Part 6: UML Class Diagrams

References:

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  Addison Wesley Longman, 1999, ISBN 0-201-30998-X, 550 pages, CD-ROM.
- Martin Fowler, Kendall Scott: UML Distilled, Second Edition.
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- Paul Dorsey, Joseph R. Hudicka: Oracle8 Design Using UML Object Modeling.
  ORACLE Press, 1998, ISBN 0-07-882474-5, 496 pages, ca. $40.
- OMG's UML page: [http://www.omg.org/technology/uml/index.htm]
- UML 1.3 Specification: [ftp://ftp.omg.org/pub/docs/formal/00-03-01.ps]
  [http://www.omg.org/technology/documents/formal/unified_modeling_language.htm]
- Rational: Unified Modeling Language Resource Center:
  [http://www.rational.com/uml/index.jsp]

Objectives

After completing this chapter, you should be able to:

- read and write UML class diagrams.
- translate ER-schemas into UML class diagrams and vice versa.
- translate a UML class diagram into a relational database schema (as far as possible).
- explain differences between the object-oriented and the classical relational approach to database design.

  Especially with regard to operations and keys. What are the implementation options for operations in a RDBMS?

Overview

1. History and Importance of UML
2. Classes, Attributes
3. Associations
4. Operations
5. Generalization

What is UML? (1)

- "The Unified Modeling Language (UML) is a general-purpose visual modeling language that is used to specify, visualize, construct, and document the artifacts of a software system. It captures decisions and understanding about systems that must be constructed."

  [Rumbaugh et.al., The UML Reference Manual, 1999]

What is UML? (2)

- The UML gives you a standard way to write a system's blueprints, covering conceptual things, such as business processes and system functions, as well as concrete things, such as classes written in a specific programming language, database schemas, and reusable software components."

  [Booch et.al., The UML User Guide, 1999]

What is UML? (3)

- "The UML, in its current state, defines a notation and a meta-model. The notation is the graphical stuff you see in models; it is the syntax of the modeling language."

  [Fowler/Scott, UML Distilled, Second Edition, 2000]

- "The UML is a modeling language, not a method. The UML has no notion of a process, which is an important part of a method."

  [Fowler/Scott, UML Distilled, Second Edition, 2000]

History of UML (1)

Object-Oriented Programming Languages:

- Simula-67 (1965–1970) is generally called the first object-oriented language.

  Simula was developed by Nygaad and Dahl at the Norwegian Computing Center.

- Smalltalk is the classical object-oriented programming language. It was developed at XEROX PARC in the 1970s and became widespread in the 1980s.

  The first version was developed by Alan Kay and others in 1972. The book "Smalltalk-80: The Language and Its Implementation" by Adele Goldberg and David Robson appeared 1983.

History of UML (2)

Object-Oriented Programming Languages, Continued:

- C++ was introduced in 1984, but further developed during the 1980s and 1990s.

  In 1979–1980 Bjarne Stroustrup developed "C with Classes" at the Computer Science Research Center of Bell Laboritories in Murray Hill. During 1982–1984 it was redesigned and called C++, 1986 appeared the book "The C++ Programming Language". However, many features were still added later. The ANSI/ISO C++ standardization started in 1989 and the standard was finally approved in 1999.

- Eiffel: Developed 1985–1986, the book by Bertrand Meyer appeared 1988. 'Design by Contract".
- Java: Introduced in 1995 (by SUN Microsystems).

History of UML (3)

Development Methods for Traditional Languages:

- E.g. Structured Analysis and Structured Design, a development method for traditional programming languages, was published by Edward Yourdon and Larry L. Constantine in 1979.
- Development methods became widespread in the 1980s.

History of UML (4)

Object-Oriented Design Methods / Influential Books:

- Shlaer/Mellor (1988/1989)
- CRC: Wirfs-Brock/Wilkerson/Wiener (1990/91).
- Coad/Yourdon (1991)
- Booch [Rational Software Corporation] (1991)
- OMT: Rumbaugh/Blaha/Premerlani/Eddy/ Lorensen (1991).
- Martin/Odell (1992).
- OOSE: Jakobson et.al. [Objectory] (1992).

History of UML (5)

- "The number of object-oriented methods increased from fewer than 10 to more than 50 during the period between 1989 and 1994."

  [Booch et.al., The UML User Guide, 1999]
- "... in 1994, the methods scene was pretty split and competitive. Each of the aforementioned authors was now informally leading a group of practitioners who liked his ideas."

  [Fowler/Scott, UML Distilled, Second Edition, 2000]

History of UML (6)

- All methods/design languages were relatively similar, but each had strengths and weaknesses.
- In addition, similar things were often expressed in different notation.
- In October 1994, James Rumbaugh joined Grady Booch at Rational. Their goal was to unify the Booch and OMT methods.

  "Grady and Jim proclaimed that 'the methods war is over — we won,' basically declaring that they were going to achieve standardization the Microsoft way." [Fowler/Scott, UML Distilled, Second Edition, 2000]

History of UML (7)

- In October 1995, the version 0.8 draft of the "Unified Method" was released.
- In Fall 1995, Rational bought Objectory and Ivar Jacobson joined the team working on UML.
- In June 1996, UML version 0.9 was published.
- In 1996, the Object Management Group (OMG) issued a request for a standard object-oriented modeling language.

History of UML (8)

- Rational formed a UML consortium (including, e.g., DEC, HP, IBM, Microsoft, Oracle, TI) that developed UML 1.0, offered for standardization to the OMG in January 1997.
- Until July/September 1997, most of the proposals for the OMG call were merged in the UML 1.1.
- UML 1.1 was adoped by the OMG on November 14, 1997.
- UML 1.3 was formally published in March 2000.

History of UML (9)

- UML 1.4.2 became ISO/IEC standard 19501:2005.
- UML 1.5 was published in March 2003.
- The UML 2.0 specification was separated into:
  - ◇ UML 2.0 infrastructure: Defines basic and commonly used elements (e.g., class, association, multiplicity), from which other model elements can be derived.
  - ◇ UML 2.0 superstructure: Defines further constructs, e.g. use cases, activities, statecharts.

History of UML (10)

- The two main parts of the UML 2.0 standard are finalized, current versions date from March 2006 (infrastructure) and August 2005 (superstructure).

  OMG makes a distinction between an adopted standard and a finalized, publically available standard. This creates some confusion about the date of a standard. It seems that in Spring 2003, UML 2.0 took an important step in the standardization, and in Fall 2005, the infrastructure specification was not yet officially finalized.
- The following two standards count as parts of the UML 2.0 standard, too (not yet finalized):
  - ◇ UML 2.0 OCL (Object Constraint Language)
  - ◇ UML 2.0 Diagram Interchange

Some Critical Remarks (1)

- It is visible in the UML that it is a monster language designed by a committee.

  It seems that everything is in what one committee member wanted in, so it is a very large language. Programming languages like PL/1 and Ada basically failed because of this.

- At least in the beginning, UML was not precisely defined.

  In some questions, the UML User Guide and the UML Reference Manual (both 1999, both from the "three amigos") directly contradict each other. Other important questions about the exact meaning of certain constructs are simply not answered. Some software engineers think that UML is an acronym for "The Undefined Modeling Language".

Some Critical Remarks (2)

- "UML is far from being new. With respect to syntax it just reinvents many ... concepts and introduces new names for them. With respect to semantics it does not present precise semantic definitions. If these were added, the limitations of the expressiveness of the UML [would] become apparent."

