Object-Oriented Software Engineering
Practical Software Development using UML and Java

Chapter 5:
Modelling with Classes

5.1 What is UML?

The Unified Modelling Language is a standard graphical language for modelling object oriented software

- At the end of the 1980s and the beginning of 1990s, the first object-oriented development processes appeared
- The proliferation of methods and notations tended to cause considerable confusion
- Two important methodologists Rumbaugh and Booch decided to merge their approaches in 1994.
  - They worked together at the Rational Software Corporation
- In 1995, another methodologist, Jacobson, joined the team
  - His work focused on use cases
- In 1997 the Object Management Group (OMG) started the process of UML standardization

UML diagrams

- Class diagrams
  - describe classes and their relationships
- Interaction diagrams
  - show the behaviour of systems in terms of how objects interact with each other
- State diagrams and activity diagrams
  - show how systems behave internally
- Component and deployment diagrams
  - show how the various components of systems are arranged logically and physically

UML features

- It has detailed *semantics*
- It has *extension* mechanisms
- It has an associated textual language
  - *Object Constraint Language* (OCL)

The objective of UML is to assist in software development

- It is not a *methodology*

What constitutes a good model?

A model should

- use a standard notation
- be understandable by clients and users
- lead software engineers to have insights about the system
- provide abstraction

Models are used:

- to help create designs
- to permit analysis and review of those designs.
- as the core documentation describing the system.

5.2 Essentials of UML Class Diagrams

The main symbols shown on class diagrams are:

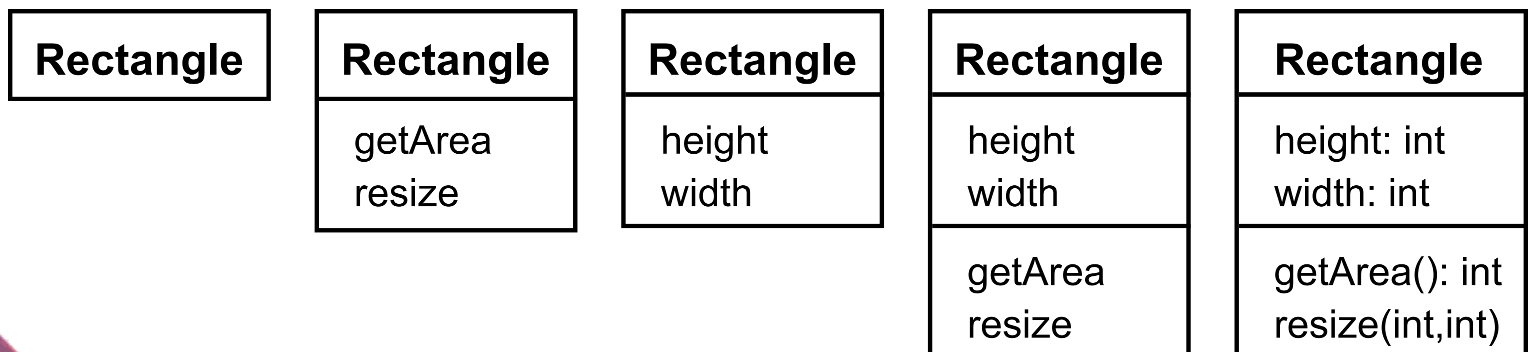
- *Classes*
    - represent the types of data themselves
- *Associations*
    - represent linkages between instances of classes
- *Attributes*
    - are simple data found in classes and their instances
- *Operations*
    - represent the functions performed by the classes and their instances
- *Generalizations*
    - group classes into inheritance hierarchies

Classes

A class is simply represented as a box with the name of the class inside

- The diagram may also show the attributes and operations
- The complete signature of an operation is:

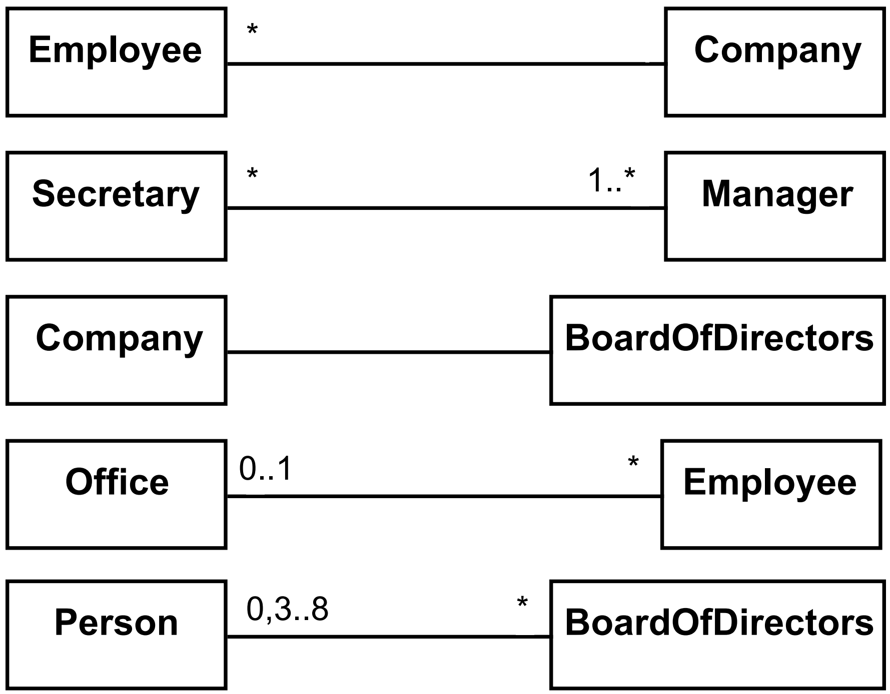
  operationName(parameterName: parameterType …): returnType



5.3 Associations and Multiplicity

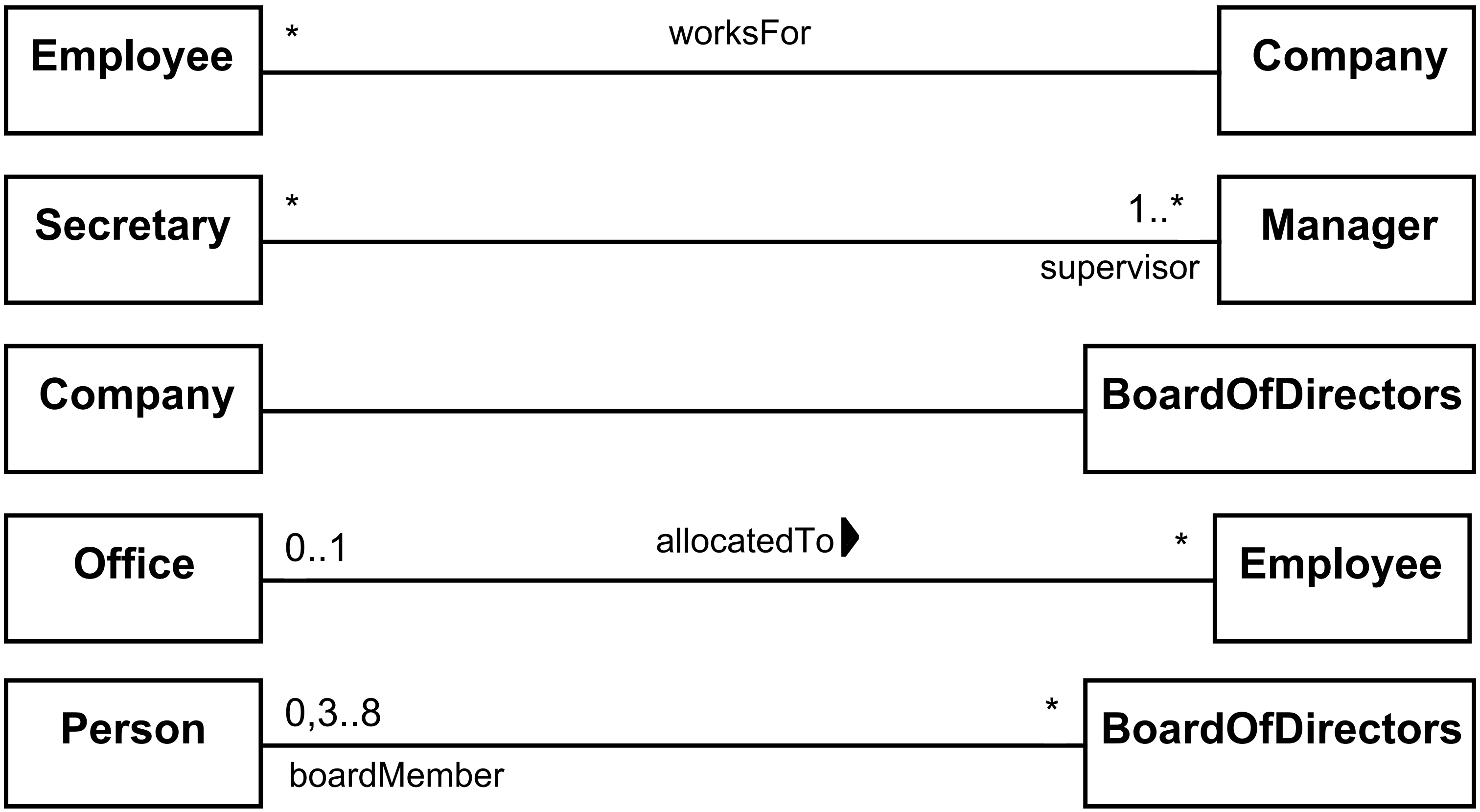
An *association* is used to show how two classes are related to each other

- Symbols indicating *multiplicity* are shown at each end of the association



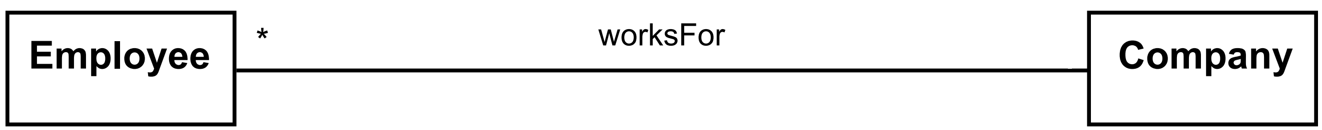
Labelling associations

- Each association can be labelled, to make explicit the nature of the association



