

# Multiobjects to Ease Schema Evolution in an OODBMS

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**Abstract.** The multiobject mechanism is a pertinent way to implement specialization in an object database and differs from the classical mechanism used in most object-oriented database systems. It supports multiple instantiation, automatic classification and object migration. Consequently it is well suited to take into account schema evolution. It makes schema changes more pertinent, easier to implement, and less expensive than with the classical implementation of specialization indeed. The multiobject mechanism is implemented in the F2 database system which supports schema evolution.

## 1 Introduction

In the classical implementation of specialization in object-oriented database systems (OODBMS) an object is an instance of one most specific class. It is completely stored in this class, i.e. all attribute values on local and inherited attributes are present in the object. This has several shortcomings for object modelling and object evolution. Since an object is an instance of only one class, one must use multiple inheritance to model real-world entities that have many facets at once. This can lead to a combinatorial explosion of sparsely populated classes, as pointed out in [34] [33] [27] [28]. Once an object is created in a class, it stays in that class until it is deleted from it. This is a serious limitation, since one is forced to model real-world entities that evolve dynamically with objects that can not, as pointed out in [30] [33] [2] [28]. Several approaches (see section 4) have been proposed to overcome these shortcomings. In this paper we address other shortcomings of the classical implementation of specialization which are related to schema evolution.

Schema evolution is an essential feature of a database system to allow database applications to run in a dynamic environment. Updating the schema of a populated database has repercussions on database objects in order to keep the database in a consistent state. Supporting single-instantiated and static objects restricts schema changes. Moreover, it requires to copy data when modifying the schema which is extremely time-consuming. Suppose for example that a class *Swiss* is added as a subclass of *Person*. With a classical implementation, it is not possible to make some of the existing *Person* objects belong now to the *Swiss* subclass. For all swiss citizens, the database administrator has to create copies of the *Person* objects in the new subclass *Swiss* and to delete the

corresponding objects in class *Person*. This may be a very expensive operation if there are many swiss persons.

Supporting classical inheritance makes many schema changes difficult to understand and to implement. *Orion* [8] requires complex propagation rules to disambiguate the effect of schema changes. *Gemstone* [29] does not support some schema changes because their motivation is to only provide schema changes which are “well understood and have a reasonable implementation”.

We propose the multiobject mechanism to implement specialization in an object-oriented database system. This mechanism supports multiple instantiation, automatic classification and object migration. It makes schema changes more pertinent, eases their implementation and understanding, and reduces their execution time. The multiobject mechanism is implemented in the F2 OODBMS. F2 is a general purpose database system developed at C.U.I. and used to experiment several features such as: updatable views [16], information system design methods [15], knowledge databases [17], database integration [13], schema evolution [7] [6] [3]. It is written in Ada and runs under SunOS, DEC/ALPHA, MacOS and Windows 95.

The remainder of the paper is organized as follows. In section 2, we present the multiobject mechanism. In section 3, we show its advantages with respect to schema evolution. In section 4, we describe related approaches and compare the multiobject mechanism to them. In section 5 we conclude with a summary.

## 2 Multiobject Mechanism

We describe in this section the multiobject mechanism. We introduce first the multiobjects and describe then the methods to manipulate them.

### 2.1 Multiobjects

**Defining a Multiobject.** In the F2 model [6] an *object* is an instance of a *class*. Objects structure is defined by class attributes. Objects behaviour is defined by primitive methods and triggered methods. A class, called *subclass*, can be declared as a specialization of another class called *superclass*. The class hierarchy is a forest, i.e. a set of *specialization trees*: a subclass has only one superclass (single inheritance), and there is not a root system-defined class. On a subclass may be defined *specialization constraints*. An object belongs to a subclass if and only if it satisfies the specialization constraints of the subclass. The *ancestors* of a subclass are its direct and indirect superclasses. The *descendants* of a class are its direct and indirect subclasses.

We assume that the reality consists of *entities*. Entities have several facets. For example, a human being may be seen as a person, an employee, a tennis player, a student, etc. An entity is implemented in the multiobject mechanism by a set of objects in distinct classes of a specialization tree,  $M_o = \{o_{C_1}, o_{C_2}, \dots, o_{C_n}\}$ , called *multiobject*. Each object  $o_{C_i}$  denotes a facet of the entity and carries data specific to its corresponding class  $C_i$ . This is referred to as multiple instantiation. A multiobject  $M_o$  satisfies the following constraint: if  $o_{C_i}$ ,  $1 \leq i \leq n$ , belongs to  $M_o$  and  $C_i$  is a subclass of  $C_j$  then there must be

an object  $o_{C_j}$ ,  $1 \leq j \leq n$  and  $j \neq i$ , which belongs to  $M_o$ . In other words, if an entity possesses an object in class  $C$ , then the entity must also possess objects for all the ancestors of  $C$ . For example, the class *Student* is a subclass of *Person*. A student is implemented by a multiobject containing two objects  $r_{Student}$  in *Student* and  $r_{Person}$  in *Person*.

Subclasses can be inclusive, i.e. a multiobject may contain two objects  $o_{C_i}$  and  $o_{C_j}$  where  $C_i$  and  $C_j$  are sibling classes. For example, the class *Person* has another subclass *Employee* (see fig. 1.a). A person who is a student and an employee is implemented by a multiobject containing three objects:  $r_{Person}$  in *Person*,  $r_{Student}$  in *Student* and  $r_{Employee}$  in *Employee* (see fig. 1.b). There is therefore no need to add an artificial intersection class *Student&Employee* as with the classical implementation of specialization.

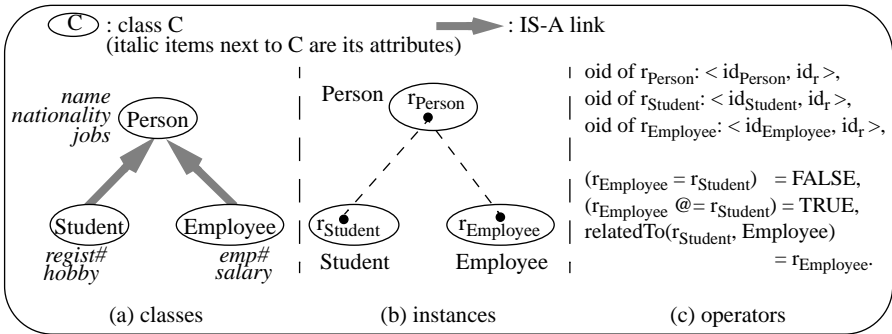


Fig. 1. Implementing a student-employee

An object  $o_C$  in class  $C$  has the oid  $\langle id_C, id_o \rangle$  where  $id_C$  is the class identifier and  $id_o$  the instance identifier within  $C$  (as in *Orion* [8]). Two objects  $p_E$  and  $q_F$  are related, i.e. they belong to the same multiobject, if:

- their classes  $E$  and  $F$  are in the same specialization tree, and
- they have the same instance identifier ( $id_p = id_q$ ).