  [Klaus-Dieter Schewe: UML: A Modern Dinosaur? — A Critical Analysis of the Unified Modeling Language. Proc. 10th European-Japanese Conference on Information Modelling and Knowledge Bases, 2000] See also [http://www.dbdebunk.com/page/page/622530.htm].

Future (1)

- After the past experience and all this work on standardization, nobody seems to want another "methods war". At least not only about notation.
- In addition, UML has several extension mechanisms that allow to introduce new concepts in the notation.
- So it seems that UML is the future and all the direct successors to it (like OMT) are dead.

Future (2)

- ER-Diagrams are no direct successor to UML, and the DB community is relatively distinct from the OO design community.

  Already object-oriented databases did not have the commercial impact that was expected and several OODBMS vendors moved to different fields.

- If you start today a large software project without using an object-oriented language and UML, people find you strange. If you use an RDBMS and ER-diagrams, this is still acceptable.

  Advantage of UML: One language for software and DB.

Future (3)

- Some DB Design tools (e.g. Power Designer) introduce support for UML, but they continue to support ER-diagrams.

  And probably for quite some time. The support for ER-diagrams might still be better than that for UML. Oracle added UML to Oracle Designer (in a separate program: ODD) and removed it again.

- "Conceptually, an object does not need a key or other mechanism to identify itself, and such mechanisms should not be included in models."

  [UML Reference Manual, p. 294]

- But keys *are* important in DB design.

Overview

1. History and Importance of UML
2. Classes, Attributes
3. Associations
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Classes (1)

- "Classes are the most important building block of any object-oriented system."
- "A class is a set of objects that share the same attributes, operations, relationships, and semantics".
- "You use classes to capture the vocabulary of the system you are developing."

  All three cited from the UML User Guide [Booch et al, 1999].

- So a class is similar to an entity type, only operations are added.

  The meaning of operations for databases is discussed below.

Classes (2)

- One can use class diagrams in UML simply like a different syntax for ER-diagrams.
- However, the UML can be used to model the entire database application system.

  I.e. not only the database design, but also the software.

- So classes describe not necessarily persistent objects that might ultimately be stored as rows in a relational table.

Classes (3)

- UML classes can also describe transient objects, e.g. C++ or Java objects that exist only for the duration of a program execution.

  Actually, the mapping to an object-oriented programming language or an OODB is more direct than to a relational database. But in this course, our intention is mainly to translate a UML class diagram into a relational DB schema.

Classes (4)

- A class is symbolized by a rectangle with normally three "compartments" (sections) that contain the class name, the attributes, and the operations:

Student
firstName: String lastName: String email[0..1]: String encryptedPW: String
totalPoints(): Integer setPassword(pw: String) checkPW(pw: String): Boolean

Classes (5)

- Either or both of the middle and bottom compartment may be suppressed, i.e. it is possible to show only attributes, only operations, or none of the two.

  Operations always have a parameter list (which may be empty), so if the rectangle has only two compartments, one can tell from the () whether operations or attributes are shown.

Student
firstName: String lastName: String email[0..1]: String encryptedPW: String

Exercise

Classes (6)

- One often sees empty compartments, e.g.

Exercise
no: Integer maxPoints: Integer

- This means that the class has no operations.

  Unless some kind of filtering is in effect, e.g. only public operations (see below) are shown.

- But some authors are so used to the three compartments that they still show the delimiting lines even if they do not show attributes or operations.

Classes (7)

Style guidelines (suggestions by the UML designers):

- One normally uses a noun or noun phrase (singular form) as class names.

  Class names should begin with an uppercase letter. One capitalizes the first letter of every word. The class name is printed centered and in boldface. Abstract classes (see next slide) are shown in italics.

- Attribute names are normally nouns/noun phrases.
- Operation names are usually verbs/verb phrases.

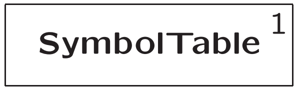
  Attribute and operation names start with a lowercase letter, but have the first letter of every following word capitalized. They are shown in normal font and left justified.

Classes (8)

- Abstract classes cannot have any direct instances (i.e. objects of that class cannot exist).

  Abstract classes can be useful to define a common interface, subclasses of this class can have instances.

- One can also define a multiplicity of a class, i.e. the number of instances (objects) of that class. It is written in the upper-right corner of the class rectangle:



Extension Mechanisms (1)

- Besides the three predefined compartments (class name, attributes, operations), a class rectangle can have further user-defined named compartments.

  One application in the database context would be a compartment for triggers.

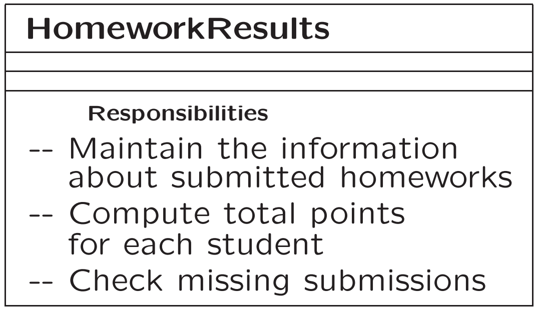
- One such user-defined compartment is already defined in the UML specification: Responsibilities.
- Responsibilities explain the purpose of a class on a higher level than attributes and operations.

  "A responsibility is a contract or an obligation of a class." [UML User Guide, p. 53]

Extension Mechanisms (2)

- The responsibility compartment contains free text.

  The responsibilities are usually written as itemized list. If a class has more than five responsibilities, it is probably too complicated.



Extension Mechanisms (3)

- Stereotypes modify/redefine the semantics of existing UML constructs.

  So in effect one can add new constructs to the UML. Stereotypes correspond to creating a new subclass in the UML meta model.

- For instance, one can use the normal class notation, but add the stereotype "`utility`". This means that
  - ◇ the attributes of the class are global variables,
  - ◇ the operations are global functions.

  In this way, existing non-object-oriented library modules can be included.

Extension Mechanisms (4)

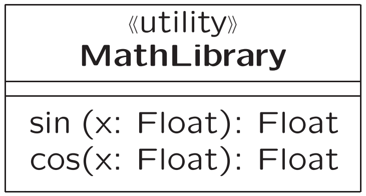
- The four standard stereotypes for classes are:
  - ◇ `metaclass`
  - ◇ `powertype`
  - ◇ `stereotype`
  - ◇ `utility`
- In addition, the following standard steoreotypes or keywords apply to classes (continued on next slide):
  - ◇ `interface`
  - ◇ `type`

Extension Mechanisms (5)

- Standard stereotypes or keywords, continued:
  - ◇ `implementationClass`
  - ◇ `actor`
  - ◇ `exception`
  - ◇ `signal`
  - ◇ `process`
  - ◇ `thread`
- However, the power of stereotypes is that the UML user can introduce new ones.

Extension Mechanisms (6)

- Steoreotypes are enclosed in « and » and are written in front of (or above) the declaration of the element that is modified:



- Instead of explicitly showing the stereotype name, one can also define new icons for the modified constructs.

Extension Mechanisms (7)

- Every element in a specification (e.g. a class, an attribute) has certain properties.
- The set of these properties is user-extensible.

  Whereas stereotypes correspond to adding a subclass to the meta-model of UML, such “tagged values” in effect add an attribute.

- Additional properties are shown in a property list/as tagged values behind or below the element declaration enclosed in { and }.