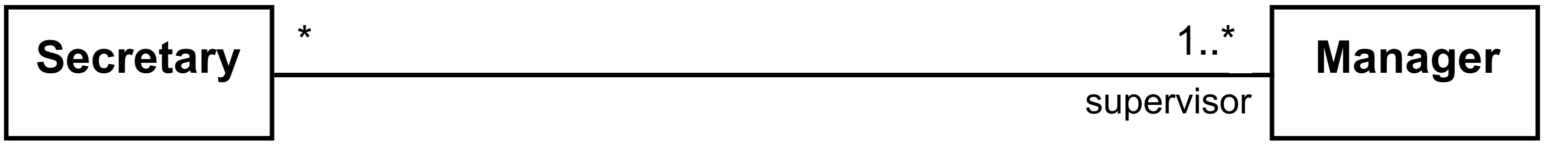
Analyzing and validating associations

- **Many-to-one**
  - A company has many employees,
  - An employee can only work for one company.
    - This company will not store data about the moonlighting activities of employees!
  - A company can have zero employees
    - E.g. a 'shell' company
  - It is not possible to be an employee unless you work for a company



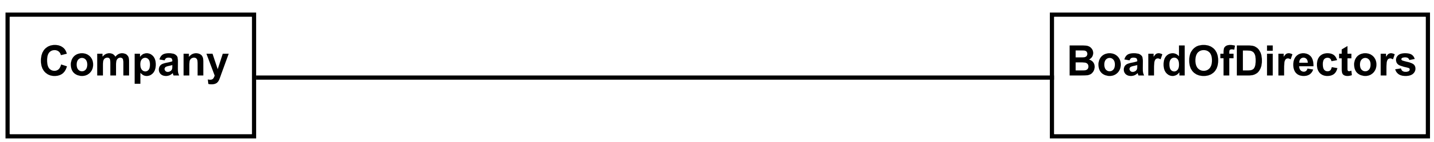
Analyzing and validating associations

- **Many-to-many**
  - A secretary can work for many managers
  - A manager can have many secretaries
  - Secretaries can work in pools
  - Managers can have a group of secretaries
  - Some managers might have zero secretaries.
  - Is it possible for a secretary to have, perhaps temporarily, zero managers?



Analyzing and validating associations

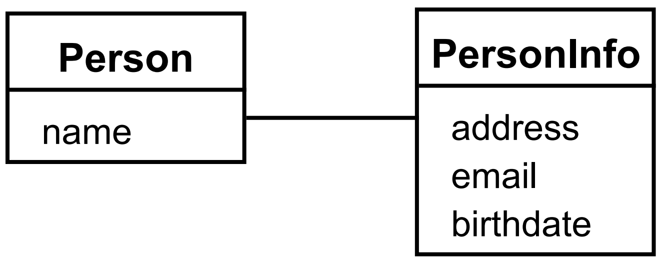
- **One-to-one**
  - For each company, there is exactly one board of directors
  - A board is the board of only one company
  - A company must always have a board
  - A board must always be of some company

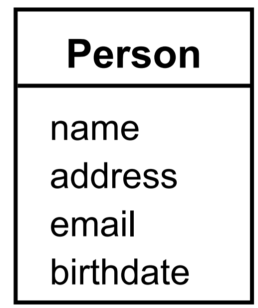


Analyzing and validating associations

Avoid unnecessary one-to-one associations

Avoid this **do this**



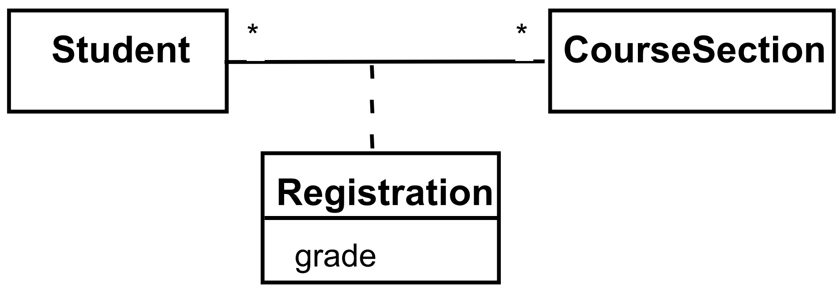


A more complex example

- A booking is always for exactly one passenger
  - no booking with zero passengers
  - a booking could *never* involve more than one passenger.
- A Passenger can have any number of Bookings
  - a passenger could have no bookings at all
  - a passenger could have more than one booking

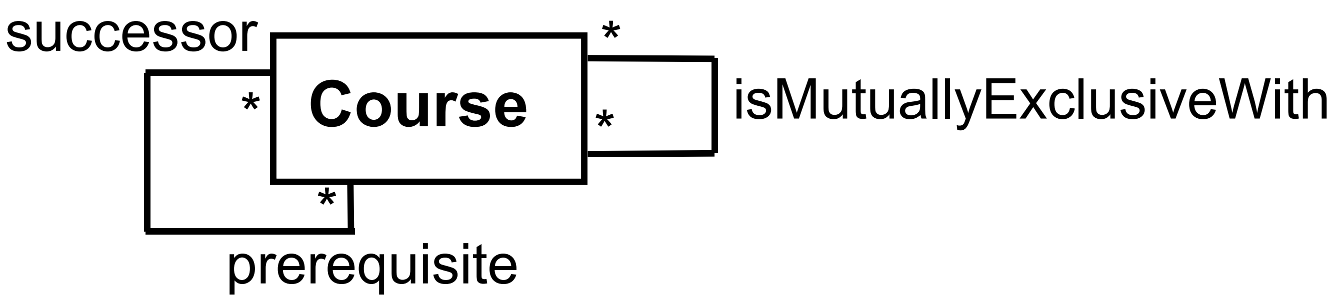
Association classes

- Sometimes, an attribute that concerns two associated classes cannot be placed in either of the classes
- The following are equivalent



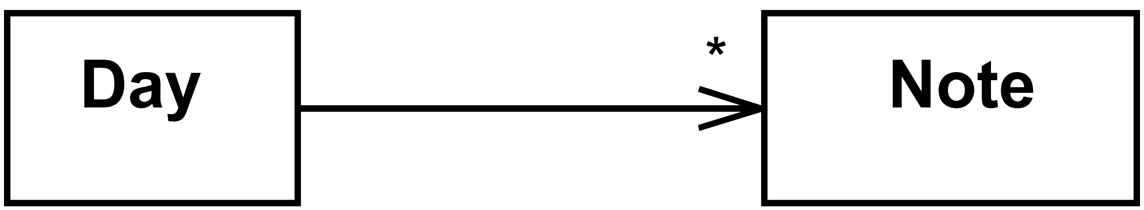
Reflexive associations

- It is possible for an association to connect a class to itself



Directionality in associations

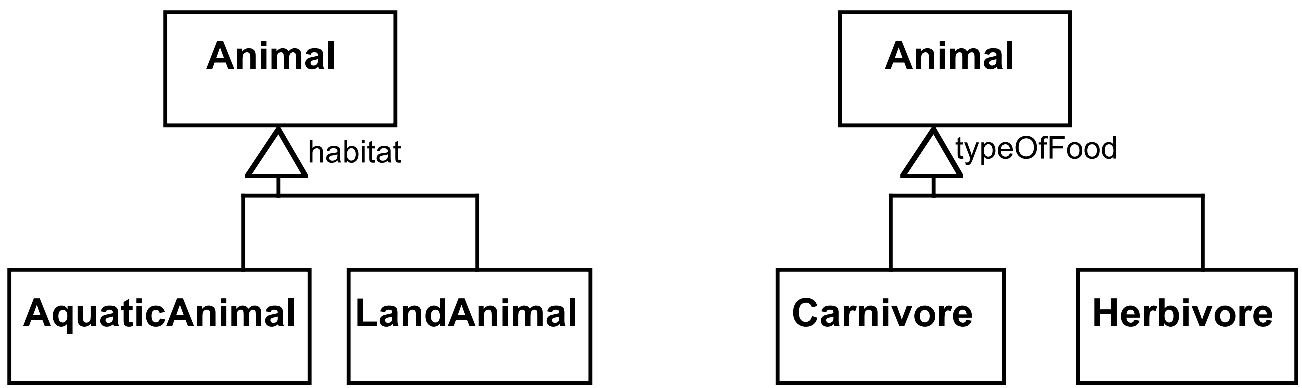
- Associations are by default *bi-directional*
- It is possible to limit the direction of an association by adding an arrow at one end



5.4 Generalization

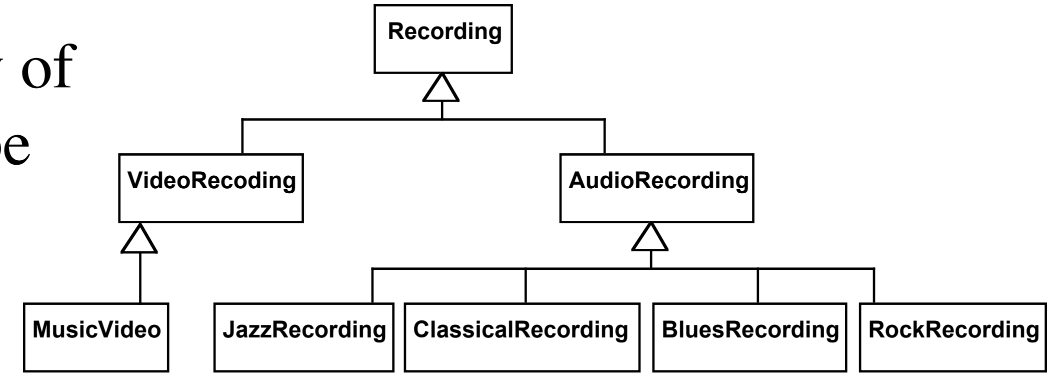
Specializing a superclass into two or more subclasses

