OO Paradigm and UML

Object Oriented Programming

https://softeng.polito.it/courses/09CBI

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Version 2.4.3

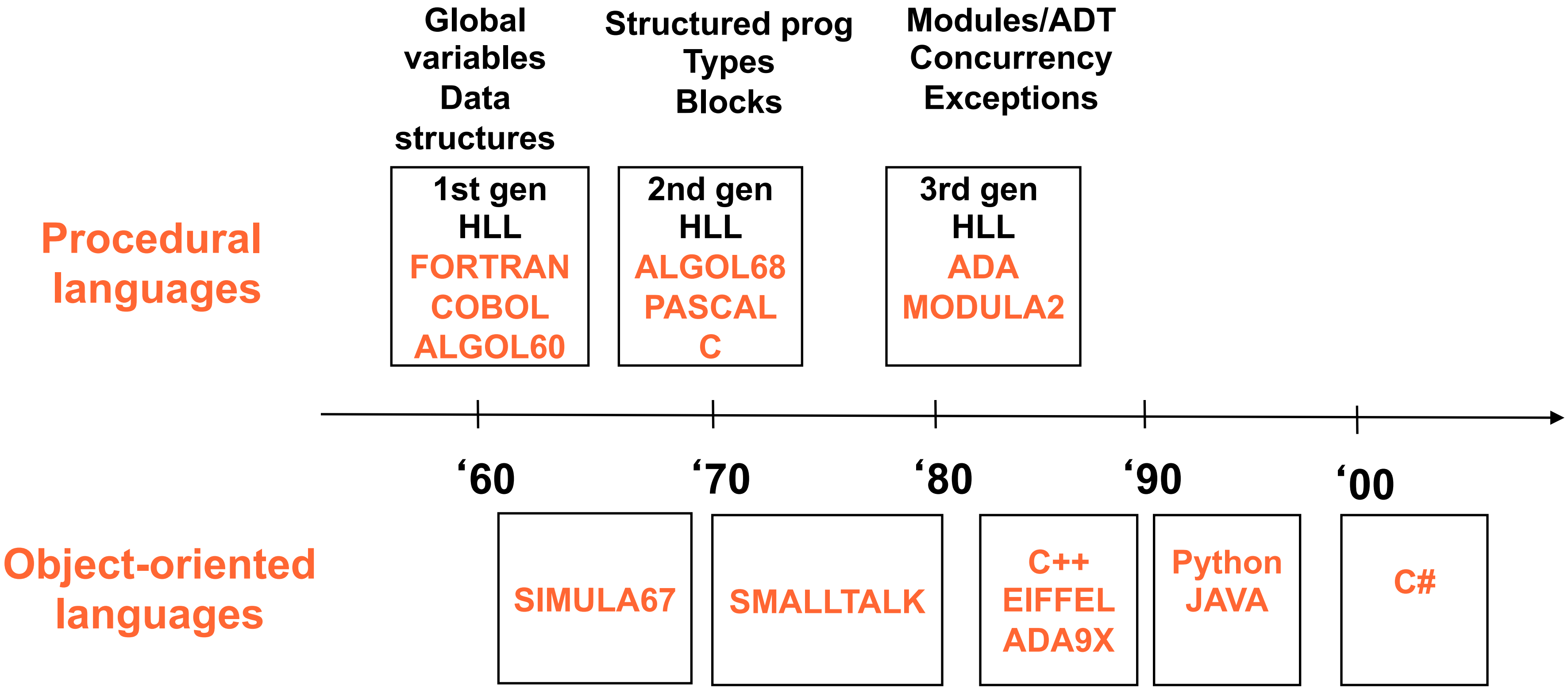
From procedural to object oriented programming paradigm

OBJECT ORIENTED PARADIGM

Programming paradigms

- Procedural (Pascal, C,…)
- Object-Oriented (C++, Java, C#,…)
- Functional (LISP, Haskell, SQL,…)
- Logic (Prolog)

Languages timeline



Global variables
Data structures

Structured prog
Types
Blocks

Modules/ADT
Concurrency
Exceptions

Procedural languages

1st gen HLL
FORTRAN
COBOL
ALGOL60

2nd gen HLL
ALGOL68
PASCAL
C

3rd gen HLL
ADA
MODULA2

‘60 ‘70 ‘80 ‘90 ‘00

Object-oriented languages

SIMULA67

SMALLTALK

C++
EIFFEL
ADA9X

Python
JAVA

C#

Example – Receipt

- Cash registers emit purchase receipts
- A receipt is made up of items
- Every item correspond to a product that has a name and a price
- Products' info is stored in a price list
- Any time a new product code is entered the corresponding item is added to the receipt
- After the last item is entered, a list of the items (with product name and price) are printed together with the total sum.

Example: Shop Receipt

- Input:
  - 13
  - 57
  - 123
  - 0 (end of receipt)
- Output

```
Receipt:
      ID13 : 16.62
      ID57 :  9.73
     ID123 :  0.06
------
Number of items: 3
          Total: 26.41
```

Procedural (C)

```
float prices[MAX_LIST];
char* names[MAX_LIST];
int receipt[MAX_RCPT];
int n_items;
void add(int) {/* add item to receipt */ }
void print(){ /* print receipt */ }
void init() { /* initialize */ }
int read() { /* read item code */
int main(){
   init();
   int code;
   while( (code = read()) ){ add(code); }
   print();
}
```

Modules and relationships

Modules:

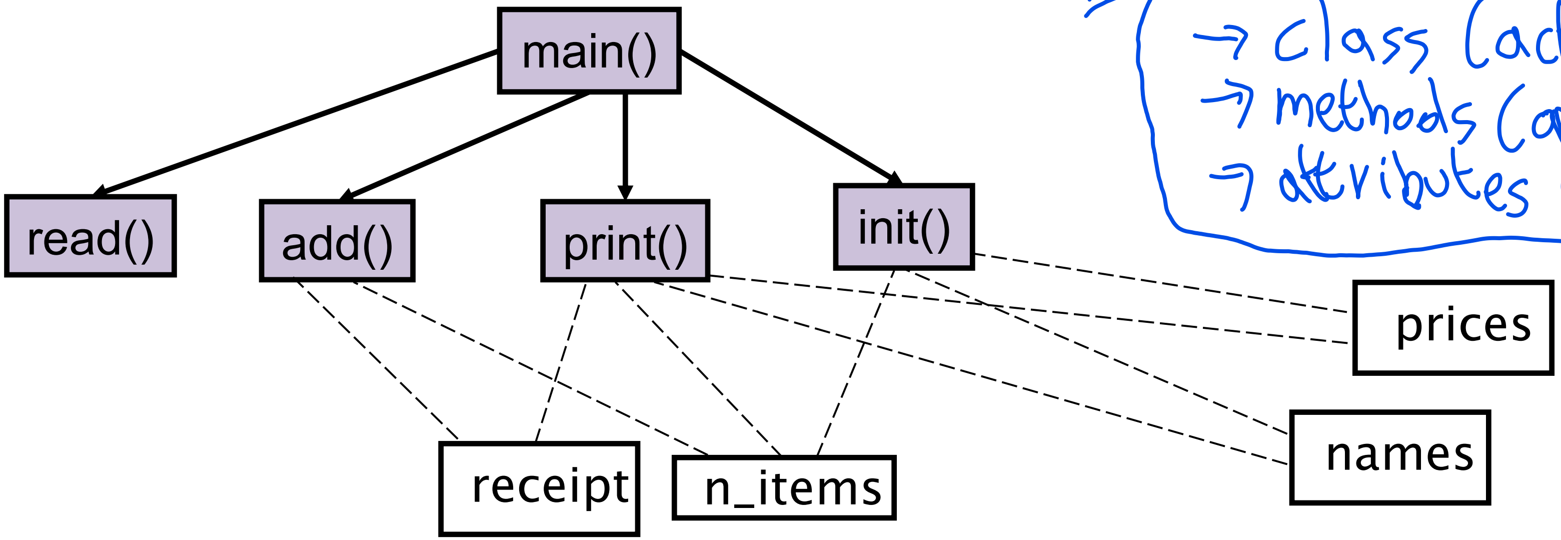
□ Data

▨ Function (Procedure)

Relationships

Call →

Read/write - - - -



OOP:

→ class (actor)

→ methods (operations)

→ attributes (data)

Problems

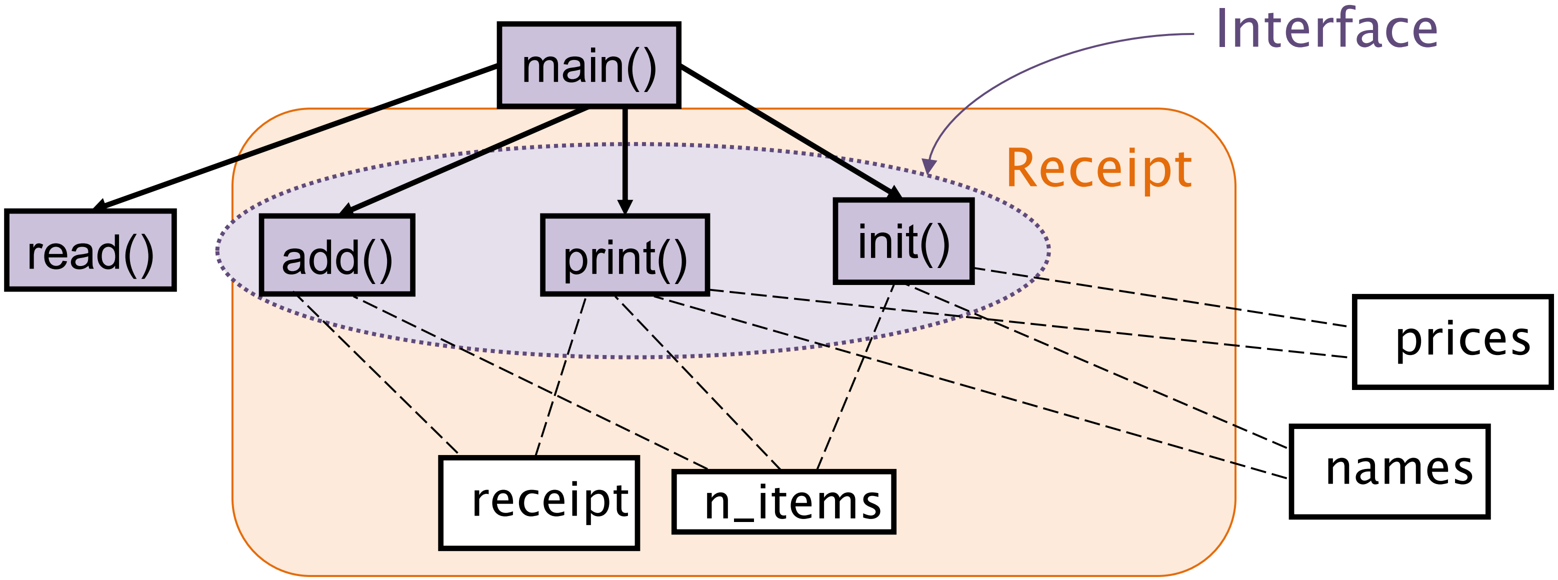
- No syntactic relationship between:
  - Arrays (**receipt, prices, names**)
  - Relative operations (**add**, **print**, **init**)
- Lack of link between coupled arrays (**prices, names**)
- No control over *size*:

```
for (i=0; i<=20; i++){ prices[i]=0; }
```

- No guarantee on initialization
  - Actually performed?

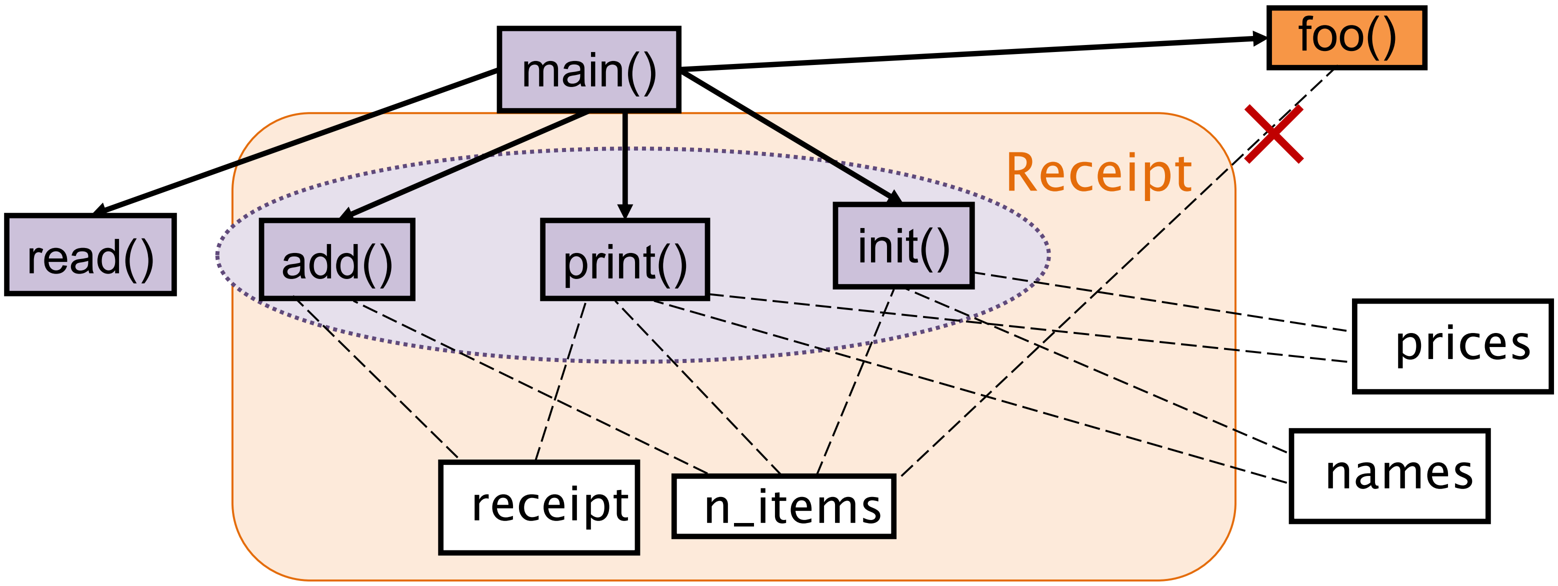
Objects – Encapsulation

- Bring together code and data
  - E.g. **`add()`** + **`receipt`** + **`n_items`**



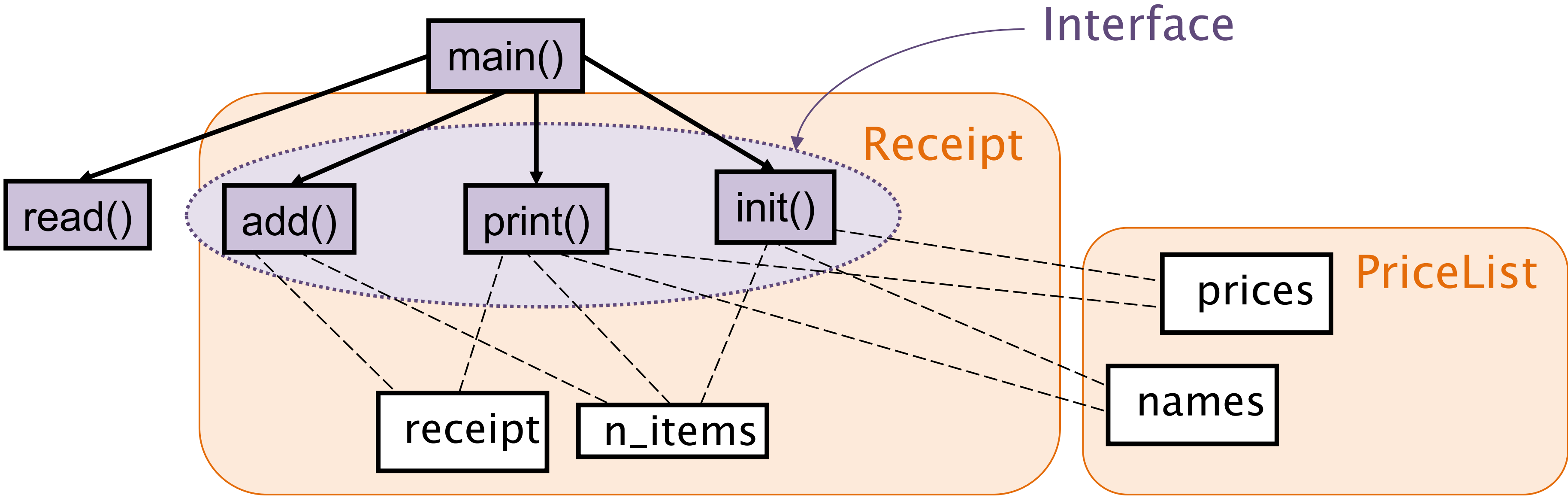
Objects – Information Hiding

- Hide object information from external modules
    - The only way to access data within an object is through its interface



