# From Concrete to Abstract
## *About Teaching UML Class Diagrams to Novice Programmers*

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Abstract: Object-oriented programming is frequently taught in the first programming course. The implicit level of indirection, expressed in the name-value duality of objects, demands an additional level of abstraction ability. This brings an additional complication for novice students, which are also fighting with flow control and composition. Graphical languages can help visualise the program structure but only if they are not seen as an additional burden. UML class diagrams are the most widely used structure diagram for object-oriented code, but they are very complex for novices. This paper presents a set of translation rules from code to a UML class diagrams that can be introduced in the first or second programming course. To that end, it discusses how to meaningfully explain the semantics of class and object relations, namely by presenting a minimal subset of the UML class diagram metamodel that supports simple and direct translations from object-oriented code. As most students learn better from concrete to abstract, this minimal subset and the respective code translation provide an intermediate step towards the use of a more complete metamodel in more advanced courses.



## 1 INTRODUCTION

When learning object-oriented programming, UML class diagrams (OMG, 2011) are an important subject in itself, but they also offer a way to improve students' abstraction capabilities, more specifically as an intermediate step between programming ability and design ability, a move from concrete to abstract. Yet, UML class diagrams is a large and complex language with lots of complex details. This is especially problematic for novice students (e.g. (Wrycza and Marcinkowski, 2007)). This has motivated the creation of simpler UML editors (e.g. (Turner et al., 2005)), which assume a subset of the UML class diagrams. Here we show how UML class diagrams can be introduced as a translation from code, so as to simplify the transition from a more concrete (Java™ code) to a more abstract one (the class diagram). To that end, we use a minimal subset of the UML class diagrams metamodel.

We do not propose yet another UML editor. In fact, any UML editor will be adequate, as long as the appropriate path to the used constructs is previously shown to the students and made available, preferably as a screen cast allowing repeated viewing. Naturally, a simple editor will be a better option, e.g. the UMLet editor (Auer et al., 2010).

To easy the move from concrete to abstract, the UML class diagrams subset, which we named *minimalCD*, is defined and presented as a direct mapping between object-oriented code, which we exemplify using Java™, and UML class diagram constructs. This mapping is the fundamental part. A clear mapping between the concrete (the code) and the abstract (the class diagram) will help students build their abstraction skills.

The following section briefly introduces UML class diagrams focusing on a metamodel subset for the specification of classes. In Section 3 we identify the set of relationships in *minimalCD*. Next, we use an example and code skeletons to informally present the mappings between object-oriented code (exemplified using Java™) and the respective relationships in the class diagram. Finally, before concluding, we briefly discuss the importance of objects' specification at the diagram level and show that the view of a class diagram as an abbreviation for a large object diagram is supported by the UML specification.


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# 2 UML CLASS DIAGRAMS

Object-oriented textual programs are often modeled by graphical specification languages. The reasons are related to the well-known fact that images help the understanding of code, typically due to an increased level of abstraction. Among graphical specification languages for object-oriented development, UML is by far the most widely used set of languages. These are usually divided in structure and behavior languages (or diagrams). Class diagrams are the most popular structure diagrams. Due to the level of detail, and also due to some more complex constructs, they are overwhelming for novices. Yet, if restricted to the more important and commonly used parts, they are also one of the easiest diagrams to present to students, as they can be seen as a very direct translation of source code. Next, we present the *minimalCD* set of relations between classes in a class diagram.

## 2.1 The minimalCD Subset of UML Class Diagrams

When presenting class diagrams to novices the first thing is to be minimalistic right from the start. More specifically, it should be stressed that class diagrams have basically two kinds of ”pieces”: rectangles, representing classes, and arrows, representing relations between those classes. Then, we should proceed to show the following mappings between code written in some class and the rectangle that represents that same class:

- Class name;
- Type and name for each attribute;
- Method headers.

This mapping is quite trivial, but its simplicity should be used to stress some important points:

- Code is a textual language and class diagrams are a visual or graphical language;
- Class diagrams are inherently more abstract than code, as they do not contain all the details we have to include in code. Most notably, we are not going to include method bodies and, often, not even method headers.

As an example of the adequate level of detail, Fig. 1 shows a Student class with several attributes and four methods.