Two objects  $p_E$  and  $q_F$  are identical, if:

- they have the same oid (i.e. same class identifier and same instance identifier).

The operator “=” checks if two objects are identical, while the operator “@=” checks if two objects are related. The function *relatedTo*( $o_D, C$ ) returns the object in class  $C$  which is related to  $o_D$  ( $C$  and  $D$  being two classes in the same specialization tree). In other words, this function returns the object which has the oid  $\langle id_C, id_o \rangle$ . If no such object exists in  $C$ , it returns the unknown object. Note that in other approaches this function is called casting or coercion. Examples are given in figure 1.c.

Since an entity may gain and lose facets during its life-time, objects can be added to and removed from its corresponding multiobject (see §2.2).

**Querying a Multiobject.** In the multiobject mechanism, attributes are not inherited in the classical sense of inheritance; they are *reached* by navigating in a specialization tree. This contrasts with the classical implementation of specialization. For the objects of a subclass  $C$ , only the values on attributes locally defined at  $C$  are stored. The values on attributes defined at the superclass  $S$  of  $C$  are not stored with  $C$  objects but with their

related  $S$  objects. For example, in figure 1, if the name of  $r_{Person}$  is “Dupont” and  $r_{Employee}$  in  $Employee$  is related to  $r_{Person}$  then  $r_{Employee}$  is named Dupont. The *name* values are stored with the objects of class  $Person$ .

While traditional inheritance is upwards, reaching attributes in the multiobject mechanism can be upwards, downwards and sideways. The  $get(o_C, att)$  primitive method reads the value that the multiobject containing the object  $o_C$  takes on the attribute  $att$ . Its algorithm (see appendix) is the following: if  $att$  is a local attribute of  $C$  then it returns the value of  $o_C$  on  $att$ , else if  $att$  is a local attribute of a class  $D$  belonging to the specialization tree of  $C$  then it returns the value of  $o_D$  on  $att$  where  $o_D$  is the object in class  $D$  which is related to  $o_C$ . Figure 2 shows some examples related to figure 1.

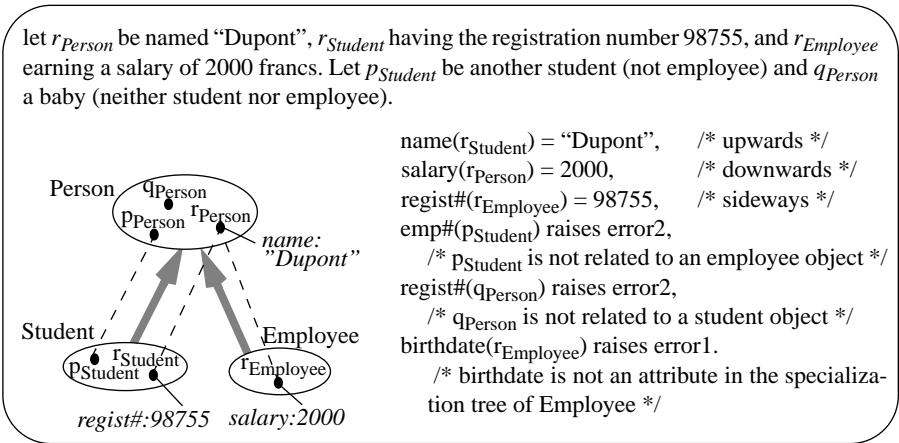


Fig. 2. Reaching attributes upwards, downwards and sideways

An attribute of class  $C$  is always reached in the descendants of  $C$  (because each of their objects is related to an object in  $C$ ) while it *may be* reached in the ancestors and sibling classes of  $C$  if some of their objects are related to an object in  $C$ .

We forbid homonym attributes in classes belonging to the same specialization tree; nevertheless we have the same potential of information as  $O_2$  [1] and *Goose* [26].

## 2.2 Manipulating Multiobjects

The algorithms for creating, deleting and updating a multiobject are provided in the appendix and are implemented in the F2 OODBMS. We briefly describe them hereafter.

**Creating a Multiobject.** The  $create(C, [a_1:v_1, a_2:v_2, \dots, a_p:v_p])$  primitive method creates a multiobject including an object in class  $C$ . The automatic classification algorithm searches the classes of the multiobject in the specialization tree of  $C$  (beginning from the root),  $SC = \{C_1, C_2, \dots, C_n\}$ , according to the attribute values  $[a_1:v_1, a_2:v_2, \dots, a_p:v_p]$  and to the classes’ specialization constraints. If  $C$  does not belong to  $SC$  or if the origin class of one of the attributes  $a_j$  does not belong to  $SC$ , an error is returned.

Otherwise, an object  $o_{C_i}$  is added to each class  $C_i$  of  $SC$  and all these objects carry the same instance identifier. Each attribute value is stored with the object  $o_{C_i}$  which belongs to the origin class of the attribute. This contrasts with the classical implementation of specialization where an object is created in one most specific class.

For example, in figure 3.a, the class *Person* has two subclasses: *Employee* which in turn has two subclasses *ManEmp* (for men employees) and *WomEmp* (for women employees), and *Student* which in turn has a subclass *SwissSt* (for swiss students). The following expression (in F2-DML) creates a multiobject containing four objects:  $o_{Person}$  in *Person* (root class of the specialization tree),  $o_{Employee}$  in *Employee* (the constraint *jobs includes "employee"* is satisfied),  $o_{ManEmp}$  in *ManEmp* (the constraint *sex = "m"* is satisfied) and  $o_{Student}$  in *Student* (the constraint *jobs includes "student"* is satisfied) (see fig. 3.b).

```

oEmployee := create Employee' [name: "Dupont", sex: "m",
nationality: "french", jobs: ("employee", "student"), emp#: 125,
salary: 2500];
    
```