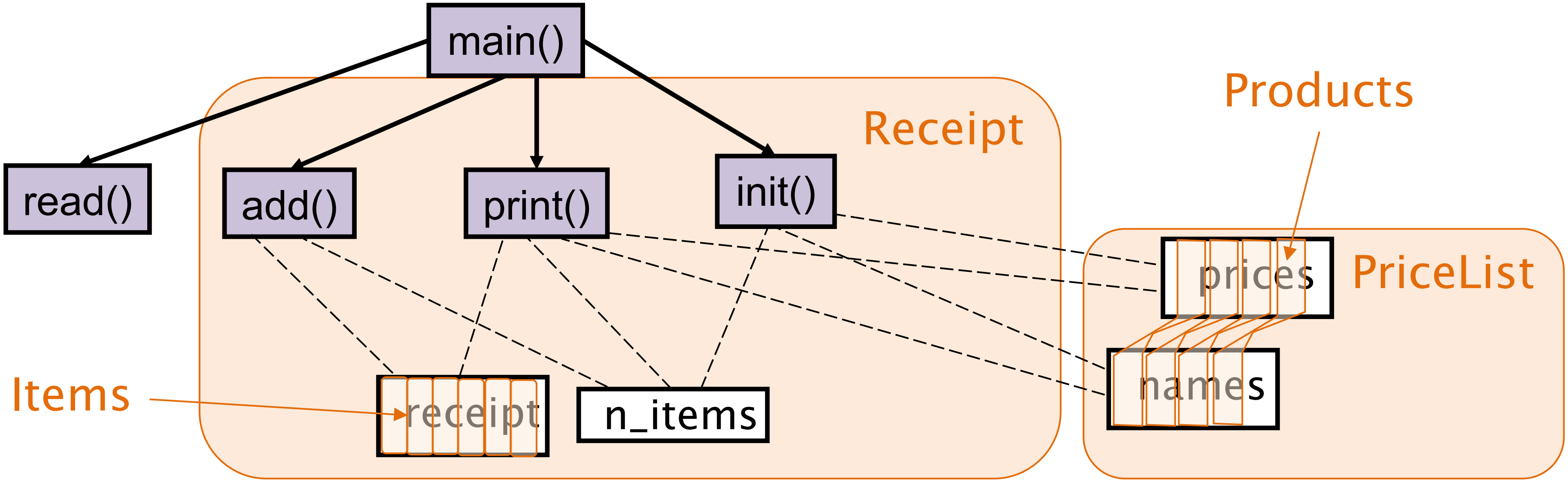
Objects

- Tie related data elements
  - E.g. **`prices`** + **`names`**



Objects

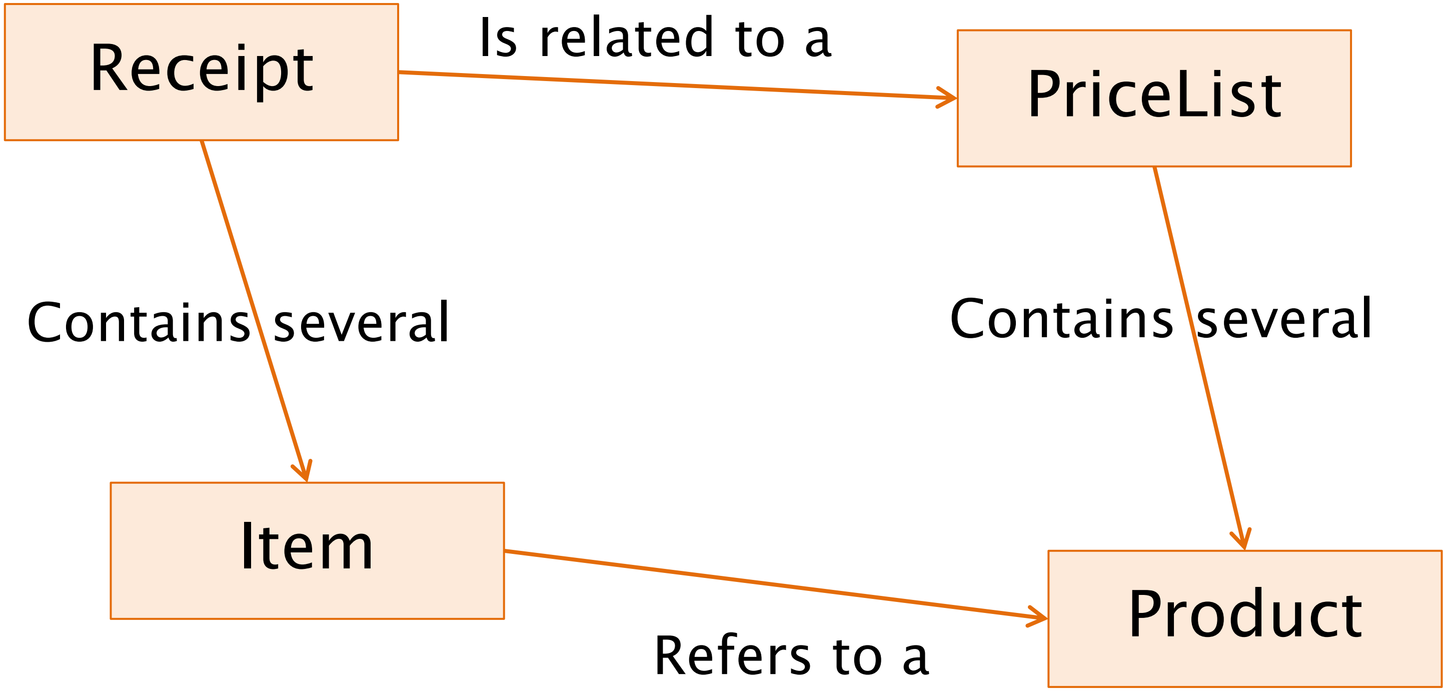
- Represent semantically consistent elements that map to problem-domain concepts
  - E.g., items and products



Classes

- Represent high level concepts
  - Often taken from problem domain
- Are instantiated into Objects
  - Define common features of Objects
- Are related to each other
  - Define links and communication patterns among their instances
- Can be defined by specialization
  - Specific classes inherit from general ones

Classes


Receipt
Is related to a
PriceList
Contains several
Contains several
Item
Product
Refers to a

Object-Oriented approach

- Defines a new component type
  - Object (and class)
  - Both data and functions accessing it are within the same module
  - Allows defining a more precise interface
- Defines a new kind of relationship
  - Message passing
  - Read/write operations are limited to the same object scope

Why OO?

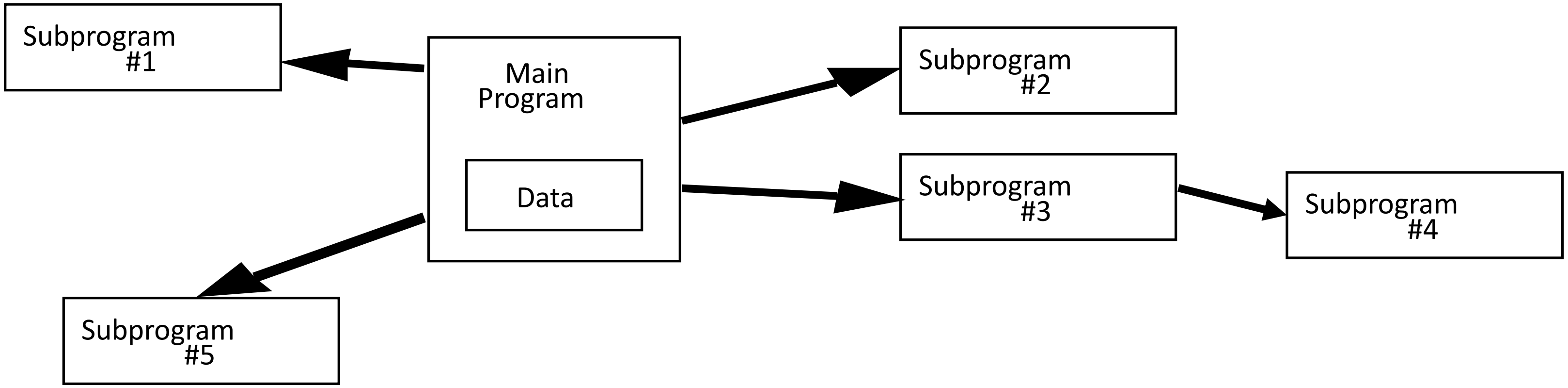
- Programs are getting too large to be fully comprehensible by any person
- There is a need for a way of managing very-large projects
- Object Oriented paradigm allows:
  - programmers to (re)use large blocks of code
  - without knowing all the picture
- OO makes code reuse a real possibility
- OO simplifies maintenance and evolution

An engineering approach

- Given a system, with components and relationships among them, we have to:
  - Identify the components
  - Define component interfaces
  - Define how components interact with each other through their interfaces
  - Minimize relationships among components

Procedural vs. OO

Procedural



Subprogram #1

Main Program

Data

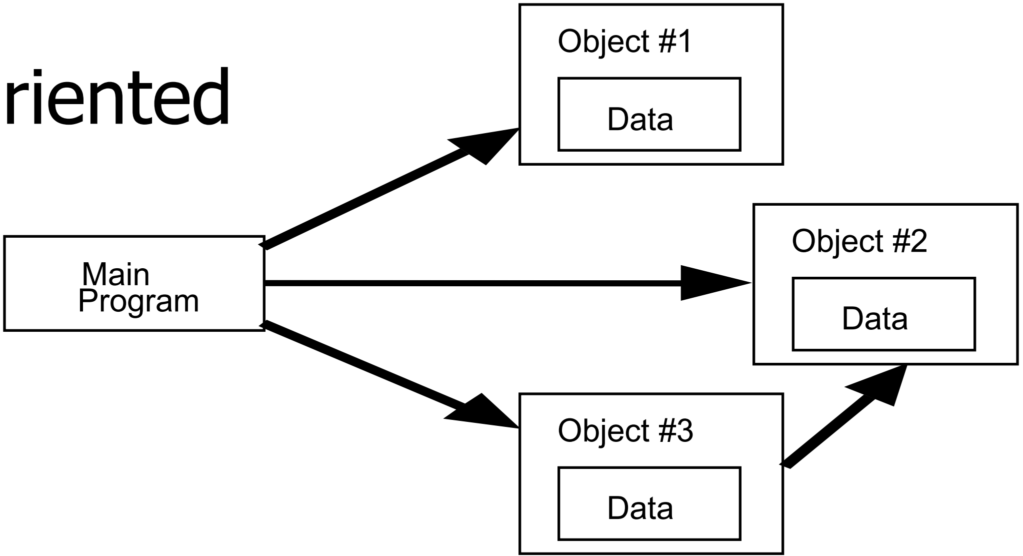
Subprogram #2

Subprogram #3

Subprogram #4

Subprogram #5

Object Oriented



Object #1

Data

Main Program

Object #2

Data

Object #3

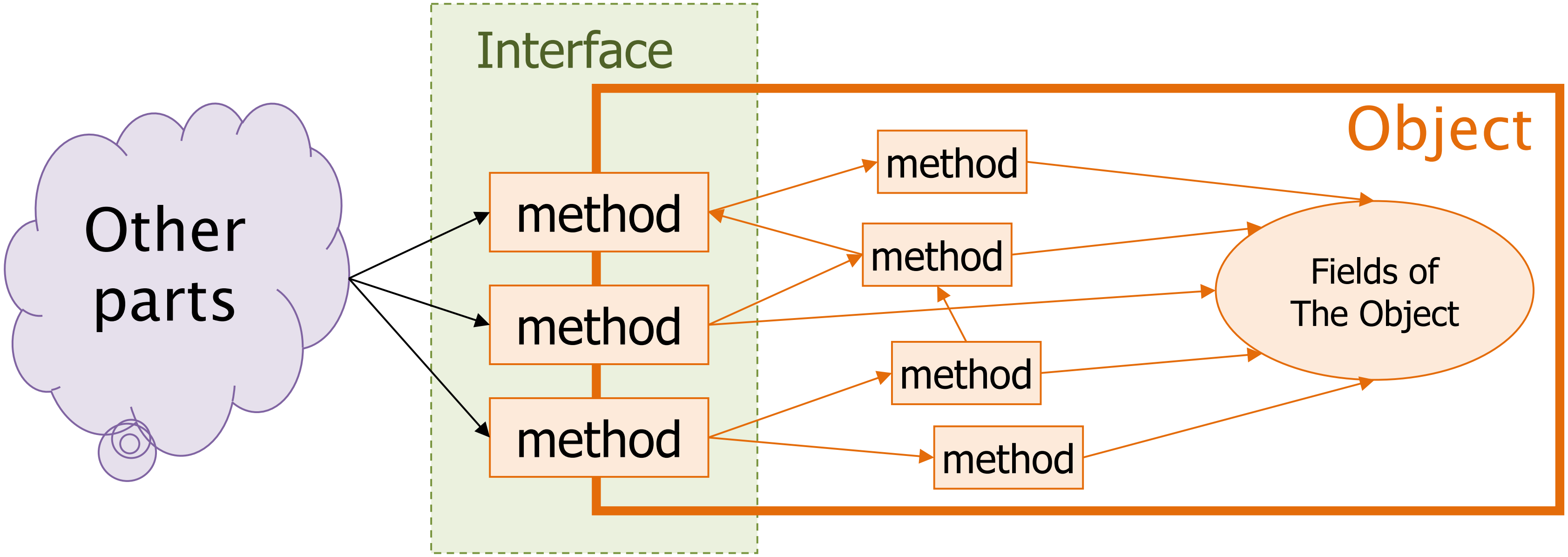
Data

Interface

- Set of messages an object can receive
  - Each message is mapped to an internal "function" within the object
  - The object is responsible for the association (message → function)
  - Any other message is illegal
- The interface
  - Encapsulates the internals
  - Exposes a standard boundary

Interface

- The interface of an object is simply the subset of methods that other "program parts" are allowed to call
  - Stable



Encapsulation

- Simplified access
  - To use an object, the user need only comprehend the interface. No knowledge of the internals are necessary
- Self-contained.
  - Once the interface is defined, the programmer can implement the interface (write the object) without interference of others

Encapsulation

- Ease of evolution
  - Implementation can change at a later time without rewriting any other part of the program (as long as the interface doesn't change)
- Single point of change
  - Any change in the data structure means modifying the code in one location, rather than code scattered around the program (error prone)

Classification of OO languages

- **Object-Based** (Ada)
  - Specific constructs to manage objects
- **Class-Based** (CLU)
  - + each object belongs to a class
- **Object-Oriented** (Simula, Python)
  - + classes support inheritance
- **Strongly-Typed O-O** (C++, Java)
  - + the language is strongly typed

The Object-Oriented Paradigm

UML AND MODELING

UML

- Unified Modeling Language
- Standardized modeling and specification language
  - Defined by the Object Management Group (OMG)
- Graphical notation to specify, visualize, construct and document an object-oriented system
- Integrates the concepts of Booch, OMT and OOSE, and merges them into a single, common and widely used modeling language

UML

- Several diagrams
  - Class diagrams
  - Activity diagrams
  - Use Case diagrams
  - Sequence diagrams
  - Statecharts

graphically describe

interactions between classes

interactions between classes

behavior of a class

UML Class Diagram

- Captures
  - Main (abstract) concepts
  - Characteristics of the concepts
    - Data associated to the concepts
  - Relationships between concepts
  - Behavior of classes

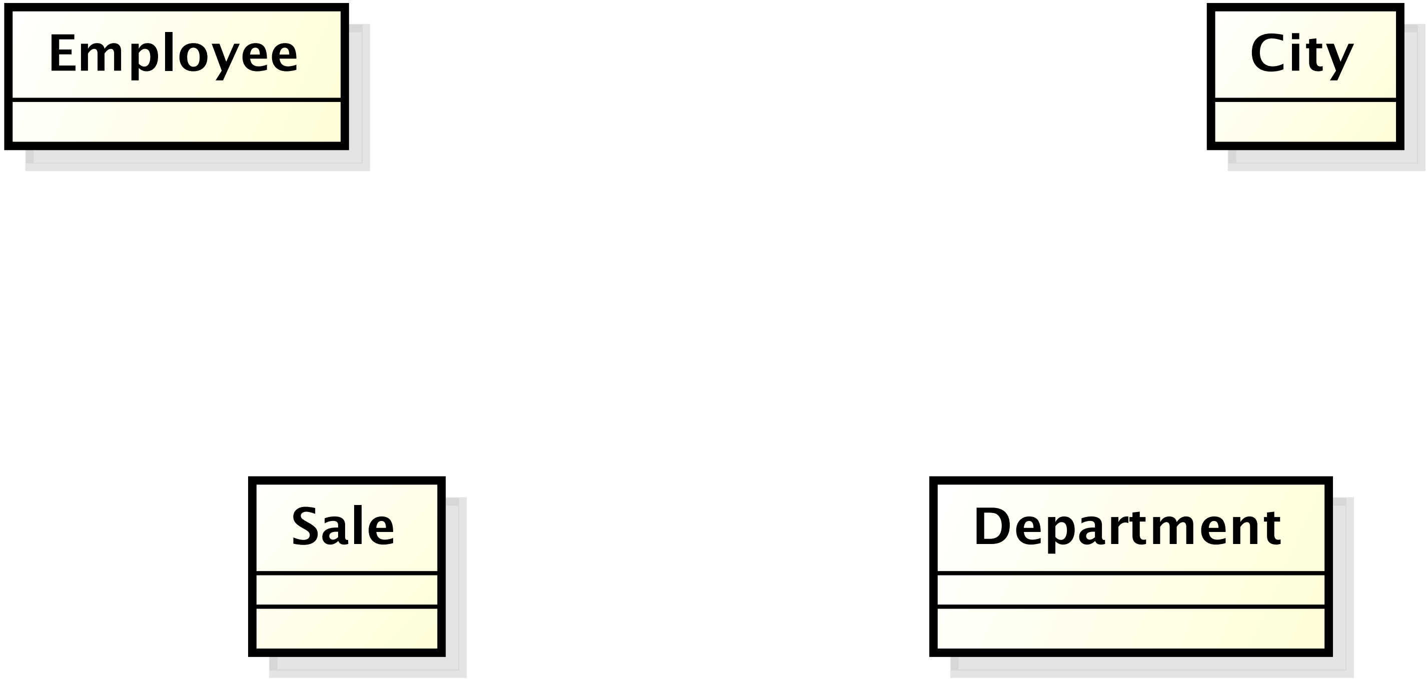
Abstraction levels

Abstract	Concept Entity Class Category Type
Concrete	Instance Item Object Example Occurrence

Class

- Represents a set of objects
  - Common properties
  - Autonomous existence.
  - E.g. facts, things, people
- An instance of a class is an object of the type that the class represents.
  - In an application for a commercial organization CITY, DEPARTMENT, EMPLOYEE, PURCHASE and SALE are typical classes.

