

Case study: Class diagram restructuring

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This case study is an update-in-place refactoring transformation on UML class diagrams. Its aim is to remove clones of attributes from a class diagram, and to identify new classes which abstract groups of classes that share common data features.

It is used as one of a general collection of transformations (such as the removal of redundant inheritance, or multiple inheritance) which aim to improve the quality of a specification or design level class diagram.

The transformation is a typical example of a model refactoring, and illustrates the issues involved in such transformations.

1 Introduction

Update-in-place transformations have specific challenges which need to be addressed by model transformation tools:

- Establishing confluence of the transformation: that it produces a unique (up to isomorphism) result from a given source model.
- Ensuring termination of a fixed-point implementation strategy.
- Ensuring control over the order of rule applications, in order to optimise some characteristics of the transformation.

We have previously used the core version of this case study to compare model transformation approaches, and it has proved to be effective as a test of the capabilities of approaches to specify and implement update-in-place transformations requiring fixed-point iteration of rules [3]. The transformation also requires relative prioritisation of rules, and fine-grained control of the order of application of individual rules to elements of a model.

The core version of the case study concerns removal of attribute clones assuming that only single inheritance exists in the model (Section 2), this is then extended in Section 3 to deal with the case where multiple inheritance is present.

In comparison to the refactoring case study of [5], the present case study is focussed upon the automated selection of refactoring steps, instead of interactive refactoring, and includes class diagrams with multiple inheritance. In addition, the evaluation criteria of [5] only cover a subset of the aspects which this case evaluates. Since we are interested in automated refactoring, termination and confluence are specific evaluation criteria which we are interested in, and the quality of the refactoring (ie., minimising any size increase in the model) is also emphasised.

2 Core problem

Figure 1 shows the metamodel for the source and target language of the simple version (dealing with single inheritance only) of the transformation.

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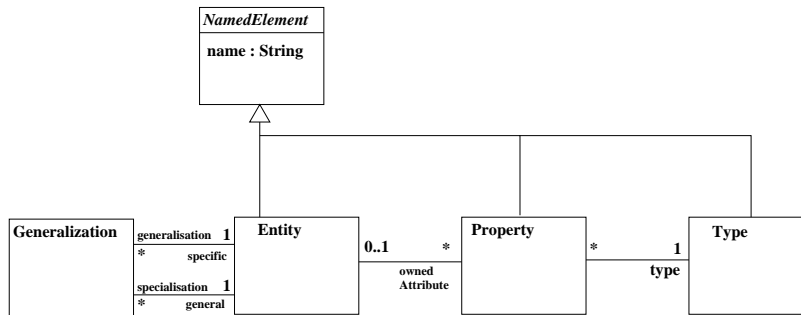


Figure 1: Basic class diagram metamodel

It can be assumed that:

- No two classes have the same name.
- No two types have the same name.
- The owned attributes of each class have distinct names within the class, and do not have common names with the attributes of any superclass.
- In this version there is no multiple inheritance, ie., the multiplicity of *generalisation* is restricted to 0..1.

These properties must also be preserved by the transformation.

The informal transformation steps are the following:

- (1) **Pull up common attributes of all direct subclasses:** If the set $g = c.\textit{specialisation}.\textit{specific}$ of all direct subclasses of a class c has two or more elements, and all classes in g have an owned attribute with the same name n and type t , add an attribute of this name and type to c , and remove the copies from each element of g . This is the “Pull up attribute” refactoring of [2].
- (2) **Create subclass for duplicated attributes:** If a class c has two or more direct subclasses g , and there is a subset $g1$ of g , of size at least 2, all the elements of $g1$ have an owned attribute with the same name n and type t , but there are elements of $g - g1$ without such an attribute, introduce a new class $c1$ as a subclass of c . $c1$ should also be set as a direct superclass of all those classes in g which own a copy of the cloned attribute. (In order to minimise the number of new classes introduced, the *largest* set of subclasses of c which all contain a copy of the same attribute should be chosen). Add an attribute of name n and type t to $c1$ and remove the copies from each of its direct subclasses. This is the “Extract superclass” refactoring of [2].
- (3) **Create root class for duplicated attributes:** If there are two or more root classes all of which have an owned attribute with the same name n and type t , create a new root class c . Make c the direct superclass of all root classes with such an attribute, and add an attribute of name n and type t to c and remove the copies from each of the direct subclasses.

2.1 Test cases

The solutions should be tested on the following three test cases of increasing size and complexity. These test cases represent both typical scenarios which could be expected to arise in class diagram modelling

(test cases 1 and 2), and pathological examples designed to check the behaviour of the transformation in extreme cases (test case 3 and the duplications of test case 2).

The first test case is a simple test for alternative applications of rule 2. Figure 2 shows the starting model.