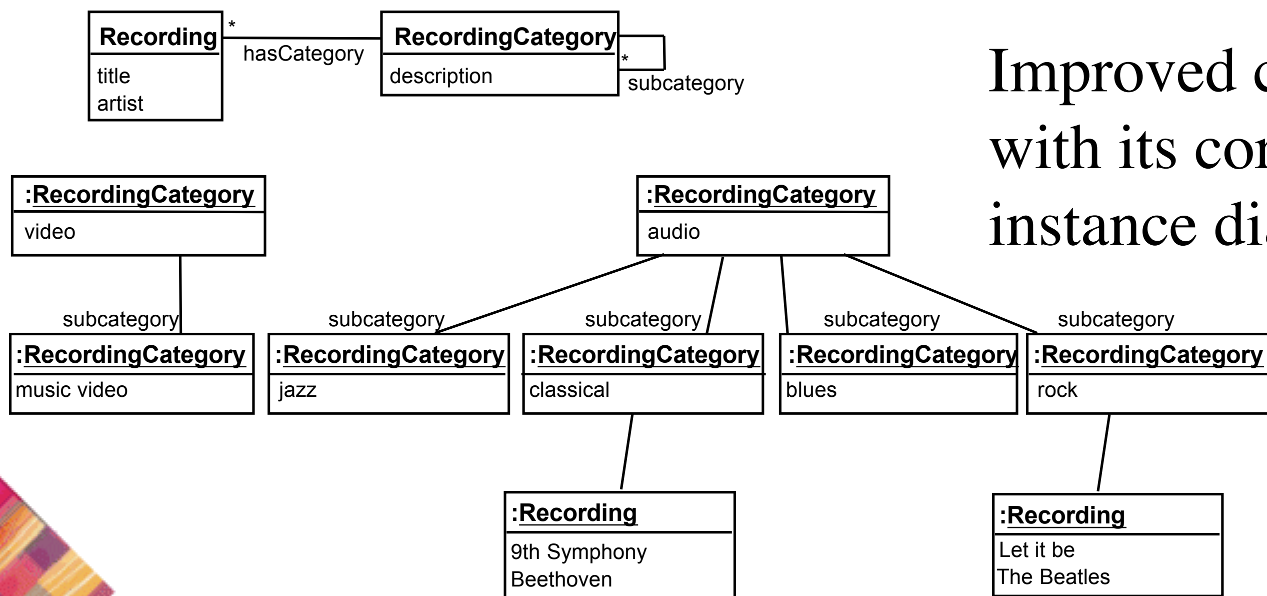
- The *discriminator* is a label that describes the criteria used in the specialization



Avoiding unnecessary generalizations

Inappropriate hierarchy of classes, which should be instances

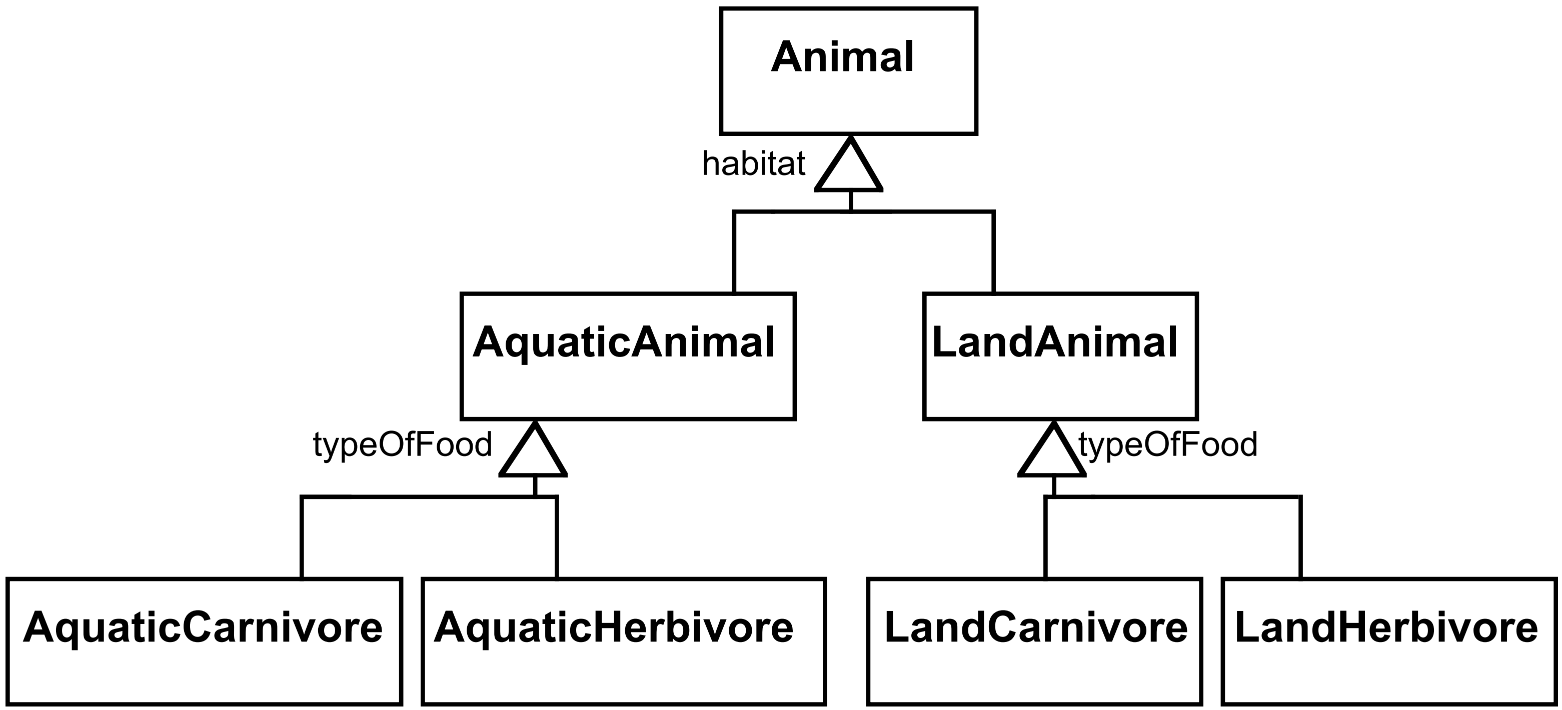




Improved class diagram, with its corresponding instance diagram

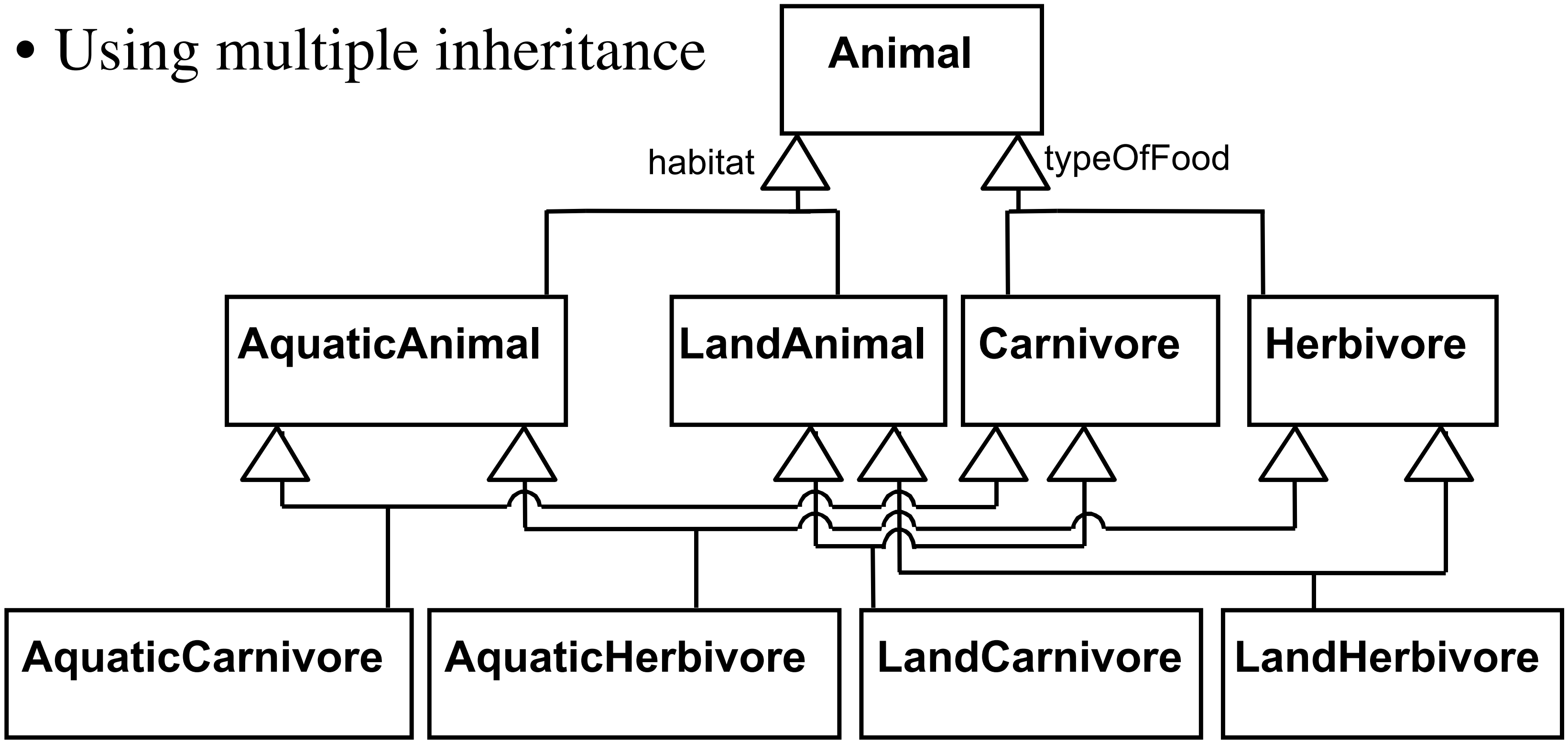
Handling multiple discriminators

- Creating higher-level generalization



Handling multiple discriminators

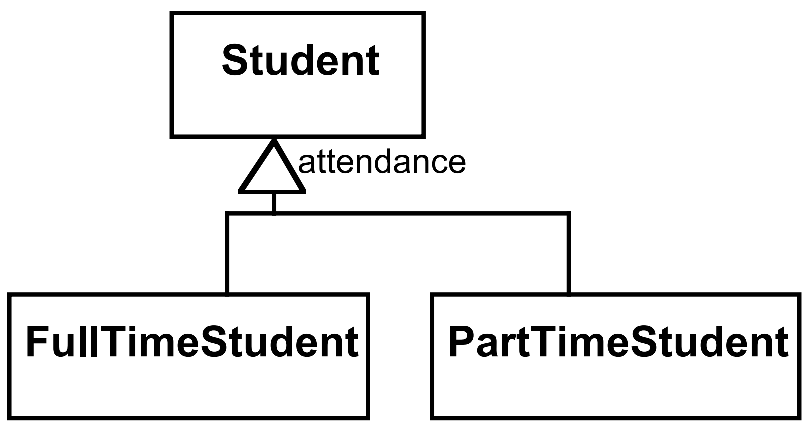
- Using multiple inheritance



- Using the Player-Role pattern (in Chapter 6)