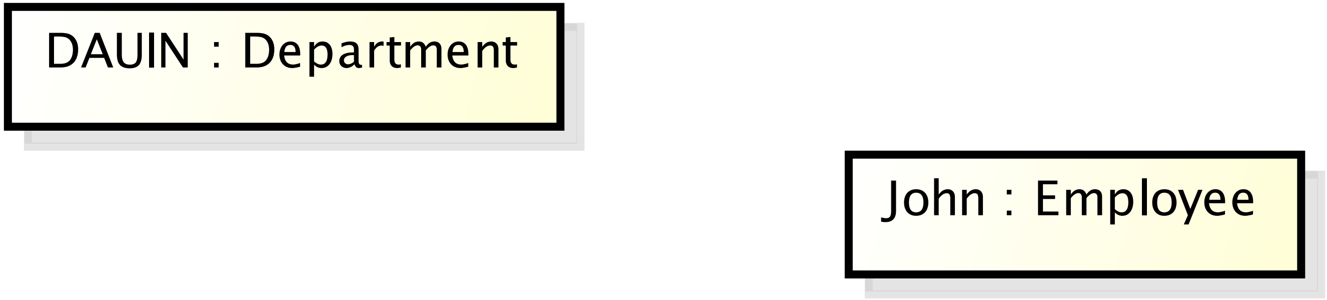
Class – Examples



Object

- Model of a physical or logical item
  - ex.: a student, an exam, a window
- Characterized by
  - identity
  - attributes (or data or properties or status)
  - operations it can perform (behavior)
  - messages it can receive

Object



DAUIN : Department

John : Employee

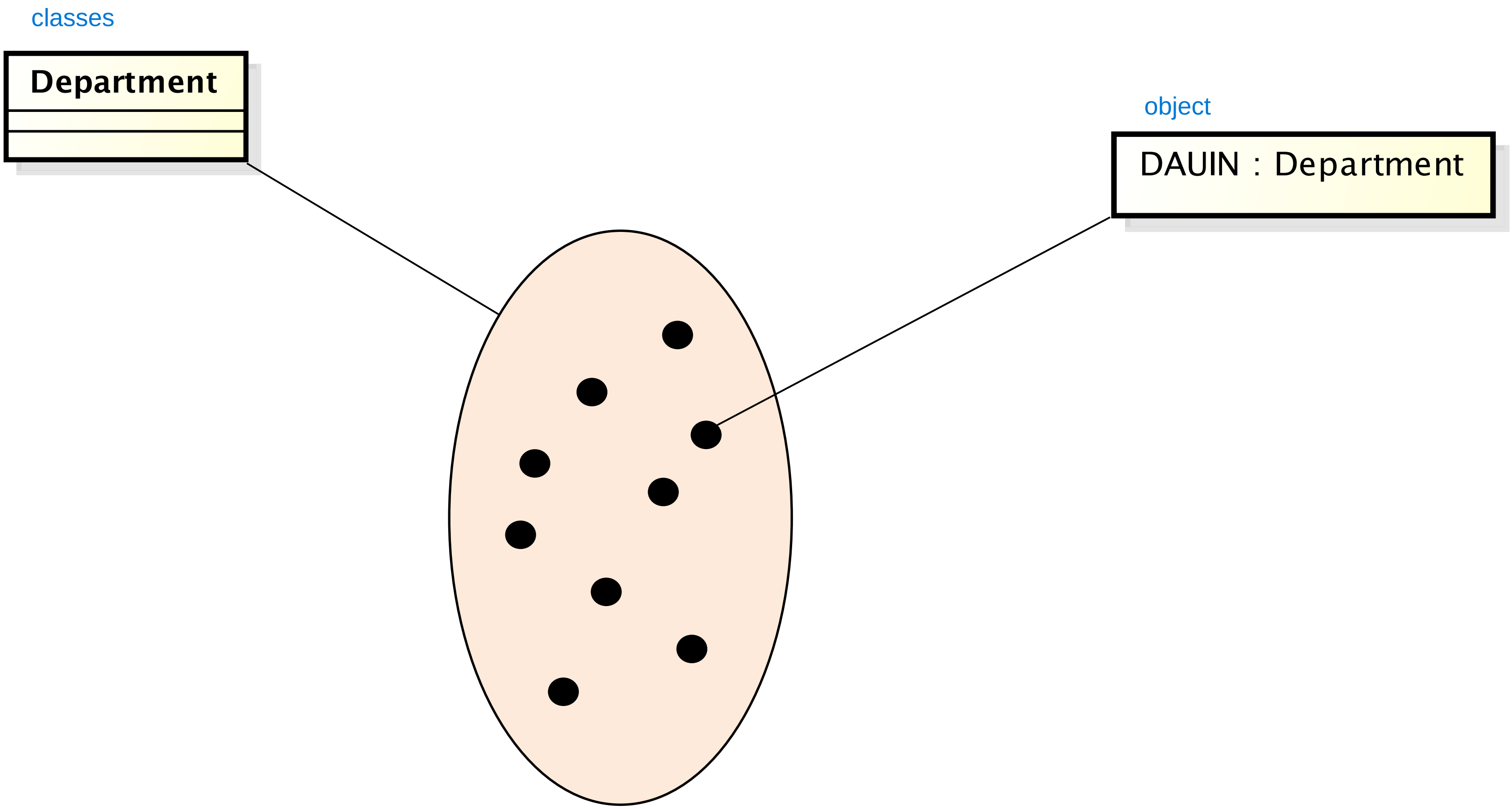
Class and Object

- Class (the description of object structure, i.e. *type*):
  - Data (ATTRIBUTES or FIELDS)
  - Functions (METHODS or OPERATIONS)
  - Creation methods (CONSTRUCTORS)
- Object (class instance)
  - State and identity

Class and object

- A class is a type definition
  - Typically no memory is allocated until an object is created from the class
- The creation of an object is called instantiation. The created object is often called an instance
- There is no limit to the number of objects that can be created from a class
- Each object is independent. Interacting with one object doesn't affect the others

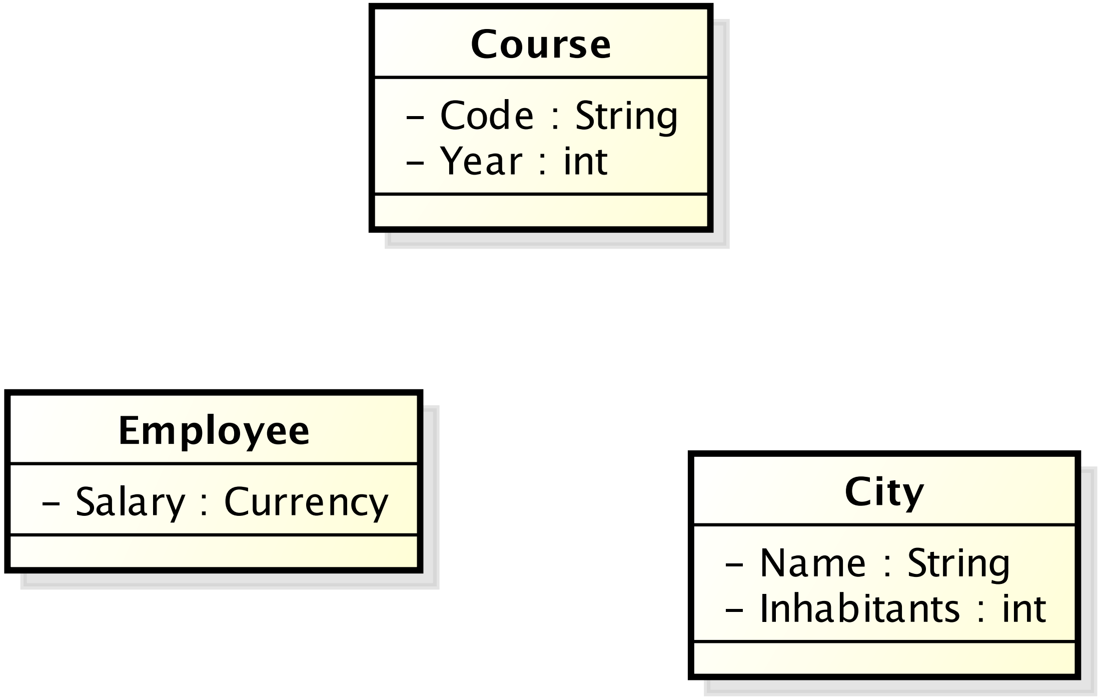
Classes and objects



Attribute

- Elementary property of classes
  - Name
  - Type
- An attribute associates to each object (occurrence of a class) a value of the corresponding type
  - Name: String
  - ID: Numeric
  - Salary: Currency

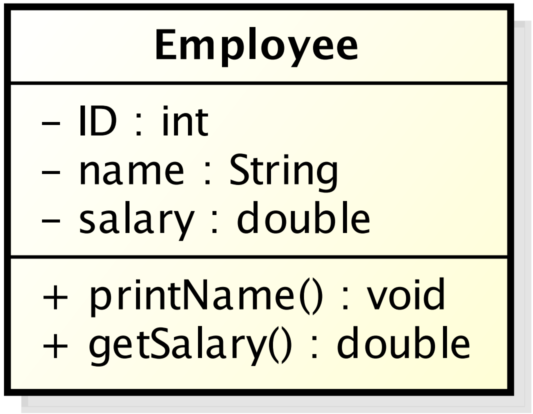
Attribute – Example



Method

- Describes an operation that can be performed on an object
  - Name
  - Parameters
- Similar to functions in procedural languages
- It represent the means to operate on or access to the attributes

Method – Example



Employee

- ID : int
- name : String
- salary : double

+ printName() : void
+ getSalary() : double

+ public
- private

Message passing

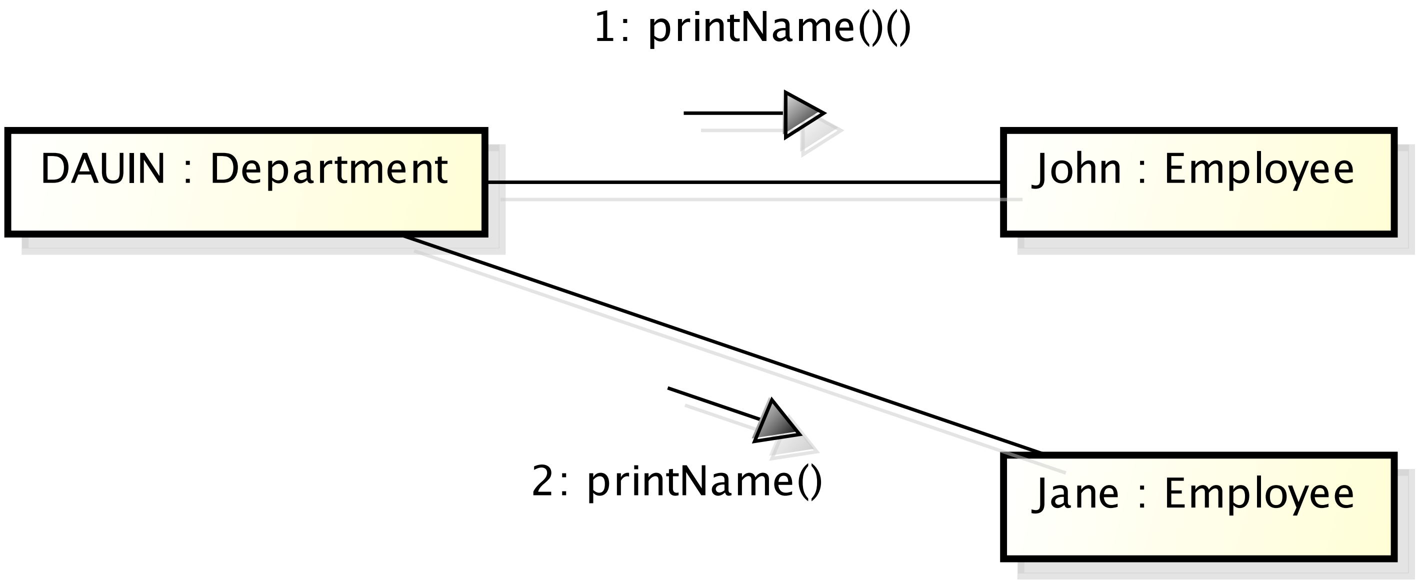
- Objects communicate by message passing
  - Not by direct access to object’s local data
- A message is a service request

Note: this is an abstract view that is
independent from specific
programming languages.

Messages

An example of an activity diagram: objects not classes

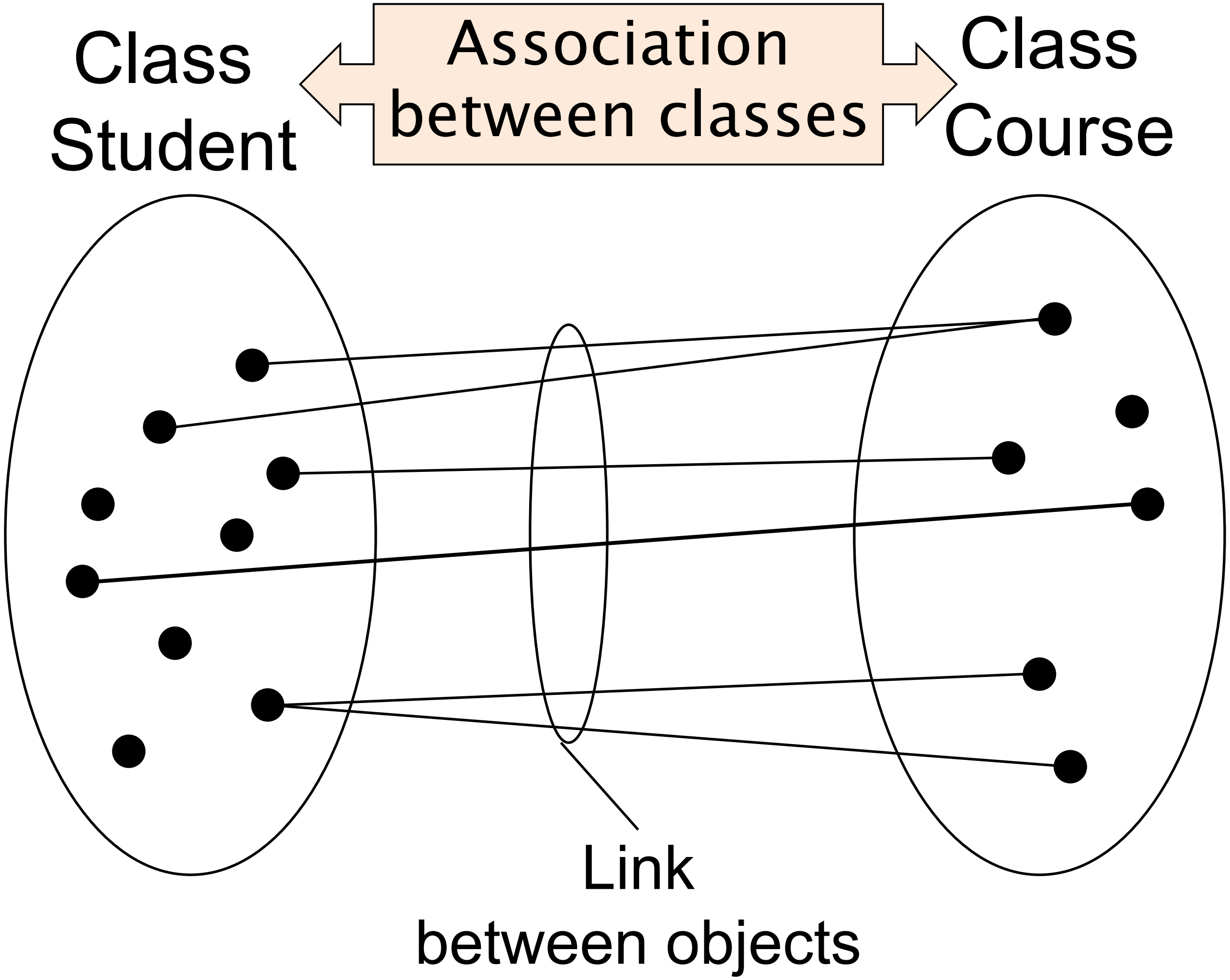
calling the method of employee
1. indicates the order of the activities



Association

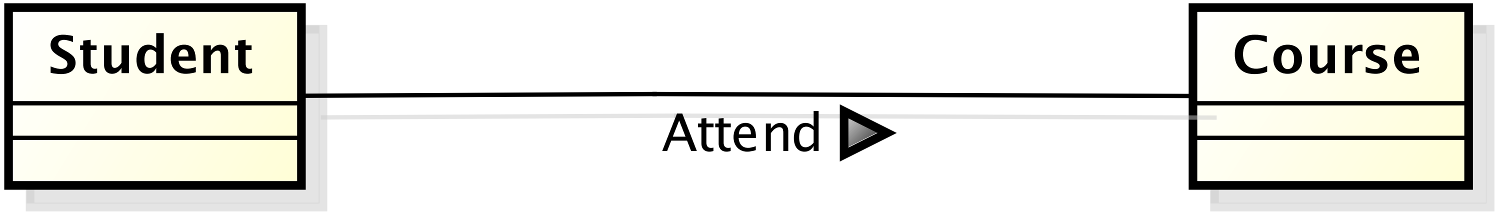
- Represents a logical link between two classes.
- An occurrence of an association is a pair made up of the occurrences of the entities, one for each involved class
    - Residence is an association between the classes City and Employee;
    - Exam is an association between the classes Student and Course.