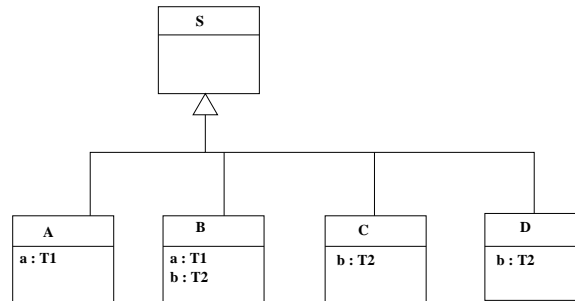


Figure 2: Test case 1

Applying the rule to classes B, C, D to remove duplicates of b is the preferred choice because it creates fewer new classes than an application to A and B, to remove the duplicate of a, followed by an application to C and D, although both solutions remove the maximum possible 2 clone attribute copies.

A larger test case, involving applications of rules 1 “Pull up attributes” and 3 “Create root class”, is shown in Figure 3.

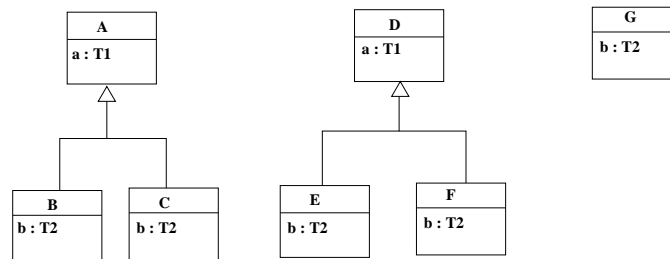


Figure 3: Test case 2

Test case 3 has 500 classes, each of which is a root class, and there are ten attributes in each class, with the attributes of each class being a copy of those in each other class (ie., 5000 attributes, with 4990 clone copies). Only one new class needs to be introduced, as a superclass of all the other classes, and all redundant copies of the attributes can be removed.

In addition we recommend carrying out ‘stress testing’ to measure the maximum capability of a transformation tool and implementation, in terms of the maximum size of models which a transformation tool or implementation is capable of processing. These tests are models formed from duplicated copies of test case 2 (omitting class D and its subclasses), of sizes up to 10000 copies (40000 classes, 40000 attributes, 20000 generalisations).

Table 1 summarises the test cases.

Solution providers should ensure that their solutions can successfully process test cases 1, 2 and 3 at a minimum, and as many of the capability test cases as possible. Models should be processed as XMI files, eg., as exported by Eclipse. Self-evaluation of the solutions using the evaluation criteria in Appendix A

<i>Test case</i>	<i>Number of classes</i>	<i>Number of attributes</i>	<i>Total size</i>
1	5	5	14
2	7	7	18
3	500	5000	5500
2*1000	4000	4000	10000
2*5000	20000	20000	50000
2*10000	40000	40000	100000

Table 1: Test cases

should be provided, in addition a survey of usability should be carried out among other TTC participants, at least 5 persons not involved in creating the solution.

3 Extension: adaption to work with multiple inheritance

In this extension the transformation should be generalised to work also on models containing multiple inheritance. This implies alternative strategies for the three rules of Section 2:

1. For rule 1, if there are multiple superclasses s_1, \dots, s_n each with a common set c_1, \dots, c_m of subclasses with an owned attribute of the same name and type, should the common attribute be moved up to all of the s_i (thereby introducing name clashes in the c_j), or to only one of them, and in that case, which one?
2. For rules 2 and 3, there is now the possibility to group together all classes which contain a common attribute, as subclasses of a new class, even if there are overlapping groups. Introducing multiple inheritance may complicate the structure of the class diagram, and probably should not be used in every such case.

The effort required to modify the case study solution to meet the extended requirement should be recorded as an evaluation measure of extensibility.

References

- [1] Botella, P., Burgués, X., Carvallo, J. P., Franch, X., Grau, G., Marco, J., Quer, C., *ISO/IEC 9126 in practice: what do we need to know?*, Software Measurement European Forum (SMEF 2004).
- [2] M. Fowler, K. Beck, J. Brant, W. Opdyke, D. Roberts, *Refactoring: improving the design of existing code*, Addison-Wesley, 1999.
- [3] S. Kolahdouz-Rahimi, K. Lano, S. Pillay, J. Troya, P. Van Gorp, *Goal-oriented measurement of model transformation methods*, Science of Computer Programming, 2013, doi:10.1016/j.scico.2013.07.013.
- [4] K. Lano, *The UML-RSDS Manual*, <http://www.dcs.kcl.ac.uk/staff/kcl/uml2web>, 2013.
- [5] J. Perez, Y. Crespo, B. Hoffmann, T. Mens, *A case study to evaluate the suitability of graph transformation tools for program refactoring*, Int. J. Softw. Tools Technical Transfer (2010), vol 12: 183–199, doi:10.1007/s10009-010-0153-y.

