UML class diagrams

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Using UML

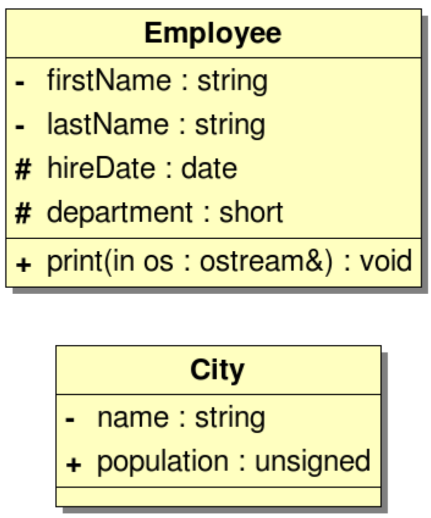
- Goal: Be able to "reason about" a design
  - i.e., understand designer's intent
  - Critique/improve the design
- Claim: Source code not best medium for communication and comprehension
  - Lots of redundancy and detail irrelevant for some program-understanding tasks
  - Especially poor at depicting relationships among classes in OO programs
  - To understand an OO design, one must be able to visualize these relationships
- Solution: Use abstract, visual representations - UML

UML diagrams

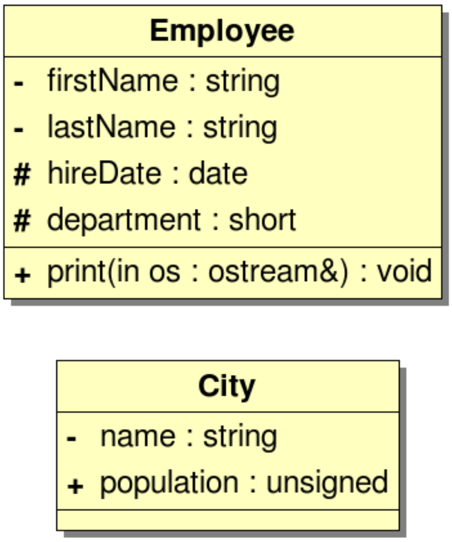
- Collection of notations representing software designs from three points of view:
  - *Class model* describes the static structure of objects and relationships in a system
  - *State model* describes the dynamics aspects of objects and the nature of control in a system
  - *Interaction model* describes how objects in a system cooperate to achieve broader results
- Generally, we need all three models to describe a system
- No single model says everything
- Here we focus on class model

UML Class diagram notation

- Boxes denote classes
- Each box comprises:
  - Class name
  - List of data attributes
  - List of operations
- More compact than code and more amenable to depicting relationship among classes



Notation



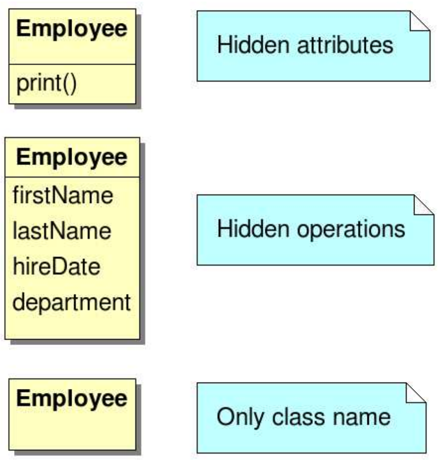
Visibility:

- \- is private
- # is protected
- \+ is public

Specification

- member type follows definition
- parameter type follow name
- optionally, can specify parameter direction (in/out)

Abstraction in class diagrams

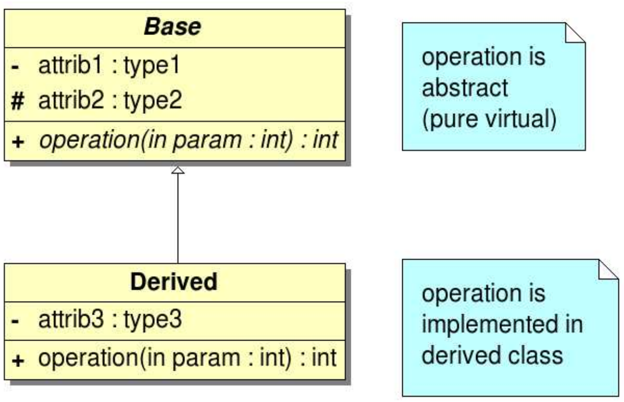


- Class diagrams often elide details
  - Method associated with an operation
  - Attribute and operations may be hidden in diagrams to improve readability
    - even if they exist in C++ code

Relationships between classes

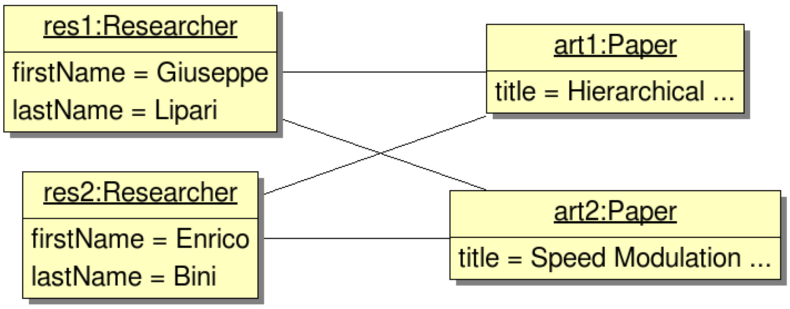
- Two classes can be related by:
  - Inheritance
  - Association
  - Aggregation
  - Composition

