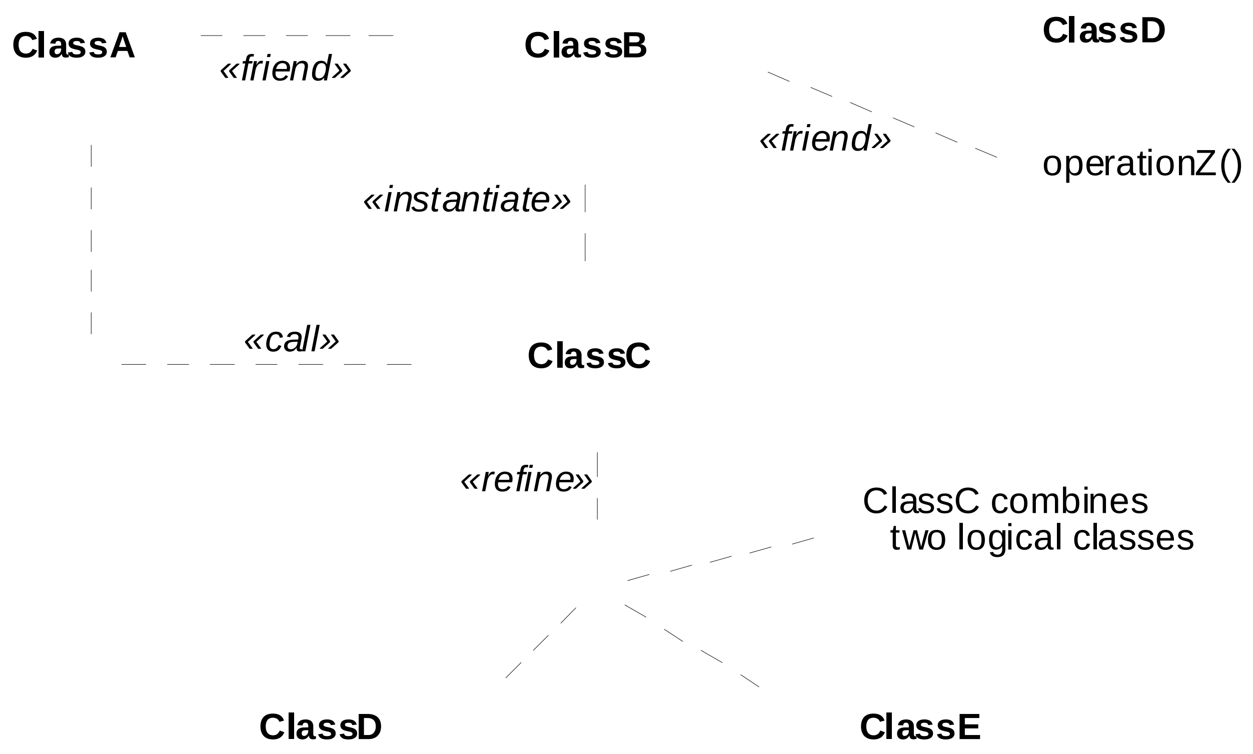


Fig. 3-50, *UML Notation Guide*

# Dependencies

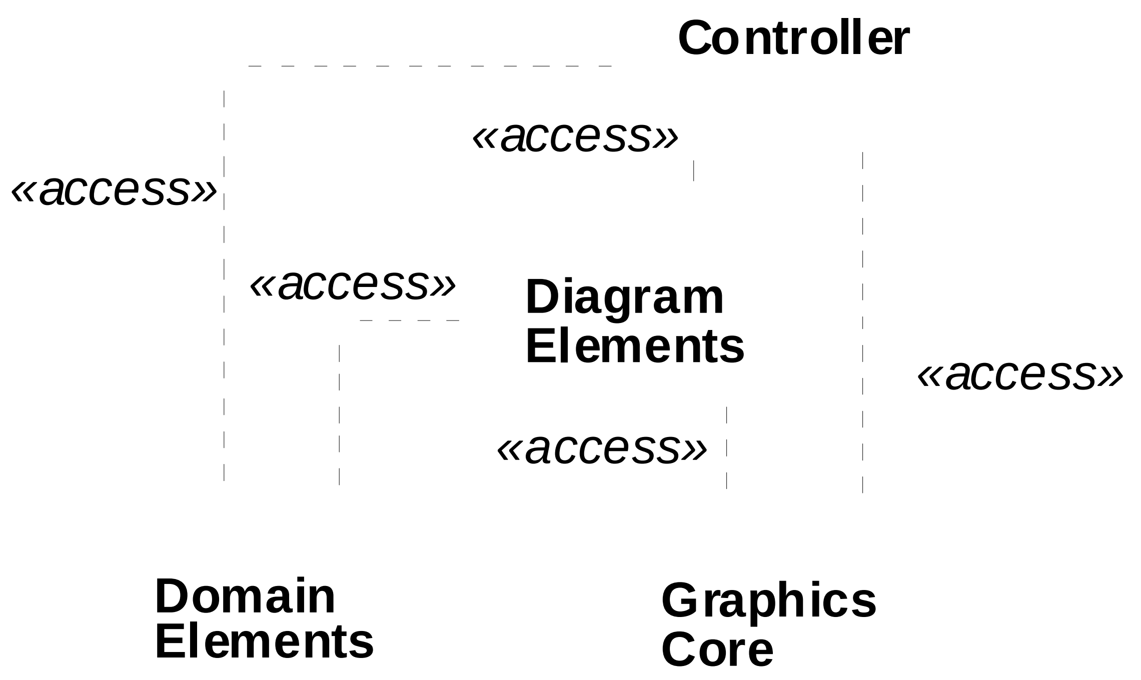


Fig. 3-51, *UML Notation Guide*

## Derived Attributes and Associations

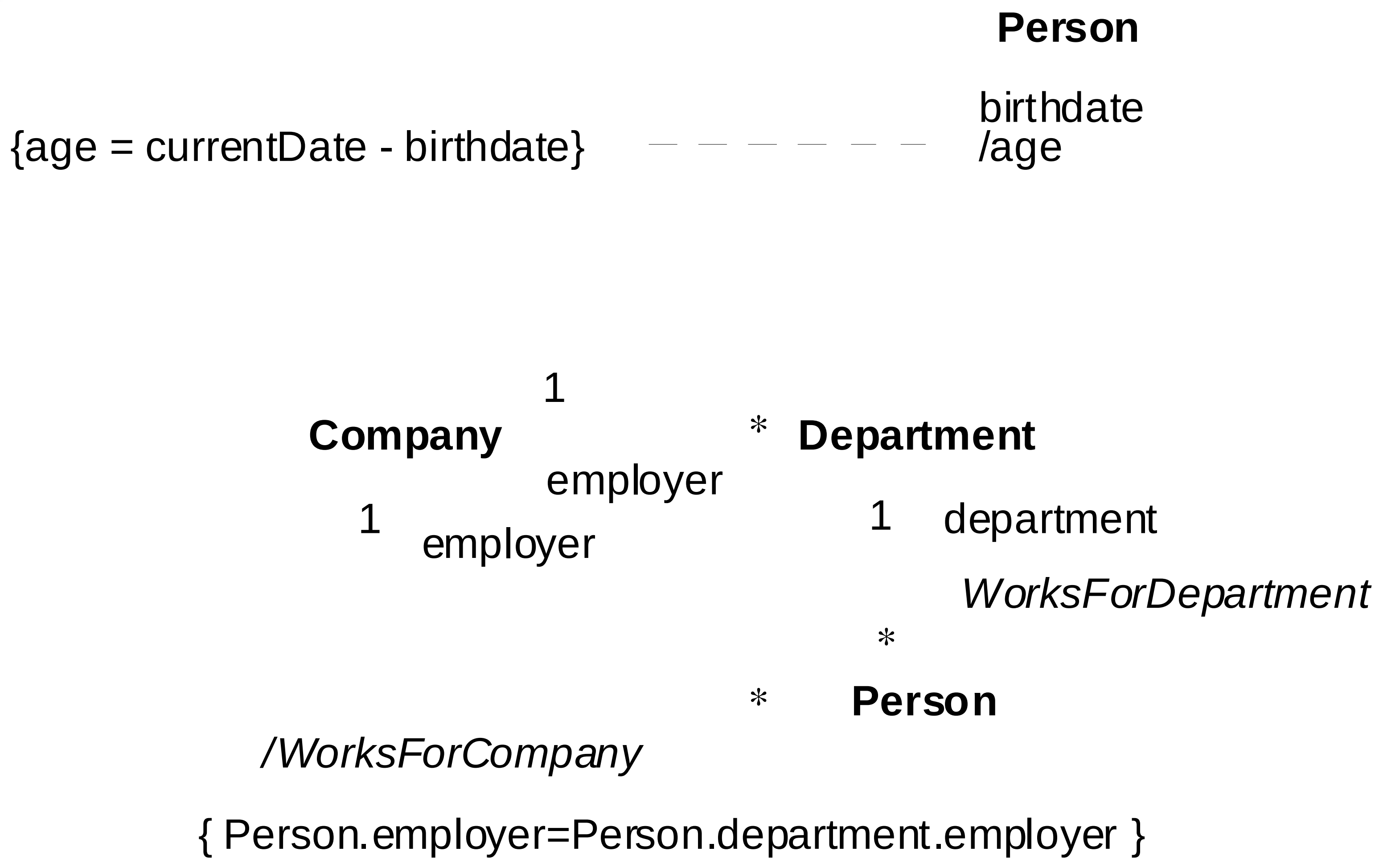


Fig. 3-52, *UML Notation Guide*

# Objects

triangle : Polygon

center = (0,0)
vertices = ((0,0),(4,0),(4,3))
borderColor = black
fillColor = white