Attributes and method visibility can be specified by the following syntax:

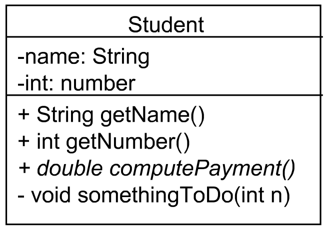



Figure 1: A class specification containing attributes (both private) and four methods: three public and one private

| Notation | Visibility |
|---|---|
| + | **public** |
| - | **private** |
| # | **protected** |
| ~ | *package visibility* |

The following step is to introduce relations. At this point it is important to stress a few more facts:

- Relationships between class are in fact ”relations” between objects of those classes.
- Different relations use different lines and arrows. Regarding arrows it is especially important to note that different arrows have different meanings, just like a colon is different from a semicolon in textual languages.
- The attributes responsible for the specification of relations (namely, associations or dependencies) should not be appear in the class specification. For example, in Fig. 2, syllabus for objects of class Course should not appear as an attribute, as it is already responsible for an association.
- As a rule, only simple numerical types and strings are represented as attributes inside each class. The others will be specified using the graphical notation.

The first point deserves especial attention, as it is one of the most confusing aspects in class diagrams, but a fundamental one that should not be avoided. We will return to this topic after presenting the recommended relationships, the ones in minimalCD.

The following section presents the six relationships used in minimalCD.

# 3 RELATIONSHIPS

We consider two sets of relationships from the UML metamodel, each one corresponding to a complexity level:

**Minimal Set:** This includes only *DirectedRelationships*, more specifically, *Generalization*, *InterfaceRealization*, and *Usage*;

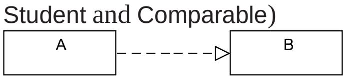
**Complete Set:** All the above, plus the *Association* relationship.

The minimal set is the one used by the BlueJ tool (Kölling et al., 2003; Kölling, 2013). The complete set adds associations, which include simple association and also shared and composite aggregation. The two levels allow the teacher to first introduce the minimal set, e.g. using the BlueJ tool, and only latter to advance to the second one (the complete set), eventually in a second course.

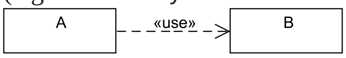
Next, we list the six *Relationship*s in minimaCD, contextualised by the respective metamodel, and accompanied by the respective graphical notation for classes A and B (see also the example in Fig. 2):

1. Directed relationships (*DirectedRelationship*—▷*Relationship*)
   (a) **Generalization/Inheritance:** (*Generalization*—▷*DirectedRelationship)* (e.g. between LocalStudent and Student)

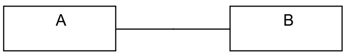

   (b) Dependency (*Dependency*—▷*DirectedRelationship*)
      i. **Interface Realization:** (*InterfaceRealization*—▷*Realization*—▷ *Abstraction*—▷*Dependency*) (e.g. between Student and Comparable)



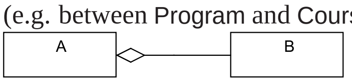

      ii. **Usage** (*Usage* —▷Dependency) (e.g. between Syllabus e Validator)




2. (*Association*—▷*Relationship*) minimalCD only includes binary associations. Each association end can have one of the following three values:
   (a) ***Simple* Association:** (*AggregationKind=none*)(e.g. between Teacher and Course)




   (b) **Shared Aggregation:** (*AggregationKind=shared*) (e.g. between Program and Course)




   (c) **Composite Aggregation:** (*AggregationKind=composite*) (e.g. between Course and Syllabus)


The following section presents the respective mapping from Java™ code to minimalCD models.

# 4 MAPPINGS

When using the minimal set presented in the previous section, all associations are modelled as generic dependencies, just like in the BlueJ tool. Here, we present our proposed mappings for the complete set where we distinguish three types of association: simple, composite, and shared. These are the mappings that should be taught to students as a first step towards the understanding of relations in class diagrams.

## 4.1 Associations

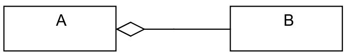
An association is the most common way to compose objects: one object *has* another one. It seems simple, but it is not, and for two reasons, which correspond to two cases:

1. An object can *have* or *be associated to* another object without being *part of* it. For example, we say that a teacher has or is associated to courses, but those courses are not part of the teacher.
2. When we say that one object *has* another object, in fact, it *has* the name of another object, not the other object itself. That allows that second object to belong to more than one object.

In the first case, where *one object has another object that it is not part of the first*, we should use a *simple association*.