A Evaluation criteria

As the basis of a systematic evaluation framework for model transformations, we propose to use the International Organisation for Standardization (ISO) standards related to software quality, specifically the

ISO/IEC 9126-1 standard, which is based upon the definition of a *Quality Model* and its use for software evaluation [1]. This framework defines quality models based on general characteristics of software, which are further refined into subcharacteristics.

Relevant characteristics and subcharacteristics for evaluation of model transformation can be selected from the ISO/IEC9126-1 framework. These characteristics and subcharacteristics can then be further decomposed into measurable attributes. Table 2 summarizes the chosen characteristics, subcharacteristics and their corresponding measurable attributes. One attribute may be related to more than one quality factor.

Characteristic	Subcharacteristic	Attribute
Functionality	Suitability	Abstraction level Size Complexity Effectiveness Development effort Execution time
	Accuracy	Correctness Completeness
	Interoperability	Embeddable in transformation process Close to well-known notation Interoperable with Eclipse
	Functionality compliance	Close to well-known notation
Reliability	Maturity	History of use
	Fault tolerance	Tolerance of false assumptions
Usability	Understandability Learnability Attractiveness	Survey results
Efficiency	Time behavior	Execution time Maximum capability
Maintainability	Changeability	Size Complexity Modularity
Portability	Adaptability	Extensibility

Table 2: Selected quality characteristics for evaluation of model transformation approaches

Characteristics such as interoperability and adaptability can be interpreted and evaluated in several different ways. Here we have evaluated these characteristics based upon key factors specific to model transformations. For example, the ability to interwork with Eclipse is an important factor for the interoperability of a transformation approach.

In cases where a numeric value is not appropriate for an attribute (such as Abstraction level, Maturity) a three-point or five-point scale is used to summarise the relative values of attributes.

The following are the specific measures which should be evaluated for each solution:

- Size: lines of specification text

- Complexity: sum of number of operator occurrences and feature and entity type name references in the specification expressions
- Effectiveness: proportion of attribute clones which are removed, relative to the theoretical maximum number that can be removed
- Development effort: developer time in person-hours spent in writing and debugging the specification
- Execution time: milliseconds
- History of use: number of years the model transformation language and tools have been publicly available
- Maximum capability: maximum size of input model, in terms of number of elements, which can be successfully processed
- Modularity: proportion of calls internal to modules, relative to the total number of calls. Value is 1 if there are no external calls.

Abstraction level is classified as High for primarily declarative solutions, Medium for declarative-imperative solutions, and Low for primarily imperative solutions.

The effectiveness measure used is the proportion of clone copies of attributes which are removed by the transformation. That is, if there are n copies of attributes which could, in principle, be removed by the rules 1, 2 and 3, and the implemented transformation removes $m \leq n$ copies, the effectiveness is m/n . In addition, a solution is optimal if the minimum possible number of new classes are introduced.

Execution time of the transformation implementation does not include the loading and unloading of models from the transformation tool.

Correctness is divided into syntactic correctness, termination and confluence. Syntactic correctness is the capability to establish the constraints of the target metamodel of a transformation, and the capability to establish or preserve correct inverse links to associations (in this case study the pairs *general/specialisation* and *specific/generalisation* of roles). Equivalently, it is the ability to ensure conformance of the target model to the target metamodel. The classification of correctness is given by an average of three separate 5-point measures for syntactic correctness, termination and confluence. Each measure separately is rated -2 (None), -1 (Low), 0 (Medium), 1 (High) and 2 (Comprehensive).

Usability is separated into:

- Understandability: how easy a transformation specification is to comprehend.
- Learnability: the degree to which the transformation language and tool can be learnt in a reasonable timescale and with reasonable effort.
- Attractiveness: how acceptable is the language and tool for the user.

Empirical studies with representative users and tasks are considered one of the best techniques to measure usability of software systems. Therefore we propose that a survey of TTC participants (at least 5 persons not involved in the surveyed case study solution) is used to measure the Understandability, Learnability and Attractiveness of solutions to the case study. The survey contains five questions, each with 5 answer options from None (0), Low (1), Medium (2), High (3), Very high (4). The first question identifies the level of knowledge of the specific transformation language by the participant. The rest of the questions are as follows:

- To what degree do the rules of the transformation satisfy the case study description / How easy is it to relate the informal to the formal specification? (Understandability)

- How well structured is the transformation specification? (Attractiveness)
- How attractive is the specification notation to read? (Attractiveness)
- How much effort is needed to understand the transformation? (Learnability)

In addition to these questions we include a small test case to assess the actual understanding of the transformation by a participant: the participant needs to explain where in the transformation specification a particular aspect of the transformation (promoting a duplicated attribute to a superclass) is dealt with. This is a factor for understandability.

