Generating Code for Mapping UML Associations Into C#

Iraky H. Khalifa[1], Ebada A. Sarhan [1] and Magdy S. A. Mahmoud[2]

[1] Helwan University, Computer Science Department, Faculty of Computer Science and information, Egypt

[2] Suez Canal University, Computer Science Department, Faculty of Computer Science and information, Ismailia, Egypt

Abstract. Object-oriented programming languages do not contain syntax or semantics to express associations directly. Therefore, UML associations have to be implemented by an adequate combination of classes, attributes and methods. This paper presents some principles for the implementation a UML binary associations in CSharp (C#), paying special attention to multiplicity and navigability. Our implementation has some specification for bidirectional associations. These principles have been used to write a series of code patterns that we use in combination with using tools which generating code for associations, such as Poseidon for UML and Enterprise Architect. These Tools are read from a UML model stored in XMI (XML Metadata Interchange) format.

1 Introduction

One of the key building blocks in the Unified Modeling Language [UML] is the concept of association. An "association" in UML is defined as a kind of relationship between classes (Actually classifiers. `Classifier` is a superclass of `Class` in the UML metamodel), which represents the semantic relationship between two or more classes that involves connections (links) among their instances [1]. As it has been denounced long ago [2], object-oriented programming languages express classification and generalization well, but do not contain syntax or semantics to express associations directly. Therefore, associations have to be implemented by an adequate combination of classes, attributes and methods [3,9,11]. The simplest idea is to provide an attribute to store the links of the association, and accessor and mutator methods to manipulate the links. Other approaches emphasize the use of Java interfaces to implement associations with some practical advantages [4, 13].

Poseidon UML[5] tools often provide some kind of code generation starting from design models, but limited to skeletal code involving only generalizations and classes, with attribute and method signatures, but no associations at all. The programmer has to manually write the code to manage the associations in a controlled way, so that all constraints and invariants are kept for correctness of the implementation. This is usually a repetitive task that could be automated to a certain extent. Besides, the number of things that the programmer should bear in mind when writing the code for the associations is so large, that he or she continuously risks forgetting some vital detail. This is specially true when dealing with multiple (with multiplicity higher than 1) or bidirectional (two-way navigable) associations. Moreover, the final written code is frequently scattered over the code of the participating classes, making it more difficult to maintain.

The aim of this work is three aims. **First**, write a series of code patterns that will help programmers in mapping UML associations into a target object oriented programming language. In this work, the language has been chosen to be CSharp (C#), although the principles we have followed may be applied to other close languages like C++, Java or the .NET framework. **Second** aim, using a tool that generates code for associations using these patterns, the associations being read from a model stored in XMI format. A **third** aim will be to enable reverse engineering, that is, obtaining the associations between classes by analyzing the code that implements them. Although it is a very simple and straightforward procedure if the code has been written with our patterns.

Associations in UML can have a great variety of features. The present work is limited to the analysis and implementation of multiplicity and navigability in binary associations. It excludes, therefore, more complex kinds of associations such as reflexive associations, whole/part associations (aggregations and compositions), qualified associations, association-classes, and n-ary associations [10]. It excludes, too, features such as ordering, changeability, etc.

The following sections of this article are devoted to studying the features of multiplicity, navigability and visibility of associations, with a detailed analysis of the possible problems and proposed solutions. Then, Section 3 contains the description of a uniform interface for all kinds of associations from the point of view of the participating classes, such as it is implemented by our patterns and source code. Finally, conclude briefly how to developed a concrete way of generating code of mapping UML associations using C# code in this works.

2 The Problem of Multiplicity

The multiplicity of a binary association, placed on an association end (the target end), specifies the number of target instances that may be associated with a single source instance across the given association, in other words, how many objects of one class (the target class) may be associated with a given single object from the other class (the source class) [2]. The classical example in Figure 1 illustrates binary multiplicity. Each instance of `Person` may work for none or one instance of `Company` (0..1), while each company may be linked to one or more persons (1..*). For those readers less familiarized with UML notation, the symbol (*) stands for "many" (unbounded number), and the ranges (1..1) and (0..*) may be abbreviated respectively as (1) and (*).