triangle

:Polygon

triangle: Polygon

scheduler

Fig. 3-38, *UML Notation Guide*

## Composite objects

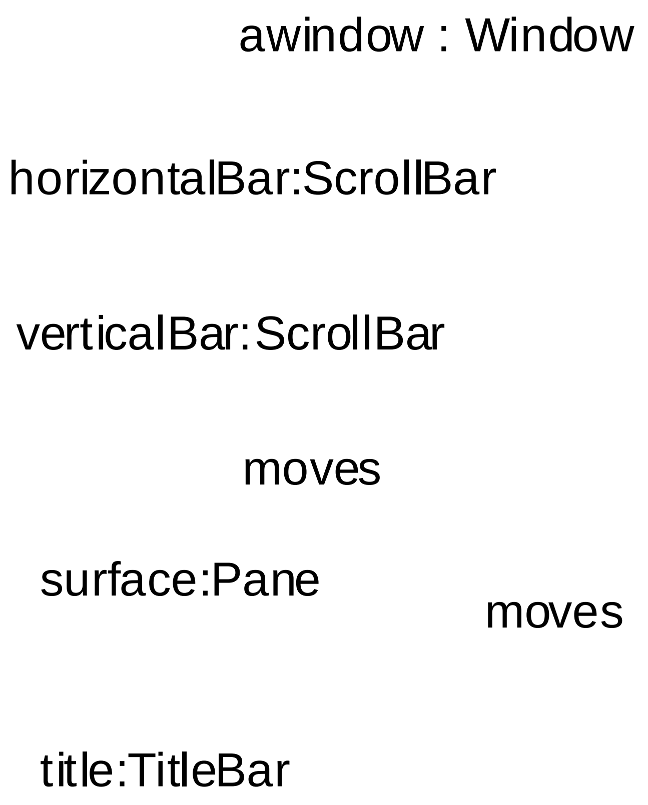


Fig. 3-39, *UML Notation Guide*

# Links

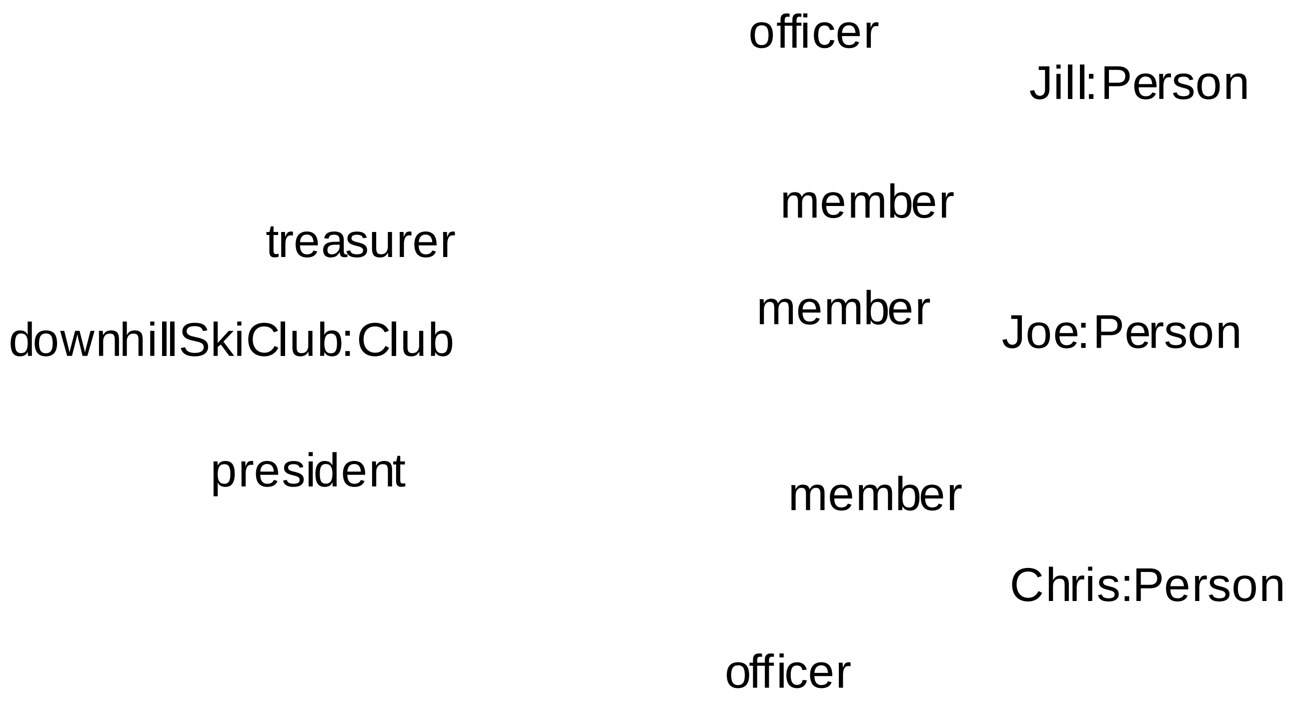


Fig. 3-46, *UML Notation Guide*

# Constraints and Comments

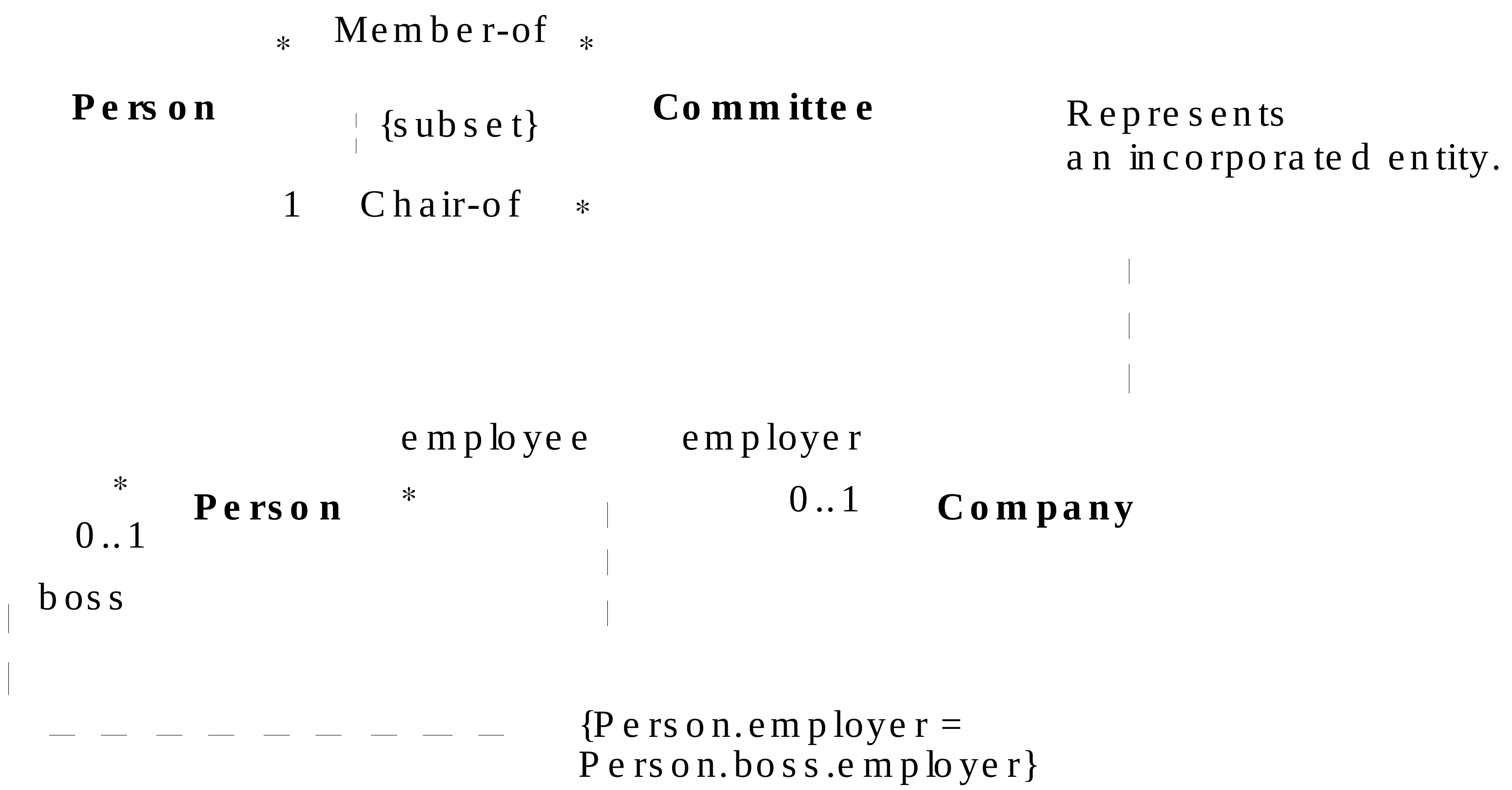
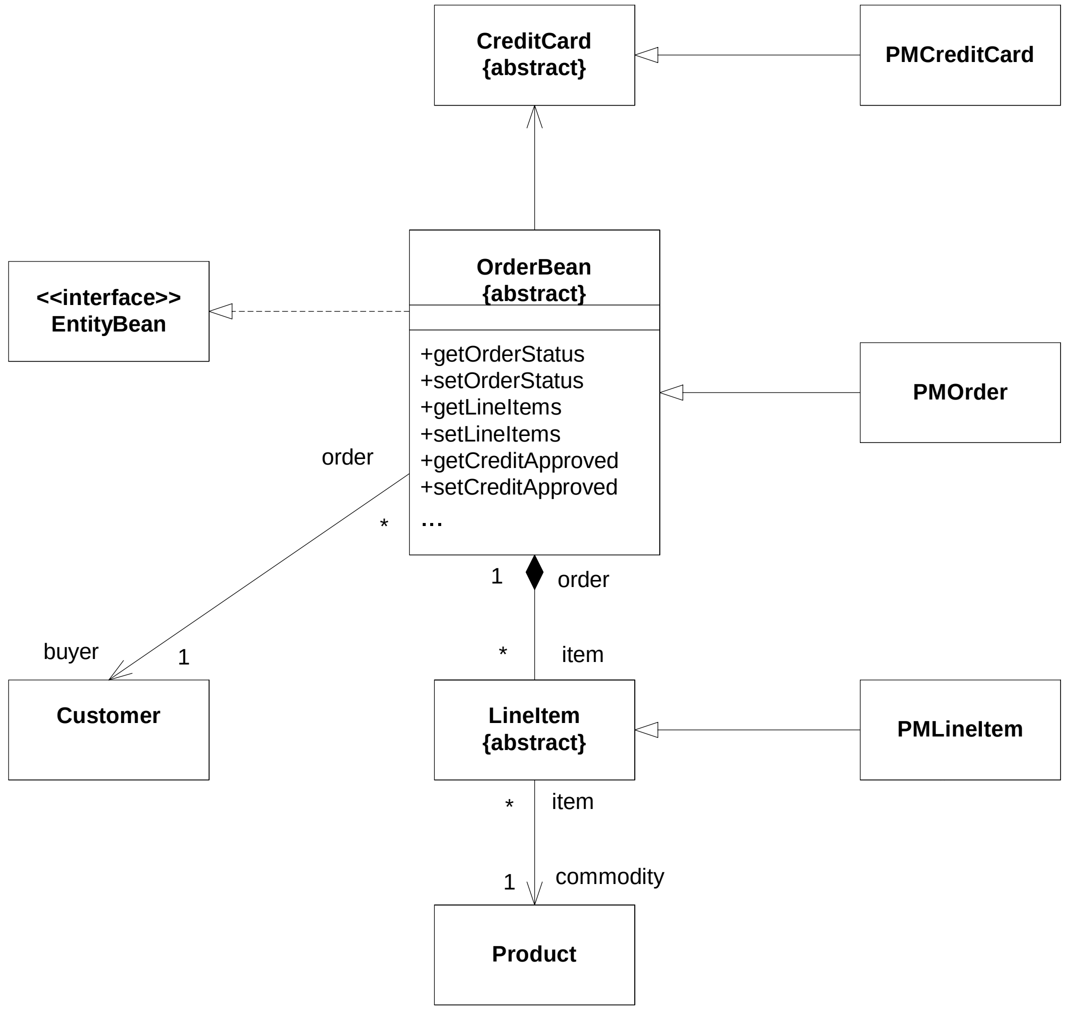