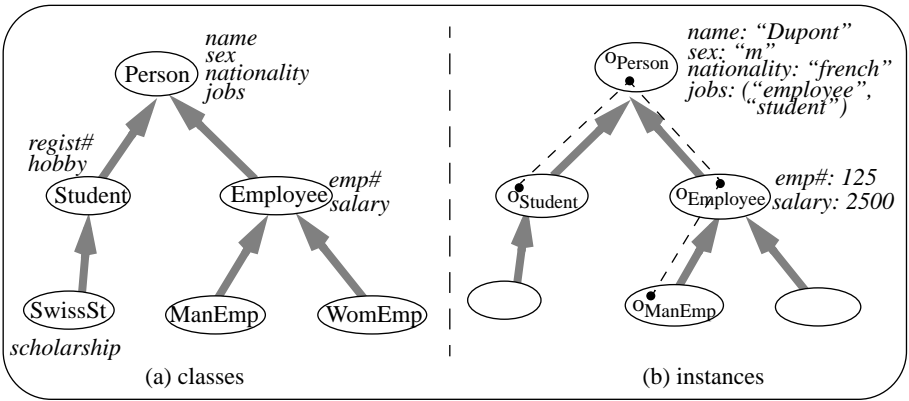


Fig. 3. Creating a multiobject

Note that if we did not give a value on the *jobs* attribute, the creation would be rejected because the multiobject would not include an object in *Employee* (*Employee* constraint not satisfied).

**Deleting a Multiobject.** The  $delete(o_C)$  primitive method deletes the multiobject containing the object  $o_C$ , i.e. it removes  $o_C$  and *all* its related objects. The algorithm searches the classes of the multiobject in the specialization tree of  $C$  (beginning from the root),  $SC = \{C_1, C_2, \dots, C_n\}$ , and removes its object  $o_{C_i}$  from each class  $C_i$  of  $SC$ . This contrasts with the classical implementation of specialization where an object is deleted from one class.

For example, the following expression (in F2-DML) deletes a multiobject (representing a male student-employee) by removing all its objects  $o_{Person}$ ,  $o_{Employee}$ ,  $o_{ManEmp}$  and  $o_{Student}$  (see fig. 4).

```

delete oEmployee;
    
```

If instead one dismisses the employee, the entity remains as a student and a person. This can be done by updating the *jobs* attribute of the corresponding multiobject.

**Updating a Multiobject.** The *update*(*o<sub>C</sub>*, [*att:val*]) primitive method sets the value of the multiobject containing the object *o<sub>C</sub>* on the attribute *att* to *val*. Like the *get* method, *update* searches the attribute *att* upwards, downwards and sideways. Since the attribute *att* could be used in specialization constraints on the descendants *SD* of its origin class *Orig*, the multiobject may gain new objects or/and lose existing objects in *SD* because it may now (with the new value *val*) validate or invalidate those specialization constraints. This is referred to as object migration. The automatic classification algorithm searches in the specialization tree of *C*, beginning from *Orig*: (i) the set of gained classes and adds an object (carrying the same instance identifier as *o<sub>C</sub>*) to each of them; (ii) the set of lost classes and removes the related object to *o<sub>C</sub>* from each of them. This contrasts with the classical implementation of specialization where an object stays in its class until it is deleted from it.

For example, figure 5.a shows a swiss female student implemented by a multiobject containing three objects {*p<sub>Person</sub>*, *p<sub>Student</sub>*, *p<sub>SwissSt</sub>*}. The following expression (in F2-DML) expresses that this person ceases to be a student and becomes an employee. As a result (see fig. 5.b), (i) *p<sub>Employee</sub>* is added to *Employee* and *p<sub>WomEmp</sub>* is added to *WomEmp*, (ii) *p<sub>Student</sub>* and *p<sub>SwissSt</sub>* are removed from *Student* and *SwissSt* respectively. The multiobject contains now the objects {*p<sub>Person</sub>*, *p<sub>Employee</sub>*, *p<sub>WomEmp</sub>*}.

```
update pPerson jobs: ("employee");
```

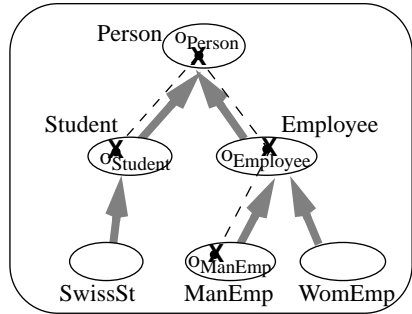


Fig. 4. Deleting a multiobject

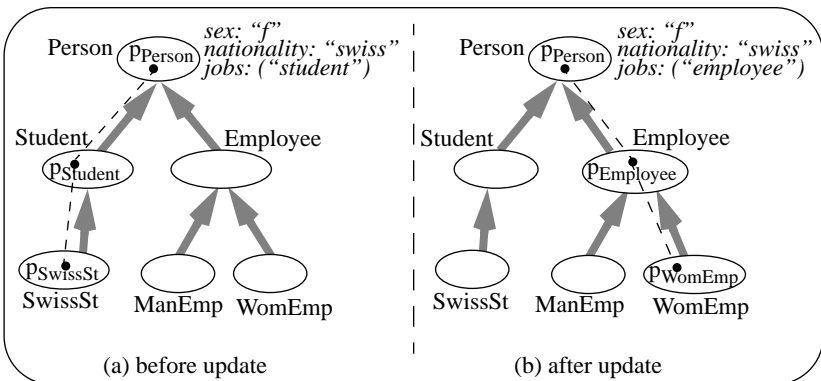


Fig. 5. Updating a multiobject (jobs attribute)

### 3 Advantages of the Multiobject Mechanism for Schema Evolution

In this section we first provide briefly the framework of schema evolution in F2. Then we discuss the advantages of the multiobject mechanism with respect to schema evolution.

#### 3.1 Schema Evolution in F2

**Set of Schema Changes in F2.** An important feature of the F2 DBMS is the uniformity of its objects described in [6] [3]. We consider objects of three levels: database objects, schema objects and meta-schema objects. Uniformity of objects in F2 includes:

- uniformity of representation. The same structures are used in F2 to represent database objects, schema objects and meta-schema objects;
- uniformity of access and manipulation. The same primitive methods are used in F2 to access and manipulate database objects, schema objects and meta-schema objects.

Thanks to the uniformity of the F2 DBMS, we built the set of schema changes in F2 as follows [6] [3]: for *each* class of the F2 meta-schema we apply the primitive methods *create*, *delete* and *update* on its objects (see fig. 6).