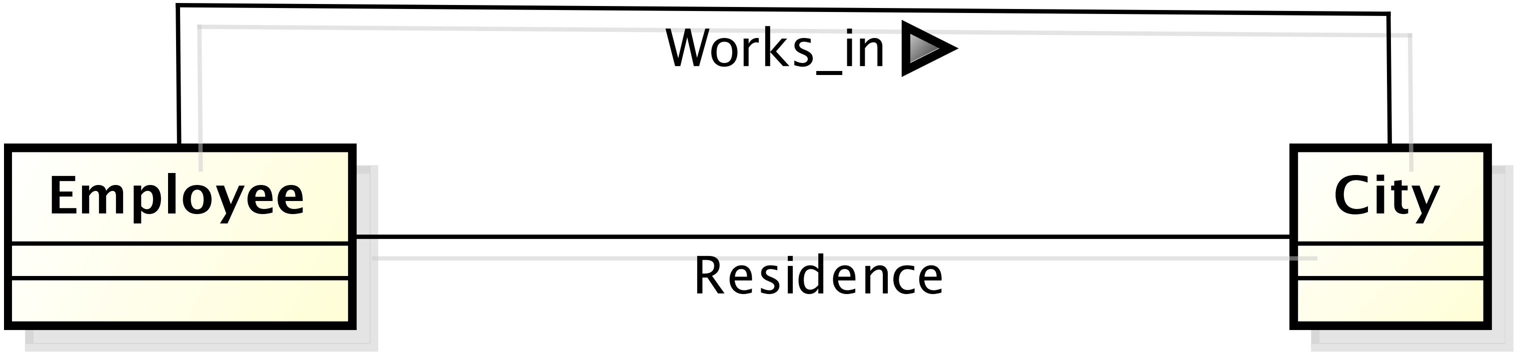
Associations



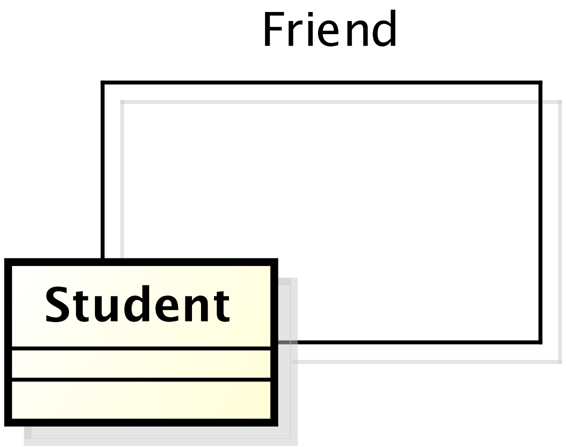
Association – Examples

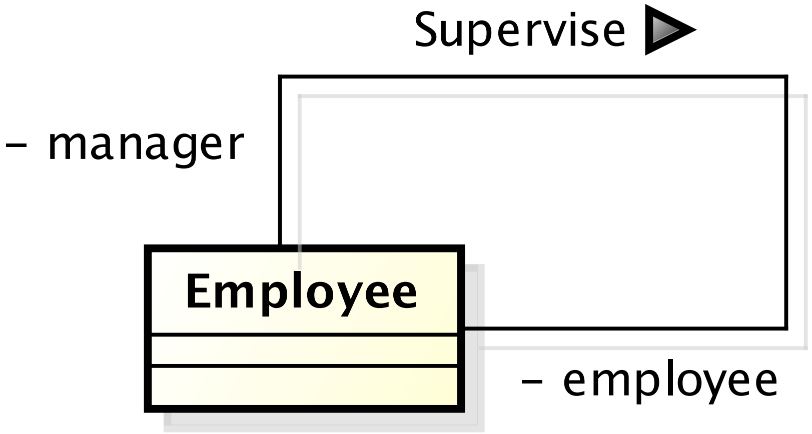
logical relation between the two classes





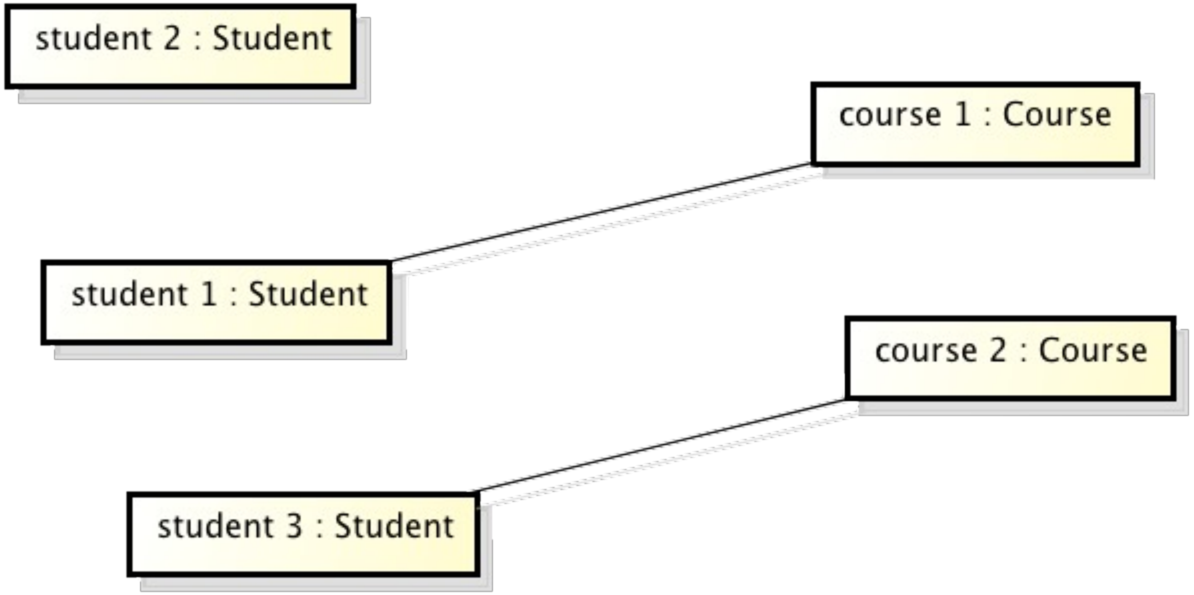
Recursive association–Samples





Link

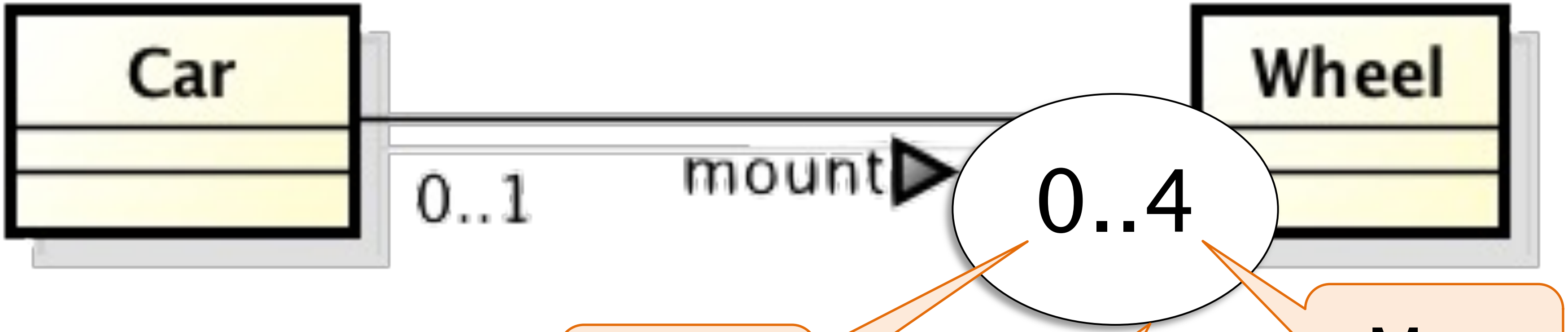
- Model of association between objects



Multiplicity

- Describes the maximum and minimum number of links in which a class occurrence can participate
  - Undefined maximum expressed as *
- Should be specified for each class participating in an association

Multiplicity – Example



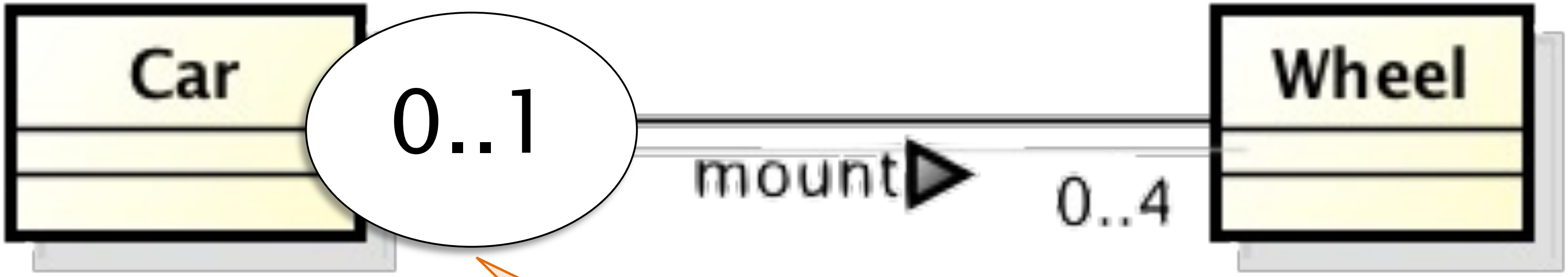
Min

Max

number of instances involved in the association

A car can mount none, up to four wheels

Multiplicity – Example

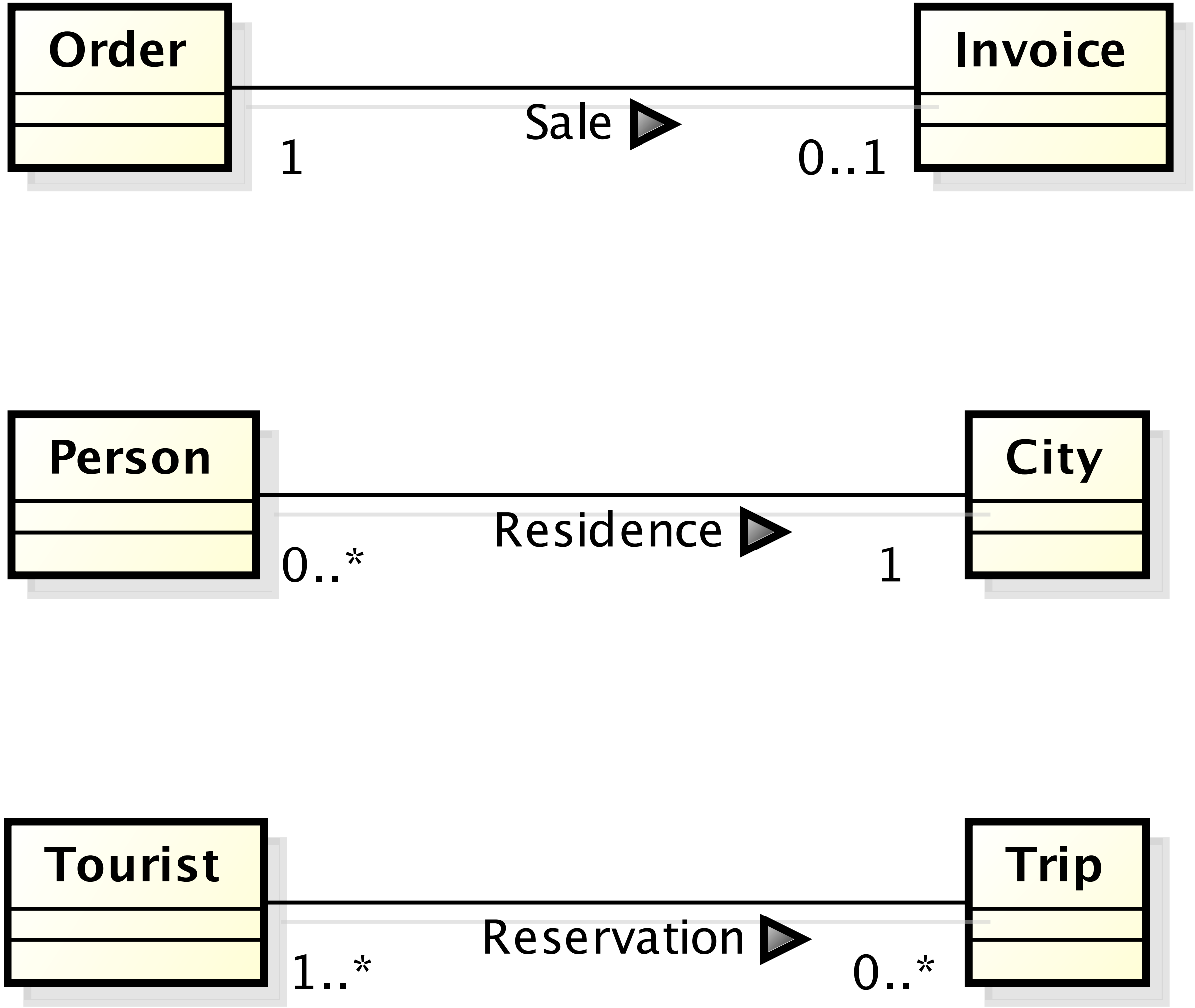


A wheel can be mounted on none or at most one car

Multiplicity

- Typically, only three values are used: 0, 1 and the symbol * (many)
- Minimum: 0 or 1
  - 0 means the participation is *optional,*
  - 1 means the participation is *mandatory;*
- Maximum: 1 or *
  - 1: object is involved in at most one link
  - *: each object is involved in many links

Multiplicity



Order 1 — Sale ▶ — 0..1 Invoice

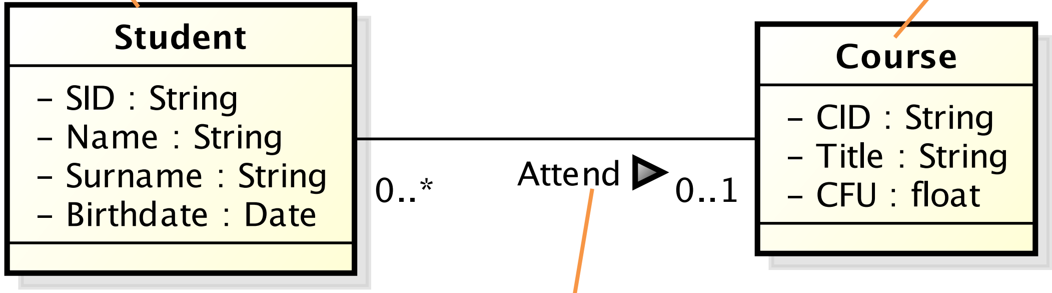
Person 0..* — Residence ▶ — 1 City

Tourist 1..* — Reservation ▶ — 0..* Trip

Operational interpretation

SID	Name	Surname	Birthdate
S2345	John	Smith	1990-4-12
S1234	Jane	Brown	1991-7-11
S5678	Mario	Rossi	1991-11-5

CID	Title	CFU
C001	Information Systems	8
C002	Advanced Programming	10
C003	Calculus	10