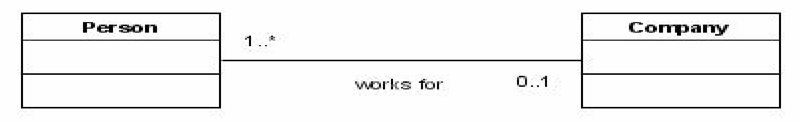


Fig. 1. A classical example of binary association with the expression of multiplicities

Listing 1. Program code to maintain the binary association between Person and Company

```
namespace model_1 {              namespace model_1 {

  public class Company              public class Person

  {                                 {

    .........................           ....................

public Person[]person;           public Company company;

 } }                                }  }
```

The potential multiplicities in UML extend to any subset of nonnegative integers [2], not only a single interval as (2..*), or a comma-separated list of integer intervals as (1..3, 7..10, 15, 19..*): specifications of multiplicity like {prime numbers} or {squares of positive integers} are also valid, although there is no standard notation for them. Nevertheless, in UML as in other modeling techniques, the most usual multiplicities are (0..1), (1..1), (0..*) and (1..*). We are going to restrict our analysis to multiplicities that can be expressed as a single integer interval in the form of *(min..max)* notation. The multiplicity constraint is a kind of *invariant*, that is, a condition that must be satisfied by the system. A possible practice when programming is: do not check always the invariant, but only at the request of the programmer, after completing a set of operations that are supposed to leave system in a valid state (a *transaction*).

This practice is more efficient in run-time, and gives the programmer more freedom and responsibility in writing the code, with the corresponding risk that he or she forgets putting the necessary checks and carelessly leaves the system in a wrong state. On the other side, we think that checking multiplicity constraints is not very time consuming (inefficient), especially when compared with the time required to manage collections or synchronize bidirectional associations (see Section 3). Therefore, we think that it is worth doing as much as we can for the programmer, so that our first target will be to analyze the possibility of performing automatic checks for multiplicity constraints.

2.1 Optional and mandatory associations

The value of minimum multiplicity can be any positive integer, although the most common values are 0 or 1. When the value is 0 we say the association is *optional* for the class on the opposite end (class `Person` in Figure 1), when the value is 1 or greater we say it is *mandatory* (class `Company`). Optional associations pose no special problems for the implementation, but mandatory associations do. From a conceptual point of view, an object participating in a mandatory association needs to be linked *at any moment* with one object (or more) on the other side of the association, otherwise the system is in a wrong state. In the example given in Figure 1, an instance of `Company` needs always an instance of `Person`. Therefore, in the same moment you create the instance of `Company`, you have to link it to an instance of `Person`.

This can happen in three different ways:

- An instance of `Company` is created by an instance of `Person` and linked to its creator.
- An instance of `Company` is created with an instance of `Person` supplied as a parameter.
- An instance of `Company` is created and it issues the creation of an instance of `Person`.

The third case poses additional problems. The creation of a `Person` will probably require additional data, such as name, address, etc., and it does not seem very sensible to supply them in the creation of a `Company`. This problem becomes much worse if `Person` has other mandatory associations, for example one with the `Country` where he or she lives: if this were the case, the creation of a `Company` would require supplying data for creating a `Person`, for creating a `Country`, etc. The most obvious solution is to allow only the first and second forms of instantiation. But then suppose the association is mandatory in both ends. Which instance is to be created first? We have not a satisfactory choice, since we will put the system in a wrong state until both creations are finished.

We could think of an *atomic creation* of both instances, but this is valid only for the simplest case in which only two classes are involved. Should we define atomic creators for two, three, any number of classes? Similar problems arise when dealing with object deletion. Imagine now that we are not creating or deleting instances, but changing links between instances.

If you want to change the instance of `Company` that is linked with a given instance of `Person`, simply delete the link with the old `Company` and add a new link with the new `Company`. This works as far as the old `Company` is linked to other instances of `Person`; you can even delete the link and add no new one, since the association is optional for `Person`. If you had only one `Person` linked to a given `Company`, you should supply a new `Person` to the `Company` before deleting the link with the old `Person`, but this is only the specified behavior (the association is mandatory for `Company`) and you cannot complain about it. Nevertheless, we find new problems here. If the association with `Company` were mandatory for `Person` too (that is, 1..1 multiplicity instead of the current 0..1), the instance of `Person` could not delete the old link with a `Company` and then add the new one, nor it could do it in the reverse order, "first add then delete", because it would go through a wrong system state. An *atomic change* of links would be valid only for the simplest cases, but not for more complex ones such as the following, rather twisted case (see Figure 2): consider classes `A` and `B`, which are associated with multiplicity 1..1 on both ends, and the corresponding instances `a1`, `a2`, `b1` and `b2`. In the initial state, we have the links `a1-b1` and `a2-b2`. In the final state, we want to have the links `a1-b2` and `a2-b1`. Even if we can change atomically `a1-b1` to `a1-b2` without violating the multiplicity constraints on `a1`, this would leave `b1` without any links and `b2` with two links until the final state is reached. We should have to perform the whole change atomically by means of an *atomic switch* implemented in a single operation.