**Semantics of Schema Changes.** We defined the semantics of each schema change in F2 with pre-conditions and post-actions [6] [3] such that the F2 model invariants are preserved. Pre-conditions must be satisfied to allow a schema change to occur; otherwise it is rejected. Post-actions are repercussions to be executed on schema objects and database objects in order to keep the database structurally consistent. We implemented pre-conditions and post-actions by triggered methods [6] [3].

**Propagation of Schema Changes.** In F2 schema changes are propagated immediately [3], i.e. the repercussions of a schema change are executed as soon as the schema change is performed.

#### 3.2 Multiobject Mechanism and Schema Evolution

Since the multiobject mechanism implements specialization, we consider among the schema changes of F2 (fig. 6) those which are involved in specialization: create a subclass (1.3), delete a class (2), change the superclass of a subclass (3.4), update a class from non-subclass to subclass (3.5) and the reverse (3.6), create (4) and delete an attribute (5), change the domain class (6.4) and the origin class of an attribute (6.5), create (10) and delete a specialization constraint (11), change the list of subclasses on which is defined a specialization constraint (12.2). By examples we will show that the multiobject mechanism makes these schema changes more pertinent and easier to implement than with the classical implementation of specialization. We will compare F2 with the following OODBMS which support schema evolution: *Orion* [8], *Gemstone* [29], *OT-Gen* [23], *Cocoon* [37], *Goose* [26] and *O<sub>2</sub>* [18]. All these systems support the classical

- |   |   |
|---|---|
| (1) Create a new class  | (9.2) Change its attributes                                 |
| (1.1) Create an atomic class  | (9.3) Enable / disable it                                   |
| (1.2) Create a tuple class  | (10) Create a new specialization constraint                 |
| (1.3) Create a tuple subclass   | (11) Delete an existing spec. constraint                    |
| (2) Delete an existing class  | (12) Update an existing spec. constraint                    |
| (3) Update an existing class  | (12.1) Change its name                                      |
| (3.1) Change its name   | (12.2) Change the list of subclasses on which it is defined |
| (3.2) Change its interval if atomic class                               | (13) Create a new trigger                                   |
| (3.3) Change its maximal length if atomic string class                  | (14) Delete an existing trigger                             |
| (3.4) Change its superclass   | (15) Update an existing trigger                             |
| (3.5) Make it a subclass, i.e. attach it to a specialization tree       | (15.1) Change the event for which it is defined             |
| (3.6) Make it a non-subclass, i.e. detach it from a specialization tree | (15.2) Change the list of methods it triggers               |
| (4) Create a new attribute of a class                                   | (16) Create a new event                                     |
| (5) Delete an existing attribute  | (17) Delete an existing event                               |
| (6) Update an existing attribute  | (18) Update an existing event                               |
| (6.1) Change its name   | (18.1) Change the class on which it is defined              |
| (6.2) Change its maximal cardinality                                    | (18.2) Change its kind                                      |
| (6.3) Change its minimal cardinality                                    | (18.3) Change its attribute                                 |
| (6.4) Change its domain class   | (19) Create a new triggered method                          |
| (6.5) Change its origin class   | (20) Delete an existing triggered method                    |
| (7) Create a new key of a class   | (21) Update an existing triggered method                    |
| (8) Delete an existing key  | (21.1) Change its name                                      |
| (9) Update an existing key  |   |
| (9.1) Change the class on which it is defined                           |   |

**Fig. 6.** F2 schema changes

implementation, except *Cocoon* which supports multiple instantiation, class predicates and automatic classification.

**Create a Subclass.** Example: The class *Person* has several attributes including *nationality*. It has four objects  $\{a, b, c, d\}$ , two of them  $\{a, d\}$  take the value “swiss” on the *nationality* attribute. The class *Car* has an attribute *owner* whose domain is *Person*. Now one creates the class *Swiss* as a subclass of *Person*. The wanted effect is that *a* and *d* become objects of the *Swiss* class.

- **Multiobject approach:** The class *Person* has four objects  $\{a_P, b_P, c_P, d_P\}$  (see fig. 7.a). When the *Swiss* subclass and a specialization constraint on it are added, the objects  $a_S$  and  $d_S$  are automatically added to the *Swiss* subclass because they satisfy its specialization constraint (see fig. 7.b). Each of the multiobjects *a* and *d* contain now two objects. The attribute values of objects  $a_P$  and  $d_P$  are not copied because attribute values are locally stored and attributes of *Person* are reached in *Swiss*.

*Cocoon* supports this schema change.



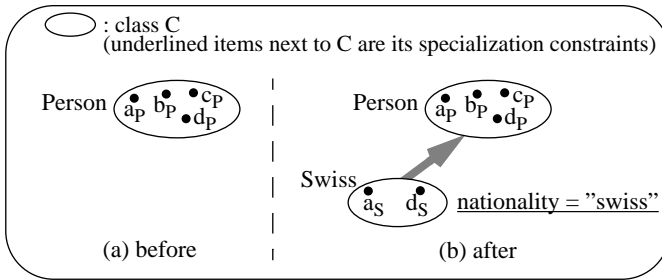


Fig. 7. Add the Swiss subclass with a specialization constraint

- Classical approach: Most of the OODBMS supporting schema evolution leave a subclass empty (without objects) when it is newly created. Thus in our example, a tool should be developed to: i) create two new objects in *Swiss*; ii) copy the value of objects *a* and *d*, on all the attributes of *Person*, to the newly created objects respectively; iii) delete the objects *a* and *d* in *Person*. If the objects *a* and *d* were referenced by *Car* objects through the *owner* attribute, the tool has also to update these references (to reference now the new objects in *Swiss*).

Only  $O_2$  (thanks to migration functions) and *OTGen* (thanks to boolean expressions) allow subclass creation with object migration down.

**Delete a Class.** Example: The class *Swiss* is a subclass of *Person* and has two objects  $\{a, d\}$ . The class *Chalet* has an attribute *owner* whose domain is *Swiss*. Now one is no more interested to classify the swiss persons and decides to delete the *Swiss* class. The wanted effect is that *a* and *d* become objects of the *Person* class (keep the swiss people as persons).

- Multiobject approach: The *Swiss* class has two objects  $a_s$  and  $d_s$  which are related to  $a_p$  and  $d_p$  respectively in *Person* (see fig. 7.b). When the subclass *Swiss* is deleted, its objects are removed while their related objects  $\{a_p, d_p\}$  remain in *Person* (see fig. 7.a). The attributes of *Swiss* are deleted and the domain of the *owner* attribute is updated to *Person*, as with the classical approach. The values on the *owner* attribute remain unchanged (see update the domain of an attribute).