Student
{author=sb, version=1.0}

Extension Mechanisms (8)

- The standard tagged values for classes are
  - ◇ `documentation` (any text),
  - ◇ `location` (e.g. client or server),
  - ◇ `persistence`, and
  - ◇ `semantics`.
- If needed, one can mark database classes with

  `{persistence=persistent}` or just `{persistent}`

  and program classes with

  `{persistence=transient}` or just `{transient}`.

Extension Mechanisms (9)

- As already shown in the example, if a property is of an enumerated type and an enumeration value implies a unique property name, if suffices to put that value in the property list.
- Of course, `{persistent}` and `{transient}` should only be used if the same diagram shows both kinds of classes. Otherwise it would overload the diagram.

Attributes (1)

- “An attribute represents some property of the thing you are modeling that is shared by all objects of that class.”

  [Booch et.al.: UML User Guide, 1999, p. 50]

- “An attribute is the description of a named slot of a specified type in a class, each object of the class separately holds a value of the type.”

  [Rumbaugh et.al.: UML Reference Manual, 1999, p. 166]

Attributes (2)

Attribute Scope:

- Attributes can have
  - ◇ class scope (class attributes, static members), or
  - ◇ instance scope (normal attributes).
- Attributes of class scope have only one value for the entire class (even if the class has no objects).

  Attributes of instance scope have one value for each object/instance of the class.
- Attributes of class scope are marked by underlining.

Attributes (3)

Attribute Visibility:

- Attribute visibility defines which classes can directly access the attribute (in their operations).
- There are three options:
  - ◇ public (+): The attribute is visible to any class that can see the class containing the attribute.
  - ◇ package (~): Visible to all classes of the package.
  - ◇ protected (#): Visible to the class itself and its subclasses.
  - ◇ private (-): Visible only to the class itself.

Attributes (4)

Multiple-Valued Attributes:

- UML permits multiple-valued attributes, i.e. sets or arrays. Example multiplicity specifications are:
  - ◇ `[0..1]`: Zero or one values.

    This corresponds to an attribute that can be null.
  - ◇ `[1..*]`: A set with at least one element.

    There is no upper bound on the number of elements. When translating a class with such an attribute into relations, one would create an extra table for this attribute. Exercise: Consider a class for web pages, where each web page has an URL, a title, and a set of keywords/search terms. Model this in UML and in the RM.
  - ◇ `[3 ordered]`: An array with three elements.

    The default is "`unordered`", i.e. a set.

Attributes (5)

Attribute Declaration:

- A full attribute declaration consists of:
  - ◇ Visibility: +, ~, #, - (see above).
  - ◇ The name of the attribute.
  - ◇ The multiplicity (array/set), e.g. `[0..1]`, `[3]`.
  - ◇ A colon ":" and the type of the attribute.
  - ◇ An equals sign "=" and the initial value of the attribute.
- Of this, everything except the name is optional.

Attributes (6)

- Example:

  `+ProgramOfStudy [0..2]: String = "MIS"`

- In addition, the standard UML extension mechanisms apply:
  - ◇ In front of an attribute declaration, a stereotype can be specified (enclosed in « and »).
  - ◇ After the attribute declaration, a property string (enclosed in { and }) can be added.

    In the property string, one can specify, e.g., the following values: `changeable` (the default), `frozen` (cannot be changed after object is initialized), `addOnly` (for attributes with multiplicity > 1).

Constraints (1)

- "With constraints, you can add new semantics or change existing rules."

  [Booch et.al.: The UML User Guide, 1999, page 82]

- This is not quite the usual notion of a constraint: In databases, a constraint can only restrict DB states.

  This shows again that database people and UML people do not speak the same language. To be fair, the UML reference manual states "A constraint is a semantic condition or restriction expressed as a liguistic statement in some textual language." [Rumbaugh et.al.: The UML Reference Manual, 1999, page 235]

- Constraints are one of the three UML extension mechanisms (besides stereotypes, tagged values).

Constraints (2)

- Constraints are enclosed in { and } and written near to the element to which they apply.

  A constraint can be connected with dashed lines to the diagram elements to which it applies (if it is not clear from its position). It can be written into a note box, or simply on the diagram background.

- Constraints can be written
  - ◇ as free-form text,
  - ◇ in a formal logical language, especially OCL: UML's Object Constraint Language,
  - ◇ in a programming language.
  - ◇ as predefined name/abbreviation.

Constraints (3)

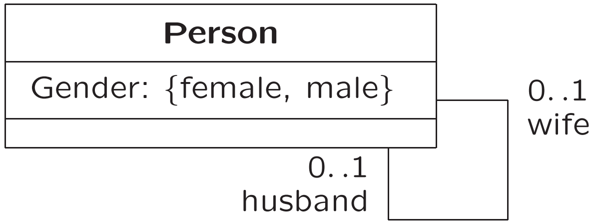
- Example (Restriction of an attribute):

Exercise
No: Integer Points: Integer {value $\geq$ 0} Headline: String

- If a constraint appears as an item of its own in the attribute list, it applies to all following attributes until it is explicitly cancelled.

Constraints (4)

- Example (using OCL for a relationship):



{self.wife.gender = female and
self.husband.gender = male}

[Booch et al., UML User Guide, 1999, p. 82]

Derived Attributes (1)

- Attributes are derived if can be computed from other attributes.

  The derivation formula can be shown as a constraint.

- Derived attributes should normally not be stored in the database, because they are redundant.

  Therefore, they seldom appear in conceptual database schemas (they do not give any additional information). However, if they are important concepts in the application domain, they can be included if they are explicitly marked as "derived". Then they will typically be translated into a view, not into a stored column. There is no real difference between a derived attribute and a query operation.

Derived Attributes (2)

- Derived attributes are marked by putting a slash "/" in front of their name:

Person
firstName: String lastName: String birthdate: Date /age: Integer

- Also other model elements can be derived. They are marked in the same way.

  E.g. relationships (called "associations" in UML, see below) might be computable from other relationships and/or attributes.

Keys

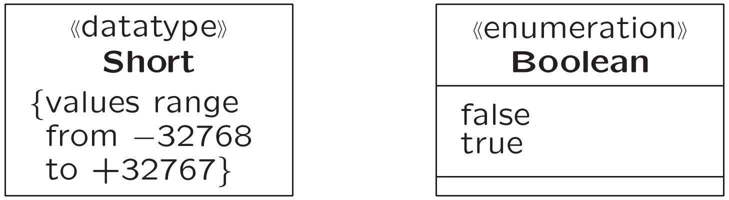
- UML has no built-in notion of keys.

  The idea is that objects automatically have an object identity, i.e. a surrogate key (an automatically generated number). However, at least externally objects must be identified in user input. Internal numbers/addresses are difficult for this purpose.

- One can extend UML in order to add keys. Several proposals exist, one is to add "`{oid}`" (or "`{pk}`") as property list to the primary key attributes.

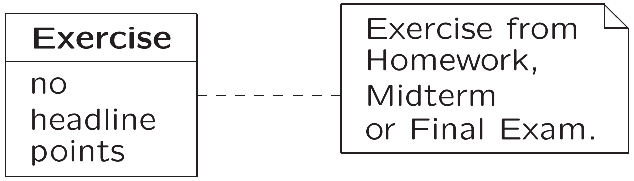
  One would use "`{oid1}`" (or "`{ak1}`") for the attributes of the first alternative key, and so on. Some proposals also permit to define the sequence of the attributes in composed keys.