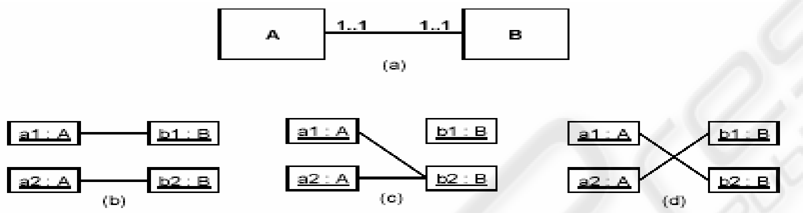


Fig 2. Multiplicity constraints can make very difficult changing links between instances without entering a wrong system state: a) class diagram; b) initial state; c) intermediate wrong state; d) final desired state.

Obviously, we cannot define a new operation to avoid any conceivable wrong state involving several instances. In consequence, we think that mandatory associations pose unsolvable problems regarding the creation and deletion of instances and links: we cannot achieve with a few primitive operations that a mandatory association is obeyed *at any time*, and we cannot isolate, inside atomic operations, the times when the constraint is not obeyed. Therefore, we have to relax the implications of mandatory associations for the implementation, as other methods do [8]. This proposal is as follows: *do not check the minimum multiplicity constraint when modifying the links of the association* (mutator methods, or setters), *but only when accessing them* (accessor methods, or getters). The programmer will be responsible for using the primitives in a consistent way so that a valid system state is reached as soon as possible.

For example, you will be allowed to create a `Company` without linking it to any `Person`, and you will be allowed to delete all the links of a `Company` with instances of `Person`; but before accessing, for other purposes, the links of that particular instance of `Company` towards any instances of `Person`, you will have to restore them to a valid state, otherwise you will get an *invalid multiplicity exception*, which shall be defined in the code that implements the associations according to this proposal [9,13].

2.2 Single and multiple associations

The value of maximum multiplicity in an association end can be any integer greater or equal than 1, although the most common values are 1 or *. When the value is 1 we say the association is *single* for the class on the opposite end (class Person in Figure 1), when the value is 2 or greater we say it is *multiple* (class Company). Single associations are easier to implement than multiple associations: to store the only possible instance of a single association we usually employ an attribute having the corresponding target class as type, but to store the many potential links of a multiple association we must use some kind of collection of objects, such as the C# predefined Length, Hashtable, etc. In the general case we cannot use an array of objects, because it gets a fixed size when it is instantiated. Since collections in C# can have any number of elements, the maximum multiplicity constraint cannot be stated in the declaration of the collection in the C# code, but it must be checked elsewhere during run-time.

We need two kinds of mutators, add and remove, which will accept as a parameter either single objects or entire collections. Because of the problems with minimum multiplicity explained above, the remover sometimes will leave the source instance in a wrong state; we can't avoid this situation. The adder, instead, leaves us a wider choice. If we try to add some links above the maximum multiplicity constraint, we can choose between rejecting the addition or performing it; in the latter case we violate temporarily the constraint until a call to the remover restores the source instance to a safe state; the wrong state would only be detected by accessor methods, as we settled in the case of minimum multiplicity. However, this is true only for multiple associations implemented with a collection; in single associations implemented by means of an attribute we simply cannot violate the maximum multiplicity constraint: we are forced to reject the addition.

If we choose to reject the addition, instead, besides having an asymmetric behavior between remover and adder, we can find precedence problems when invoking the adder and the remover in succession. Consider class Game associated with class Player with multiplicity 2..4 (see Figure 3), and suppose an instance g1 of Game is linked to two instances p1, p2 of Player. We want to replace these two players by four new different players q1, q2, q3, q4. If we issue "first remove then add", we get finally what we want; if we issue "first add then remove", the addition is rejected and the remotion leaves the instance of Game in a wrong state.