*Cocoon* supports this schema change.

- Classical approach: Most of the OODBMS supporting schema evolution delete the objects of a class when the class is deleted (*Gemstone* prevents the deletion of a class if it is not empty). This implies loss of information. Thus in our example, a tool should be developed to: i) create two new objects in *Person*; ii) copy the value of objects *a* and *d*, only on the inherited attributes from *Person*, to the newly created objects respectively; iii) delete the *Swiss* class (consequently its objects are deleted). If the objects *a* and *d* were referenced by *Chalet* objects through the *owner* attribute, the tool has also to update these references (to reference now the new objects in *Person*).

Note that if the wanted effect in our example was not to keep the swiss persons, this could be achieved in the multiobject approach by first deleting the multiobjects containing *Swiss* objects and then deleting the *Swiss* class. Thus both semantics are possible in

our approach and the database administrator can choose the most suitable for a given situation.

**Update the Superclass of a Subclass.** Example: The class *Person* has two subclasses *Student* and *Employee*. *Student* has a subclass *Young* (see fig. 8.a). Now one updates the superclass of *Young* from *Student* to *Employee*. The wanted effect is that the *Young* class stores the young employee objects instead of the young student objects, and that it inherits the attributes of *Employee* instead of those of *Student*.

- Multiobject approach: The class *Young* has the specialization constraint  $age < 30$ . Changing its superclass to *Employee* reclassifies automatically its objects: i) for each object in *Young*, if it is not related to an *Employee* object, it is removed from *Young*; ii) for each object in *Employee* whose *age* value is under 30, a related object to it is added to *Young* (if it does not already exist). The *Young* class reaches now another set of attributes; the physical storage of its objects remains unchanged.
- Classical approach: Most of the OODBMS supporting schema evolution keep the same objects in a subclass when modifying its superclass. This may lead to an inconsistent semantics. They re-evaluate the inheritance of the subclass according to defined rules. In our example, the *Young class* inherits now the attributes of *Employee* instead of those of *Student*. This results in the modification of the physical storage of *Young* objects. To reclassify objects in the *Young* class, a tool should be developed to: i) migrate the *Young* objects up to *Student* (like when deleting a class); ii) migrate some objects of *Employee* down to *Young* (like when creating a subclass). Note that *Gemstone* does not support this schema change in order to only provide well understood schema changes. In F2, updating a subclass to non-subclass and the reverse are special cases of updating the superclass of a subclass. Due to lack of space we do not describe them.

**Create an Attribute.** Example: One adds the attribute *hobby* to class *Person* which has several descendants. The wanted effect is that the descendants of *Person* inherit *hobby*.

- Multiobject approach: Adding the new attribute *hobby* to class *Person* does not need to be propagated to the descendants of *Person*; instead *hobby* will be reached in them.
- Classical approach: Most of the OODBMS supporting schema evolution, as *Orion* and *Gemstone*, propagate recursively this schema change to *Person*'s subclasses according to propagation rules. On storage, this requires to physically add the attribute to the objects of each descendant of *Person* inheriting it.

**Delete an Attribute.** Example: One deletes the attribute *hobby* from class *Person*. The wanted effect is that the descendants of *Person* do no longer inherit *hobby*.

- Multiobject approach: Removing the attribute *hobby* from class *Person* does not need to be propagated to the descendants of *Person*; instead *hobby* will not be reached in them.
- Classical approach: There are different approaches, *Orion* removes recursively the attribute *hobby* from subclasses inheriting it while *Gemstone* does not. In the latter case, one has to delete the *hobby* attribute from each class inheriting it. On storage, both approaches require to physically delete the attribute from the objects of each descendant of *Person* inheriting it.

**Update the Domain Class of an Attribute.** Example: The class *Book* has an attribute *owner* whose domain is *Person*. *Student* is a subclass of *Person*. The book *book1* is owned by *c* (student object) and *book2* is owned by *d* (person object). Now one updates the domain of *owner* to *Student*.

- Multiobject approach: As with the classical approach, the *owner* value of *book1* is unchanged:  $c_S$  in *Student* is related to  $c_P$  in *Person* and they have the same instance identifier. In F2, only instance identifiers are physically stored in attribute values (the class identifier is the same for all values on the same attribute; it can be obtained by getting the domain class of the attribute). The *owner* value of *book2* is replaced by the unknown object. Updating the domain class of *owner* does not need to be propagated to the descendants of *Book*, because the *owner* values are stored with *Book* objects. Note that one can update the domain of *owner* to an ancestor, a descendant or a sibling class of *Person*.
- Classical approach: All the OODBMS supporting schema evolution support this schema change but some with restrictions. For example, *Orion* allows only to generalize a domain while *Gemstone* can generalize and specialize it. *Orion* propagates this schema change to subclasses inheriting the attribute according to propagation rules while *Gemstone* does not.

**Update the Origin Class of an Attribute.** Example: The class *Young* is a subclass of *Student* which is a subclass of *Person* (see fig. 8.a). Class *Person* has the objects  $\{d\}$ , class *Student* has  $\{c\}$  and class *Young* has  $\{a, b\}$ . Class *Employee*, another subclass of *Person*, has the objects  $\{e\}$ . *Hobby* is a local attribute of *Student*. Now one wants to store the hobbies of all persons and updates the origin class of *hobby* to *Person*. Updating the origin class of an attribute is very useful and is not equivalent to dropping the attribute and adding it to another class because in this case the values taken on the attribute are lost.

- Multiobject approach: The classes and their objects are shown in figure 8.a. When the origin class of the *hobby* attribute is updated to *Person* (see fig. 8.b), the objects  $a_P, b_P, c_P$  keep the same *hobby* value as  $a_S, b_S, c_S$  respectively. The *hobby* value of  $d_P$  and  $e_P$  is set to unknown. Thanks to the transposed storage of objects [6] in F2, the *hobby* values are not copied. Note that one can update the origin class of *hobby* from *Student* to *Person* (ancestor), to *Young* (descendant) or to *Employee* (sibling class). Changing the origin class of an attribute does not need to be propagated to the descendants of its old and new origin classes; the attribute will be reached in another set of classes. *Cocoon* supports this schema change.
- Classical approach: Most of the OODBMS supporting schema evolution do not support this schema change. In our example, a tool should be developed to: i) create a new attribute *hobby2* in *Person* (it becomes inherited in *Student*, *Young* and *Employee*); ii) copy the *hobby* values on this new attribute for *Student* objects  $\{c\}$  and *Young* objects  $\{a, b\}$ ; iii) delete the attribute *hobby* of *Student*; iv) rename the attribute *hobby2* to *hobby*. Note that if instead one creates a new attribute *hobby* in *Person*, the semantics would be different because the attribute *hobby* of *Student* would not be considered as inherited from *Person*.