Specification of Data Types



Annotations/Comments

- A note can contain a comment, a constraint, or a method.
- It is shown in a dog-eared rectangle with its upper-right corner bent over:



Overview

Associations (1)

- Relationships are called "associations" in UML:

- Note that the cardinalities are written on the opposite side of the standard (min,max)-cardinalities:
  - ◇ Each exercise belongs to exactly one chapter.
  - ◇ A chapter can contain any number of exercises.
- Cardinalities are called multiplicities in UML.

Associations (2)

- Of course, in a relational database, associations are implemented as usual:
  - ◇ For a one-to-many relationship, one adds the key of the “one” side (Chapter) as a foreign key to the “many” side (Exercise).
  - ◇ For a many-to-many relationship, one constructs an “intersection table”.
- But in order to understand UML better, it is also important to look at the implementation in object-oriented programming languages or databases.

Associations (3)

- In OODBs, associations are usually implemented by pointers that are the inverse of each other:

```
class Chapter (extent chapters)
{   attribute unsigned short number;
    attribute string title;
    relationship set<Exercise> contains
                 inverse Exercise::belongs_to;
};
class Exercise (extent exercises)
{   ...;
    relationship Chapter belongs_to
                 inverse Chapter::contains;
};
```


Associations (4)

- The example above is in the ODMG ODL.

  The Object Data Management Group has defined a standard for object-oriented database systems. The Object Definition Language is used for defining database schemas.
- In order to traverse the relationship efficiently in both directions, pointers are needed in both participating classes.
- If the system knows the inverse relationship, it can ensure the consistency.

  In particular, when an object is deleted, dangling pointers can be avoided, since the system knows which other objects contain pointers to the deleted object.

Multiplicity (1)

- A multiplicity specification consists of a comma-separated list of intervals, e.g. `0..2,5..6` means that the following numbers are possible: `0,1,2,5,6`.
- An interval consisting only of a single number can be denoted by that number, e.g. `1` is an abbreviation for the interval `1..1`.
- “*” denotes an unbounded number, e.g. `0..*` is the most general interval (any number).
- `0..*` can be shortend to `*`.

Multiplicity (2)

- The multiplicity specification near an entity type E_1 counts how many entities of this type can be related to a single entity of the other type E_2.

  The other notation counts the number of outgoing edges from a single entity of type E_1.

- The advantage of the UML notation is that the multiplicities for one-to-many relationships are as expected: `1` (or `0..1`) on the "one" side and `*` (or `1..*`) on the "many" side.

Multiplicity (3)

- The disadvantage of this notation is that if "intersection entities" are introduced for many-to-many relationships, multiplicities must be moved around:

- With the standard (min,max)-notation this does not happen.

Multiplicity (4)

- Another disadvantage is that if associations are implemented by pointers (as usual in object-oriented languages), the multiplicity is on the opposite side:

- Here, each Exercise object contains a single pointer to a Chapter object.
- But each Chapter object contains a set of pointers to Exercise objects (if this direction is supported).

Reading Direction

- One can use the symbol "▸" to make the direction of the name clear (this is optional):

- Also ◂ ▴ ▾ can be used:

- Of course, it is best to choose names that read from left to right and from top to bottom.

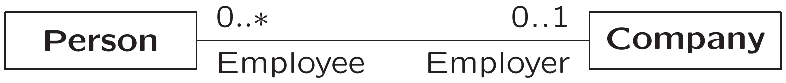
Role Names (1)

- Instead of or in addition to association names, one can also use role names:

- Here the person has the role of an employee in the association, and the company has the role of an employer.
- In other associations, objects of the two classes can play different roles (e.g., customer and contractor).

Role Names (2)

- The role names on the opposite site can often be used as attribute names for the pointers or foreign keys.

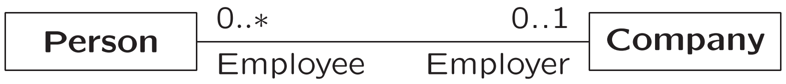


- In the example, "`PERSONS`" would have a foreign key (or pointer attribute) called "`EMPLOYER`".

  It can contain 0 or 1 key values (pointers/addresses) of companies. In relational databases, this means that the attribute can be null.

Role Names (3)

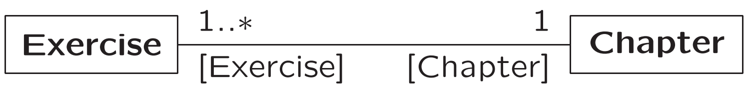
- If necessary, the "Company" class would have an attribute "Employees" that is a set of pointers to "Person" objects.



- Of course, in relational databases this is not necessary because with the foreign key on the "Person" side, the join can also find employees for a given company.

Role Names (4)

- Often, the class name itself can be used as role names. Then it is not necessary to add an explicit role name (actually, it is difficult to invent one).



  Note: The brackets "[...]" are not UML notation. They are intended to indicate that it does not matter wether these role names are explicitly written or not: They are the default.

- Then the table/class "Exercises" would have a foreign key/pointer attribute "Chapter".

  Conversely, "Chapter" might have a set-valued attribute "Exercises".

Role Names (5)

- The names used in Oracle Designer on both ends of the relationship are not role names in the sense of UML:

- UML tools would add a foreign key/pointer attribute "Contains" to the table/class "Exercises".

  I.e. just the wrong way around.

- The names in Oracle Designer are really association names for both directions, not role names.

Uniqueness of Names

- Names of classes and associations must be unique.

  It is not even allowed to have an association and a class with the same name (since there are association classes, see below). UML has packages, and the uniqueness is only required within each package.

- Role names (labels of association ends) must be unique within the association (each end must have a different name) and within the connected class.

  A role may not have the same name as an attribute (since associations are typically implemented by pointer attributes).

- If there is only one connection between the two classes, it is possible to have neither association name nor role names.

Navigability (1)

- In UML, it is possible to specify that an association will be traversed only in one direction:

- Then Exercise objects would contain a pointer to the Chapter to which they belong, but there would be no inverse pointer.

  Even with the pointer implementation it might be possible to find exercises for one chapter (e.g. if there is a linked list of all exercise objects in the system). So the arrow only specifies in which direction an efficient traversal is possible.

Navigability (2)

- Without inverse pointers, it might be difficult to ensure that when a Chapter object is deleted, the corresponding Exercise objects are deleted, too.

  An important reason for having pointers in both directions is to avoid dangling pointers. OODBMS can do this automatically.

- For a relational databases, the navigability specification is not important: Joins are always both ways.
- But for programs written e.g. in C++, one seldom has pointers in both directions, thus there the arrow will be often used.

Visibility (1)

- Since relationships are implemented by attributes or operations, it possible to specify a visibility at the association ends:

[Example from Booch et.al: UML User Guide, 1999, p. 145]

- This means that everybody who has access to a Password object, can navigate from there to the corresponding User.

Visibility (2)

- However, only operations of the User class can follow the link to the passwords.
- Thus the visibility is denoted at the opposite end of the association (the end to which one wants to navigate).

  This is natural, since the role name and the multiplicity on the opposite end of the assocation determine the pointer attribute for this class.

Collection-Type (1)

- Consider again the relationship between chapters and exercises:

- As explained above, in an OODB, the class "Chapter" will contain a set-valued attribute with pointers to "Exercise" objects.
- If one iterates over the elements of this set, they are returned in no specific order.