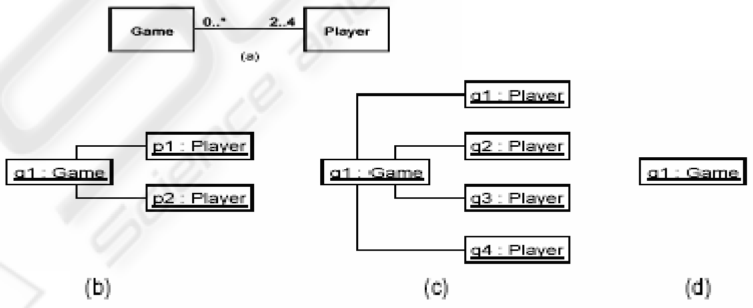


Fig 3. Precedence problems found when invoking the adder and the remover in succession: a) class diagram of Game-Player association; b) initial state with players p1, p2; c) final desired state after removing players p1, p2 and then adding players q1, q2, q3, q4; d) final wrong state after unsuccessfully trying to add players q1, q2, q3, q4 and then removing players p1, p2 .

Listing 2. Program Code to maintain the binary association between Person and Company

```
namespace model_2 {

public class Game {

public Player m_Player;

public Game(){

         }

~Game(){

         }

public virtual void
Dispose(){

}   }//end Game }//end
namespace model_2
```

```
namespace model_2  {

public class Player {

public Player(){

         }

         ~Player(){

         }

public virtual void
Dispose(){

         }

}//end Player }//end
namespace model_2
```

In the end, we have preferred to *reject the addition if it violates the maximum allowed*, and ask the users of mutator methods to use them always in the right order, first remove then add, so that we can get an analogous behavior for single and multiple associations. Therefore, the remover does not check the minimum multiplicity constraint (possibly leaving empty a mandatory association), the adder does check the maximum multiplicity constraint, and the getter raises an exception if either constraint is not fulfilled. Accessor methods of multiple associations have another peculiarity, when compared with the accessors of single associations: they return a collection of objects, not a single object, therefore the returned type is that of the collection, not that of the target class. In our implementation, the returned type is the C# interface `Collection`, which is implemented by all standard collections. Internally, we use a `Hashtable` collection, which ensures that there are no duplicate links in an association, as the UML requires [7].

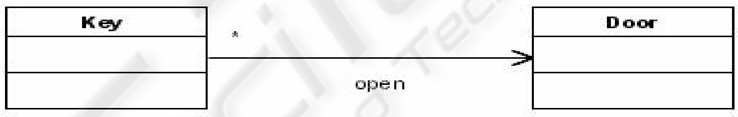
Finally, the standard collections in C# are specified to contain instances of the standard class `Object`, which is a superclass of every class in C#. You cannot specialize these collections to store objects pertaining only to a particular class (That is, you cannot specialize them to modify their storage structure, but you can modify their behavior so that they) store in effect only the required objects, precisely by means of the run-time type checking method we describe.. This means that, if we use a `Hashtable` inside `Company` to store the links to instances of `Person`, we must ensure on our own that no one puts a link to an instance of another class such as `Dog` or `Report` (this could happen if a collection of objects is passed as a parameter to the `add` method). Therefore, the mutator methods must perform a run-time type checking by means of explicit *casting*. If the type-check fails, then the link is not set to that object, and a *class cast exception*, which is predefined in C#, is raised.

3 The Problem of Navigability

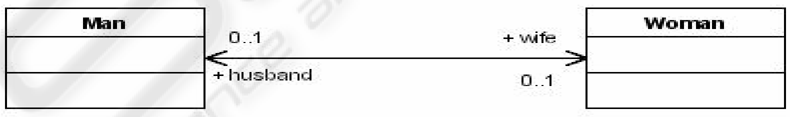
The directionality, or navigability, of a binary association, graphically expressed as an open arrow at the end of the association line that connects two classes, specifies the ability of an instance of the source class to access the instances of the target class by means of the association instances (links) that connect them (An alternate definition: the possibility for a source object to designate a target object through an association instance (link), in order to manipulate or access it in an interaction with message interchanges. The Standard does not give a clear definition of navigability, as we have shown in previous works where we have tried to clarify this topic [9,10,13]). In this paper, we take navigability and directionality as synonyms. If the association can be traversed in both directions, then it is *bidirectional* (two-way), otherwise it is *unidirectional* (one-way).