Fig. 3-17, *UML Notation Guide*

# Class Diagram Example



Adapted from Fig. 23 [EJB 2.0].

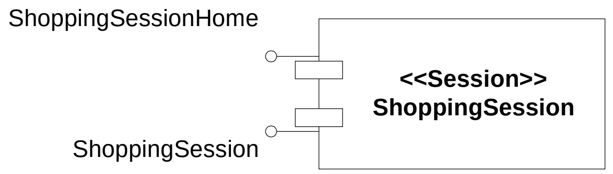
## Implementation Diagrams

- Show aspects of model implementation, including source code structure and run-time implementation structure
- Kinds
  - component diagram
  - deployment diagram

## Component Diagram

- Shows the organizations and dependencies among software components
- Components may be
  - specified by classifiers (e.g., implementation classes)
  - implemented by artifacts (e.g., binary, executable, or script files)

# Components



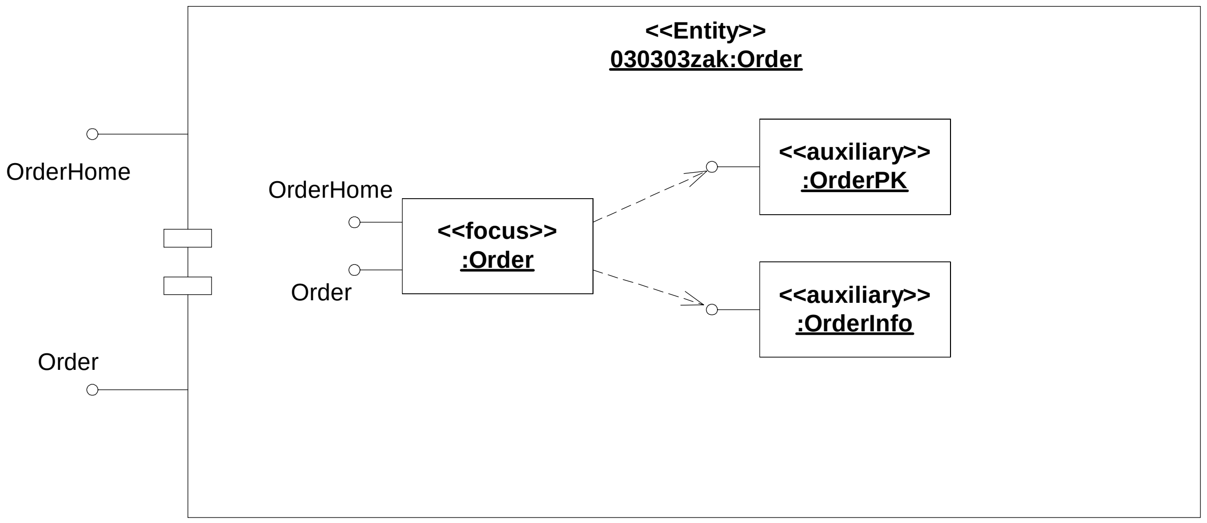


Fig. 3-99, *UML Notation Guide* (corrected)