Collection-Type (2)

- However, one can specify in UML that the order of exercises in a chapter is significant:

- Then not a set, but a list will be used to hold the pointers to exercises (but duplicates are still not allowed).
- "{ordered}" can also be used on one or both sides of a many-to-many relationship.

  Only for multiplicities 0..1 and 1 it makes no sense.

Collection-Type (3)

- In the ODMG proposal, **set**, **list**, or **bag** can be used in relationships:

  class Chapter (**extent** chapters)
  { . . . ;
  relationship **list**<Exercise> contains
  inverse Exercise::belongs_to;
  };

- However, one must exclude duplicates from the list.

  An "ordered set" as in UML is not quite the same as a list.

Collection-Type (4)

- In a relational implementation, one would add a number to the exercises table (exercise number within chapter) in addition to a foreign key referencing the chapter.

  EXERCISES(<u>ID</u>, ..., CHAPTER→CHAPTERS, SORT_NO)

- CHAPTER and SORT_NO together are an alternative key for EXERCISES.

  This ensures that there is really a defined sequence for the exercises within one chapter.

Collection-Type (5)

- Note that "{ordered}" means that additional information needs to be stored besides the set of links between objects.
- If the exercise objects already contain an exercise number, so that the order can be derived from this information, "{ordered}" would not be correct (redundant information).

  One can use "{sorted}" to indicate that for a more efficient implementation, it would be good to store the links sorted by some criterion, e.g. the exercise number.

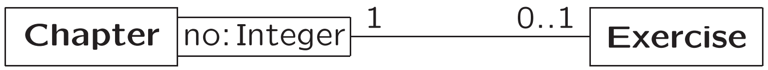
Exercise

- Consider the following class diagram:

- If a book has several authors, their sequence is important (it is not always the alphabetical sequence). How would you specify that?
- Translate this diagram into the relational model.

Qualifiers (1)

- If each exercise has a unique number within a chapter, this can be expressed by means of a "qualifier":



- Chapter objects now basically contain an array of links to Exercise objects.
- The array is indexed by a number, and returns 0 or 1 exercises for a given number.

  A normal association would map "Chapter" objects into sets of "Exercise" objects. Now a "Chapter" object and a value for the qualifier "no" are mapped into at most one "Exercise" object.

Qualifiers (2)

- More general, the qualifier can be of any data type, e.g. also a string. Then a "dictionary" data structure would be stored within the Chapter objects, e.g. a hash table or a search tree.
- Arrays and dictionaries are also collection types.

  Qualifiers are strongly related to the use of "{ordered}" etc. to determine the collection type of the association. An array could be used to implement an ordered association (at least if the maximum number of related objects is known), but the qualifier makes clear that the specific value of the array index is important for the application.

Qualifiers (3)

- A qualifier can also be used when there is more than one related object for a given qualifier value.

  I.e. the qualifier only partitions the set of related objects into subsets. It could then be represented by an attribute in an association class (or in the target class), but the qualifier makes clear that some kind of efficient access should be possible.

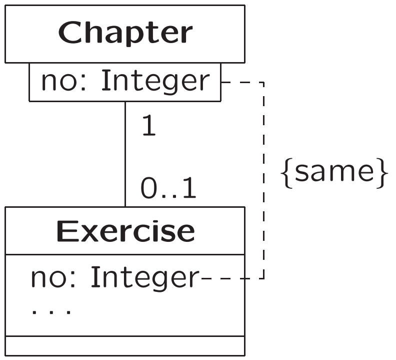
- The multiplicity on the opposite association end is influenced by the qualifier: E.g. `0..1` at the Exercise end is the number of objects that may be related to a single Chapter object for a given qualifier value.

  So "Chapter" and the qualifier now form some kind of composite object for the purpose of determining multiplicities.

Qualifiers (4)

- With qualifiers, UML gets something like keys, but only in the context of a given object.
- The situation is similar to a weak entity, but the qualifier value (the exercise number) is not part of the Exercise class.
- If that is required, the exercise number must be stored redundantly as an attribute of the Exercise class, and a constraint is needed to enforce the equality (see next slide).

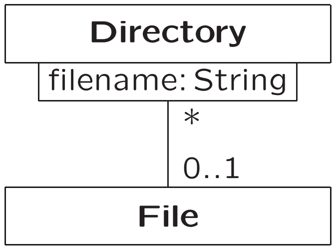
Qualifiers (5)



Qualifiers (6)

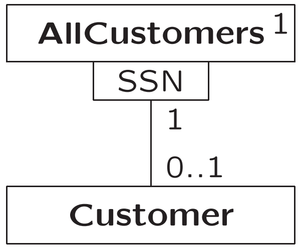
- In the UNIX file system, the filename is not part of the file objects, but appears only in the directory. This would be a classical example of a qualifier.

  The same file may actually appear in different places of the file system (in different directories or under different names).



Qualifiers (7)

- If one has a globally unique object a qualifier from there corresponds to a key:



  If direct access from a customer to his/her social security number is needed, a duplication of SSN as shown on slide 6-85 is required.

- Does it have to be so complicated?

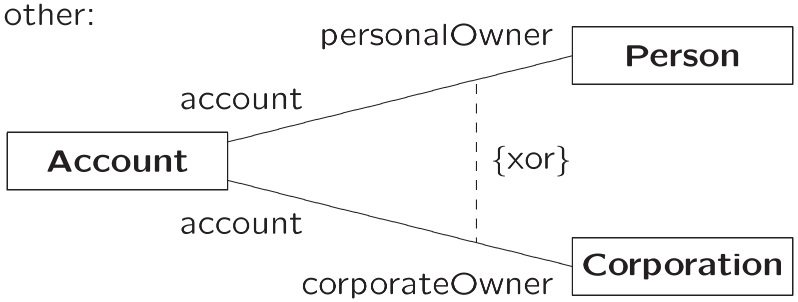
Qualifiers (8)

- The “AllCustomers” object is in effect a unique index that supports the key “SSN” for the class “Customer”.
- If UML is not extended in order to support keys, one must show the index explicitly as in this example.
- This is clearly a relapse to pre-relational times.

  An index is something big and complicated, so one might argue that when designing an object-oriented program (e.g., in C++), the index should be shown explicitly if it is needed. However, when designing a database, creating an index is easy, and furthermore indexes should not be part of the conceptual design. By the way, the ODMG model has the notion of keys (for extents).

Constraints (1)

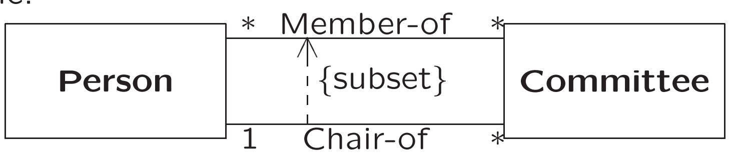
- One can specify that two associations exclude each other:



[Rumbaugh et.al.: The UML Reference Manual, 1999, p. 156]
Note that "xor" is not quite right: If the minimum cardinality is 0, it is possible that an Account has no link at all.

Constraints (2)

- One can specify that an association implies another one:



[Rumbaugh et.al.: The UML Reference Manual, 1999, p. 237]

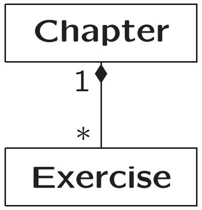
- As attributes, associations can be marked
  - ◇ **`changeable`** (the default),
  - ◇ **`addOnly`** (links can only be inserted, not deleted)
  - ◇ **`frozen`** (links of an object cannot be changed).