Only *Goose* allows to update the origin class of an attribute with retaining values for objects.

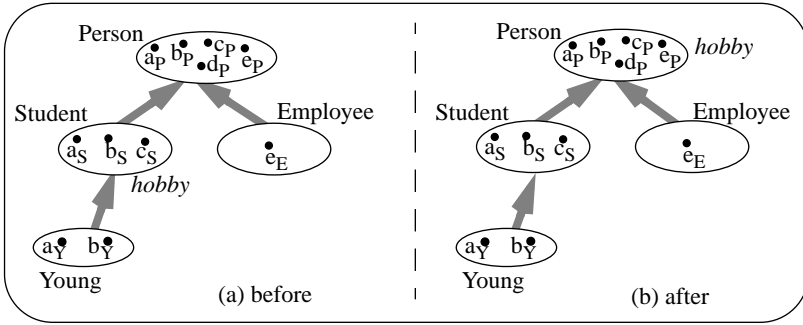


Fig. 8. Update the origin class of the hobby attribute

**Create/Delete a Specialization Constraint.** Example: The class *Person* has a subclass *European* (citizen of a country of the european community) which has a subclass *Young* (under 30 years old) (see fig. 9.a). Class *Young* has one object *a* (young european), class *European* has one object *b* (old european), class *Person* has two objects *c* (young african) and *d* (young swiss). Suppose now that Switzerland joins the european community. One replaces (delete followed by create) then the specialization constraint of *European* by a new one taking into account Switzerland. The wanted effect is that the object *d* belongs now to *Young* instead of *Person*.

- Multiobject approach: The classes and their objects are shown in figure 9.a. Specialization constraints are defined on the subclasses *European* and *Young*. When the specialization constraint of *European* is replaced, the objects *d<sub>E</sub>* and *d<sub>Y</sub>* are automatically added to the classes *European* and *Young* respectively (see fig. 9.b). *Cocoon* supports class predicates and allows to change them.

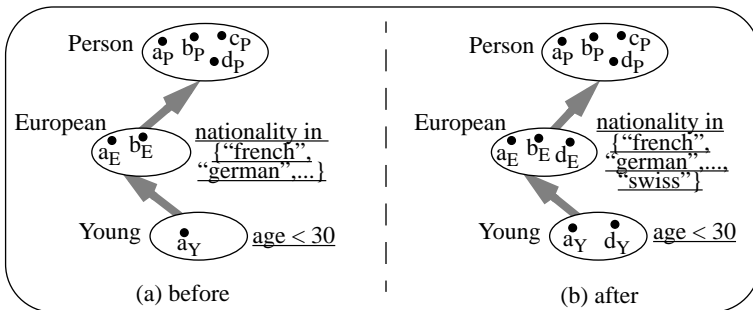


Fig. 9. Replace the specialization constraint of European

- Classical approach: Most of the OODBMS do not support specialization constraints. In our example, a tool should be developed to migrate the object *d* down to *Young*.

In F2, a specialization constraint (e.g. *age < 30*) can be defined on several subclasses (e.g. *YoungStudent* and *YoungEmployee*). Changing the list of subclasses of a specialization constraint is similar to create/delete a specialization constraint.

## 4 Related Work

**Approaches for Multi-faceted and Dynamic Entities.** We proposed and implemented a previous version of the multiobject mechanism in the extended entity-relationship DBMS *Ecrins* [20]. Several object approaches have been proposed to model the multi-faceted and dynamic nature of entities. We summarize them in the following table. Then we compare our approach to them. Null entries (--) mean not known (we do not have the data).

	approach (how an entity is implemented)	creation	extension	object internal representation	inheritance
Object hierarchies [34]	entity: set of objects (object hierarchy) (parent attribute)	create an object hierarchy	add/remove an object to/from an object hierarchy	local attributes	upwards in object hierarchy (per-object)
Roles in ORM [30]	entity: object of a class + role instances	create an object in a class	add/remove a role instance to/from an object	--	no inheritance
Aspects [33]	entity: object of a class + aspect instances (same oid)	create an object in a class	add an aspect to an object	--	no inheritance (aspect exports selected parts of a class)
Roles in Fibonacci [2]	entity: object with a set of roles (same identity)	create an object with several roles	add/drop a role to/from an object	local attributes	upwards in role hierarchy
Category classes [28]	entity: object of several classes (roles) (same oid)	create an object in several classes	add/remove a role to/from an object (manual), or update an object (automatic)	--	upwards in class hierarchy
Object-slicing [22]	entity: conceptual object + set of implementation objects (bi-directional link)	create a conceptual object with implementation objects	create/delete an implementation object	local attributes	upwards in class hierarchy
Our approach: Multiobjects	entity: set of objects (multi-object) (same instance identifier)	create a multi-object (automatic classification)	update a multi-object (objects are added/removed to/from a multiobject automatically)	local attributes	upwards, downwards and sideways in specialization tree

The multiobject mechanism differs from *ORM roles* and *aspects* because they do not integrate the class hierarchy. As in *object hierarchies*, *Fibonacci roles*, *category classes* and *object-slicing*, an entity in our approach is implemented by a set of objects which can be enlarged and reduced (automatically as in *category classes*). However, our approach has several differences:

- an object can access attribute values of related objects not only upwards but also downwards and sideways in the class hierarchy.
- two related objects are neither linked by a parent attribute as in *object hierarchies*, nor by a bi-directional link via a conceptual object as in *object-slicing*. Both objects have the same instance identifier (same identity in *Fibonacci roles* and *category classes*). Thus there is no overhead when accessing related objects in our approach.
- we provide the algorithms to manipulate multiobjects.
- we use the multiobject mechanism not only to ease object modelling and object evolution but also to ease schema evolution.