A navigable association end, which is referenced by its rolename, defines a pseudo attribute of the source class, so that the source instance can use the rolename in expressions in the same way as it uses its own attributes [6]. An instance can communicate (by sending messages) with the connected instances of the opposite navigable end [11], and it can use references to them as arguments or reply values in communications [7]. Similarly, if the association end is navigable, the source instance can query and update the links that connect it to the target instances.

The examples in Figure 4 illustrate navigability. The association `Key-Door` is unidirectional, meaning that a `Key` can access the `Door` it can open, but an instance of `Door` does not know the set of instances of `Key` that can open it: the `Door` cannot traverse the connections (links) against the navigability of the association. On the other side, the association `Man-Woman` is bidirectional, meaning that connected instances of these classes know each other.



a) Unidirectional



b) Bidirectional

Fig 4. Examples of a) Unidirectional and b) Bidirectional Associations.

The arrowheads can be shown or omitted in a bidirectional association [14]. Unfortunately, this leads to an ambiguity in the graphical notation, because we cannot. distinguish between bidirectional associations and associations with unspecified navigability. Or, worse, unspecified associations are assumed to be bidirectional without further analysis [10].

Listing 3. Program code to maintain the unidirectional and bidirectional associations

```
   namespace model_3 {              namespace model_4 {

     public class Key_ {              public class Woman {

      ......................            ............................ .

     public Door door;                public Man husband;

             }      }                 }      }

     public class Door {              public class Man {

        ..............                 ......................

            }                        public Woman woman; }
```

3.1 Unidirectional associations

A *single unidirectional association* is very similar to a single valued attribute in the source class, of the type of the target class: an embedded reference, pointer, or whatever you want to call it. The equivalence, however, is not complete. Whereas the *attribute value* is "owned" by the class instance and has no identity, an *external referenced object* has identity and can be shared by instances of other classes that have a reference to the same object [12] (see Figure 5). Anyhow, the equivalence is satisfactory enough to serve as a basis for the implementation of this kind of associations. In fact, in C# there is no difference at all: except for the case of primitive values, attributes in C# are objects with identity, and if they are public you cannot avoid them to be referenced and shared by other objects.

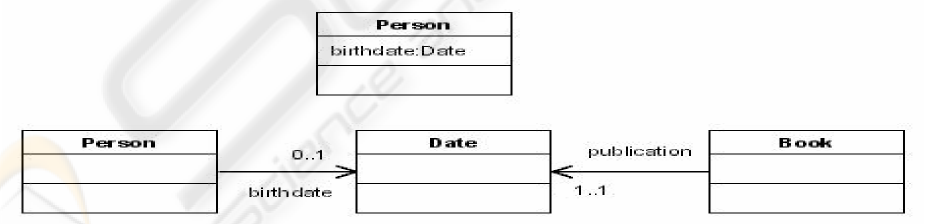


Fig. 5. Partial equivalence between a) attribute and b) single unidirectional association.

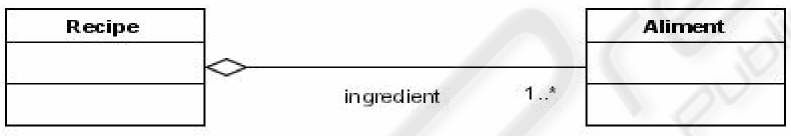
Listing 4. Program code to maintain the Partial equivalence between attribute and single unidirectional association

```
  namespace model_2 {                 ............................. . .

   public class Person {            public Date birthdate;
```

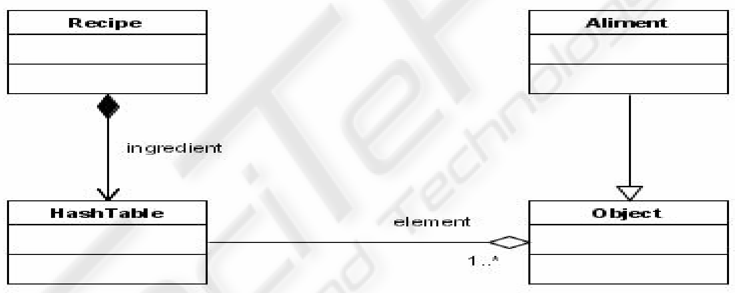
```
                }
               }
 public class Date {
 /// Attributes – Asso-
 ciation End
 public class Book {
```

```
  ........................................
public Date publica-
tion;
                    }
                    }
```

A *multiple unidirectional association* is a bit more complicated, although the implementation can be based on the same principles, since it can be assimilated to a multivalued attribute (UML allows multiplicity in attributes, thus multivalued attributes [8]). To manage the collection of objects on the navigable end, however, we need an additional object of a standard collection class, which is a `Hashtable` in our implementation (see Figure 6).