Composition/Aggregation (1)

- Composite aggregation (or composition) is the relationship between a whole and its parts.

  Or really vice versa: parts are aggregated to a whole.

- An association becomes a composition (a form of aggregation association) by marking the side of the whole with a black diamond:



Composition/Aggregation (2)

- An object can only be part of one composite object at a time:
  - ◇ The multiplicity on the side of the composition must be `1` or `0..1`.
  - ◇ From every class, there can be at most one outgoing composite aggregation relationship.

    Actually, there could be more, but they must be linked with a `xor`-constraint.

Composition/Aggregation (3)

- On the instance level, composite aggregations may not be cyclic (an object cannot be part of itself).
- On the class level, recursive composition relationships are allowed: A class has many objects, so an object of a class may be part of another object of the same class.

Composition/Aggregation (4)

- The whole is responsible for disposing its parts: If the whole is deleted, it must delete its parts.
  - ◇ In relational databases, this means that the foreign key is specified with `ON DELETE CASCADE`.
  - ◇ In C++, the destructor for the composite object would call the destructors for its parts.

    In C++, there is no automatic garbage collection, so one needs to think about memory management.

Composition/Aggregation (5)

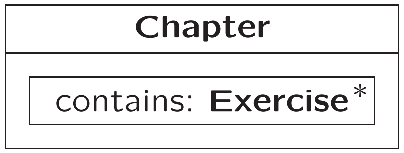
- It is legal that
  - ◇ a part is created after the composite or destroyed before it,
  - ◇ a part is moved from one composite object to another,

  but this would normally be done by operations of the composite object (it manages its parts).

Composition/Aggregation (6)

- Alternative notation: The part class is drawn within the rectangle for the composite class.

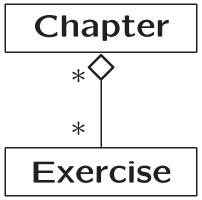
  Composition is the relationship between an object and its attributes. Attribute name: role name of the part.



- If an association is drawn within the boundaries of the rectangle of the composite class, it can exist only between parts of the same composite object.

Composition/Aggregation (7)

- UML also has a weak form of aggregation, called "simple aggregation" or "aggregation".
- It is denoted by an open diamond:

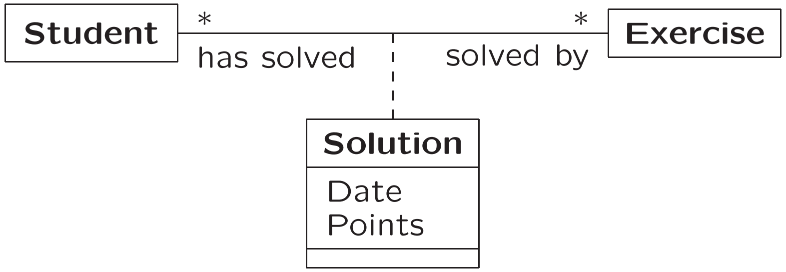


- It has no semantic consequences: An object can be part of more than one aggregated object.

  "Think of it as a modeling placebo" [Rumbaugh cited after Fowler, 1999].

Association Classes (1)

- If an association has attributes (or operations), an "association class" must be used:



- An association class is shown as a class that is linked by a dashed line to an association.

Association Classes (2)

- There is exactly one object of the association class "Solution" for every pair of objects from Student and Exercise that are linked via the association.
- In UML, there cannot be two links between the same two objects via the same association.

  I.e. associations are sets (as relationships in the ER-model).

- Thus, the above class diagram enforces that the same student cannot submit two solutions for the same exercise.

Association Classes (3)

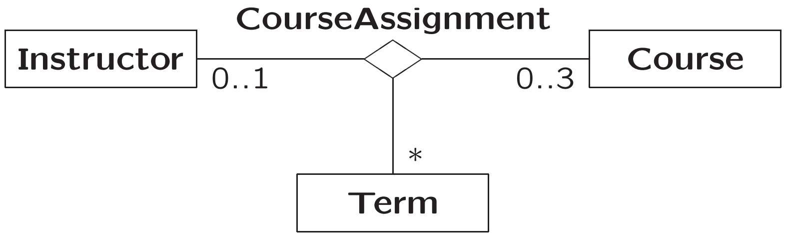
- In this schema, the same student can have two (or more) solutions for the same exercise:

  In the ER-model, "Solution" would be a weak entity with owners "Student" and "Exercise". Then the constructed key enforces the required uniqueness. But in UML, one can specify keys only via user-defined extensions to the standard UML syntax.

- For one-to-many associations, attributes of the association can be added to the class at the "many" side. An association class is not required.

Non-Binary Associations (1)

- UML is not restricted to binary associations, although that is by far the most common case.
- An n-ary association is symbolized by a diamond with n connections to the participating classes:



Non-Binary Associations (2)

- The multiplicities specify how many objects of that class can exist for a given combination of objects from the other classes.

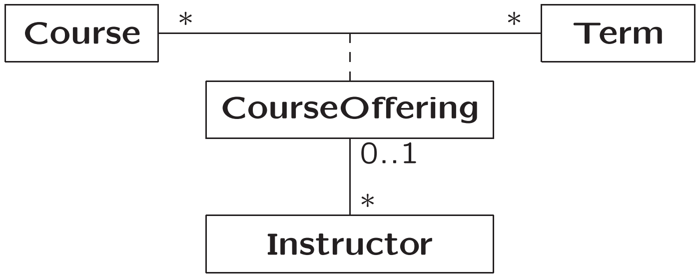
  E.g. the same instructor can offer in the same term not more than three courses. For a given course and a given term, there is at most one instructor. Zero instructors would mean that this combination of course and term do not appear in the association. With this ternary association, it is not possible to store that a course is offered in a term, but with a yet unknown instructor.

- Navigability, aggregation, and qualifiers are not permitted for non-binary associations.

  Their semantics is too complicated.

Non-Binary Associations (3)

- If there is only one instructor per term for a course, the following model might be better:



This permits to store course offerings for which an instructor is not yet assigned. It does not permit multiple sessions of the same course in the same term. It does not enforce the maximal teaching load.

Overview

1. History and Importance of UML
2. Classes, Attributes
3. Associations
4. Operations
5. Generalization

Operations (1)

- "An operation is a specification of a transformation or query that an object may be called to execute. It has a name and a list of parameters."
- "A method is a procedure that implements an operation. It has an algorithm or procedure description." [Rumbaugh et.al.: The UML Reference Manual, 1999, p. 369.]
- UML distinguishes between
  - ◇ operations (the interface) and
  - ◇ methods (the implementation).

Operations (2)

- E.g. if an operation o from the superclass is overridden in the subclass, there is one operation and two methods.

  Most people do not take this distinction very strictly.
- "An operation is the implementation of a service that can be requested from any object of the class to affect behavior. In other words, an operation is an abstraction of something you can do to an object and that is shared by all objects of that class."

  [Booch et.al.: The UML User Guide, 1999, p. 51.]

Operations (3)

- UML allows that there are two operations with the same name, but different lists of parameter types.

  This corresponds to the overloading of functions in languages like C++: The compiler can decide by the types of the arguments in the function call which function is meant.
- UML is used to specify programs written in C++, Java etc. Thus, the basic C++ constructs should be expressible in UML.

Operations (4)

- A full operation declaration consists of:
  - ◇ Visibility: + (public), # (protected), – (private).