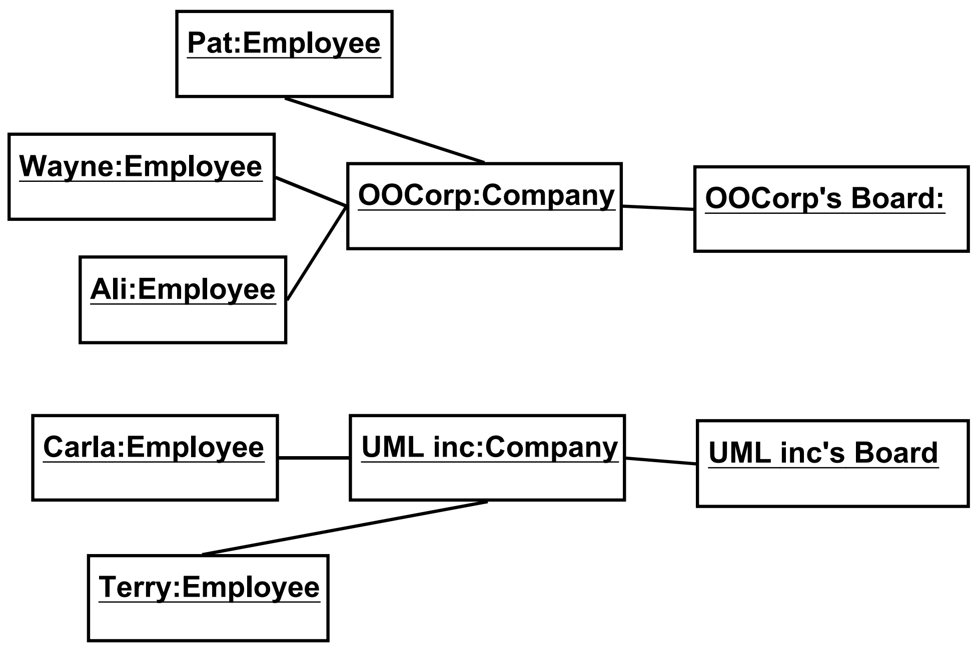
Avoiding having instances change class

- An instance should never need to change class



5.5 Instance Diagrams

- A *link* is an instance of an association
  - In the same way that we say an object is an instance of a class



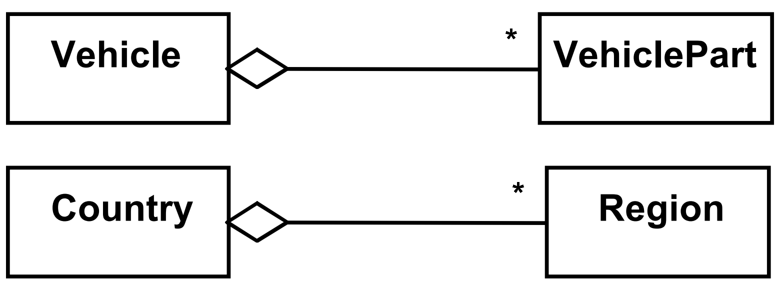
Associations versus generalizations in instance diagrams

- Associations describe the relationships that will exist between *instances* at run time.
  - When you show an instance diagram generated from a class diagram, there will be an instance of *both* classes joined by an association

- Generalizations describe relationships between *classes* in class diagrams.
  - They do not appear in instance diagrams at all.
  - An instance of any class should also be considered to be an instance of each of that class's superclasses

5.6 More Advanced Features: Aggregation

- Aggregations are special associations that represent 'part-whole' relationships.
  - The 'whole' side is often called the *assembly* or the *aggregate*
  - This symbol is a shorthand notation association named `isPartOf`



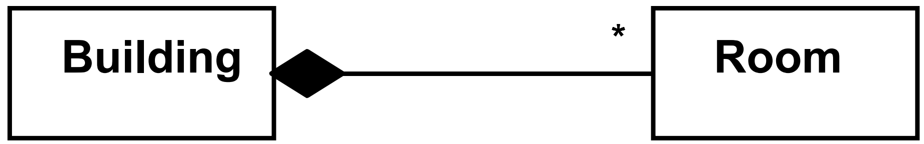
When to use an aggregation

As a general rule, you can mark an association as an aggregation if the following are true:

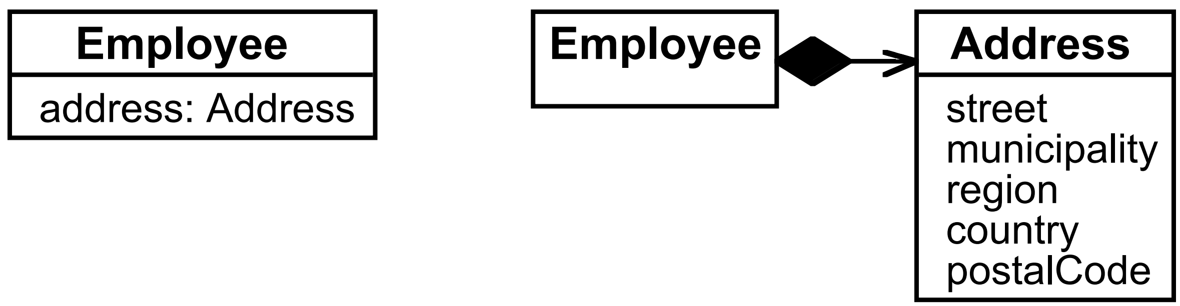
- You can state that
  - the parts 'are part of' the aggregate
  - or the aggregate 'is composed of' the parts
- When something owns or controls the aggregate, then they also own or control the parts

Composition

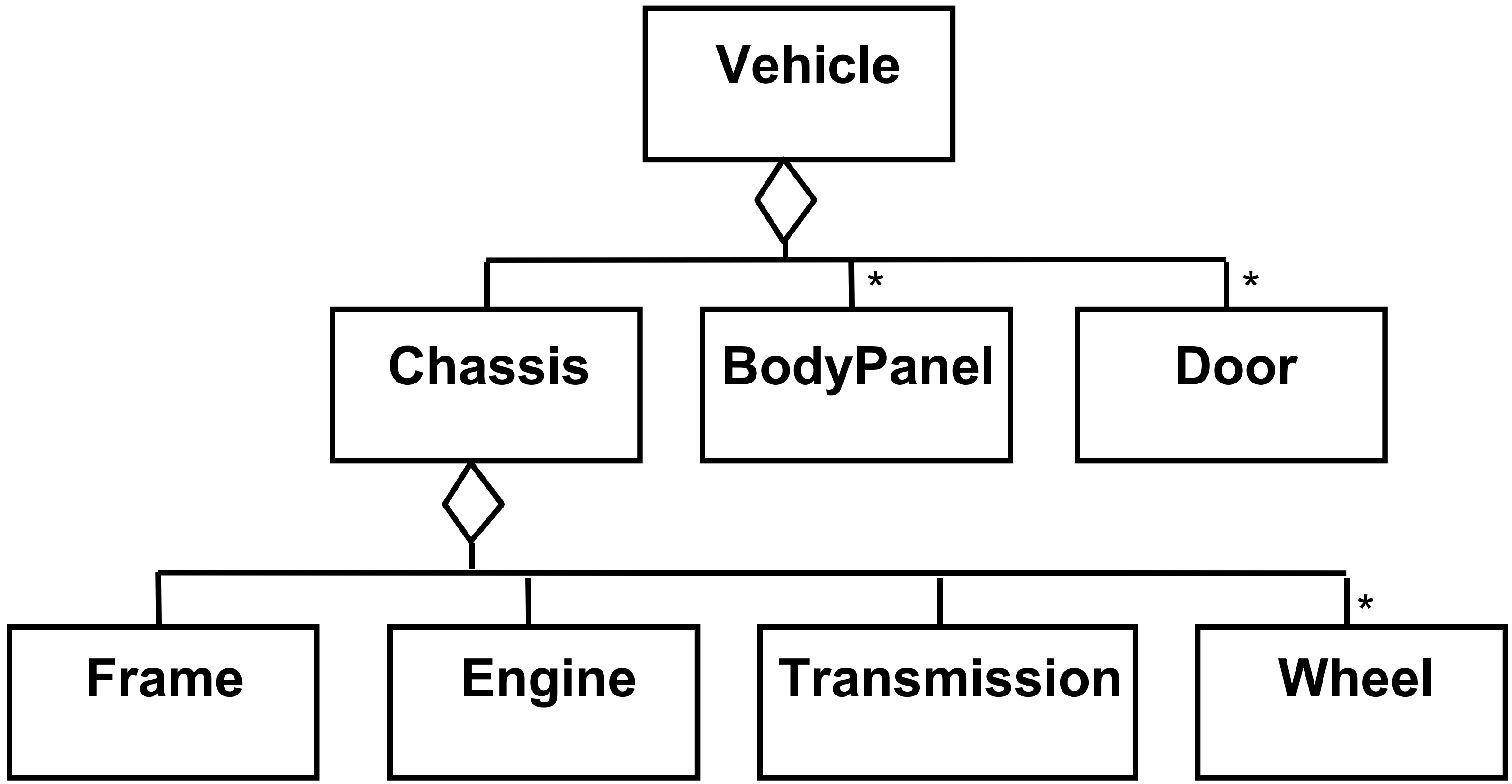
- A *composition* is a strong kind of aggregation
  - if the aggregate is destroyed, then the parts are destroyed as well