# Component Diagram

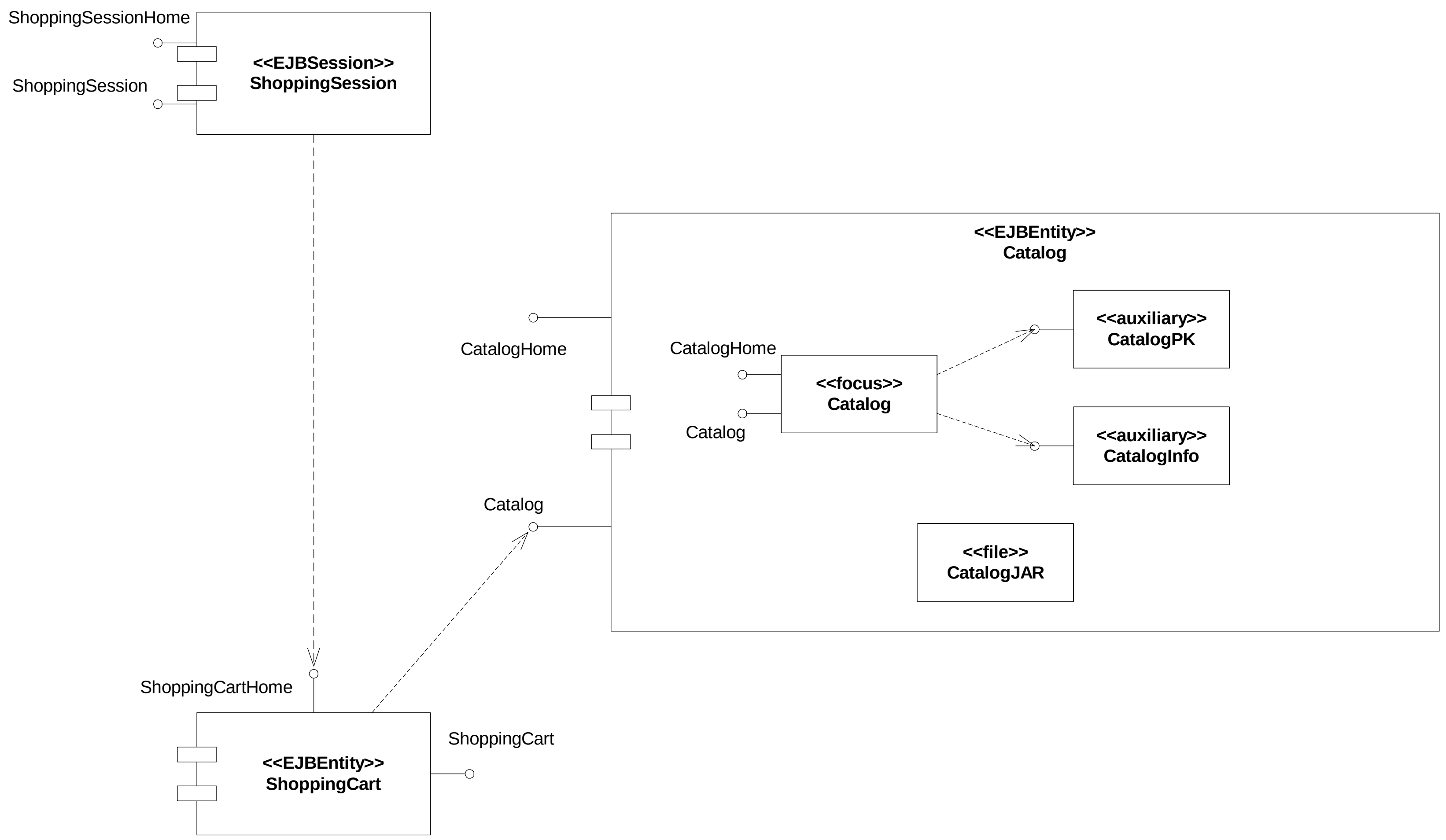


Fig. 3-95, *UML Notation Guide*

# Component Diagram with Relationships

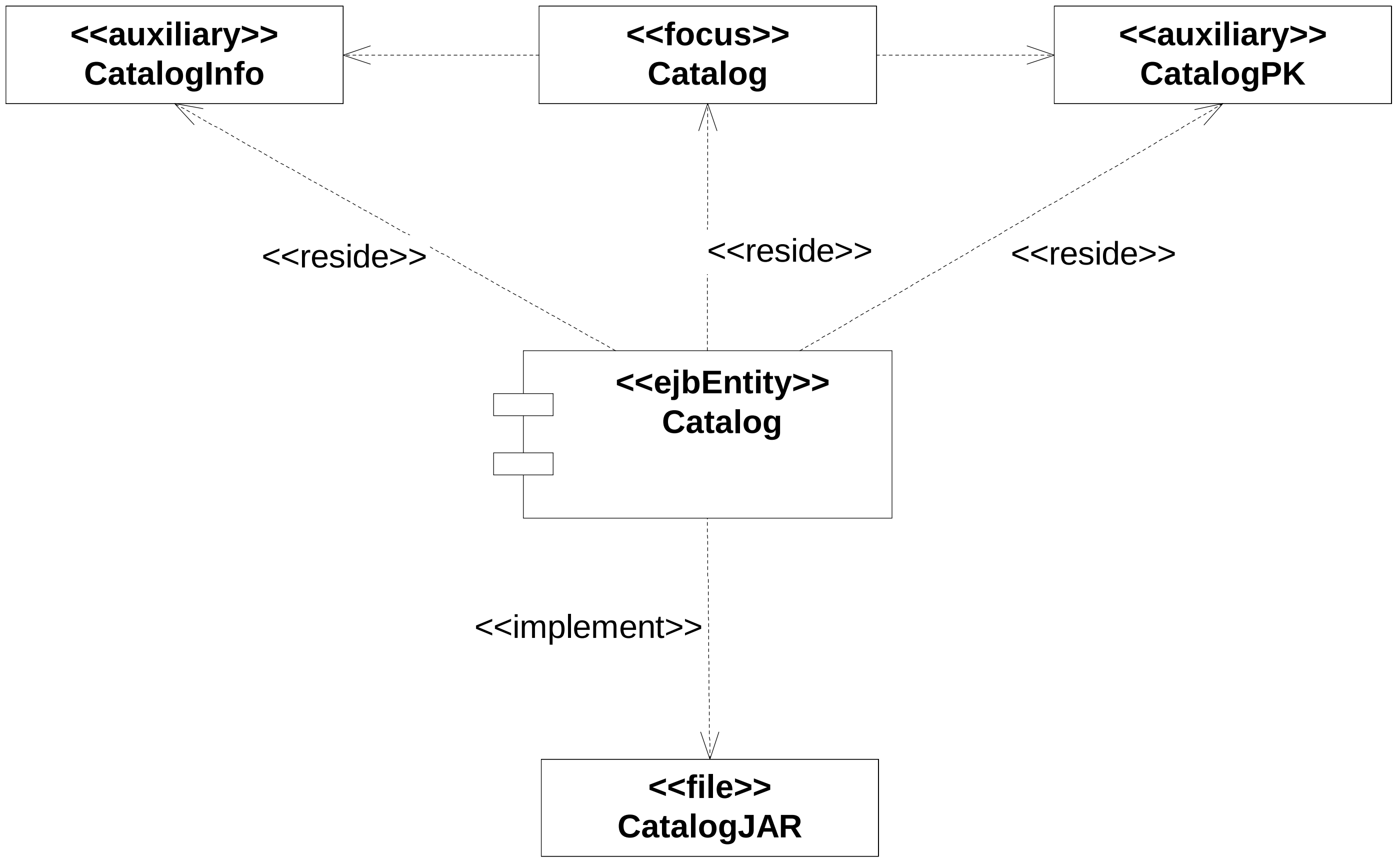


Fig. 3-96, *UML Notation Guide*

## Deployment Diagram

- Shows the configuration of run-time processing elements and the software components, processes and objects that live on them
- Deployment diagrams may be used to show which components may run on which nodes