    The visibility specification is optional.
  - ◇ The name of the operation.
  - ◇ The parameter list, enclosed in "(" and ")".

    The parameters can be suppressed. But even if only the name is shown, it is usually followed by () to make clear that this is an operation and not an attribute.
  - ◇ A colon and the return type.

    This is optional. The default is "null" (i.e. no result).
    In UML even a list of return types is possible.
    Parameter list and return type can only be suppressed together.

Operations (5)

- The parameter list is a comma-separated list of parameter declarations consisting of
  - ◇ A direction (optional): `in`, `out`, or `inout`.

    The default is `in` (input parameter, i.e. read-only access).
  - ◇ Parameter name, colon ":", and parameter type.
  - ◇ An equals sign "=" and a default value for the parameter.

    This is optional. If a default value is declared, a call to the operation does not have to specify a value for the parameter. This is also a feature of C++: E.g. if a function has two parameters, but a default value for the second one is declared, it can be called with one parameter.

Operations (6)

- Example of an operation declaration:

```
+getTotal(StudID: Integer,
          InclExtra: Boolean = true): Float
```

- In front of an operation declaration, a stereotype can be specified. It is enclosed in «...».

  A stereotype can even apply to an entire group of operations. In a list compartment (e.g. attributes, operations), stereotypes can be specified as list elements by themselves. Then they apply to all following list entries until the next stereotype that appears as a list element.
- After an operation declaration, a property list can be specified. It is enclosed in {...}.

Operations (7)

- The scope of an operation can be "instance" or "class". Operations of class scope are marked by underlining.
  - ◇ Operations of instance scope apply to individual objects, so they have a hidden parameter for an object of their class.
  - ◇ Operations of class scope apply to the class as a whole, not a specific object. Therefore, they can access only attributes of class scope.

Operations (8)

- An operation may be declared a query operation (stereotype keyword «`query`»). Then this operation is guaranteed not to modify the state of the object.

  It is equivalent to specify the property `isQuery=true`. The default is `isQuery=false`, i.e. the operation can assign values to the attributes and change associations.
- Operations can be marked as «`constructor`». Such operations create and initialize instances (objects) of the class.

  They have class scope, but can access the attributes of the newly created instance. They implicitly return the created instance, but no return type needs to be specified.

Hiding Attributes (1)

- The main difference between the object-oriented and the relational approach are the operations.

  Of course, generalization and non-atomic attributes are nice object-oriented features, which relational databases would like to have (this lead to object-relational DBs). But the cultural clash lies in operations and identity.

- Usually, all attributes are declared as private and can only be accessed via operations of the class.

  Of course, one can have public attributes in UML and e.g. in C++, but this is generally considered bad style. E.g. in Smalltalk-80, it was impossible: "A crucial property of an object is that its private memory can be manipulated only by its own operations." [Goldberg/Robson, 1983, p. 6]

Hiding Attributes (2)

- Classes often have operations `get_A` and `set_A` for many of their attributes `A`.

  This is especially true if the class basically corresponds to a relation.

- The reason why the object-oriented approach distinguishes between private attributes and public operations is that
  - ◇ the implementation can be changed
  - ◇ while the interface is kept stable.

Hiding Attributes (3)

- In relational databases, this corresponds to physical data independence: E.g. indexes can be changed while the table structure remains stable.
- In relational databases, the table structure normally is the interface, it does not need to be hidden (except for security purposes, but that is a different issue).

  In the ANSI/SPARC architecture, there is a second interface level that gives logical data independence.

Hiding Attributes (4)

- Complex programs like compilers or DB management systems have a relatively small user interface, but difficult algorithms. Different levels of interfaces (system layers) are needed.
- DB application system have a large user interface (many screens), but simple algorithms. Thus, a single level distinction between interface and implementation might be enough.

Hiding Attributes (5)

- Basically, somebody who invested money and work to build a relational database does not understand why he/she should restrict the access to the data by permitting only to call query operations, not direct read access to all attributes.

  Having to write program code for queries is a step back from the declarative language SQL.

- Views usually only extend the interface, but do seldom hide details below them (except for security).

Implementing Operations (1)

- Of course, query operations that are not simply a "get attribute", but compute some derived value, are interesting for relational databases, too.
- They can normally be mapped into view definitions.
- In order to avoid unnecessary joins, one will often have one view for a relation that gives access to all explicitly stored attributes as well as all derived attributes (query operations).

  If, however, a join is necessary for the computation of the result of the query operation, it might be better to have it in a distinct view.

Implementing Operations (2)

- Query operations with parameters are not in general implementable in this way.

  If the parameter can take only values that appear in the database (or else one of a few enumeration constants), the parameter can be implemented as an attribute of the view. Otherwise, this method does not work since views must be finite. (Deductive DBs have "binding restrictions" for this purpose, i.e. values for certain attributes must be specified.)

- If necessary, operations can be mapped to stored procedures or procedures in a library for developing application programs.

  This is also necessary if the algorithm cannot be expressed in SQL, e.g. requires a transitive closure.

Implementing Operations (3)

- For attributes that participate in complex constraints, it is useful to exclude direct write access via `UPDATE`, and permit changes only via procedures (operations of the class).
- Some other attributes should be non-updateable (E.g. attributes participating in a primary key.)
- So for write accesses, the object-oriented distinction between the internal state (attributes) and the external interface (operations) might make sense.

Implementing Operations (4)

- The more data structure invariants need to be protected, the more important it is to exclude direct attribute modifications.
- Direct updates can be excluded if
  - ◇ the tables are installed under an account that is only used by the DBA,
  - ◇ real users (and programs) log in under a different account and can be granted selective access rights.

    Especially, they get update rights only for certain attributes.

Implementing Operations (5)

- Operations can be implemented as stored procedures on the server, or library procedures that are linked to client programs.

  Library procedures don't give the access protection.

- Triggers can be used if the operation mainly sets an attribute, but additional constraints need to be checked and redundantly stored values (e.g. sums) must be updated.

Overview

Generalization (1)

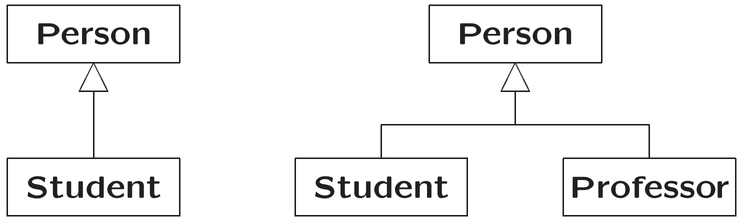
- "A generalization is a relationship between a general thing (called the superclass or parent) and a more specific kind of thing (called the subclass or child). Generalization is sometimes called an "is-a-kind-of" relationship."

  [Booch et.al.: The UML User Guide, 1999, page 64/141]
  Generalization: "A taxonomic relationship between a more general element and a more specific element. The more specific element is fully consistent with the more general element and contains additional information." [Rumbaugh et.al.: UML Reference Man., 1999, p. 287]

- The four kinds of relationships in UML are: Dependency, Association, Generalization, Realization.

Generalization (2)

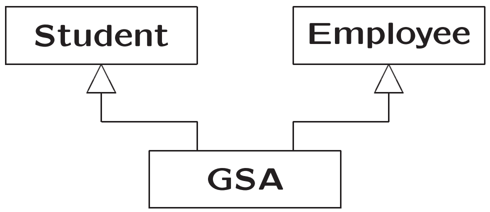
- Generalization is shown in UML as an arrow (with a large open triangle at the end) pointing from the subclass to the superclass (in the "is a" direction):



- If a class has several subclasses, either single arrows can be used or the combined "tree notation".