(a)



(b)

Fig. 6. Multiple unidirectional association: a) analysis diagram and b) design diagram.

A new object must be inserted to manage the collection of target objects. The standard collections in C#, such as `Hashtable`, are defined for the standard class `Object`, which is a superclass of every class; therefore, mutator methods must ensure that the objects contained in the collection parameter are of the appropriate type before adding them to the collection attribute. Therefore, the type of the attribute used to implement the association inside the source class is not any more the target class itself, but the `Hashtable` class or another convenient collection class. The methods to manage the association will have to accomplish some additional tasks. *Mutators* can add or remove not only single objects of the class target, but also entire collections; thus, the type of the parameter will be either the target class of the association or the intermediate collection class.

In this case, mutator methods must ensure that the objects contained in the collection parameter are of the appropriate type before adding them to the collection attribute. *Accessors*, as we have already explained (see Section 2), do not return a single object, but a collection of objects, even when the collection is made up of only one element. The returned collection object is not identically the same one that is stored inside the source class, but a clone (a new object with a collection of references to the same target elements), because the original collection object must remain completely encapsulated inside the source object (represented by the composition in Figure 6).

Listing 6. Program code to maintain the Multiple unidirectional association analysis and design diagrams

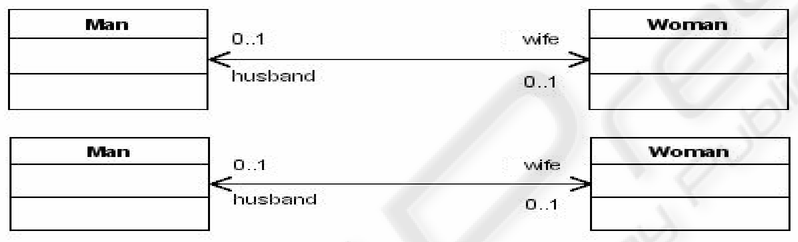
```
namespace model_6  {

   public class Recipe
         {

    ........................

    public Aliment[]
ingredient;

    ........................ .

   public Aliment ali-
ment;

         }   }

public class Aliment {

    ..................

public Recipe recipe;

         }

public class Recipe {

   ................. .

public HashTable
hashTable;
```

```
public HashTable
hashTable_1; }

public class Aliment :
Object {

           }

public class HashTable
{

   ......................

public Recipe recipe;

   ....................

public Object[] object;

            }

public class Object {

    .................... . .

public HashTable
hashTable_2;

           }
```

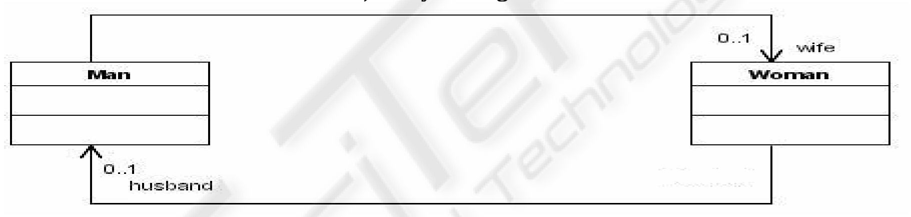
As the diagrams in Figures 5 and 6 show, in our opinion *the multiplicity constraint in a design model can be specified only for a navigable association end*. Indeed, the multiplicity is a constraint that must be evaluated within the context of the class that owns the association end; if that class knows the constraint, then it knows the association end, that is, the end is navigable. You cannot restrict the number of objects connected to a given instance unless this instance has some knowledge of the connected objects, that is, unless you make the association end navigable. Therefore, *the need for a multiplicity constraint other than 0..** (that is, unrestricted) *is an indication that the association end must be navigable*. In consequence, unidirectional associations with multiplicity constraints on the nonnavigable association end must be rejected in code generation.

3.2 Bidirectional associations

The partial equivalence between attributes and unidirectional associations is not any more found among bidirectional associations. Instead, an instance of a bidirectional association is more like a *tuple of elements* [14]. Combining the multiplicities in both association ends, we can have three cases: single-single, single-multiple, and multiple_multiple.



a) analysis diagram



b) design diagram.