- Two alternatives for addresses

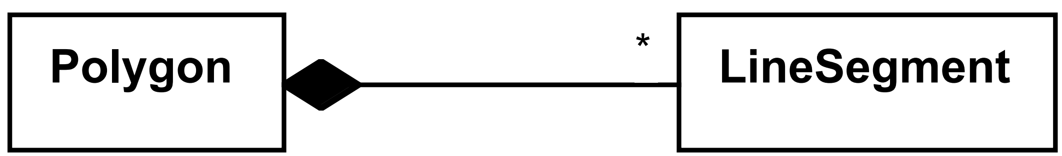


Aggregation hierarchy



Propagation

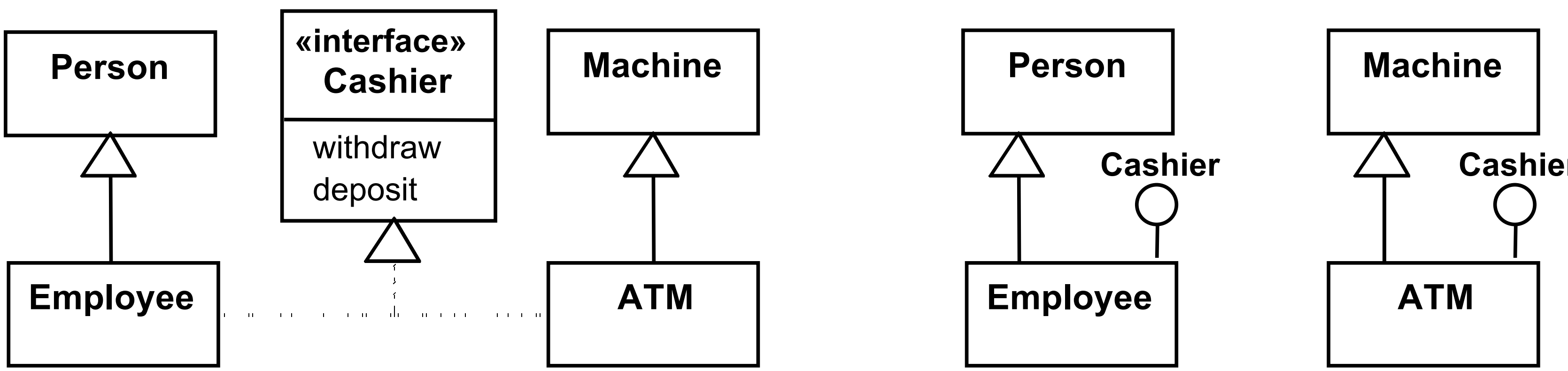
- A mechanism where an operation in an aggregate is implemented by having the aggregate perform that operation on its parts
- At the same time, properties of the parts are often propagated back to the aggregate
- Propagation is to aggregation as inheritance is to generalization.
    - The major difference is:
        - inheritance is an implicit mechanism
        - propagation has to be programmed when required



Interfaces

An interface describes a *portion of the visible behaviour* of a set of objects.

- An *interface* is similar to a class, except it lacks instance variables and implemented methods



Notes and descriptive text

- **Descriptive text and other diagrams**
  - Embed your diagrams in a larger document
  - Text can explain aspects of the system using any notation you like
  - Highlight and expand on important features, and give rationale
- **Notes**:
  - A note is a small block of text embedded *in* a UML diagram
  - It acts like a comment in a programming language

Object Constraint Language (OCL)

OCL is a *specification* language designed to formally specify constraints in software modules

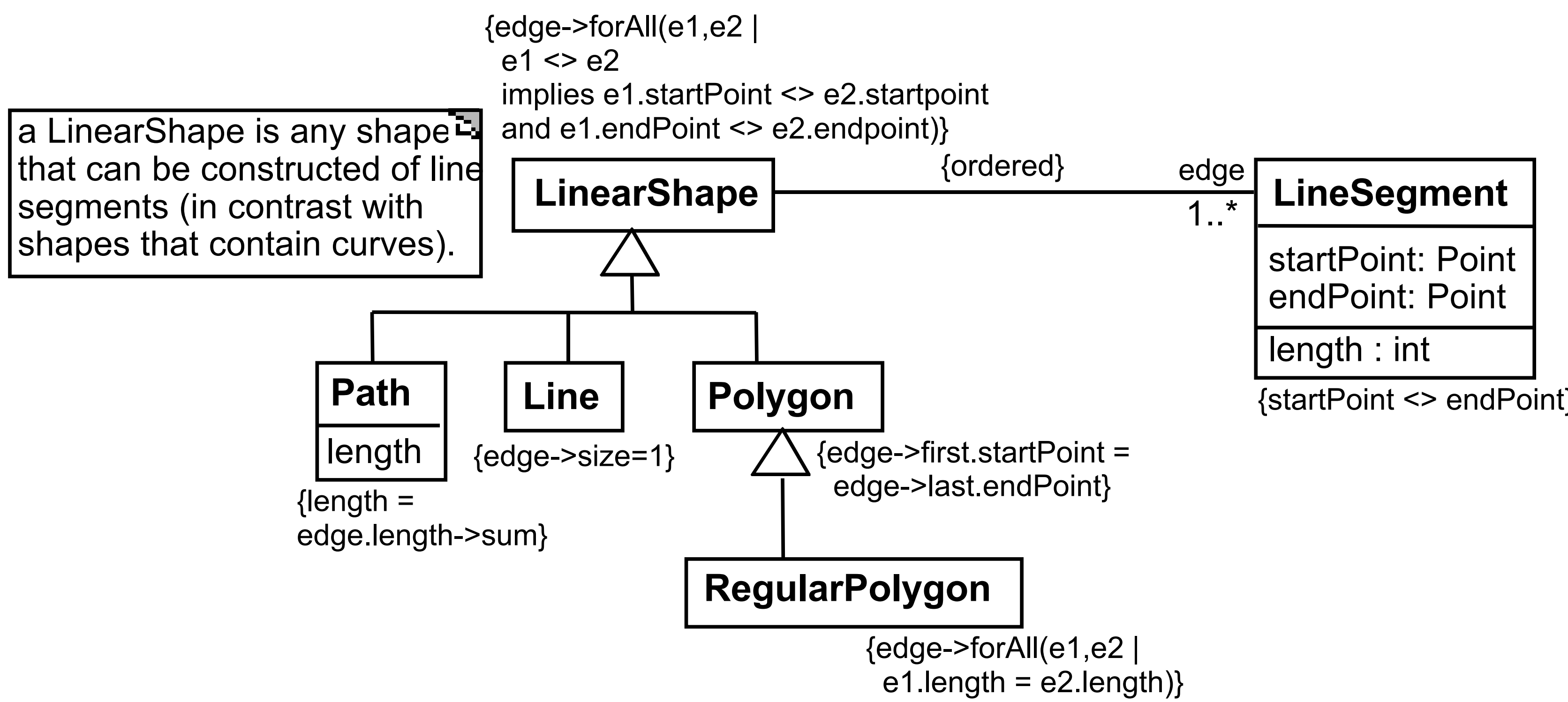
- An OCL expression simply specifies a logical fact (a constraint) about the system that must remain **true**
- A constraint cannot have any side-effects
  - it cannot compute a non-Boolean result nor modify any data.
- OCL statements in class diagrams can specify what the values of attributes and associations must be

OCL statements

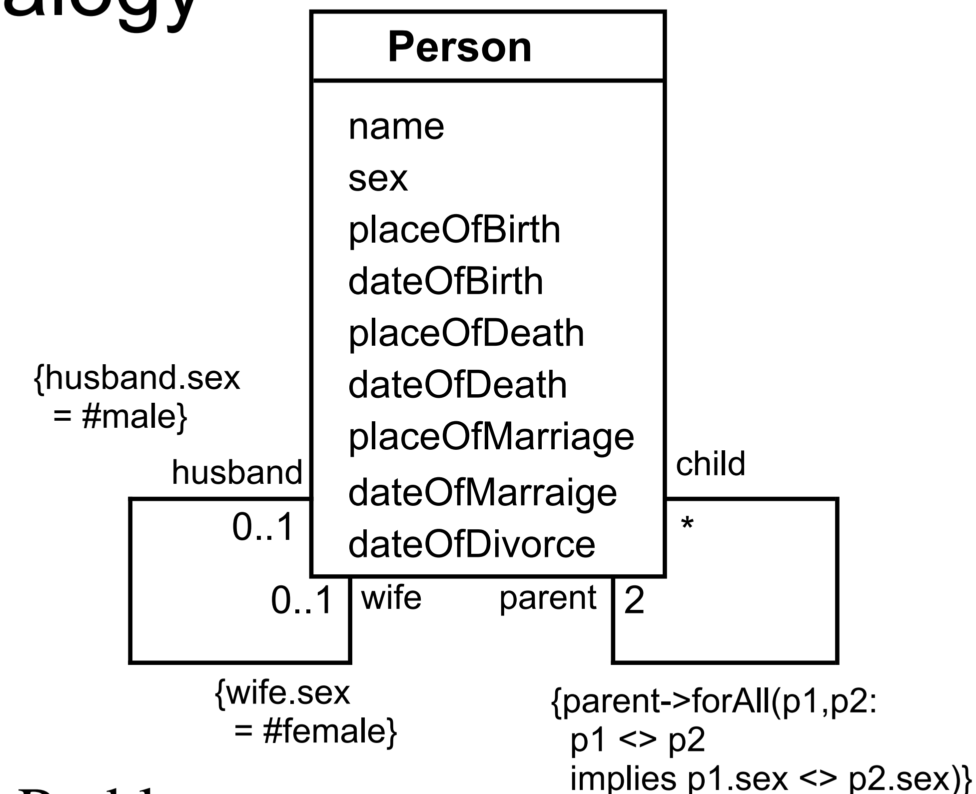
OCL statements can be built from:

- References to role names, association names, attributes and the results of operations
- The logical values **true** and **false**
- Logical operators such as **and**, **or**, **=**, **>**, **<** or **<>** (not equals)
- String values such as: **'a string'**
- Integers and real numbers
- Arithmetic operations *****, **/**, **+**, **-**