Student

- SID : String
- Name : String
- Surname : String
- Birthdate : Date

0..* Attend ▶ 0..1

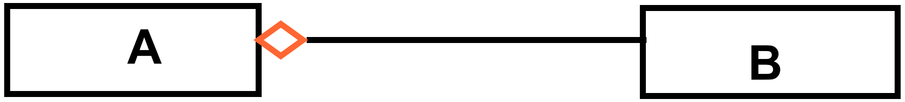
Course

- CID : String
- Title : String
- CFU : float

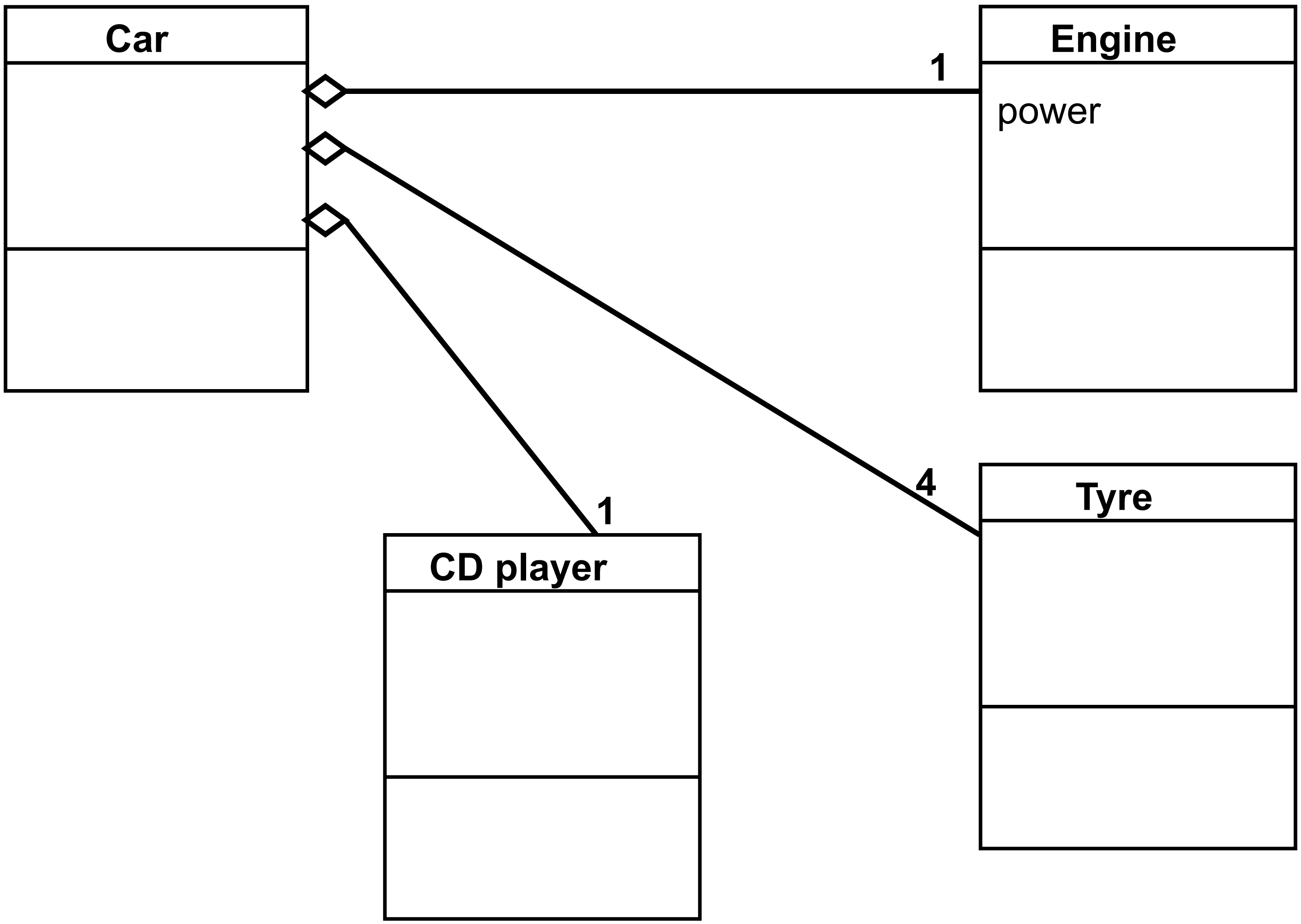
	C001	C002	C003
S2345			X
S1234	X		
S5678	X		

Aggregation

- B *is-part-of* A means that objects described by class B can be attributes of objects described by A



Example



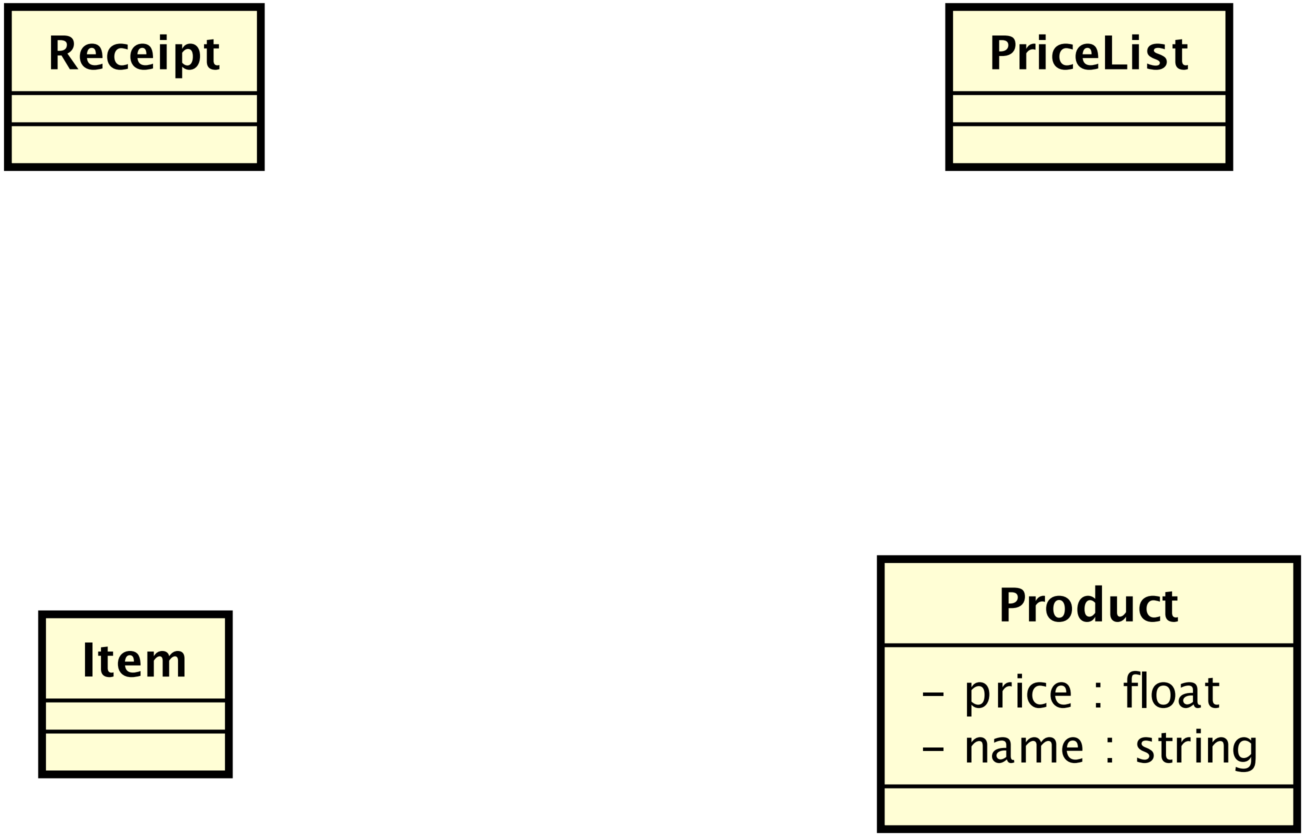
Essential guidelines

- If a concept has significant properties and/or describes types of objects with an autonomous existence, it can be represented by a class.
- If a concept has a simple structure, and has no relevant properties associated with it, it is likely an attribute of a class.
- If a concept provides a logical link between two (or more) entities, it is convenient to represent it by means of an association.
- Any operation that implies access to the attributes of a class should be defined as a method.

Example – Receipt

- Cash registers emit purchase receipts
- A receipt is made up of items
- Every item correspond to a product that has a name and a price
- Products' info is stored in a price list
- Any time a new product code is entered the corresponding item is added to the receipt
- After the last item is entered, a list of the items (with product name and price) are printed together with the total sum.