# Deployment Diagram (1/2)

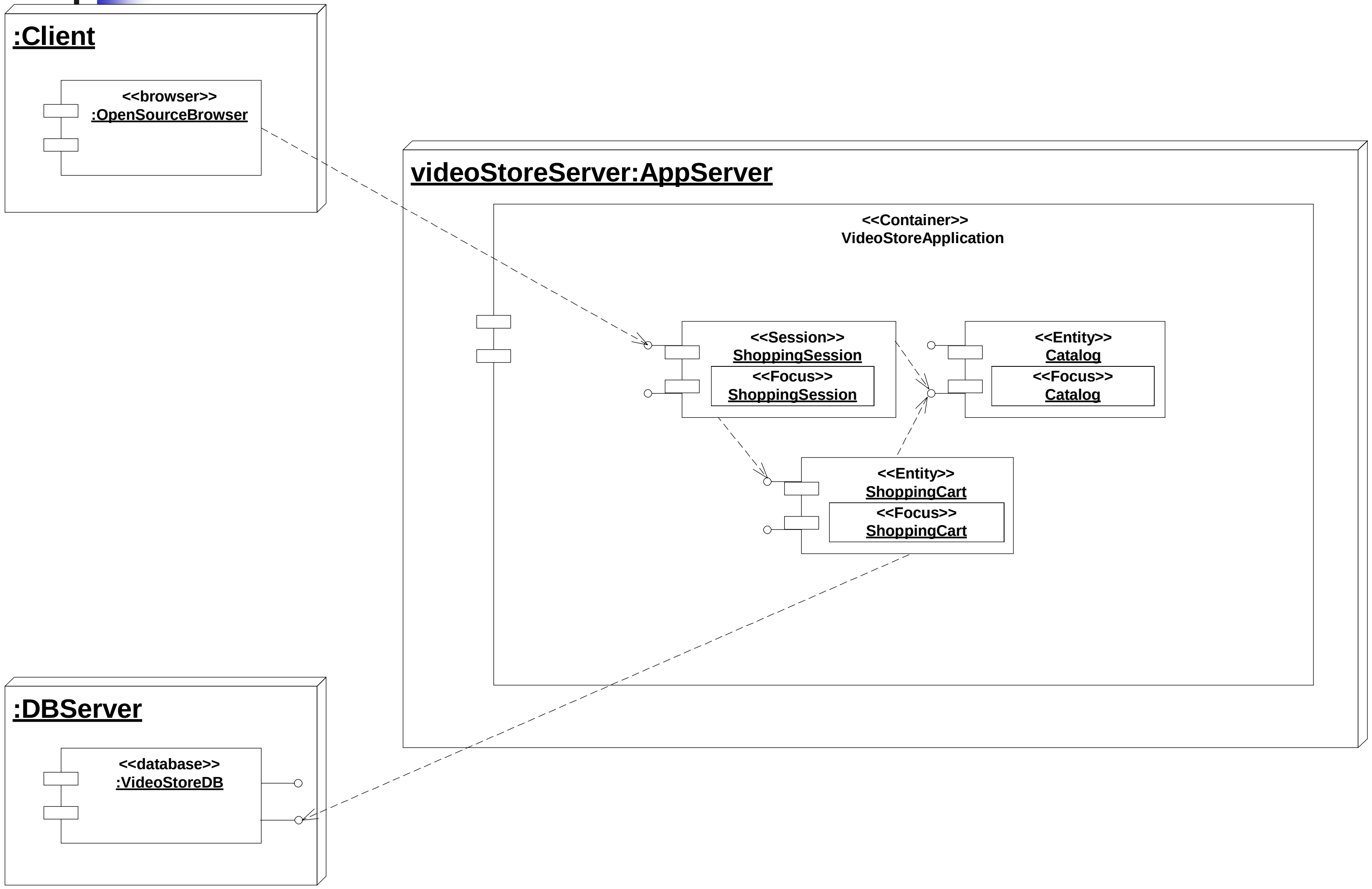


Fig. 3-97, *UML Notation Guide*

# Deployment Diagram (2/2)

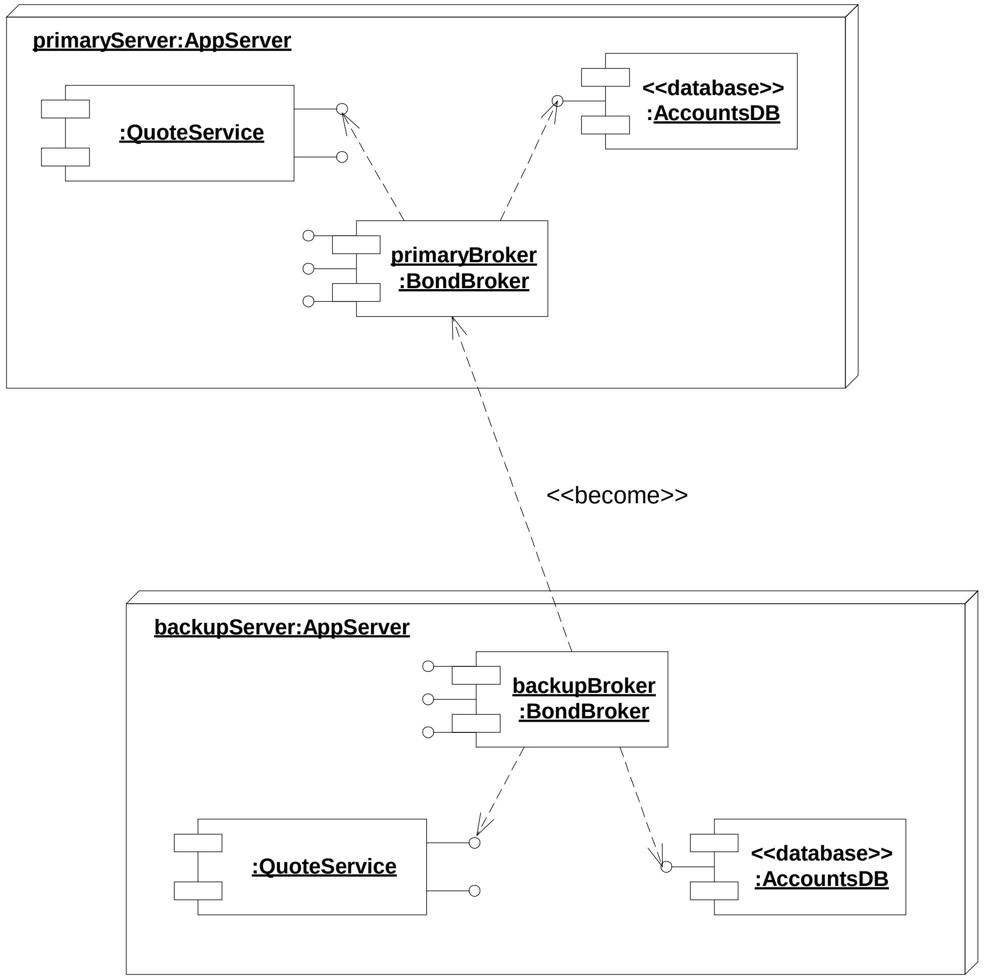


Fig. 3-98, *UML Notation Guide*

## When to model structure

- Adopt an opportunistic top-down+bottom-up approach to modeling structure
  - Specify the top-level structure using “architecturally significant” classifiers and model management constructs (packages, models, subsystems; see Tutorial 3)
  - Specify lower-level structure as you discover detail re classifiers and relationships
- If you understand your domain well you can frequently start with structural modeling; otherwise
  - If you start with use case modeling (as with a use-case driven method) make sure that your structural model is consistent with your use cases
  - If you start with role modeling (as with a collaboration-driven method) make sure that your structural model is consistent with your collaborations

## Structural Modeling Tips

- Define a “skeleton” (or “backbone”) that can be extended and refined as you learn more about your domain.
- Focus on using basic constructs well; add advanced constructs and/or notation only as required.
- Defer implementation concerns until late in the modeling process.
- Structural diagrams should
  - emphasize a particular aspect of the structural model
  - contain classifiers at the same level of abstraction
- Large numbers of classifiers should be organized into packages (see Lecture 3)

## Example: Point-of-Sale

- The following example shows how UML can model the interfaces for a Point of Sale application originally specified in CORBA IDL. From [Kobryn 01b].

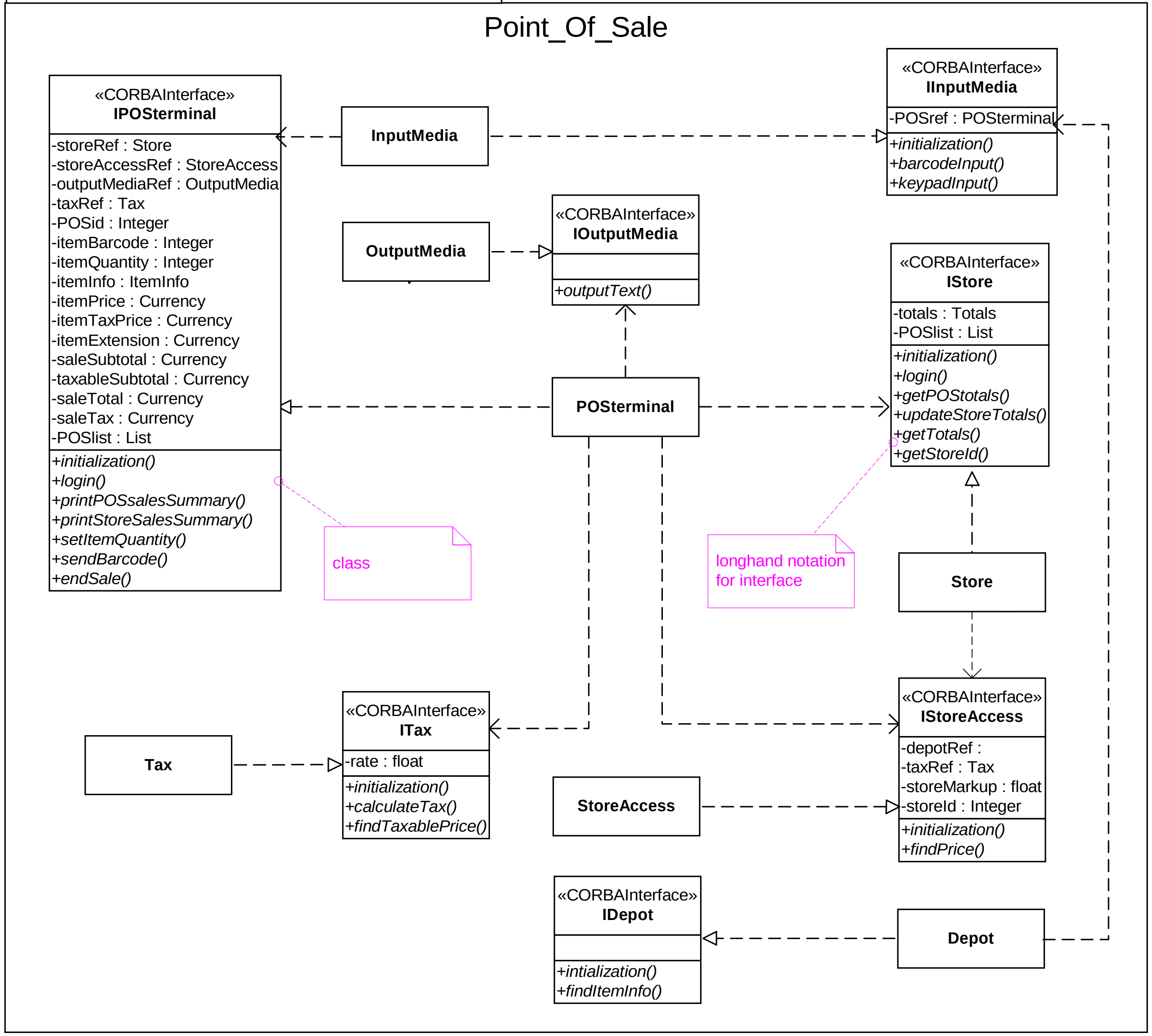
# Point-of-Sale Example

```
module POS
{
   typedef long   POSId;
   typedef string Barcode;

   interface InputMedia
   {
      typedef string OperatorCmd;
      void         BarcodeInput(in Barcode Item);
      void         KeypadInput(in OperatorCmd Cmd);
   };
   interface OutputMedia
   {...};
   interface POSTerminal
   {...};
    };
```