Generalization (3)

- Multiple inheritance is allowed in UML, i.e. a class can have two or more superclasses:



- "Use multiple inheritance carefully. You'll run into problems if a child has multiple parents whose structure or behaviour overlap."

  [Booch et.al.: The UML User Guide, 1999, p. 142.]

Generalization (4)

- Of course, the subclass can be a superclass for other classes, i.e. there can be a whole hierarchy of subclass-superclass relationships.

  Cycles are forbidden. Generalization is a transitive, anti-symmetric relationship (partial order, lattice). So transitive edges (directly to a super-super-class) should semantically change nothing. In practice, they should be avoided.

- The superclass is also called parent of the subclass, direct and indirect superclasses its ancestors. Correspondingly, the subclass is called child of the superclass, direct and indirect subclasses its decendants.

Inheritance (1)

- A Subclass inherits structure and behaviour, i.e. attributes and operations, from its superclass.
- An instance of the subclass can be used in any context where an instance of the superclass is required.

  The value of a variable/parameter of type S can actually be an instance of a subclass of S. Liskov substitutability principle.

- If the generalization arrow is marked with the stereotype «`implementation`», the inherited attributes and operations become private.

  This is not a real use of generalization, since the basic substitutability principle is violated. C++ has such a notion of "private inheritance".

Inheritance (2)

- In the model/diagrams, only attributes and operations are shown that are added to the inherited ones.

  It is illegal in UML to redeclare an inherited attribute. An inherited operation may be redeclared to show overriding.

- In case of multiple inheritance, it is forbidden if a class inherits the same attribute/operation from two different classes.

  Then it would be unclear which of the two methods for the operation should be used. Of course, it is legal if the operation is inherited from a common superclass on two different inheritance paths.

Inheritance (3)

- To override an inherited operation (usually) means to replace its implementation (method) for objects of the subclass.

  However, complicated techniques for combining the inherited method with method declared in the subclass have been proposed and UML does not require the simple replacement semantics (depends on programming language).

Inheritance (4)

- Operations have a property `isPolymorphic`. If it is `false`, the operation cannot be overridden.

  The default value is `true`. In C++, polymorphic operations must be declared as `virtual` (called via a pointer in the object: "late binding").

- A class can have the property `leaf`, in which case it is not legal to declare a subclass of it.

  In the same way, there is a property `root` which means that this class cannot have a superclass. Operations can also be declared as `root` or `leaf`, `leaf` seems to mean the same as `isPolymorphic=false`. A polymorphic operation may be declared `leaf` in a descendant class which means that further down in the hierarchy it cannot be overridden.

Abstract Classes (1)

- An abstract class is a class that cannot have direct instances, i.e. there can be no objects of this class.
- However, subclasses of the abstract class can have instances.

  Otherwise, the class could only be interesting because of operations of class scope.

- Abstract classes correspond to total specialization.
- Abstract classes / abstract operations (see below) are marked by writing their declaration in italics.

Abstract Classes (2)

- Abstract classes can have abstract and concrete operations:
  - ◇ For a concrete operation, a method (implementation) is already specified in the abstract class.
  - ◇ For an abstract operation, a method must be specified in each subclass.

    Abstract operations must be polymorphic since they can only be used when the non-existant implementation is overridden (in C++: pure virtual functions).

Generalization Constraints (1)

- A generalization can be marked as "`{complete}`" which means that all possible subclasses have been declared and no further subclasses may be added.

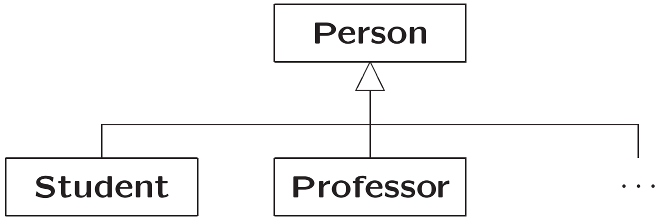
  A generalization can be marked as complete even if not all subclasses are shown on the diagram. It suffices that all have been declared in the model.

- Conversely, it can be marked as "`{incomplete}`" which means that more subclasses are known or expected but have not been declared yet.

  Note that this is not the same as total and partial specialization in the ER-model. E.g. the UML Reference contains incomplete generalization with an abstract superclass (p. 290).

Generalization Constraints (2)

- It is possible to use an ellipses symbol in a diagram to mark that there are more subclasses that are not shown on the diagram ("elided"):



Generalization Constraints (3)

- A generalization can be marked as "`{disjoint}`" or "`{overlapping}`".
- Disjoint means that an object of the superclass can only have one of the subclasses as type.
- E.g., if "Person" has subclasses "Student" and "Employee", and both are declared `{disjoint}`, it is impossible to later introduce a class "GSA" that has both, Student and Employee, as superclasses.

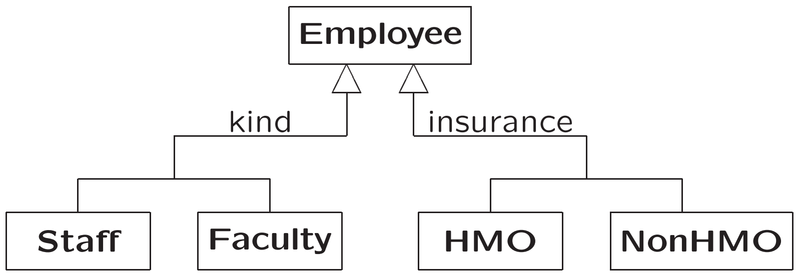
Multiple Classification (1)

- In most programming languages, objects must have a unique "direct class" (i.e. most specific class).
- It is then automatically an indirect instance of all ancestors (superclasses etc.) of its direct class.
- UML permits "multiple classification", i.e. an object can be a direct instance of more than one class.

  This basically corresponds to multiple inheritance with anonymous subclasses. E.g. with multiple classification, an object can be at the same time "Student" and "Employee", even if no "GSA" class is explicitly declared. If there are a lot of possible combinations, it would be too much effort to declare them all explicitly.

Multiple Classification (2)

- Generalization arrows can be marked with "discriminators" (names) to show the different dimensions along which objects can be classified:



Multiple Classification (3)

- "All subtypes with the same discriminator are disjoint; that is, any instance of the supertype may be an instance of only one of the subtypes within that discriminator." [UML Distilled, 2nd Ed, 2000, p. 83]
- "A parent with multiple discriminators has multiple dimensions, all of which must be specialized to produce a concrete element. Therefore, children within a discriminator group are inherently abstract. . . . A concrete element requires specializing all the dimensions simultaneously." [UML Ref. Man., p. 262/263]

Multiple Classification (4)

- If no discriminators are specified, all generalizations with the same parent form one discriminator group. (Consistent?)
- Discriminators become attributes of the instances.

Dynamic Classification

- Dynamic classification means that an object can change its class over time.

  Most programming languages use static classification: The type of an object is fixed at runtime.

- This is normally used together with multiple classification: An object has a static base class and can gain or lose additional "roles" over time.

  Fowler uses the stereotype ⟪`dynamic`⟫ on the generalization relationship. It does not appear in the UML Reference or the User Guide.

  The Reference Manual says dynamic or static classification is a semantic variantion point and that either assumption may be used in a UML model.