Example – Classes



Receipt

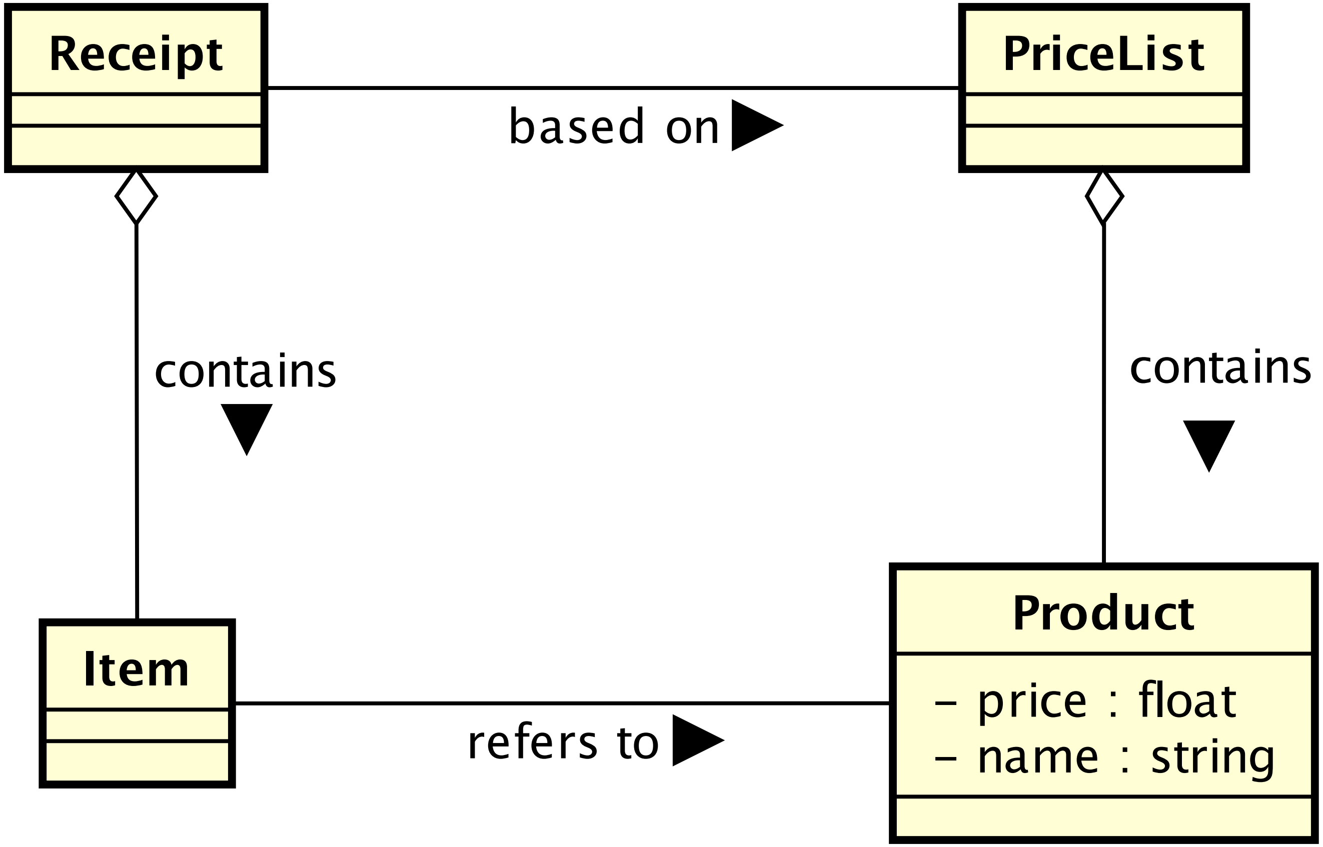
PriceList

Item

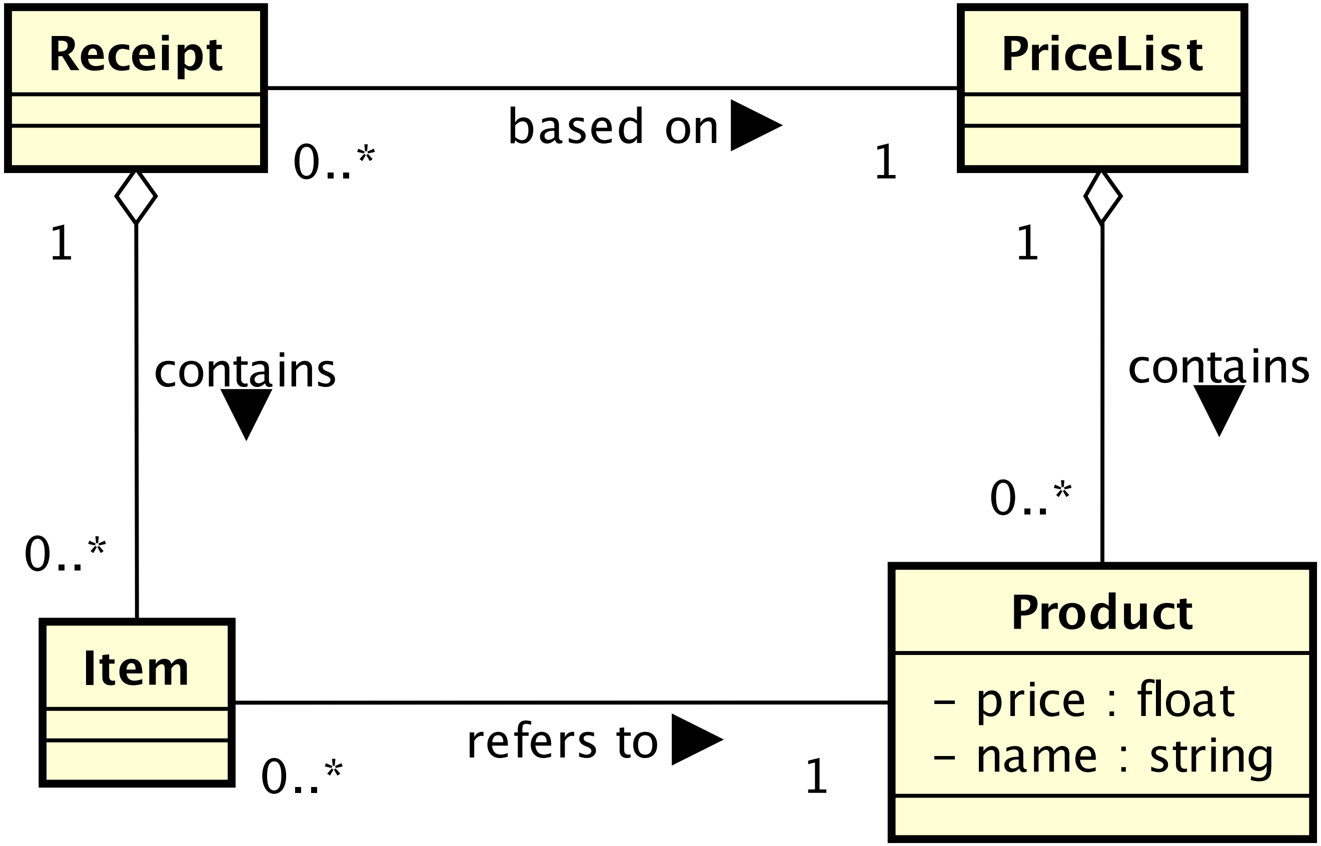
Product

– price : float
– name : string

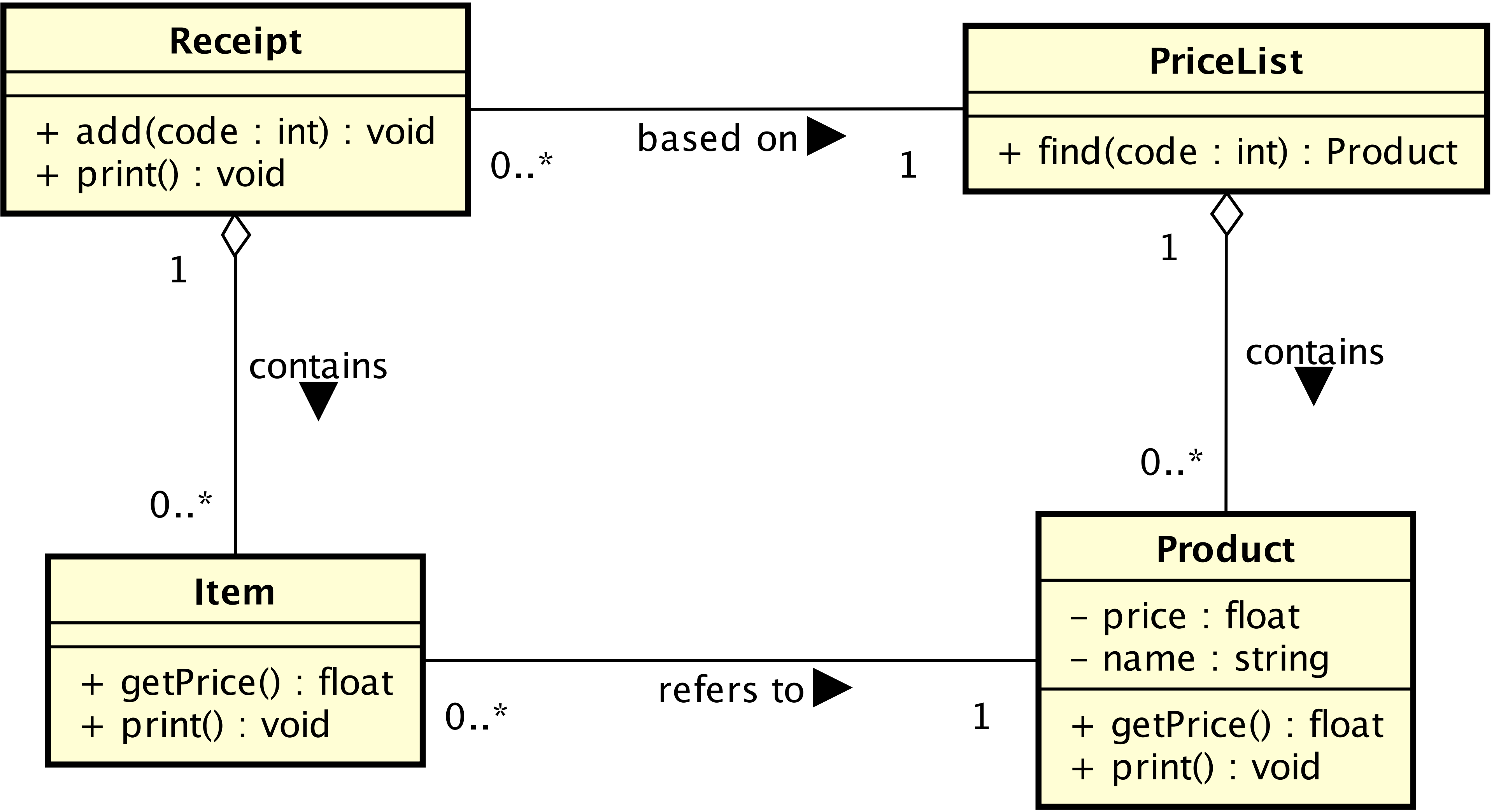
Example – Associations



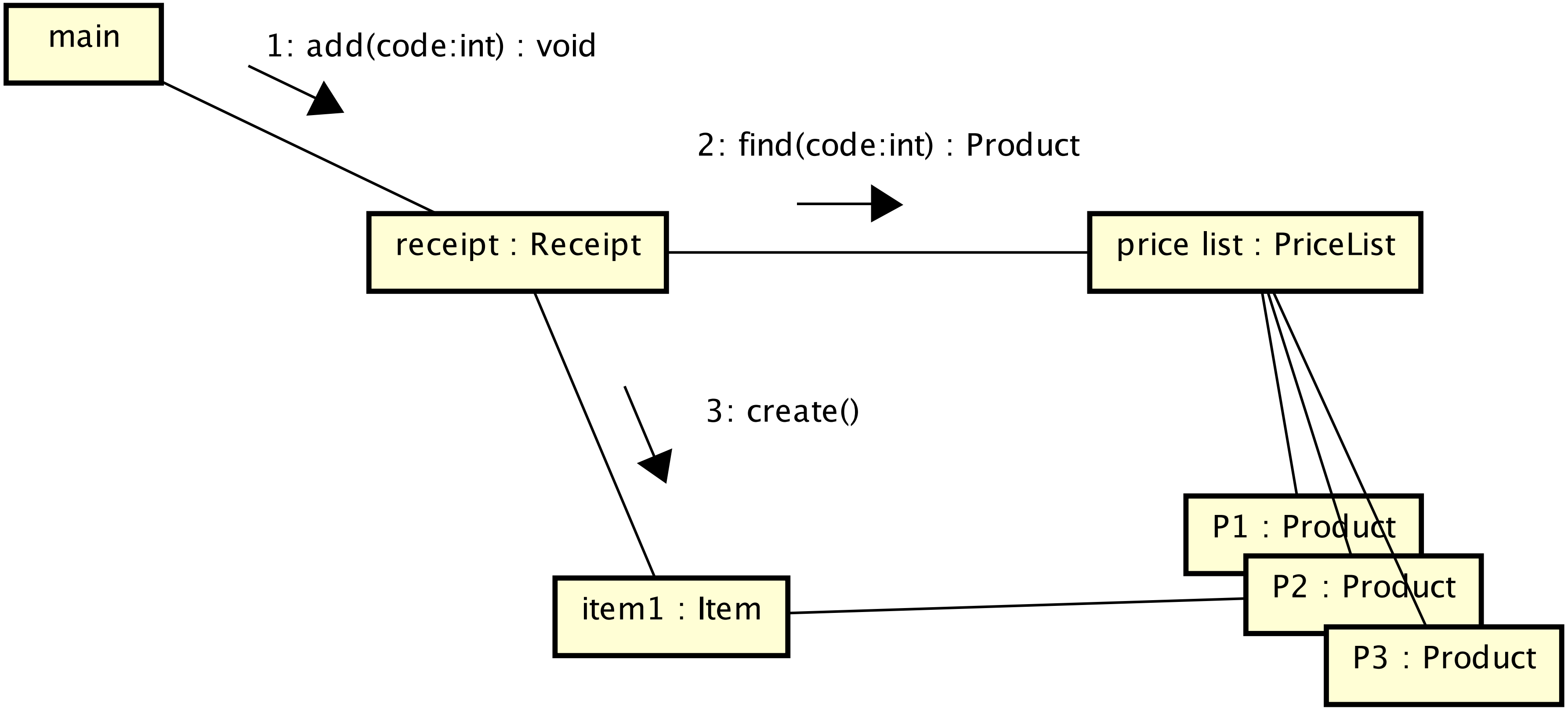
Example – Multiplicity



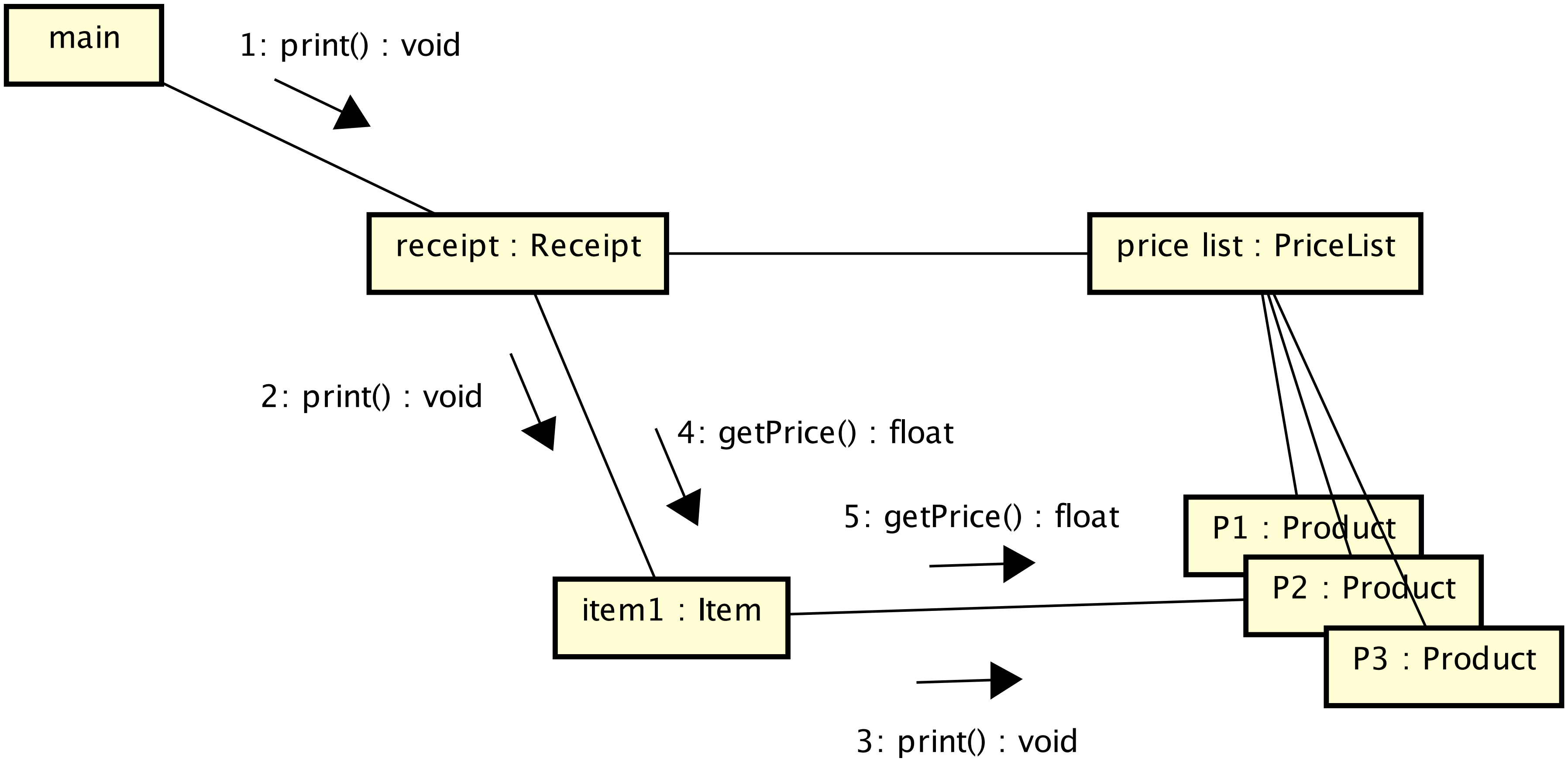
Example – Methods



Example – Messages (Add)



Example – Messages (Print)



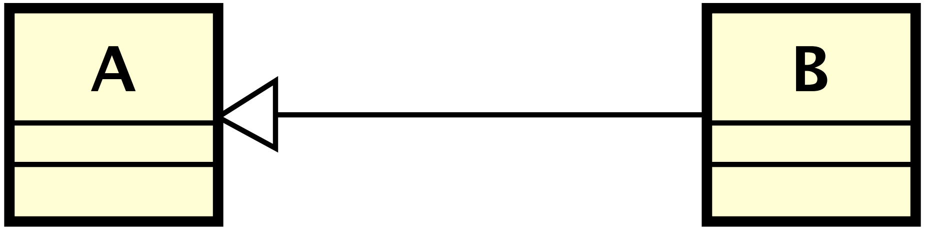
Inheritance

Inheritance

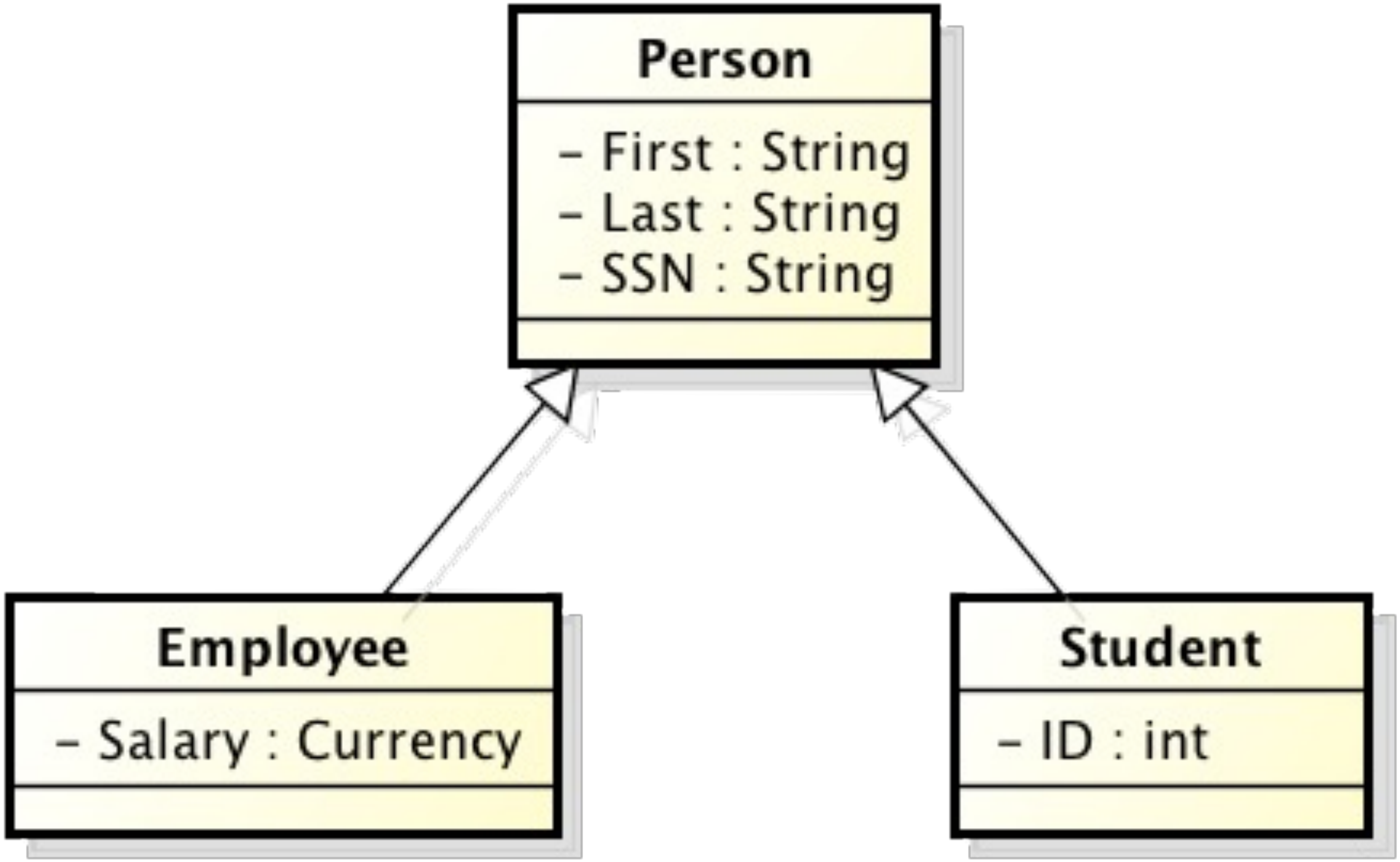
- A class can be a sub-type of another class
- The inheriting class contains all the methods and fields of the class it inherited from plus any methods and fields it defines
- The inheriting class can override the definition of existing methods by providing its own implementation
- The code of the inheriting class consists only of the changes and additions to the base class

Specialization / Generalization

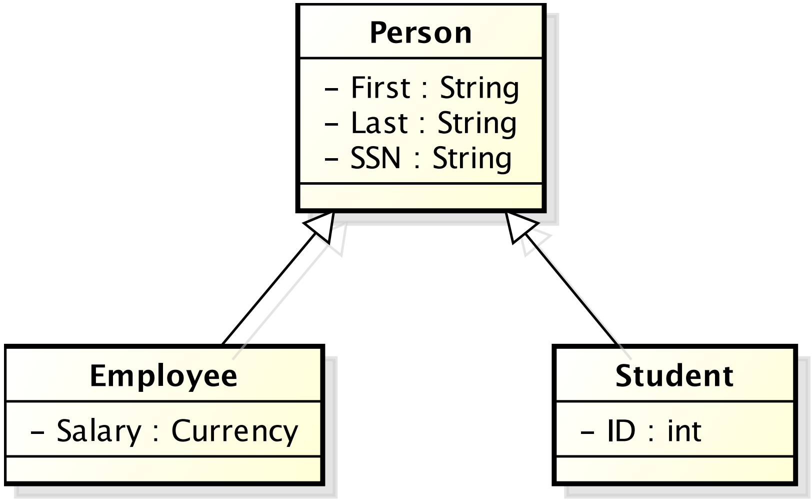
- B *specializes* A means that
  - B has the same characteristics as A
    - Attributes
    - Participation in associations
  - B may have additional characteristics
  - B is a special case of A
  - A is a generalization of B