In the second case, when we feel secure to say that one object is *part of* another object, our association is in fact an *aggregation*. When in doubt, we should avoid it and use a ”simple” association, without aggregation. Yet, if we decide that it is in fact an aggregation (one object is *part of* another), then we should decide between two forms:

**Shared aggregation** The class A object contains (the name of) one of the class B objects, but without exclusivity. Hence, other objects can contain the name of the same class B object. As already shown, this is specified by the addition of a small unfilled diamond next to the composite object.




**Composite aggregation** In each instant, only one class A object contains the name of the classe B object. This is specified by a small filled rectangle next to the composite object. The composite object is responsible for the existence and storage of the component object.


As a general rule, associations are implemented in code (e.g. Java™) putting object names inside other

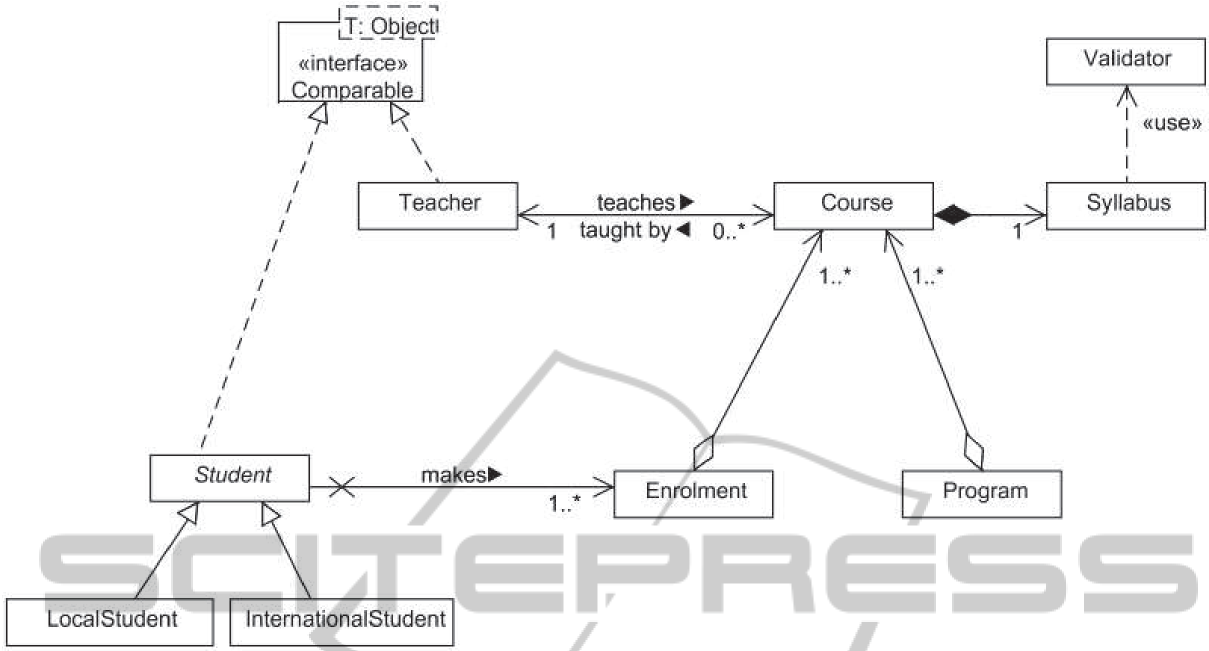



Figure 2: An example with all the minimalCD relationships.

objects. Sometimes different associations can have the same textual specification. This happens because the decision if one object is part of another one forces a real world interpretation.

Next, we present Java™ code skeletons that exemplify the textual specification of the several associations in Fig. 2.

```
class Teacher implements Comparable<Teacher>
{
   // association:
   private List<Course> courses;
   ...
}

abstract class Student implements
Comparable<Student>
{
   // association:
   private List<Enrolment> es;
   ...
}

class Course
{
   // association:
   private Teacher teacher;

   // composite aggregation:
   private Syllabus syllabus;
   ...
}

class Enrolment
{
   // shared aggregation:
   private List<Course> courses;
   ...
}

class Program
{
   // shared aggregation:
   private List<Course> courses;
   ...
}
```

Code skeletons like these should be used to provide the set of "recipes" for the translation. Initially this should be done from code to class diagrams (increasing abstraction), and latter from class diagrams to code (decreasing abstraction).

## 4.2 *Is-a* Relations

Generalization, or inheritance, and interface realization are probably the most characteristic relations in object-oriented development as they are the basis for dynamic binding and polymorphism. Fortunately, they are easily recognizable in code. For example, Java™ even has specific reserved words for generalization/inheritance (extends) and interface realization (implements). Sometimes it can be tricky to choose from the three kinds of association, hence their replacement by a generic dependency; yet, generalization and interface realization are straightforward to identify and translate to UML.