Inheritance



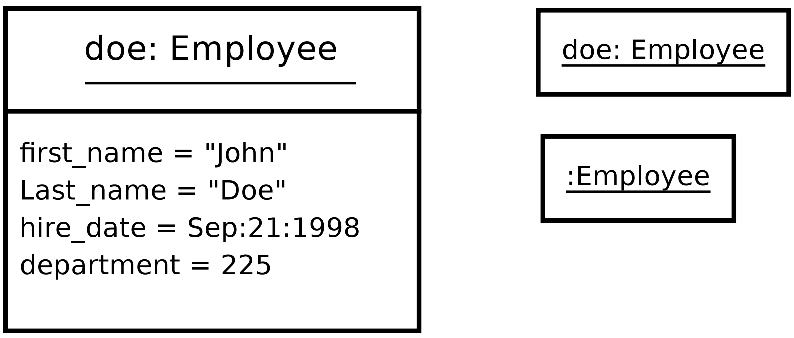
- `DerivedClass` is derived from `BaseClass`
- `BaseClass` class has an abstract method (in italic)
  - *operation()* is a pure virtual method
- `DerivedClass` implements the virtual method

Object notation



- Notes:
  - The UML symbol for an object is a box with an object name followed by a colon and the class name. The object name and class name are both underlined.
  - Attribute values and the object name are optional.
  - Only list attributes that have intrinsic meaning. Attributes of computer artifacts (such as pointers) should not be listed.

Example



- We can also remove the member values, and even the object name

Associations - II

- A Link is represented as a line connecting two or more object boxes
- It can be shown on an object diagram or class diagram.
- A link is an instance of an association

A More formal distinction

- Value: Primitive “piece of data”
  - E.g., the number 17, the string “Canada”
  - Unlike objects, values lack identity
- Object: Meaningful concept or “thing” in an application domain
  - Often appears as a proper noun or specific reference in discussions with users.
  - May be attributed with values
  - Has identity
- Two objects containing the “same values” are not the same object!
  - They are distinct objects
  - They may be considered “equivalent” under a certain definition of “equality”

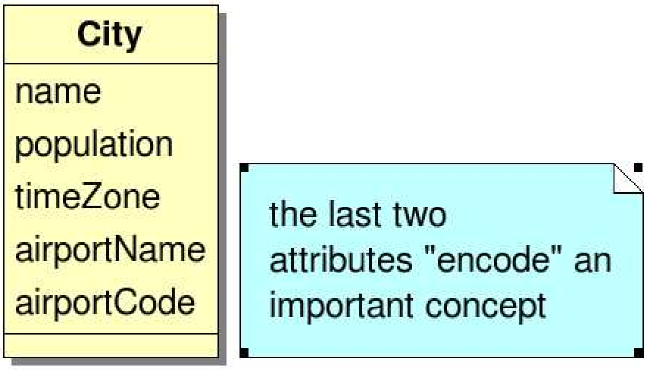
What's the big deal about identity?

- Useful in reasoning about "goodness" of a design
  - Many poor designs result from an "encoding" of one object within another, using attribute values
  - By reasoning about identity, one may identify such a design flaw early
  - Best illustrated by example
- Also allows us to model relationships among objects and classes more explicitly

Exercise: Travel-planning system

- A city has a name, a certain population, and a specific time zone
- A city has one or more airports
- An airport has a name and a unique code
- How many classes should you design?

Is this design correct?



- These attributes are “hiding” an object (the airport) that is meaningful by itself in this domain
- Why it might be bad to encode one object as a collection of attribute values within another?