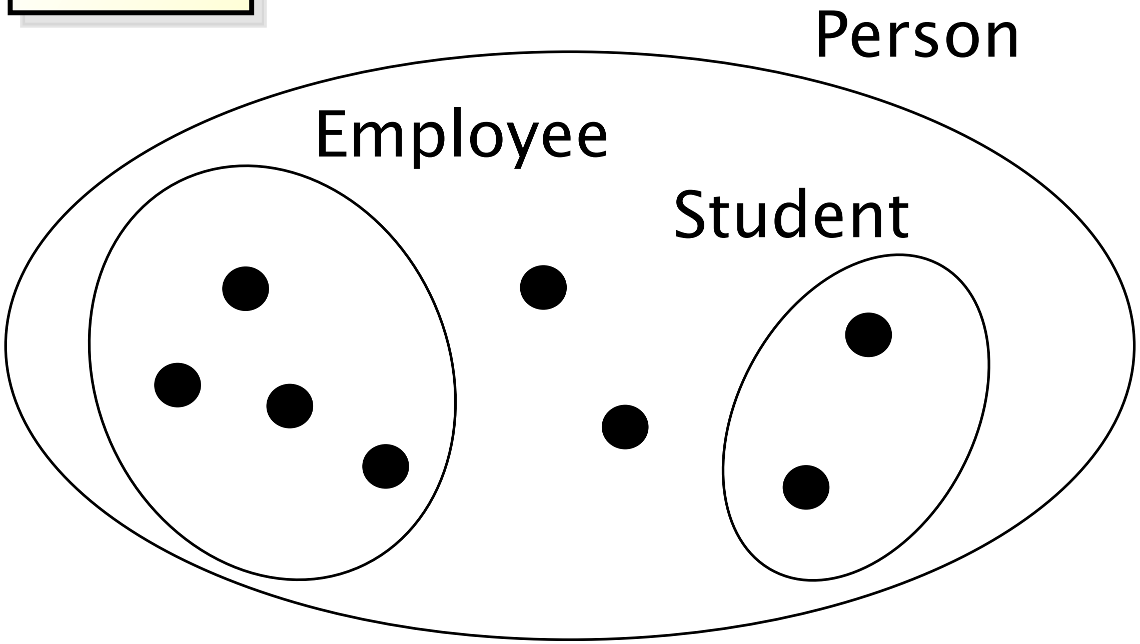


Generalization



Set–Specialization





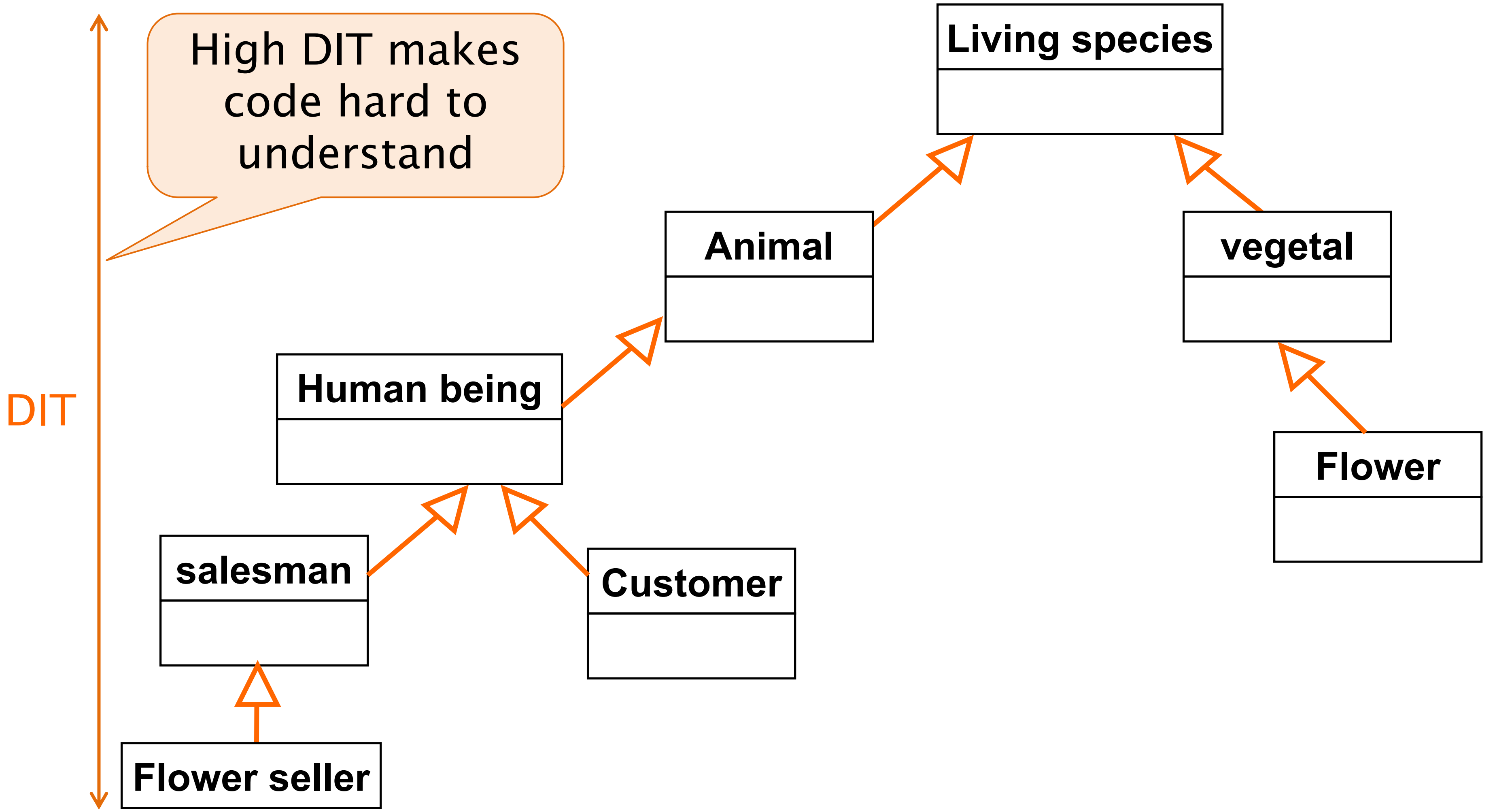
Inheritance terminology

- Class one above
  - Parent class
- Class one below
  - Child class
- Class one or more above
  - Superclass, Ancestor class, Base class
- Class one or more below
  - Subclass, Descendent class, Derived class

Why inheritance

- Frequently, a class is merely a modification of another class. In this way, there is minimal repetition of the same code
- Localization of code
    - Fixing a bug in the base class automatically fixes it in the subclasses
    - Adding functionality in the base class automatically adds it in the subclasses
    - Less chances of different (and inconsistent) implementations of the same operation

Example of inheritance tree

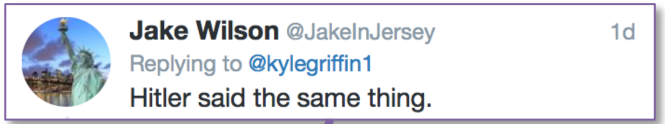


Twitter (simplified)

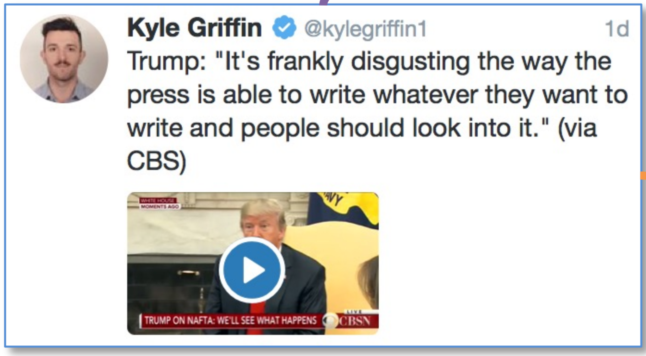
- A registered user can
  - Post a tweet
  - Follow another user
  - Reply to a tweet
  - Add a like to a tweet

Example

Reply

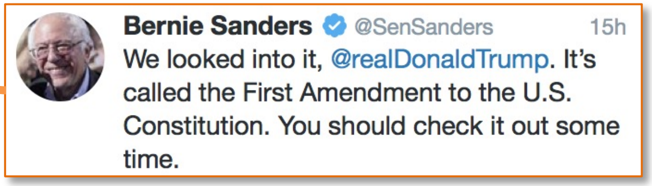


Jake Wilson @JakeInJersey 1d
Replying to @kylegriffin1
Hitler said the same thing.



Kyle Griffin @kylegriffin1 1d
Trump: "It's frankly disgusting the way the press is able to write whatever they want to write and people should look into it." (via CBS)

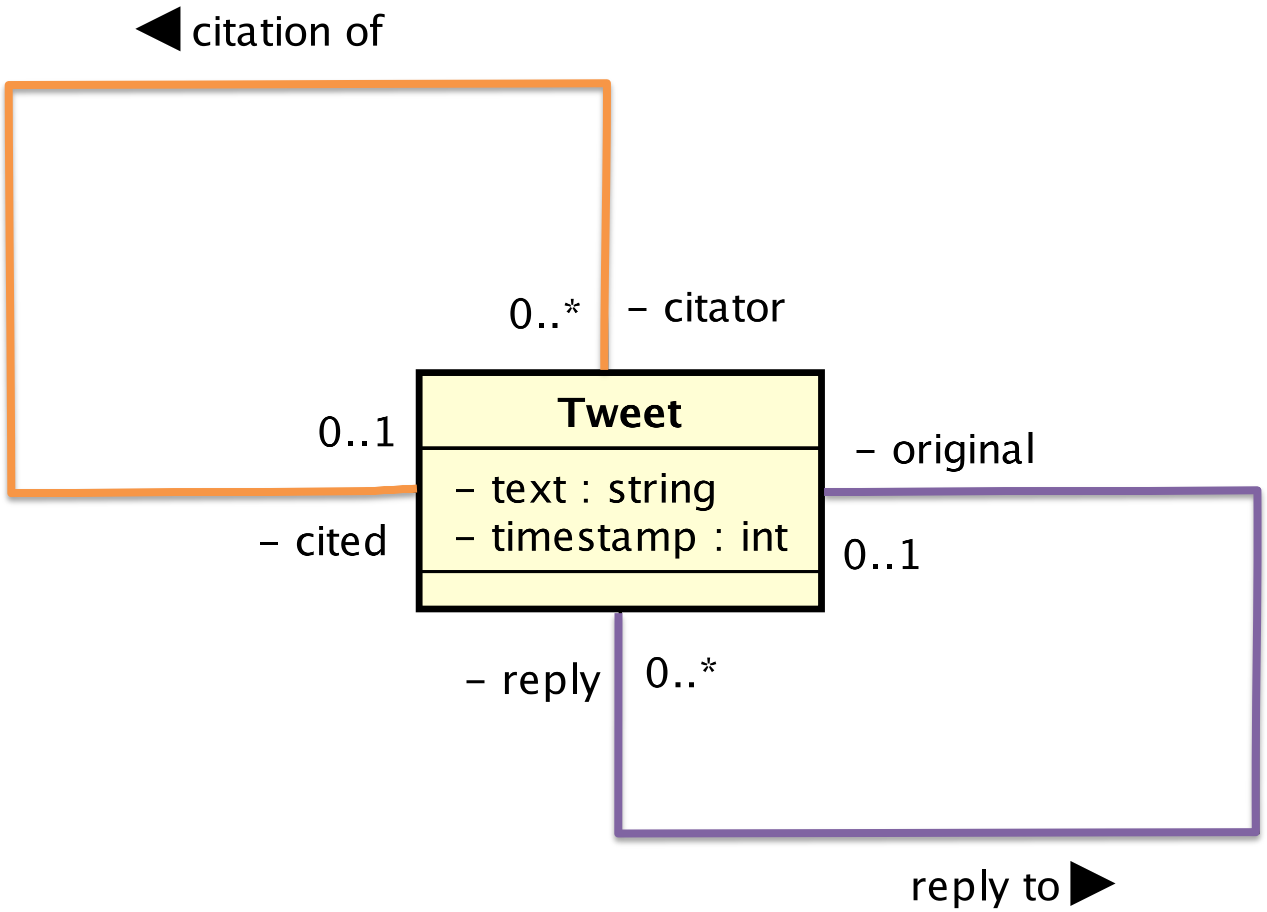
Original



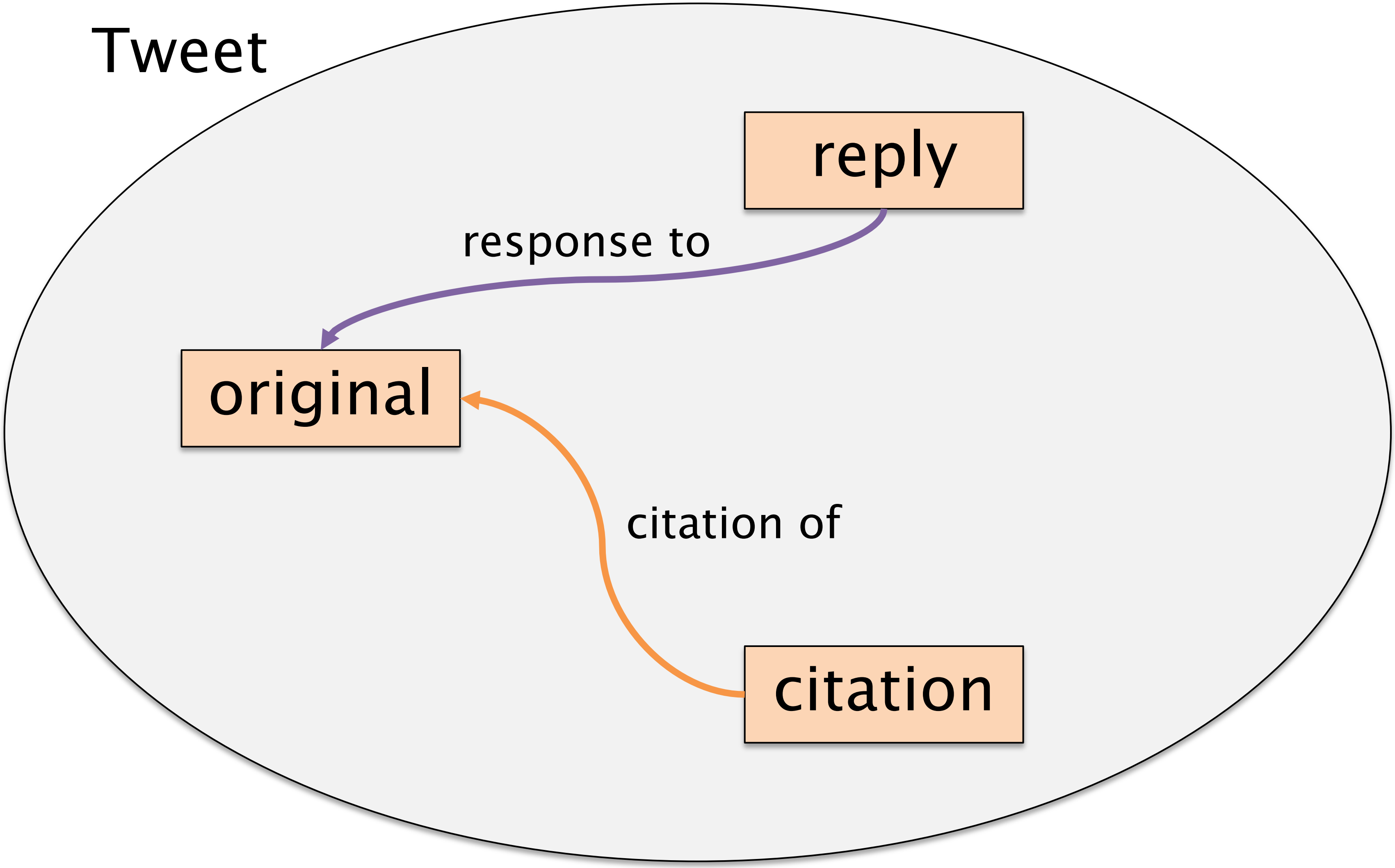
Bernie Sanders @SenSanders 15h
We looked into it, @realDonaldTrump. It's called the First Amendment to the U.S. Constitution. You should check it out some time.