**OODBMS Supporting Schema Evolution.** Several OODBMS support schema evolution. We can classify them in three categories: schema evolution without versioning (*Orion* [8], *Gemstone* [29], *OTGen* [23], *Cocoon* [37], *Goose* [26], *O2* [18]), schema evolution with versioning (*Encore* [35], *Orion*, *Goose*, *Closql* [25]), schema evolution with views (*Contexts* [7], *Goose*, *Views* [11], *TSE* [32]). The two last categories are out of the scope of this paper. Approaches of the first category differ by the set of supported schema changes, the semantics of schema changes, and the propagation of schema changes (immediate, deferred, mixed).

## 5 Conclusion

We presented the multiobject mechanism to implement specialization in object-oriented databases. We described how this mechanism models multi-faceted and dynamic real-world entities. We showed its advantages with respect to schema evolution. The multiobject mechanism makes schema changes more pertinent than with the classical implementation of specialization. It makes them easier to implement and less time-consuming since it needs neither to copy objects nor to propagate schema changes. It makes schema changes easier to understand since it avoids complex propagation rules. We implemented the multiobject mechanism in F2. We submitted the F2 DBMS to the OO7 benchmark [14]. We obtained in [3] good results for the queries and traversals, because objects in the multiobject approach have smaller size than objects in the classical object model; this consequently reduces the number of input/output operations. For the insert and delete operations of the benchmark, the multiobject approach is more expensive than the classical object model; this is due to the automatic classification (which is not supported in the classical object model) and to the fact that several objects are created/deleted instead of one. The execution times could be improved by using a parallel algorithm; this issue deserves to be investigated.

Extensions of the multiobject mechanism in F2 include: i) allow several objects of the same class in a multiobject; ii) allow several attributes with the same name in a spe-

cialization tree; iii) handle methods and virtual binding (see interpretation of messages in [2]); iv) model the life-cycle of an entity [4] and restrict the way objects may be added to and removed from a multiobject. Extensions of schema evolution in F2 include: i) take into account schema changes on methods; ii) study the behavioural consistency of the database; iii) test schema changes in a real application.

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## Appendix

### 1. Get Algorithm

Let  $att$  be an attribute and  $o_C$  be an object of class  $C$  (an object carries the class it is instance of, thus  $C$  can be known from  $o_C$ );  $origin\_class(att)$  be a function which returns the origin class of attribute  $att$ ;  $root(C)$  be a function which returns the root class of the specialization tree of class  $C$ .

**function**  $get(o_C, att)$  **return**  $val$  **is**

```
begin
  /* call the check_valid_attribute procedure which
  checks that att is a local attribute of C (sets obj to
  o_C) or a reached attribute by o_C (sets obj to the
  object in the origin class of att which is related to
  o_C) */
  check_valid_attribute(att, o_C, obj);
  return the value val of obj on att;
```

**end get;**

**procedure**  $check\_valid\_attribute(att, o_C, obj)$  **is**

```
begin
  Orig := origin_class(att);
  /* if att is a local attribute of class C */
  if (C = Orig) then
    obj := o_C;
  /* if classes Orig and C are in same spec. tree */
  elsif (root(C) = root(Orig)) then
    o_Orig := relatedTo(o_C, Orig);
    /* if o_C is related to an object in Orig */
    if (o_Orig ≠ unknown_object) then
      obj := o_Orig;
    else error2;
  end if;
  else error1;
  end if;
```

**end check\_valid\_attribute;**

### 2. Create Algorithm

Let  $C$  be a class and  $[a_1:v_1, a_2:v_2, \dots, a_p:v_p]$  be an array of  $\langle$ attribute:value $\rangle$  pairs;  $subclasses(C)$  be a function which returns the direct subclasses of class  $C$ ;  $satisfy\_constraints([a_1:v_1, a_2:v_2, \dots, a_p:v_p], C)$  be a function which indicates whether the given attribute values satisfy all the spec. constraints of class  $C$ ;  $root()$  and  $origin\_class()$  have been defined before.

**function**  $create(C, [a_1:v_1, a_2:v_2, \dots, a_p:v_p])$  **return**  $o_C$  **is**

```
begin
  TheRoot := root(C);
  /* initialize SC to the empty set */
  SC := {};
  /* call the classify procedure which puts in SC the
  classes of the new multioject */
  classify(TheRoot, [a_1:v_1, a_2:v_2, \dots, a_p:v_p], SC);
```

```
/* check that C belongs to SC */
```

```
if (C not in SC) then error1;
```

```
end if;
```

```
/* check that all the given attributes will be
```

```
reached by the new multioject */
for each attribute  $a_i$  in  $[a_1:v_1, a_2:v_2, \dots, a_p:v_p]$ 
loop
```

```
  if (origin_class( $a_i$ ) not in SC) then error2;
  end if;
end loop;
```

```
/* add objects, store attribute values */
```

```
ID := the instance identifier for the objects of
the new multioject;
for each class  $C_i$  in SC loop
  add an object  $o_{C_i}$  (having the instance identifier
  ID) to  $C_i$ ;
  store the value of  $o_{C_i}$  on the attributes whose
  origin class is  $C_i$ ;
end loop;
return  $o_C$ ;
```

**end create;**

**procedure**  $classify(C, [a_1:v_1, a_2:v_2, \dots, a_p:v_p],$  **TheSet**) **is**

```
begin
  /* add class C to TheSet */
  TheSet := TheSet  $\cup$  C;
  Sub := subclasses(C);
  for each  $S_i$  in Sub loop
    /* if the attribute values satisfy all the spec.
    constraints of class  $S_i$  */
    if satisfy_constraints( $[a_1:v_1, a_2:v_2, \dots, a_p:v_p]$ ,
       $S_i$ ) then
      classify( $S_i, [a_1:v_1, a_2:v_2, \dots, a_p:v_p],$ 
        TheSet); -- recursive call
    end if;
  end loop;
```

**end classify;**

### 3. Delete Algorithm

Let  $o_C$  be an object of class  $C$ ;  $root()$  and  $subclasses()$  have been defined before.