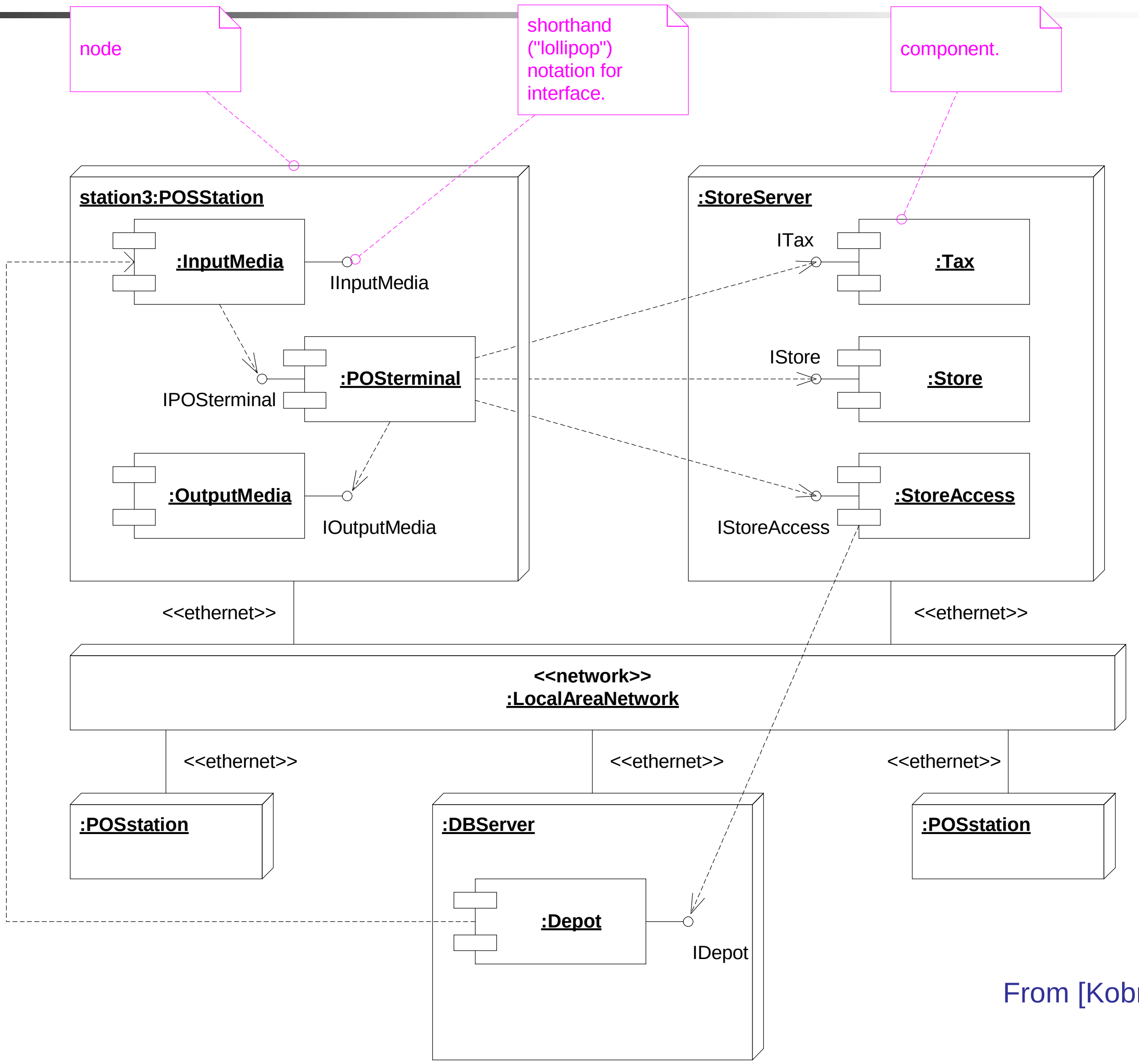
Ch. 26, *CORBA Fundamentals and Programming* (2nd ed.), [Siegel 00]

# POS Class Diagram



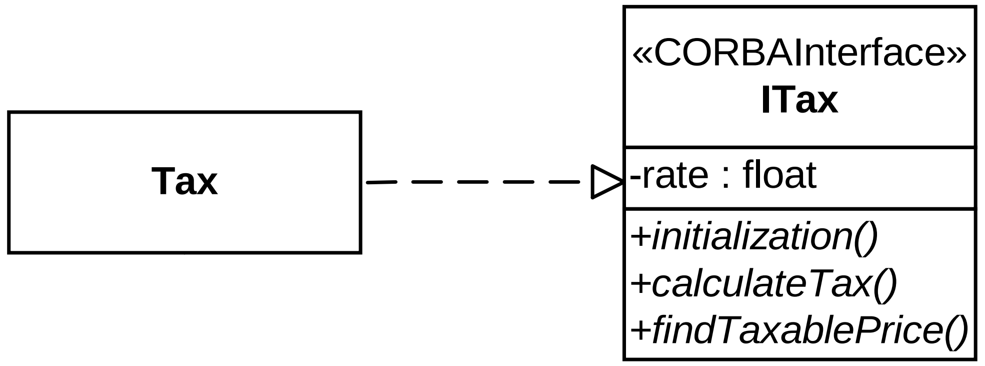
From [Kobryn 2001b]

## POS Deployment Diagram



From [Kobryn 2001b]

# Model Fragment from POS Example



From [Kobryn 2001b]

# XML Generated by XMI Facility

```
<XMI xmi.version = '1.1' xmlns:UML='//org.omg/UML/1.3' ...>
 <XMI.header>
  <XMI.metamodel xmi.name = 'UML' xmi.version = '1.3'/>
 </XMI.header>
<XMI.content>
<!--  POS_Example_R2    [Model]  -->
<UML:Model xmi.id = 'G.0'
  name = 'POS_Example_R2' visibility = 'public' isSpecification =
'false'
  isRoot = 'false' isLeaf = 'false' isAbstract = 'false' >
  <UML:Namespace.ownedElement>
    <!--  POS_Example_R2::Tax    [Class]  -->
    <UML:Class xmi.id = 'S.1'
      name = 'Tax' visibility = 'public' isSpecification = 'false'
      isRoot = 'true' isLeaf = 'true' isAbstract = 'false'
      isActive = 'false'
      namespace = 'G.0' clientDependency = 'G.1' />
    ...
```

From [Kobryn 2001b]

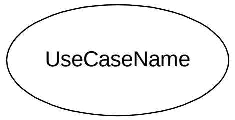
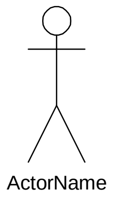
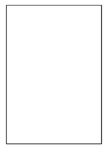
## Use Case Modeling

- What is use case modeling?
- Core concepts
- Diagram tour
- When to model use cases
- Modeling tips
- Example: Online HR System

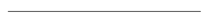
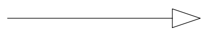
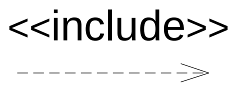
## What is use case modeling?

- use case model: a view of a system that emphasizes the behavior as it appears to outside users. A use case model partitions system functionality into transactions (‘use cases’) that are meaningful to users (‘actors’).

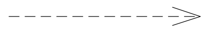
## *Use Cases:* Core Elements

| Construct | Description | Syntax |
|---|---|---|
| **use case** | A sequence of actions, including variants, that a system (or other entity) can perform, interacting with actors of the system. |  |
| **actor** | A coherent set of roles that users of use cases play when interacting with these use cases. |  |
| **system boundary** | Represents the boundary between the physical system and the actors who interact with the physical system. |  |

## *Use Cases:* Core Relationships

| **Construct** | **Description** | **Syntax** |
|---|---|---|
| **association** | The participation of an actor in a use case. i.e., instance of an actor and instances of a use case communicate with each other. |  |
| **generalization** | A taxonomic relationship between a more general use case and a more specific use case. |  |
| **include** | a relationship from a *base* use case to an *inclusion* use case, specifying how the behavior for the base use case contains the behavior defined for the inclusion use case. *The base use case depends on the inclusion use case.* Compare: extend. |  |

## *Use Cases:* Core Relationships (cont'd)

| **Construct** | **Description** | **Syntax** |
|---|---|---|
| **extend** | A relationship from an *extension* use case to a *base* use case, specifying how the behavior for the extension use case augments (subject to conditions in the extension) the behavior defined for the base use case. *The base use case does not depend on the extension use case.* Compare: include. | <<extend>>  |

## Use Case Diagram Tour

- Shows use cases, actors and their relationships
- Use case internals can be specified by text and/or interaction diagrams (see Lecture 2)
- Kinds
  - use case diagram
  - use case description