An example: constraints on Polygons

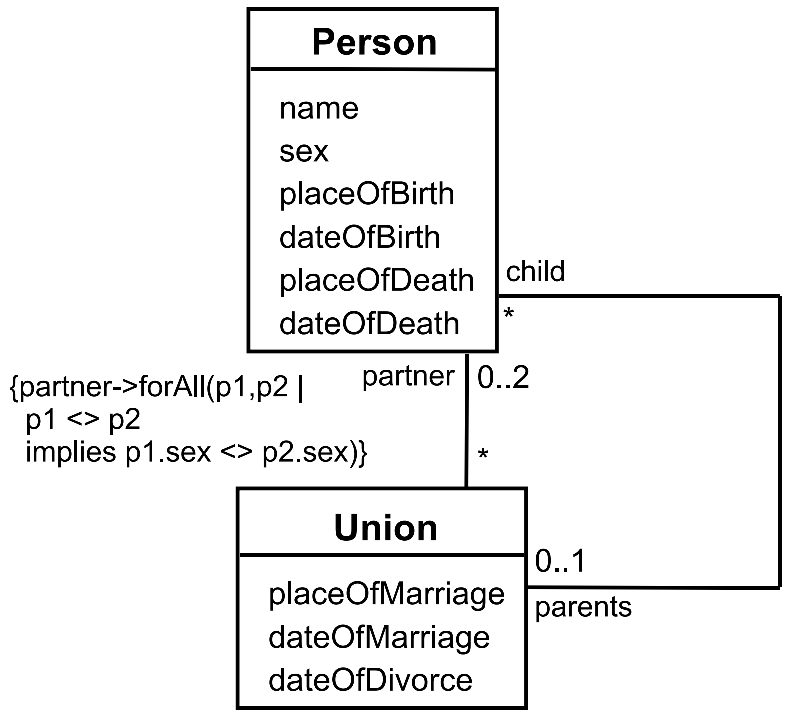


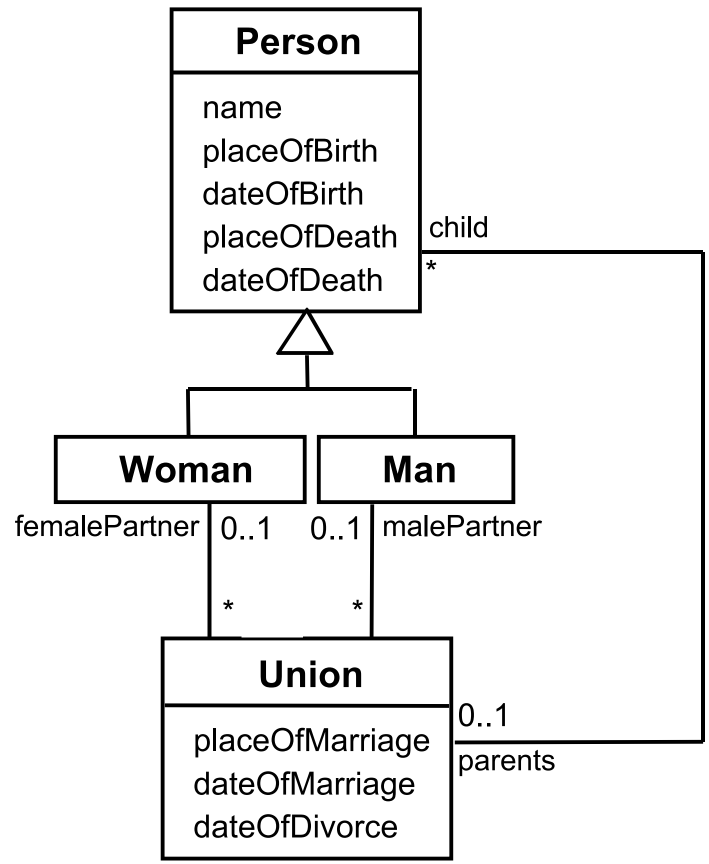
5.7 Detailed Example: A Class Diagram for Genealogy



- Problems
  - A person must have two parents
  - Marriages not properly accounted for

Genealogy example: Possible solutions





5.8 The Process of Developing Class Diagrams

You can create UML models at different stages and with different purposes and levels of details

- **Exploratory domain model**:
  - Developed in domain analysis to learn about the domain
- **System domain model**:
  - Models aspects of the domain represented by the system
- **System model**:
  - Includes also classes used to build the user interface and system architecture

System domain model vs System model

- The *system domain model* omits many classes that are needed to build a complete system
  - Can contain less than half the classes of the system.
  - Should be developed to be used independently of particular sets of
    - user interface classes
    - architectural classes
- The complete *system model* includes
  - The system domain model
  - User interface classes
  - Architectural classes
  - Utility classes

Suggested sequence of activities

- Identify a first set of candidate **classes**
- Add **associations** and **attributes**
- Find **generalizations**
- List the main **responsibilities** of each class
- Decide on specific **operations**
- **Iterate** over the entire process until the model is satisfactory
  - Add or delete classes, associations, attributes, generalizations, responsibilities or operations
  - Identify interfaces
  - Apply design patterns (Chapter 6)

Don't be too disorganized. Don't be too rigid either.

Identifying classes

- When developing a domain model you tend to *discover* classes
- When you work on the user interface or the system architecture, you tend to *invent* classes
  - Needed to solve a particular design problem
  - (Inventing may also occur when creating a domain model)
- Reuse should always be a concern
  - Frameworks
  - System extensions
  - Similar systems

A simple technique for discovering domain classes

- Look at a source material such as a description of requirements
- Extract the *nouns* and *noun phrases*
- Eliminate nouns that:
  - —are redundant
  - —represent instances
  - —are vague or highly general
  - —not needed in the application
- Pay attention to classes in a domain model that represent *types of users* or other actors

Identifying associations and attributes

- Start with classes you think are most **central** and important
- Decide on the clear and obvious data it must contain and its relationships to other classes.
- Work outwards towards the classes that are less important.
- Avoid adding many associations and attributes to a class
  - A system is simpler if it manipulates less information

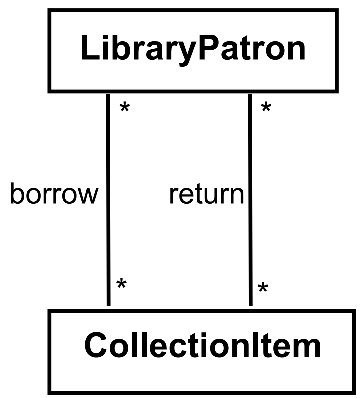
Tips about identifying and specifying valid associations

- An association should exist if a class
    - *possesses*
    - *controls*
    - *is connected to*
    - *is related to*
    - *is a part of*
    - *has as parts*
    - *is a member of*, or
    - *has as members*

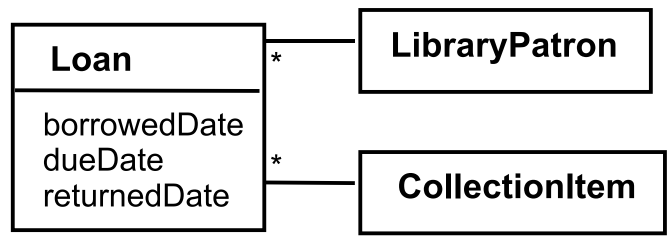
  some other class in your model
- Specify the multiplicity at both ends
- Label it clearly.

Actions versus associations

- A common mistake is to represent *actions* as if they were associations



Bad, due to the use of associations that are actions



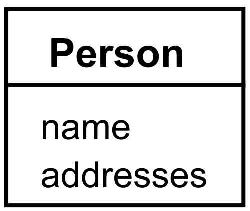
Better: The **`borrow`** operation creates a **`Loan`**, and the **`return`** operation sets the **`returnedDate`** attribute.

Identifying attributes

- Look for information that must be maintained about each class
- Several nouns rejected as classes, may now become attributes
- An attribute should generally contain a simple value
  - E.g. string, number

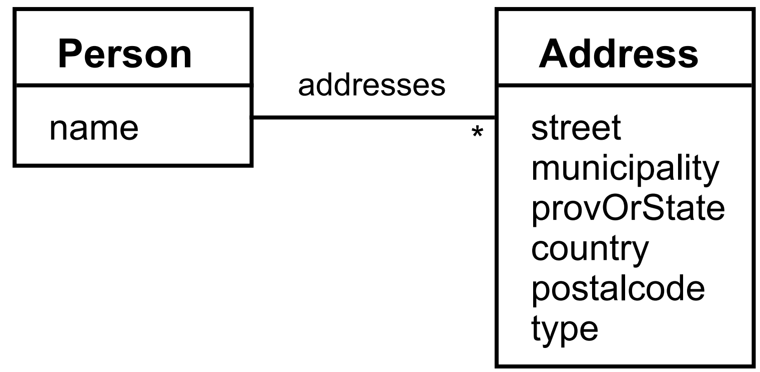
Tips about identifying and specifying valid attributes

- It is not good to have many duplicate attributes
- If a subset of a class's attributes form a coherent group, then create a distinct class containing these attributes