**procedure**  $delete(o_C)$  **is**

```
begin
  TheRoot := root(C);
  o_Root := relatedTo(o_C, TheRoot);
  /* initialize SC to the empty set */
  SC := {};
  /* call the facets procedure which puts in SC the
  classes of the multioject containing o_Root */
  facets(o_Root, SC);
```

```
/* remove objects */
```

```
for each class  $C_i$  in SC loop
   $o_{C_i}$  := relatedTo( $o_C, C_i$ );
  remove the object  $o_{C_i}$  from  $C_i$ ;
end loop;
```

**end delete;**

**procedure**  $facets(o_C, TheSet)$  **is**

```
begin
  /* add class C to TheSet */
  TheSet := TheSet  $\cup$  C;
  Sub := subclasses(C);
```

```

for each  $S_i$  in Sub loop
   $o_{S_i} := \text{relatedTo}(o_C, S_i)$ ;
  /* if an object in  $S_i$  is related to  $o_C$  */
  if ( $o_{S_i} \neq \text{unknown\_object}$ ) then
    facets( $o_{S_i}$ , TheSet); -- recursive call
  end if;
end loop;
end facets;

```

#### 4. Update Algorithm

Let  $o_C$  be an object of class  $C$  and  $[a:v]$  be an <attribute:value> pair;  $\text{constraint\_on\_att}(C, \text{att})$  be a function which indicates whether class  $C$  has a specialization constraint involving the attribute  $\text{att}$ ;  $\text{satisfy\_constraints\_att}([a:v], C)$  be a function which indicates whether the value  $v$  satisfies the specialization constraints of class  $C$  involving the attribute  $a$ ;  $\text{check\_valid\_attribute}()$ ,  $\text{origin\_class}()$ ,  $\text{subclasses}()$ ,  $\text{satisfy\_constraints}()$ ,  $\text{facets}()$  and  $\text{classify}()$  have been defined before.

##### procedure $\text{update}(o_C, [a:v])$ is

```

begin
   $\text{check\_valid\_attribute}(a, o_C, \text{obj})$ ;
   $\text{Orig} := \text{origin\_class}(a)$ ;

  /* initialize ToAdd and ToRemove to empty set */
   $\text{ToAdd} := \{\}$ ;
   $\text{ToRemove} := \{\}$ ;
  /* call the reclassify procedure which puts in
  ToAdd the classes to which a related object will be
  added and in ToRemove the classes from which a
  related object will be removed */
   $\text{reclassify}(o_C, [a:v], \text{Orig}, \text{ToAdd}, \text{ToRemove})$ ;

  /* add objects */
  for each class  $C_i$  in  $\text{ToAdd}$  loop
    add an object  $o_{C_i}$  (having the same instance
    identifier as  $o_C$ ) to  $C_i$ ;
  end loop;
  /* remove objects */
  for each class  $C_i$  in  $\text{ToRemove}$  loop
     $o_{C_i} := \text{relatedTo}(o_C, C_i)$ ;
    remove the object  $o_{C_i}$  from  $C_i$ ;
  end loop;

  /* store the new attribute value */
  store the new value  $v$  of the object  $\text{obj}$  on the
  attribute  $a$ ;
end update;

```

##### procedure $\text{reclassify}(o_C, [a:v], D, \text{TheSetAdd}, \text{TheSetRemove})$ is

```

begin
   $\text{Sub} := \text{subclasses}(D)$ ;
  for each  $S_j$  in Sub loop
    /* if class  $S_j$  has a spec. constraint involving the
    attribute  $a$  */
    if  $\text{constraint\_on\_att}(S_j, a)$  then
      /* call the migrate procedure which (i) adds
       $S_j$  (and possibly its descendants) to
      TheSetAdd if a related object  $o_{S_j}$  should be
      added, (ii) adds  $S_j$  (and possibly its
      descendants) to TheSetRemove if the related
      object  $o_{S_j}$  should be removed, (iii) sets

```

```

    continue to true if the related object  $o_{S_j}$  exists
    and stays in  $S_j$  */
     $\text{migrate}(o_C, [a:v], S_j, \text{TheSetAdd},$ 
       $\text{TheSetRemove}, \text{continue})$ ;
    if continue then
       $\text{reclassify}(o_C, [a:v], S_j, \text{TheSetAdd},$ 
         $\text{TheSetRemove})$ ; -- recursive call
    end if;
    /* else if an object in  $S_j$  is related to  $o_C$  */
    elseif ( $\text{relatedTo}(o_C, S_j) \neq \text{unknown\_object}$ ) then
       $\text{reclassify}(o_C, [a:v], S_j, \text{TheSetAdd},$ 
         $\text{TheSetRemove})$ ; -- recursive call
    end if;
  end loop;
end reclassify;

```

##### procedure $\text{migrate}(o_C, [a:v], D, \text{TheSetAdd}, \text{TheSetRemove}, \text{continue})$ is

```

begin
   $\text{continue} := \text{false}$ ;
  /* is related indicates if  $o_C$  is related to an object
  in  $D$  (before update); will_be_related indicates if
   $o_C$  will be related to an object in  $D$  (after update)
  */
   $o_D := \text{relatedTo}(o_C, D)$ ;
   $\text{is\_related} := (o_D \neq \text{unknown\_object})$ ;
  if  $\text{is\_related}$  then
    /* does the new attribute value satisfy the spec.
    constraints of  $D$  involving the attribute  $a$  */
     $\text{will\_be\_related} :=$ 
       $\text{satisfy\_constraints\_att}([a:v], D)$ ;
  else
    /* does the object  $o_C$  (take into account the new
    attribute value) satisfy all the spec. constraints
    of  $D$  */
     $\text{will\_be\_related} := \text{satisfy\_constraints}(\text{attribute values of } o_C, D)$ ;
  end if;

  /* case 1: there is a related object in  $D$  and it will
  stay in it */
  if ( $\text{is\_related}$  and  $\text{will\_be\_related}$ ) then
     $\text{continue} := \text{true}$ ;
  /* case 2: there is a related object in  $D$  but it will
  be removed from it */
  elseif ( $\text{is\_related}$  and not  $\text{will\_be\_related}$ ) then
    /* add  $D$  and each of its descendants where an
    object is related to  $o_C$  to TheSetRemove */
     $\text{tempRemove} := \{\}$ ;
     $\text{facets}(o_D, \text{tempRemove})$ ;
     $\text{TheSetRemove} := \text{TheSetRemove} \cup$ 
       $\text{tempRemove}$ ;
  /* case 3: no related object in  $D$  but a new one will
  be added to it */
  elseif (not  $\text{is\_related}$  and  $\text{will\_be\_related}$ ) then
    /* add  $D$  and possibly its descendants to
    TheSetAdd */
     $\text{tempAdd} := \{\}$ ;
     $\text{classify}(D, \text{attribute values of } o_C, \text{tempAdd})$ ;
     $\text{TheSetAdd} := \text{TheSetAdd} \cup \text{tempAdd}$ ;
  /* case 4: no related object in  $D$  and no one will
  be added to it */
  else null; -- nothing to do
  end if;
end migrate;

```