Fig. 7. Single-single bidirectional association: a) analysis diagram and b) design diagram

Listing 7. Program code to maintain the Single-single bidirectional association analysis and design diagrams

```
namespace model_7 {

public class Man {

   ........................

public Woman woman;    }    }

public class Woman {
```

```
/// Attributes – AssociationEnd and AssociationEnd hus-
band

public Man husband;   } }
```

The implementation of the association's mutators must ensure that the husband of the wife of a given man is that man himself, and vice versa.An easy way to implement a *single-single* bidirectional association is by means of two synchronized single unidirectional associations (see Figure 7). The synchronization of the two halves must be preserved by the mutator methods on each side: every time an update is requested on one side, the other side must be informed to perform the corresponding update; the update is accomplished only if both sides agree that they can perform it while keeping maximum multiplicity constraints.

A *single-multiple* bidirectional association can be implemented in a similar way, combining a single unidirectional association and a multiple unidirectional association. And, finally, a *multiple-multiple* bidirectional association is achieved by means of two multiple unidirectional associations (see Figure 8).

Synchronization becomes progressively a more and more complex issue when one or both association ends are multiple. Consider the example given in Figure 8. Suppose you want to add an author to a particular `Book` instance; you do this by issuing the `add` method on the `Book` instance, and passing a `Person` instance as a parameter. If the `Book` can have more authors without violating its maximum multiplicity (which is 3), then it requests the author to add the `Book` itself to the collection of publications the `Person` has; this can fail if the maximum multiplicity constraint for the number of publications (in this case, 10) is violated. If the request to the author succeeds, then the `Book` updates its side.

Now, you can try adding a collection of authors to a `Book`, too. As one can expect, the `Book` requests each one of the authors to add the `Book` itself as a publication; if only one of the authors fails to add the `Book`, then the whole operation must be undone, since an update must be atomic: all or none.

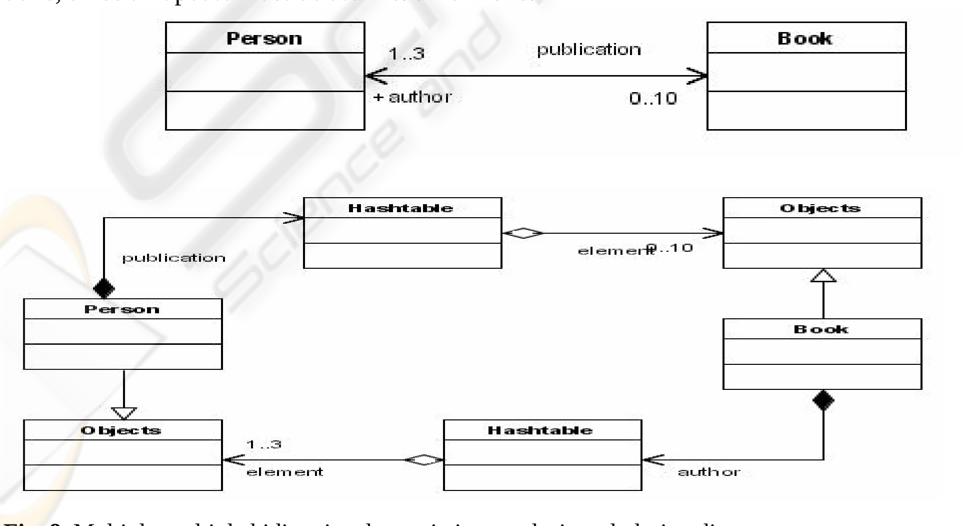


Fig. 8. Multiple-multiple bidirectional association: analysis and design diagrams

SciTePress Science and Technology Publications

Similar considerations apply to the `remove` mutator, bearing in mind that the `remove` method is performed even if the minimum multiplicity constraint is not kept, therefore it can leave the source instance or any of the affected target instances in an invalid state.

4 Conclusions

In this work we have developed a concrete way of generating code of mapping UML associations using C# code: we have written specific code patterns, and we have using a tool that reads a UML design model stored in XMI format and generates the necessary C# files. We have paid special attention to two main features of associations: multiplicity and navigability. This analysis has encountered difficulties that may reveal some weaknesses of the UML Specification.

However, different tool options will allow the user to override the automatic multiplicity and type checks when generating code, in favor of efficiency. Besides, we have argued that unidirectional associations should not have a multiplicity constraint on the source end in a design model, and bidirectional associations should not have both ends with private (or protected) visibility; therefore, the tool will reject the generation of code for these associations. Again, the user will be able to disable this model-correctness checking and issue the code generation at his/her own risk.