The difference between this score for detailed understanding and the level of initial knowledge is also taken as a learnability factor.

Interoperability consists of Embeddability: how effectively the transformation can be reused within a larger quality improvement process, consisting of transformations to (1) remove redundant inheritance, (2) remove multiple inheritance, (3) replace concrete superclasses by an abstract class and a new concrete subclass of this class. Embeddability is High if both internal and external composition of these transformations is possible, Medium if only one composition is possible, and Low if no composition is possible.

Another factor for interoperability is the closeness to a well-known notation, which is graded by a three-point scale: High (+1) for a common syntax and semantics to a well-known notation (eg., OCL); Medium (0) for a variant syntax and/or variant semantics; Low (-1) for no similarity.

Interoperability with Eclipse is given by a three-point scale: High (+1) for complete integration; Medium (0) for interoperability via exported/imported data files only; Low (-1) for no interoperation mechanism.

Maturity is considered low (-1) for languages/tools of less than 4 years public availability, medium (0) for 4 up to eight years availability, and high (+1) for more than 8 years.

Extensibility is measured by evaluating how successfully the solution for the core problem can be generalised to solve the extended case study problem in Section 3. It is measured quantitatively by the effort required to extend the solution, in person-hours.

B UML-RSDS Solution

The case study transformation has been specified in UML-RSDS [4]. This specification consists of the class diagram of Figure 1, and a single use case which represents the transformation. The use case has precondition constraints expressing the assumptions of the transformation, and a sequence of three postcondition constraints (C1), (C2), (C3) corresponding to the three informal rules. Each of these operates on instances of *Entity*:

```
(C1) :
a : specialisation.specific.ownedAttribute &
specialisation.size > 1 &
specialisation.specific→forall(
  ownedAttribute→exists(b | b.name = a.name & b.type = a.type)) ⇒
  a : ownedAttribute &
  specialisation.specific.ownedAttribute→select(
    name = a.name)→isDeleted()
```

This specifies that an instance (*self*) of *Entity*, and instance *a* of *Property* match the constraint LHS if: (i) *a* is in the set of attributes of all direct subclasses of *self*, (ii) there is more than one direct subclass of *self*, and (iii) every direct subclass of *self* has an attribute with the same name and type as *a*.

The conclusion specifies that (i) the property *a* is moved up to the superclass *self*, (ii) all other attributes with name *a.name* are deleted from all direct subclasses of *self*.

$s \rightarrow isDeleted()$ is a built-in operator of UML-RSDS, which deletes the object or set of objects *s* from their model, removing them from all entity types and association ends.

```
(C2) :
a : specialisation.specific.ownedAttribute &
v = specialisation→select(
    specific.ownedAttribute→exists(b | b.name = a.name & b.type = a.type)) &
v.size > 1 &
specialisation.specific.ownedAttribute→forall(c | specialisation→select(
    specific.ownedAttribute→exists(d |
        d.name = c.name & d.type = c.type))→size() ≤ v.size) ⇒
Entity→exists(e | e.name = name + "_2_" + a.name &
    a : e.ownedAttribute &
    e.specialisation = v &
    Generalization→exists(g | g : specialisation & g.specific = e)) &
v.specific.ownedAttribute→select(name = a.name)→isDeleted()
```

The assumption specifies that an instance (*self*) of *Entity*, and instance *a* of *Property* match the constraint LHS if: (i) *a* is in the set of attributes of all direct subclasses of *self*, (ii) the set *v* of all specialisations of *self* whose class contains a clone attribute of *a* has size greater than 1, (iii) *v* is of maximal size over all groups of specialisations of *self* which contain a common attribute.

The conclusion specifies that: (i) a new entity *e* is created, and the property *a* is moved up to *e*, (ii) the specialisations of *e* are *v*, (iii) *e* is made a subclass of *self*, and (iv) all the clone copies of *a* in *v* are deleted.

```
(C3) :
a : ownedAttribute &
generalisation.size = 0 &
v = Entity→select(generalisation.size = 0 &
    ownedAttribute→exists(b | b.name = a.name & b.type = a.type)) &
v.size > 1 ⇒
Entity→exists(e | e.name = name + "_3_" + a.name &
    a : e.ownedAttribute &
    v.ownedAttribute→select(name = a.name)→isDeleted() &
    v→forall(c | Generalization→exists(
        g | g : e.specialisation & g.specific = c)))
```

The Java executable of this solution is provided in the Share VM, as GUI.java. This can be executed by the command `java GUI` from the command line. The executable reads its input model from `in.txt` and produces output in the file `out.txt`, when the button for the transformation is selected. XMI output is also produced, in `xsi.txt`.