## Use Case Diagram

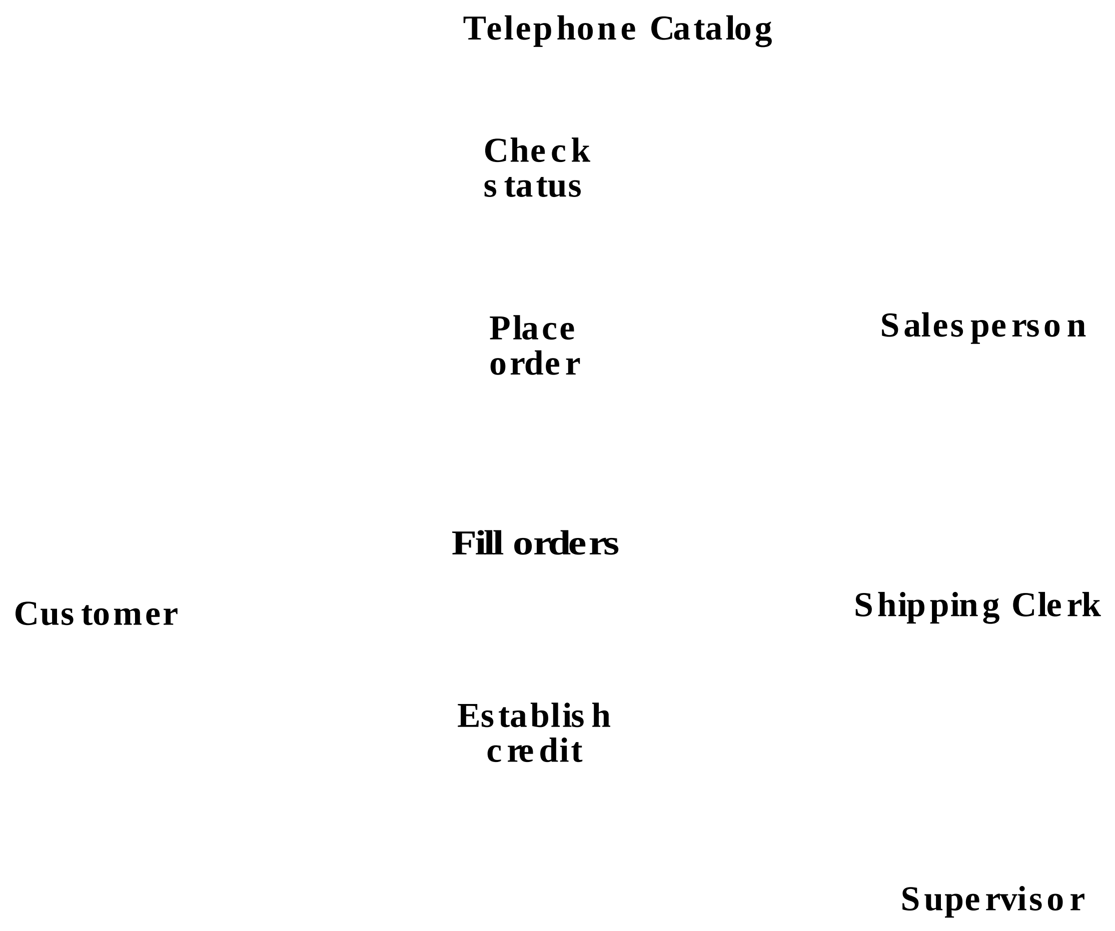


Fig. 3-53, *UML Notation Guide*

# Use Case Relationships

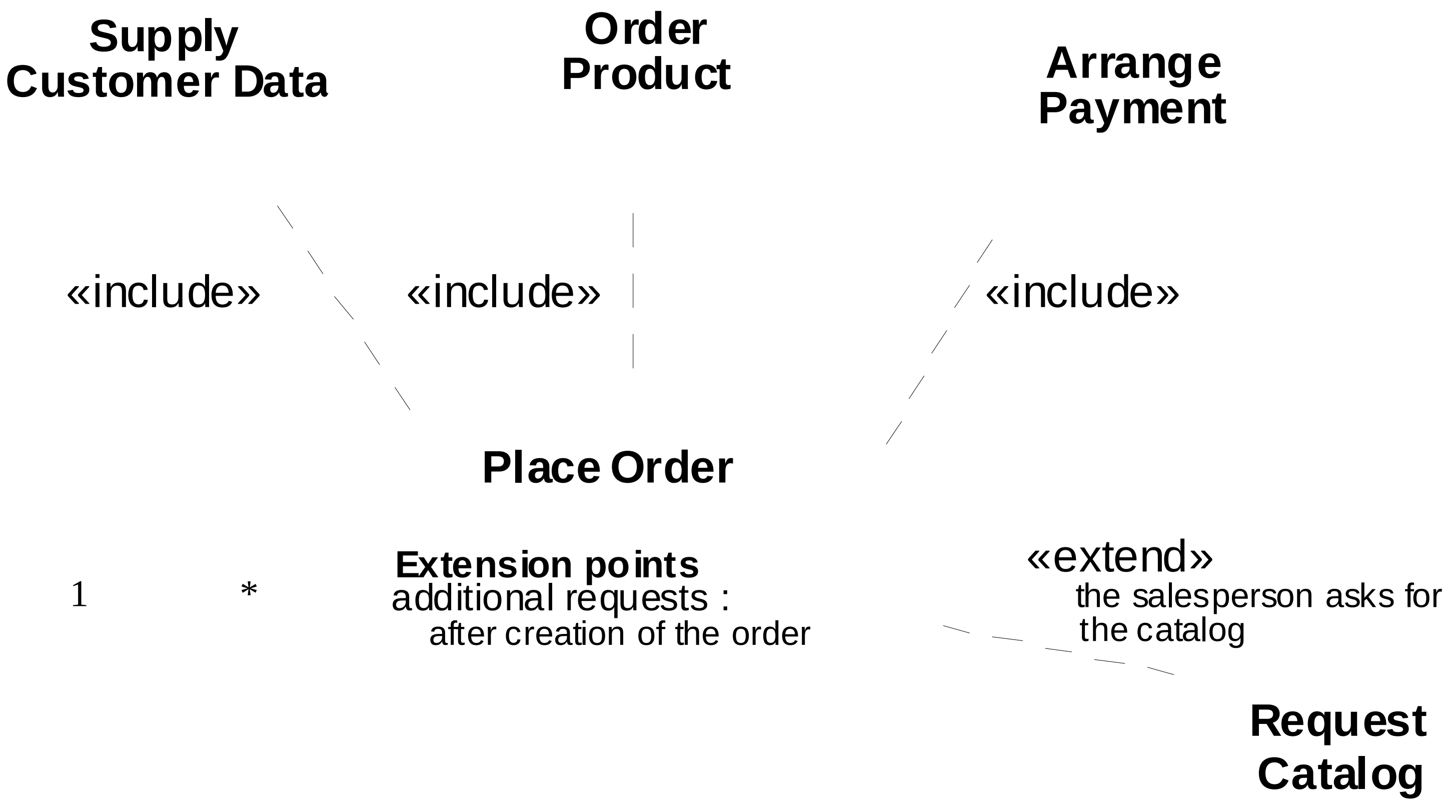


Fig. 3-54, *UML Notation Guide*

# Actor Relationships

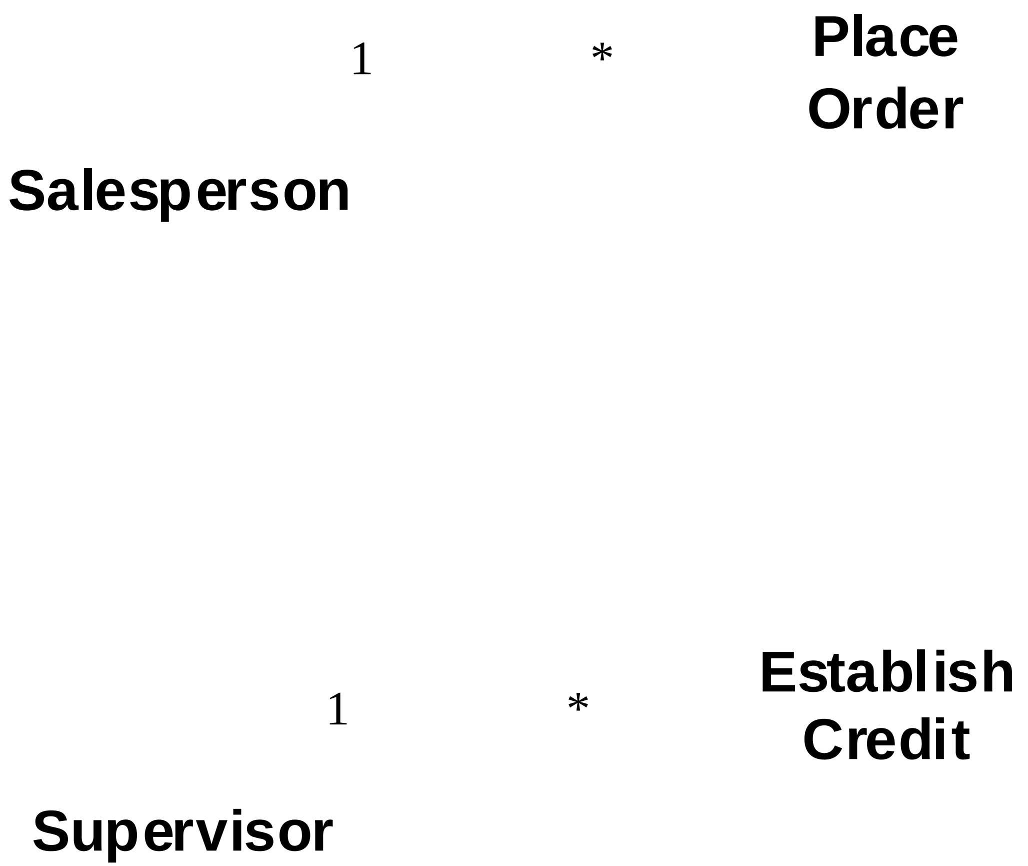


Fig. 3-55, *UML Notation Guide*

## Use Case Description: Change Flight

- **Actors:** traveler, client account db, airline reservation system
- **Preconditions:**
  - Traveler has logged on to the system and selected ‘change flight itinerary’ option
- **Basic course**
  - System retrieves traveler’s account and flight itinerary from client account database
  - System asks traveler to select itinerary segment she wants to change; traveler selects itinerary segment.
  - System asks traveler for new departure and destination information; traveler provides information.
  - If flights are available then
  - …
  - System displays transaction summary.
- **Alternative courses**
  - If no flights are available then …