This work can be continued on several lines. First, implementation of other association end properties, such as ordering, changeability, interface specified, xored associations, and so on. Second, specific implementation of particular kinds of binary associations, such as reflexive associations, aggregations and compositions. Third, implementation of more complex associations: qualified associations, associations classes, and n-ary associations. Fourth, expand the tool to perform reverse engineering, that is, obtaining the associations between classes by analyzing the code that implements them.

References

1. Object Management Group. *XML Metadata Interchange (XMI) Specification*, Version 1.2, January 2002. Available at http://www.omg.org/.
2. James Rumbaugh. "A Search for Values: Attributes and Associations". *Journal of Object Oriented Programming*, 9(3):6-8, June 1996.
3. Scott W. Ambler. “An Overview of Object Relationships”, “Unidirectional Object Relationships”, “Implementing One-to-Many Object Relationships”, “Implementing Many-to-Many Object Relationships”. A series of tips to be found at IBM Developer Works, http://www-106.ibm.com/developerworks/.
4. Hermann Kaindl. “Difficulties in the Transition from OO Analysis to Design”. *IEEE Software*, 16(5):94-102 (1999).
5. The Poseidon UML tool, http://www.gentleware.com//
6. James Rumbaugh. "Relations as Semantic Constructs in an Object- Oriented Language", In *Proceedings of the ACM Conference on Object-Oriented Programming: Systems, Languages and Applications*, pp. 466-481, Orlando, Florida, 1987.

7. Object Management Group. *Unified Modeling Language (UML) Specification*, Version 1.4, September 2001 (Version 1.3, June 1999). Available at http://www.omg.org/.
8. Perdita Stevens. “On the Interpretation of Binary Associations in the Unified Modelling Language”, *Journal on Software and Systems Modeling*, 1(1):68-79 (2002). A preliminar version in: Perdita Stevens. "On Associations in the Unified Modeling Language". *The Fourth International Conference on the Unified Modeling Language*, UML'2001, October 1-5, 2001, Toronto, Ontario, Canada. Published in *Lecture Notesin Computer Science 285*, Springer 2001, pp. 361-375.
9. Gonzalo Génova. "Semantics of Navigability in UML Associations". *Technical Report UC3M-TR-CS-2001-06*, Computer Science Department, Carlos III University of Madrid, November 2001, pp. 233-251.
10. Gonzalo Génova, Juan Llorens, Paloma Martínez. “The Meaning of Multiplicity of N-ary Associations in UML”, *Software and Systems Modeling*, 1(2): 86-97, 2002. A preliminary version in: Gonzalo Génova, Juan Llorens, Paloma Martínez. “Semantics of the Minimum Multiplicity in Ternary Associations in UML”. *The 4th International Conference on the Unified Modeling Language-UML'2001*, October 1-5 2001, Toronto, Ontario, Canada. Published in *Lecture Notes in Computer Science 285*, Springer 2001, pp. 329-341.
11. Gonzalo Génova, Juan Llorens, Vicente Palacios. "Sending Messages in UML", *Journal of Object Technology*, vol.2, no.1, Jan-Feb 2003, pp. 99- 115, http://www.jot.fm/issues/issue_2003_01/article3.
12. Il-Yeol Song, Mary Evans, E.K. Park. "A Comparative Analysis of Entity- Relationship Diagrams", *Journal of Computer and Software Engineering*, 3(4):427-459 (1995).
13. William Harrison, Charles Barton, Mukund Raghavachari. "Mapping UML Designs to Java". *The 15th Annual ACM Conference on Object-Oriented Programming, Systems, Languages, and Applications-OOPSLA’2000*, October 15-19 2000, Minneapolis, Minnesota, United States. *ACM SIGPLAN Notices*, 35(10): 178-187. ACM Press, New York, NY, USA.
14. Guy Genilloud. "Informal UML 1.3 - Remarks, Questions, and some Answers". *UML Semantics FAQ Workshop* (held at ECOOP'99), Lisbon, Portugal, June 12th 1999.
15. *The Fujaba CASE Tool*, University of Paderborn, http://www.fujaba.de/.
16. Java Community Process. *Java Metadata Interface (JMI) Specification*, Version 1.0, June 2002. Available at http://www.jcp.org/.