Citation

Optional Recursive Associations

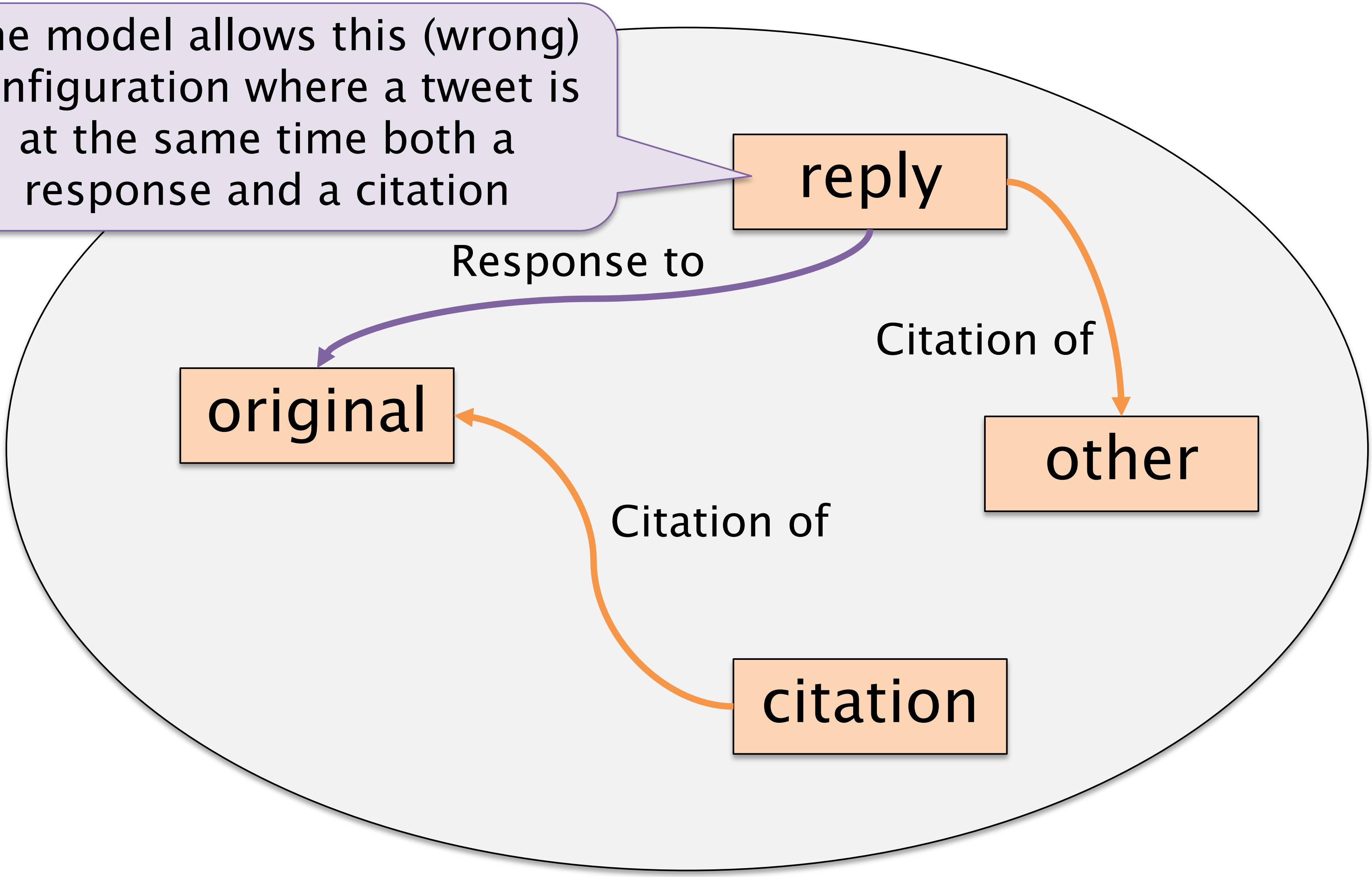


Optional Recursive Associations

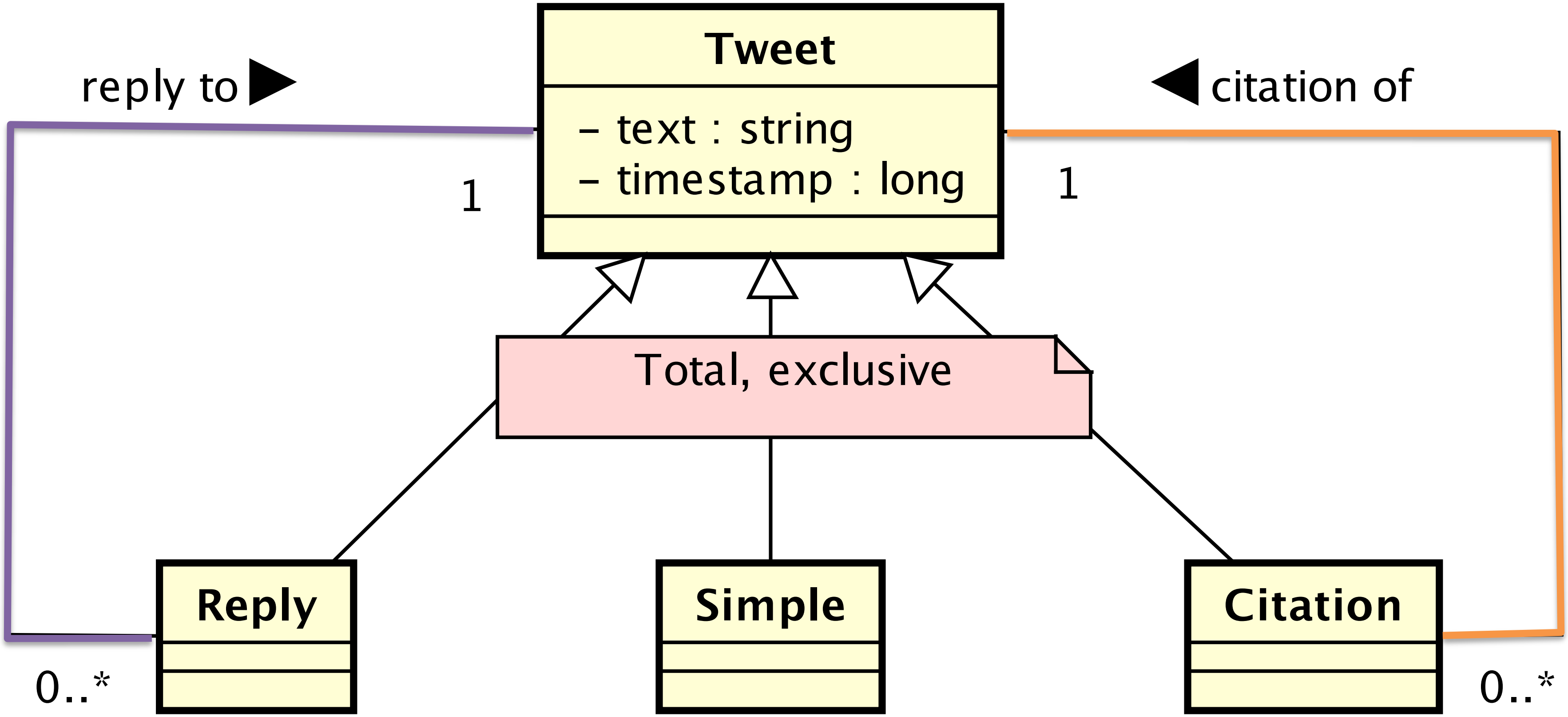


Optional Recursive Associations

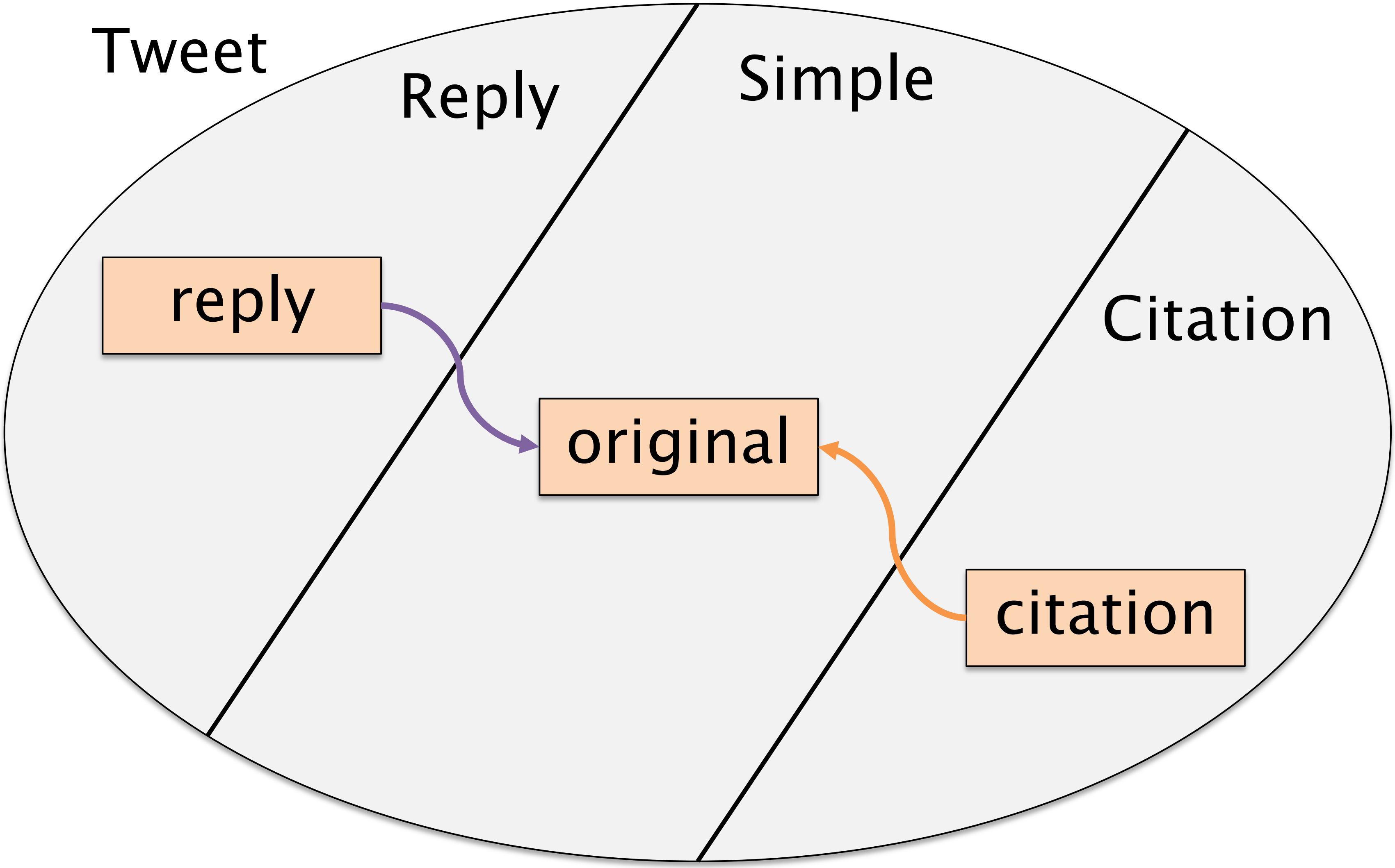
The model allows this (wrong) configuration where a tweet is at the same time both a response and a citation



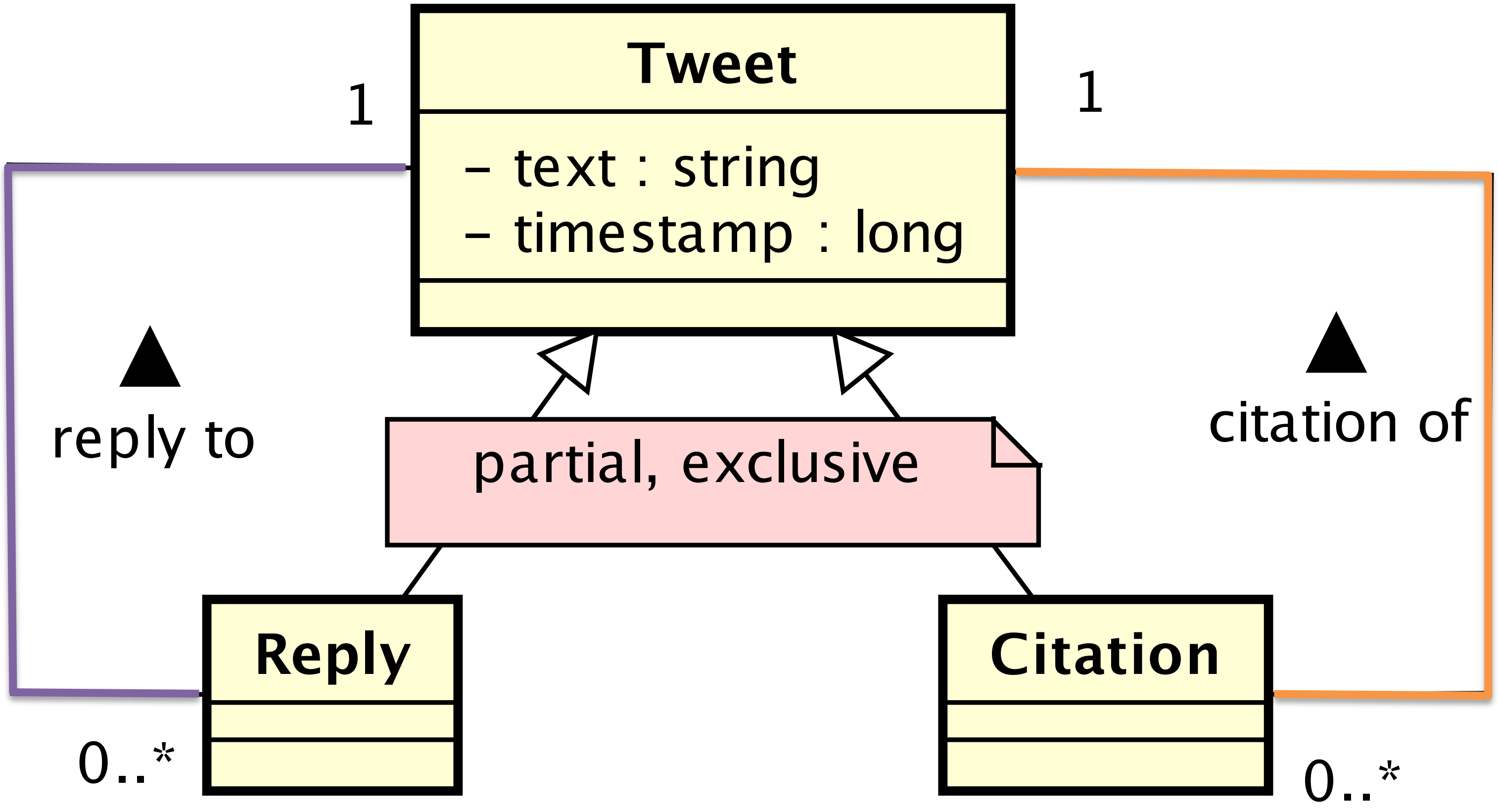
Specialization



Specialization



Partial Specialization



Tweet

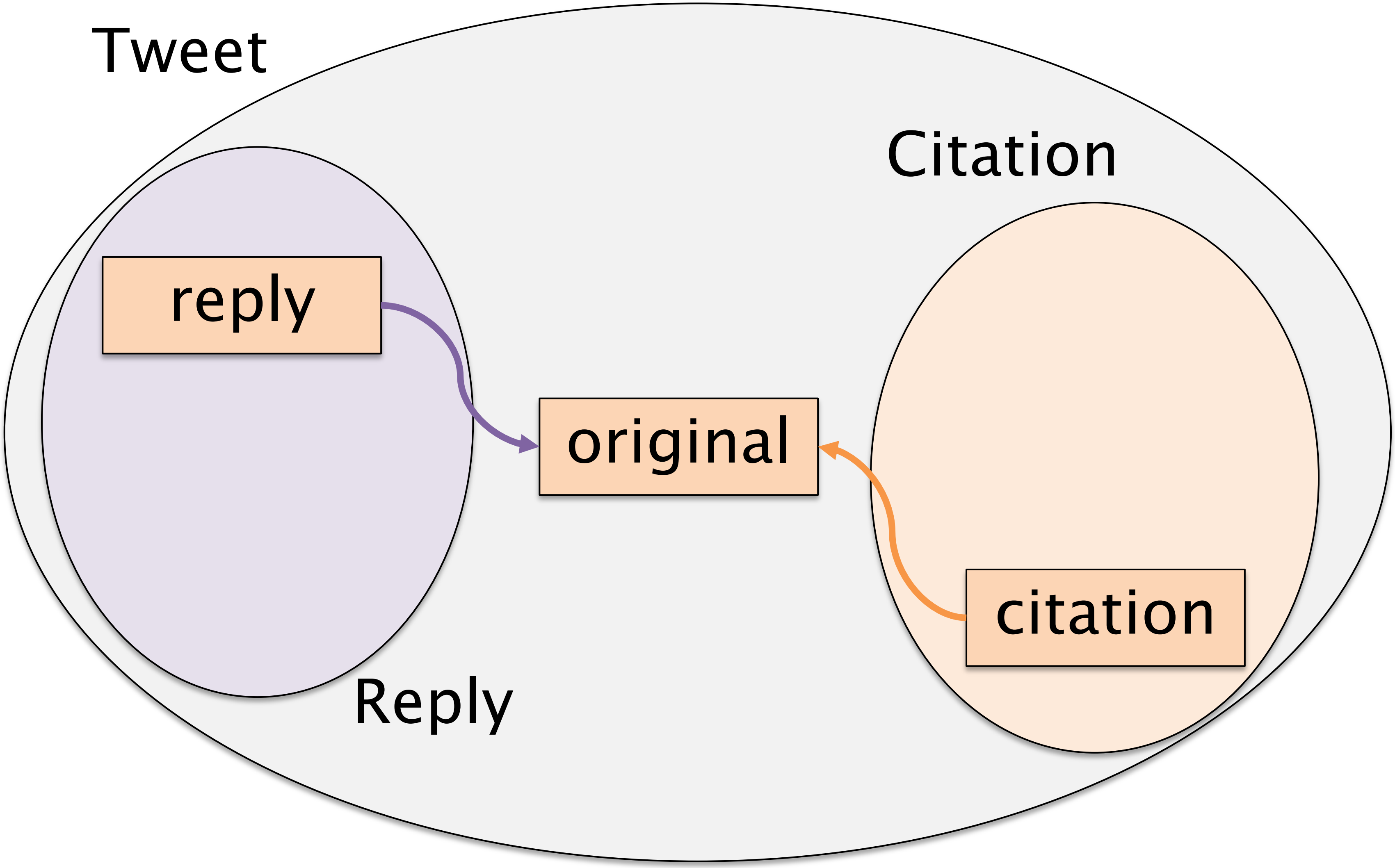
- text : string
- timestamp : long

partial, exclusive

Reply

Citation

Partial Specialization



Essential guidelines (II)

- If one or more concepts are special cases of another concept, it is convenient to represent them by means of a generalization.
- When distinct classes may play the same role w.r.t. an association to a given class it is common to represent this commonality by generalization
  - Inheritance includes also associations

Modeling strategies

- Top–down
  - Start with abstract concepts and perform successive refinements
- Bottom–up
  - Start with detailed concepts and proceed with integrating different pieces together
- Inside–out
  - Like bottom–up but beginning with most important concepts first
- Hybrid

Model quality

- Correctness
  - No requirement is misrepresented
- Completeness
  - All requirements are represented
- Readability
  - It is easy to read and understand
- Minimality
  - There are no avoidable elements

References

- Fowler, M. “UML Distilled: A Brief Guide to the Standard Object Modeling Language – 3rded.”, Addison-Wesley Professional (2003)