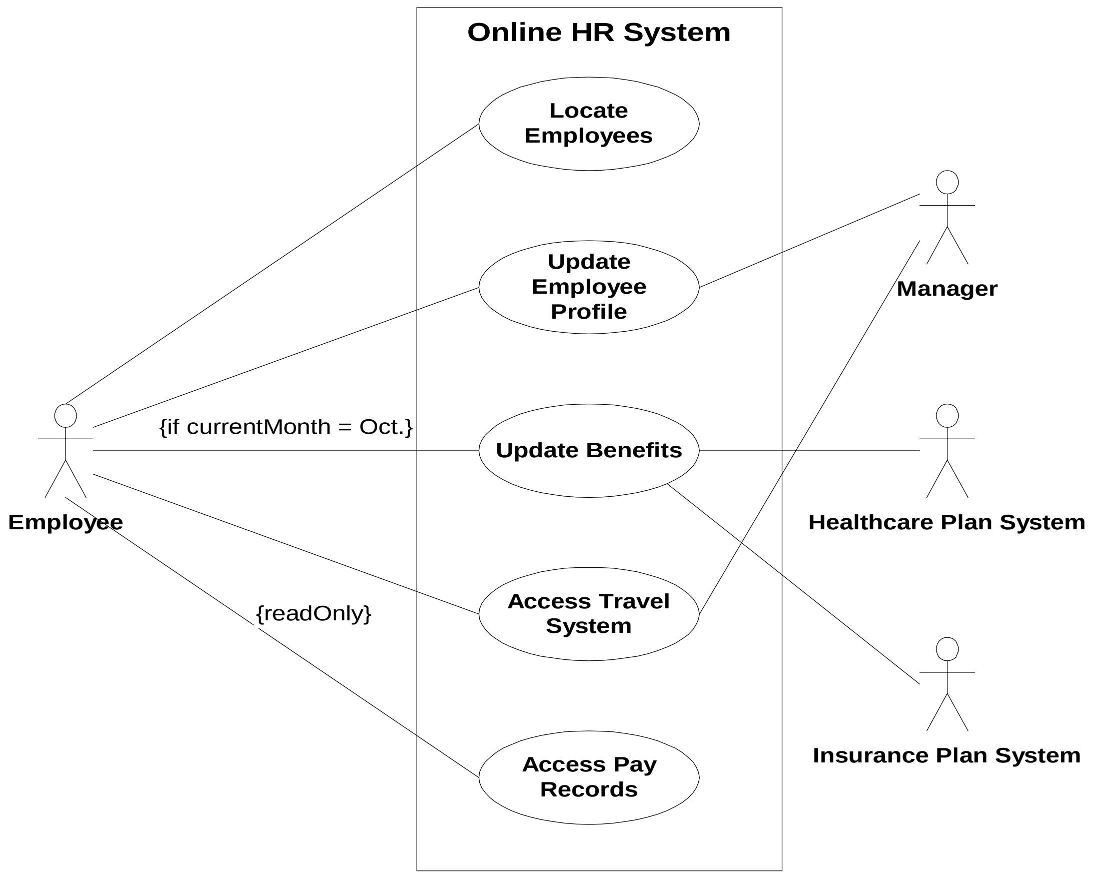
## When to model use cases

- Model user requirements with use cases.
- Model test scenarios with use cases.
- If you are using a use-case driven method
  - start with use cases and derive your structural and behavioral models from it.
- If you are not using a use-case driven method
  - make sure that your use cases are consistent with your structural and behavioral models.

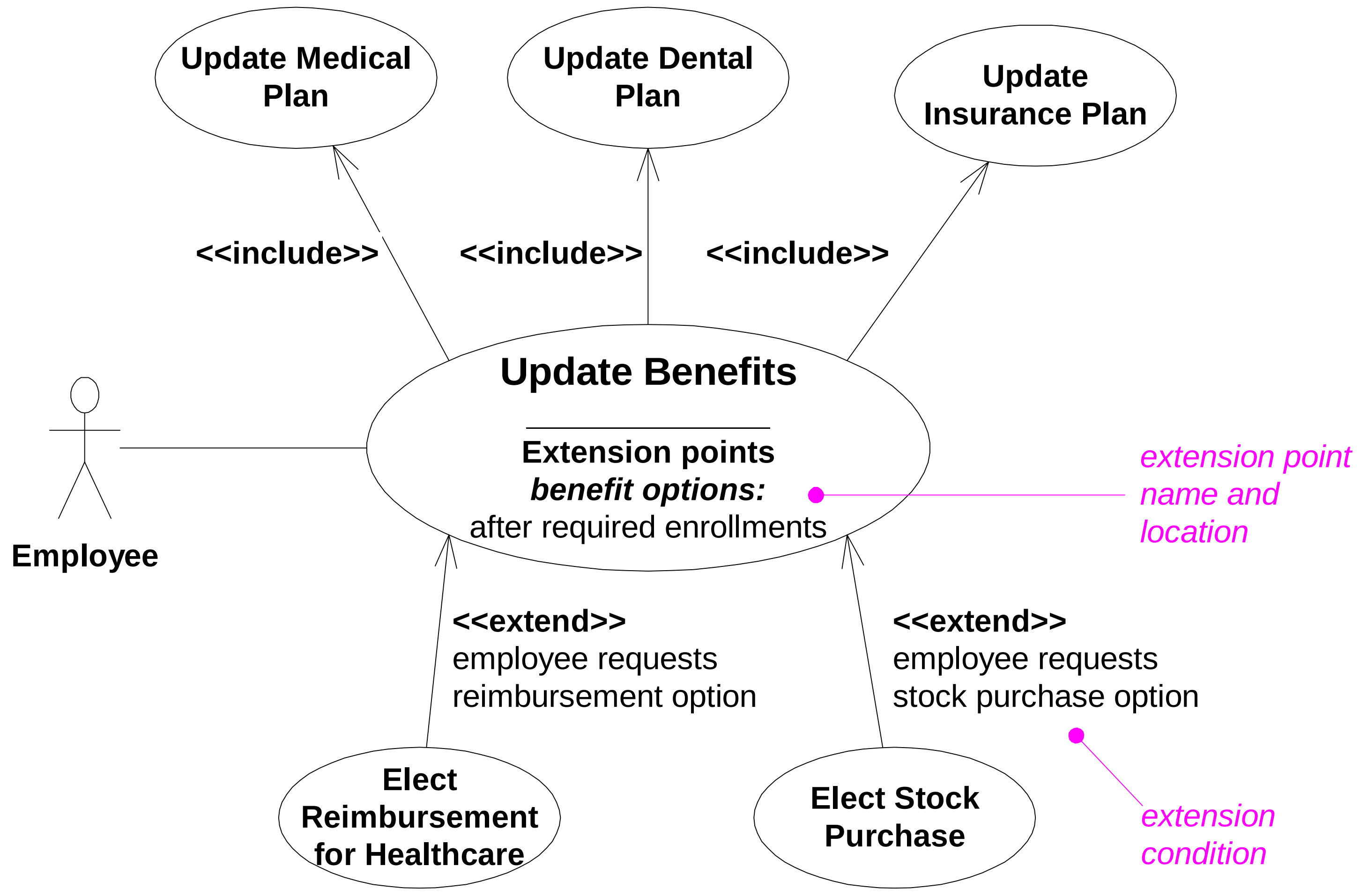
# Use Case Modeling Tips

- Make sure that each use case describes a significant chunk of system usage that is understandable by both domain experts and programmers
- When defining use cases in text, use nouns and verbs accurately and consistently to help derive objects and messages for interaction diagrams (see Lecture 2)
- Factor out common usages that are required by multiple use cases
  - If the usage is required use «include»
  - If the base use case is complete and the usage may be optional, consider use «extend»
- A use case diagram should
  - contain only use cases at the same level of abstraction
  - include only actors who are required
- Large numbers of use cases should be organized into packages (see Lecture 3)

# Example: Online HR System



# Online HR System: Use Case Relationships



## Online HR System: Update Benefits Use Case

- **Actors:** employee, employee account db, healthcare plan system, insurance plan system
- **Preconditions:**
  - Employee has logged on to the system and selected ‘update benefits’ option
- **Basic course**
  - System retrieves employee account from employee account db
  - System asks employee to select medical plan type; **include** Update Medical Plan.
  - System asks employee to select dental plan type; **include** Update Dental Plan.
  - …
- **Alternative courses**
  - If health plan is not available in the employee’s area the employee is informed and asked to select another plan...

## Wrap Up

- Ideas to take away
- Preview of next tutorial
- References
- Further info

## Ideas to Take Away

- UML is effective for modeling large, complex software systems
- It is simple to learn for most developers, but provides advanced features for expert analysts, designers and architects
- It can specify systems in an implementation-independent manner
- 10-20% of the constructs are used 80-90% of the time
- Structural modeling specifies a skeleton that can be refined and extended with additional structure and behavior
- Use case modeling specifies the functional requirements of system in an object-oriented manner

## Preview - Next Tutorial

- Behavioral Modeling with UML
  - Behavioral modeling overview
  - Interactions
  - Collaborations
  - Statecharts
  - Activity graphs

## References

- [UML 1.4] *OMG UML Specification* v. 1.4, UML Revision Task Force, OMG doc# ad/01-02-13.
- [Kobryn 01a] C. Kobryn, “UML 2.0 Roadmap: Fast Track or Detours?,” *Software Development*, April 2001.
- [Kobryn 01b] C. Kobryn, “Modeling Distributed Applications with UML,” Part IV: Chapter 1 in [Siegel 01] *Quick CORBA 3*, Wiley, 2001.
- [Kobryn 00] “Modeling CORBA Applications with UML,” chapter 21 in [Siegel 00] *CORBA 3 Fundamentals and Programming* (2nd ed.), Wiley, 2000.
- [Kobryn 99] *UML 2001: A Standardization Odyssey*, Communications of the ACM, Oct. 1999.
- [EJB 2.0] *Enterprise JavaBeans Specification* v. 2.0, Sun Microsystems, March 31, 2000.

## Further Info

- Web:
  - UML 1.4 RTF: www.celigent.com/omg/umlrtf
  - OMG UML Tutorials: www.celigent.com/omg/umlrtf/tutorials.htm
  - UML 2.0 Working Group: www.celigent.com/omg/adptf/wgs/uml2wg.htm
  - OMG UML Resources: www.omg.org/uml/
- Email
  - uml-rtf@omg.org
  - Cris.Kobryn@telelogic.com
- Conferences & workshops
  - UML World 2001, New York, June 11-14, 2001
  - UML 2001, Toronto, Canada, Oct. 1-5, 2001
  - OMG UML Workshop 2001, San Francisco, Dec. 3-6, 2001
  - UML Forum/Tokyo 2002, Tokyo, Japan, April 2002.