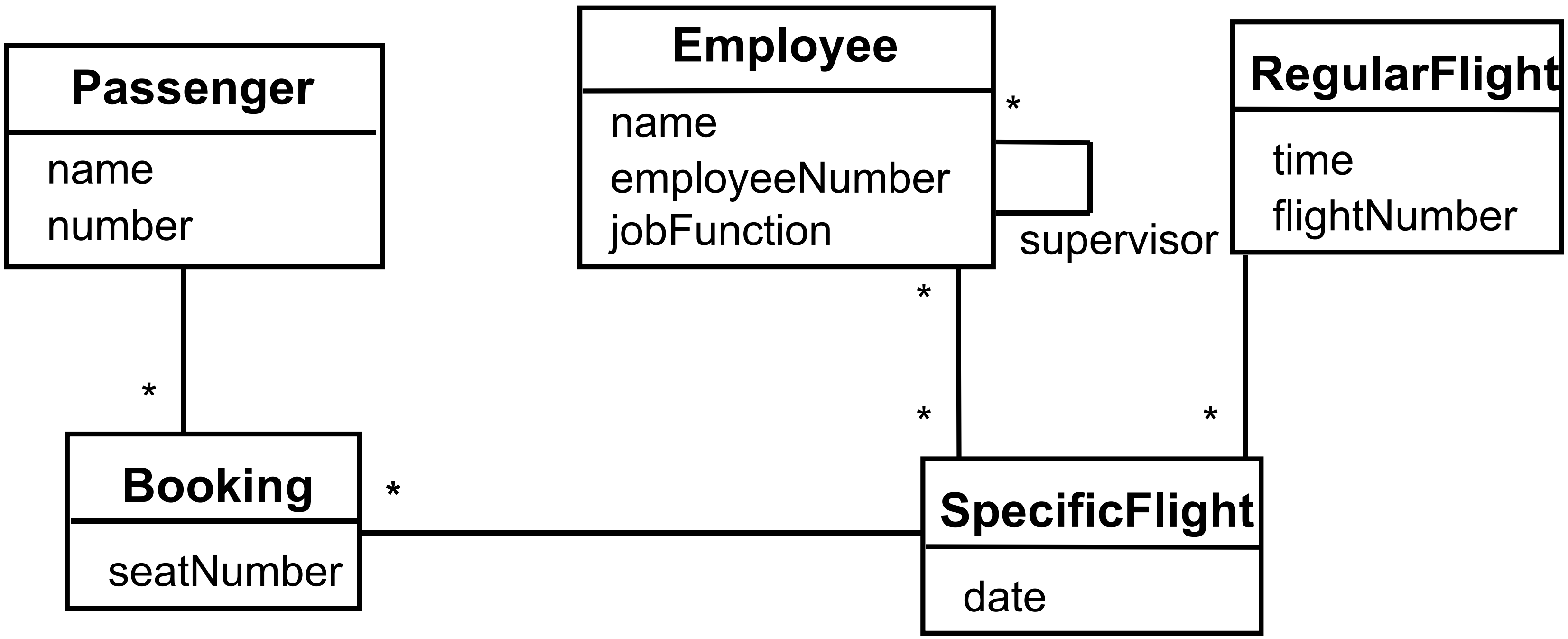
Bad due to a plural attribute

Bad due to too many attributes, and inability to add more addresses



Good solution. The type indicates whether it is a home address, business address etc.

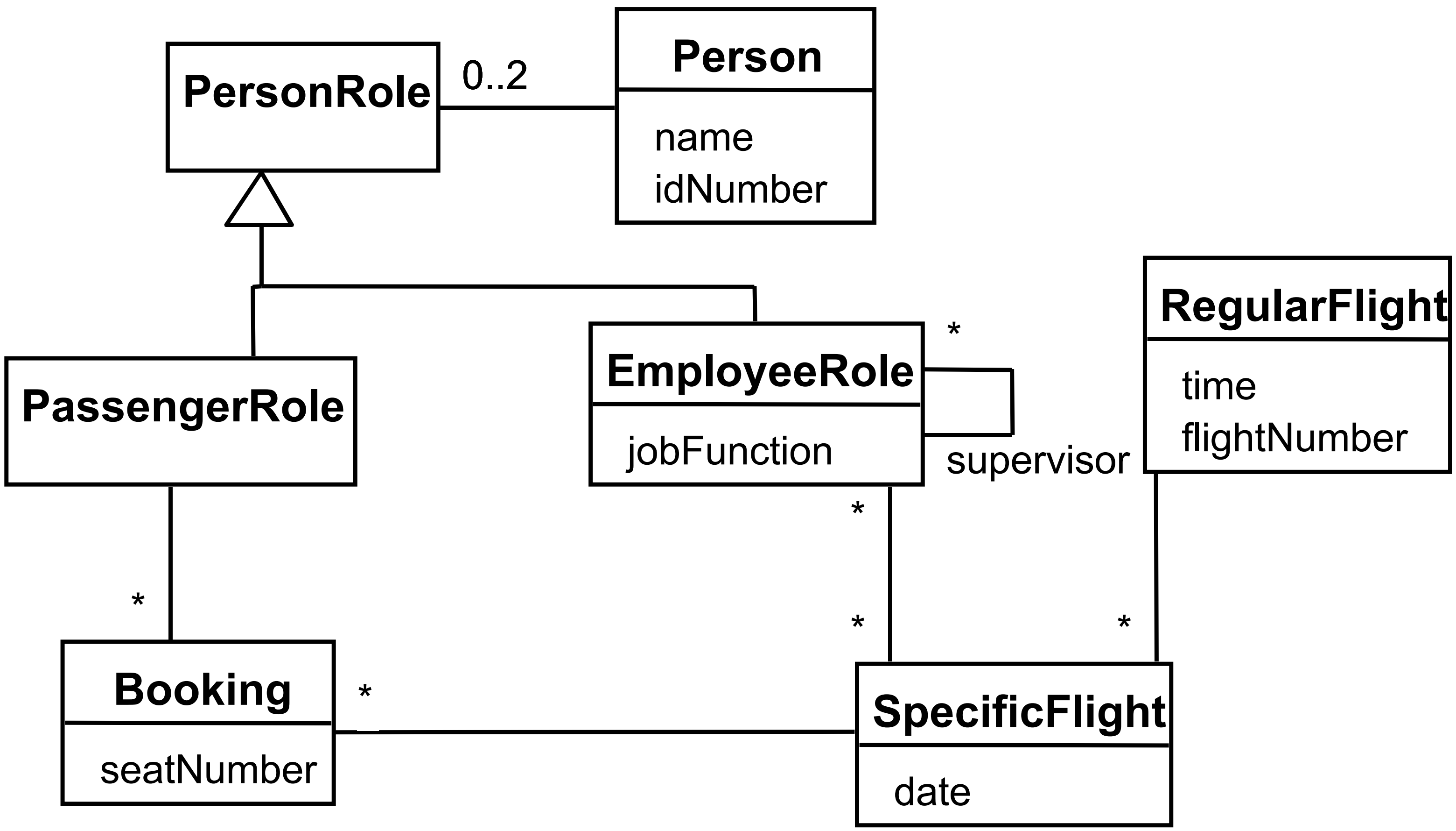
An example (attributes and associations)



Identifying generalizations and interfaces

- There are two ways to identify generalizations:
  - bottom-up
    - Group together similar classes creating a new superclass
  - top-down
    - Look for more general classes first, specialize them if needed
- Create an *interface*, instead of a superclass if
  - The classes are very dissimilar except for having a few operations in common
  - One or more of the classes already have their own superclasses
  - Different implementations of the same class might be available

An example (generalization)



Allocating responsibilities to classes

A *responsibility* is something that the system is required to do.

- Each functional requirement must be attributed to one of the classes
  - All the responsibilities of a given class should be *clearly related*.
  - If a class has too many responsibilities, consider *splitting* it into distinct classes
  - If a class has no responsibilities attached to it, then it is probably *useless*
  - When a responsibility cannot be attributed to any of the existing classes, then a *new class* should be created

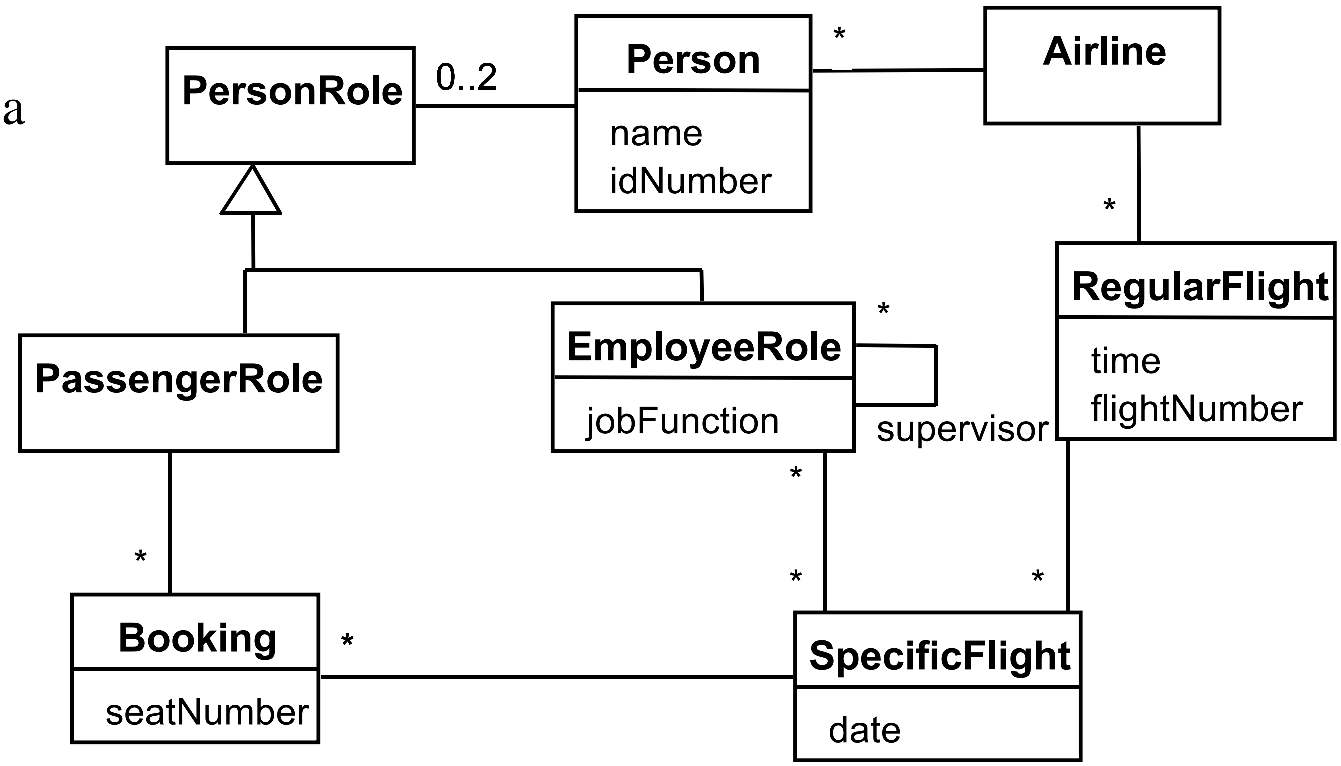
- To determine responsibilities
  - Perform use case analysis
  - Look for verbs and nouns describing *actions* in the system description

Categories of responsibilities

- Setting and getting the values of attributes
- Creating and initializing new instances
- Loading to and saving from persistent storage
- Destroying instances
- Adding and deleting links of associations
- Copying, converting, transforming, transmitting or outputting
- Computing numerical results
- Navigating and searching
- Other specialized work

An example (responsibilities)

- Creating a new regular flight
- Searching for a flight
- Modifying attributes of a flight
- Creating a specific flight
- Booking a passenger
- Canceling a booking