Next, we present Java™ code skeletons that exemplify the textual specification of the several generalizations and interface realizations in Fig. 2.

```
class Teacher implements Comparable<Teacher>
{
   private List<Course> courses;
   ...
}

abstract class Student
        implements Comparable<Student>
{
   private List<Enrolment> enrolments;
   ...
}

class LocalStudent extends Student
{
   ...
}

class InternationalStudent extends Student
{
   ...
}
```

### 4.3 usage

Formally, *usage* is a kind of dependency. Yet, this is not very useful when teaching novices when to use it in a class diagram, as all relations model some kind of ”dependency”, even if not the formal one. Regarding *usage*, novices can use the following rule of thumb: *usage* should be used when there is a compiler dependency and none of the other relationships is applicable. The typical cases where we have a *usage* relation without association, generalization, or interface generalization are the following:

1. When the class A object uses a class B object as a local variable, but not as an attribute. Then, A uses B.
2. When a class A object receives a class B object as a parameter, but does not store it as an attribute. Then, A uses B.

Two additional concepts should also be introduced: navigability and multiplicity.

### 4.4 Navigability and Multiplicity

For each association, the students should learn to specify the navigability and multiplicity between objects. Regarding the former, the rule to be taught is the following: if one object has the name of another object as an attribute, then it can navigate to that other object, as it knows about it. The association between Student and Enrolment, in Fig. 2, exemplifies the two important notations for specifying navigability: the cross and the open arrow.

Students should also learn to specify multiplicity. The UML allows the following possibilities, which are simple enough to be taught to novices:

| Notation | Multiplicity |
|---|---|
| 0..1 | zero or one |
| 1 | one |
| 0..* or just * | zero or more |
| 1..* | one or more |
| n..* | *n* or more (with $n > 1$) |
| n | only *n* (with $n > 1$) |
| 0..n | zero to *n* (with $n > 1$) |
| 1..n | one to *n* (with $n > 1$) |
| n..m | *n* to *m* (with $n > 1$, $m > 1$ and $n < m$) |

The letters n and m represent natural numbers.

## 5 RELATIONS AND LINKS

Frequently it is useful to model objects as a way to better grasp the program dynamic structure and also as an intermediate step when identifying classes. Hence, it should be made clear that the class diagram allows an abbreviation for a large object model that would contain all objects of all classes. This view is supported by the UML specification as each relationship can be seen as a set of ”relations” between objects. More specifically, here is what the UML specification says:

Regarding *association* and *generalization* relationships, we find the following semantics:

**Association:** ”An association declares that there can be *links* between instances of the associated types.” (page 37 in (OMG, 2011)).

**Generalization:** ”A generalization is a taxonomic relationship between a more general classifier and a more specific classifier. Each instance of the specific classifier is also an indirect instance of the general classifier.” (page 70 in (OMG, 2011)).

Hence, an *association* models a set of *links*. These can be seen as ”relations” between the class instances (the objects). Something similar happens with the *generalization* relationship, where ”each instance of the specific classifier” (the class) ”is also an indirect instance of the general classifier”.

The *dependency* relationships that we consider, *Usage* and *InterfaceRealization*, do not exhibit this duality so clearly, but it is still there:

**Usage:** ”A usage is a relationship in which one element requires another element (or set of elements) for its full implementation or operation. In the metamodel, a Usage is a Dependency in which the client requires the presence of the supplier." (page 139 in (OMG, 2011));

**InterfaceRealization:** "A classifier that implements an interface specifies instances that are conforming to the interface and to any of its ancestors." (page 89 in (OMG, 2011)).

Both semantics can be read at the level of instances. Therefore, for all relationships that we propose, the lines between classes can be seen not only as relationships between classes, but also as "relationships" between the respective objects. This can be presented as a "compact" notation: instead of modeling the relationships between all objects, we model relationships between the respective classes.

## 6 CONCLUSIONS

We have proposed a way to introduce UML class diagrams to novice programmers, more specifically we have shown how the main relations can be related to Java™ code, which students typically know. To that end, we presented a proposal for a subset of the UML class diagram metamodel. The mapping between a small set of simple programming constructs and UML classes and relationships should allow students to begin applying more abstract models, hence improving their abstraction skills while learning how to construct models from code. The presented translations can also provide a foundation for a more complete use of class diagrams in more advanced courses.

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