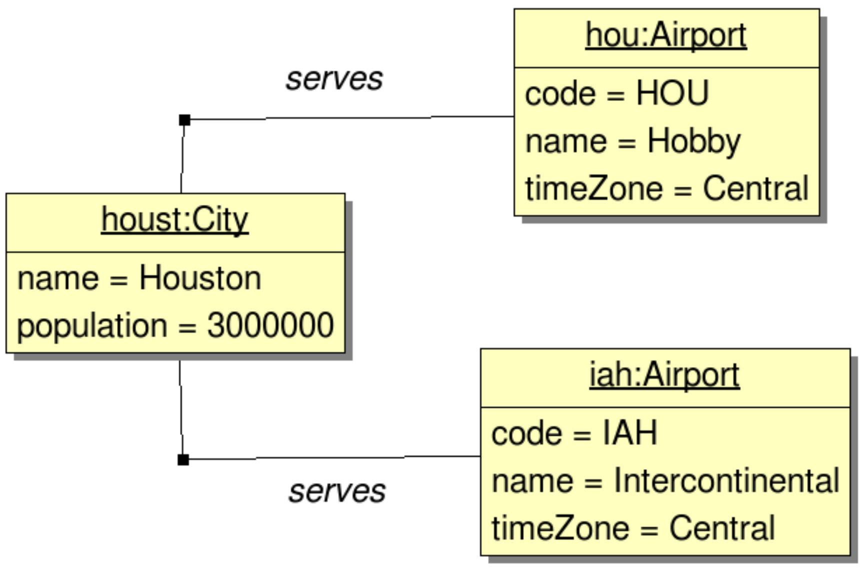
Design tip

- Answer:
  - Potential for redundancy/inconsistency due to duplication
    - some airports serve multiple cities
    - some cities served by no airports
    - some cities served by multiple airports
  - Operations over Airport objects may not need to know details associated with cities, such as population
- When designing a class:
  - Apply the identity test to each attribute (including attributes in combination)
  - Never use an attribute to model an “object identifier”
- UML notation helps enforce this discipline
- So then how do we model connections between objects, such as Cities and Airports?

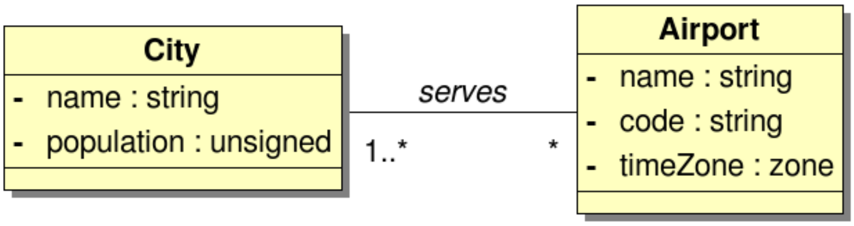
Relationships among objects

- **Link:** Physical or conceptual connection between objects
  - Much more abstract than pointers/references
  - Most (not all) links relate exactly two objects
- **Association:** Description of a group of links with common structure and semantics
- A link is an instance of an association:
  - Links connect objects of same classes
  - Have similar properties (link attributes)
  - Association describes set of potential links just like a class describes a set of potential objects

Examples of links



From links to association



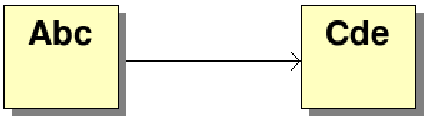
Association

- Association represents the ability of one instance to send a message to another instance
- This is typically implemented with a pointer or reference instance variable, although it might also be implemented as a method argument, or the creation of a local variable.


```
class Researcher {
  vector<Paper *> paper_list;
  ...
};
class Paper {
  vector<Researcher *> author_list;
  ...
};
```

Directional association

- Association can be directed if the link only goes in one direction




```
class Abc {
private:
   Cde *c;
public:
   ...
};
```


Bidirectionality

- During early design, it is often difficult to predict the navigation directions that will be needed
  - Especially true for many-to-many associations
  - Better to model connections as bidirectional associations and later refine these associations into more implementation-level structures (e.g., pointers, vectors of pointers, maps, etc.)
- Often several ways to implement an association and the details are not salient to the “essence” of the design

Implementation of “serves” association

```
class City {
  ...
protected:
  string cityName;
  unsigned population;
  vector<Airport*> serves;
};

class Airport {
  ...
protected:
  string airportName;
  CODE airportCode;
  ZONE timeZone;
  vector<City*> serves;
};
```

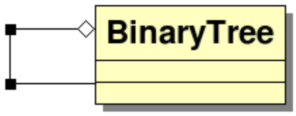

Alternative implementation of “serves” association

```
class City {
  ...
protected:
  string cityName;
  unsigned population;
};

class Airport {
  ...
protected:
  string airportName;
  CODE airportCode;
  ZONE timeZone;
};

multimap<City*, Airport*> cityServes;
multimap<Airport*, City*> airportServes;
```

Aggregation

- Association is a general relationship
- When we have a "whole/part" relationship, we can use a special kind of association, called "aggregation"

- instances cannot have cyclic aggregation relationships (i.e. a part cannot contain its whole)

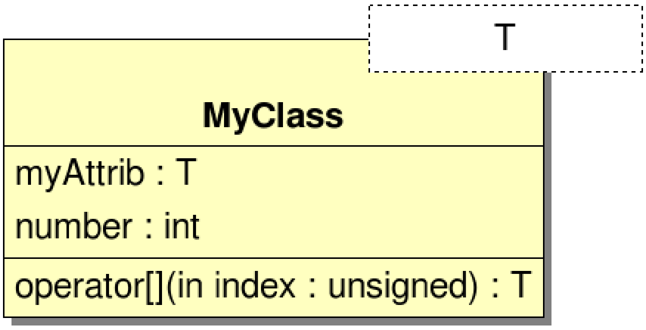


Composition

- Composition is the same as aggregation, but in addition the "whole" controls the "part"


```
class Car {
  public:
    virtual ~Car() {delete itsCarb;}
  private:
    Carburetor* itsCarb
};
```

Template notation



- Equivalent to:

```
template<class T>
class MyClass {
    T var;
    int number;
public:
    ...
    T operator[](int index);
};
```