Prototyping a class diagram on paper

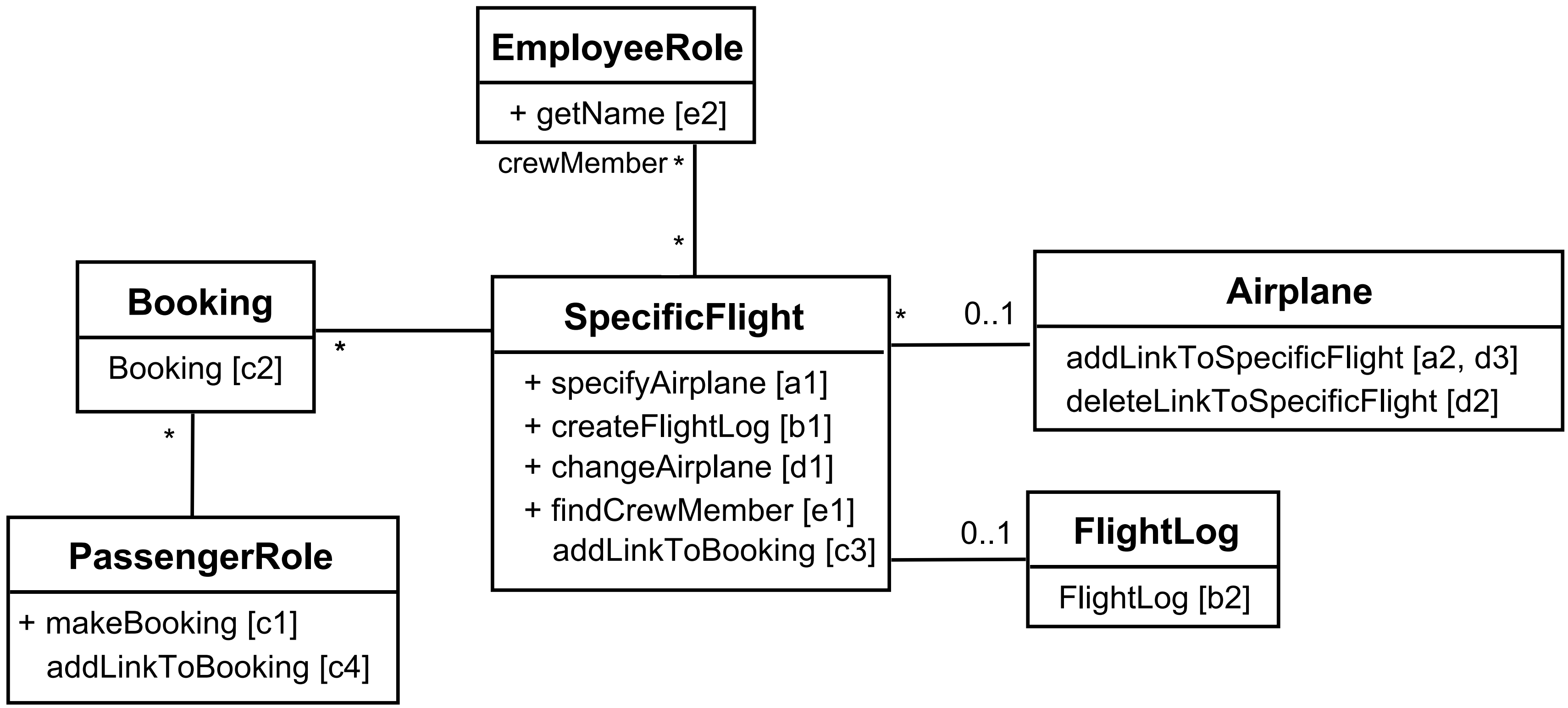
- As you identify classes, you write their names on small cards
- As you identify attributes and responsibilities, you list them on the cards
  — If you cannot fit all the responsibilities on one card:
    - this suggests you should split the class into two related classes.
- Move the cards around on a whiteboard to arrange them into a class diagram.
- Draw lines among the cards to represent associations and generalizations.

Identifying operations

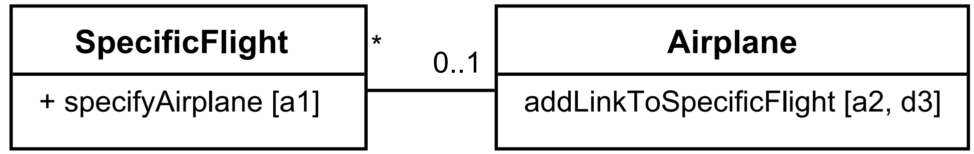
Operations are needed to realize the responsibilities of each class

- There may be several operations per responsibility
- The main operations that implement a responsibility are normally declared `public`
- Other methods that collaborate to perform the responsibility must be as private as possible

An example (class collaboration)



Class collaboration ‘a’

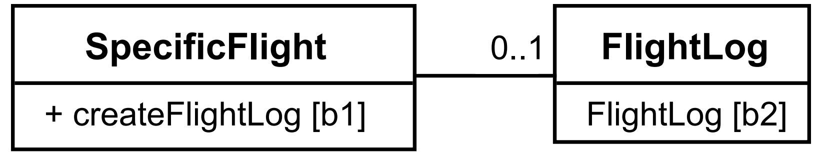


Making a bi-directional link between two existing objects;

e.g. adding a link between an instance of **`SpecificFlight`** and an instance of **`Airplane`**.

1. (public) The instance of **`SpecificFlight`**
   — **makes a one-directional link to the instance of** `Airplane`
   — **then calls operation 2.**
2. (non-public) The instance of **`Airplane`**
   — **makes a one-directional link back to the instance of** `SpecificFlight`

Class collaboration 'b'



Creating an object and linking it to an existing object

e.g. creating a **`FlightLog`**, and linking it to a **`SpecificFlight`**.

□

1. (public) The instance of **`SpecificFlight`**
   - **calls the constructor of `FlightLog` (operation 2)**
   - **then makes a one-directional link to the new instance of `FlightLog`.**
2. (non-public) Class **`FlightLog`**'s constructor
   - **makes a one-directional link back to the instance of `SpecificFlight`.**

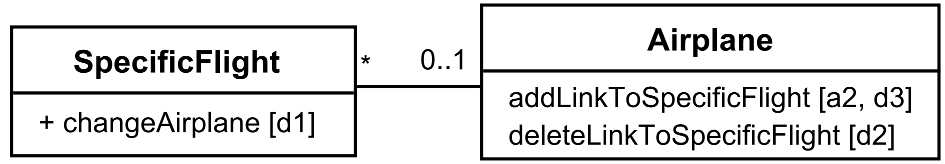
Class collaboration ‘c’

Creating an association class, given two existing objects

e.g. creating an instance of **`Booking`**, which will link a **`SpecificFlight`** to a **`PassengerRole`**.

1. (public) The instance of **`PassengerRole`**
   — calls the constructor of **`Booking`** (operation 2).
2. (non-public) Class **`Booking`**’s constructor, among its other actions
   — makes a one-directional link back to the instance of **`PassengerRole`**
   — makes a one-directional link to the instance of **`SpecificFlight`**
   — calls operations 3 and 4.
3. (non-public) The instance of **`SpecificFlight`**
   — makes a one-directional link to the instance of **`Booking`**.
4. (non-public) The instance of **`PassengerRole`**
   — makes a one-directional link to the instance of **`Booking`**.

Class collaboration ‘d’

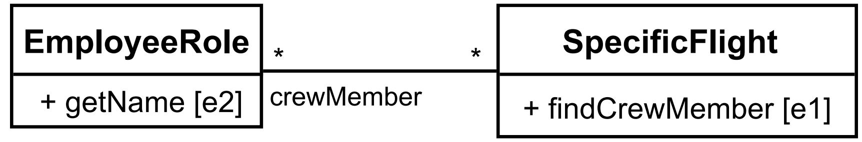


Changing the destination of a link

e.g. changing the **`Airplane`** of to a **`SpecificFlight`**, from **`airplane1`** to **`airplane2`**

1. (public) The instance of **`SpecificFlight`**
   - deletes the link to **`airplane1`**
   - makes a one-directional link to **`airplane2`**
   - calls operation 2
   - then calls operation 3.
2. (non-public) **`airplane1`**
   - deletes its one-directional link to the instance of **`SpecificFlight`**.
3. (non-public) **`airplane2`**
   - makes a one-directional link to the instance of **`SpecificFlight`**.

Class collaboration ‘e’



Searching for an associated instance

e.g. searching for a crew member associated with a **`SpecificFlight`** that has a certain name.

□

1. (public) The instance of **`SpecificFlight`**
   — creates an `Iterator` over all the `crewMember` links of the `SpecificFlight\`
   — for each of them call operation 2, until it finds a match.
2. (may be public) The instance of **`EmployeeRole`** returns its name.

5.9 Implementing Class Diagrams in Java

- Attributes are implemented as instance variables
- Generalizations are implemented using `extends`
- Interfaces are implemented using `implements`
- Associations are normally implemented using instance variables
    - Divide each two-way association into two one-way associations
        — so each associated class has an instance variable.
    - For a one-way association where the multiplicity at the other end is 'one' or 'optional'
        — declare a variable of that class (a reference)
    - For a one-way association where the multiplicity at the other end is 'many':
        — use a collection class implementing `List`, such as `Vector`

Example: **SpecificFlight**

```
class SpecificFlight
{
  private Calendar date;
  private RegularFlight regularFlight;
  private TerminalOfAirport destination;
  private Airplane airplane;
  private FlightLog flightLog;

  private ArrayList crewMembers;
   // of EmployeeRole
  private ArrayList bookings
  ...
}
```

Example: **SpecificFlight**

```
// Constructor that should only be called from
// addSpecificFlight
SpecificFlight(
  Calendar aDate,
  RegularFlight aRegularFlight)
{
  date = aDate;
  regularFlight = aRegularFlight;
}
```

Example: **RegularFlight**

```
class RegularFlight
{
  private ArrayList specificFlights;
  ...
  // Method that has primary
  // responsibility

  public void addSpecificFlight(
    Calendar aDate)
  {
    SpecificFlight newSpecificFlight;
    newSpecificFlight =
      new SpecificFlight(aDate, this);
    specificFlights.add(newSpecificFlight);
  }
  ...
}
```