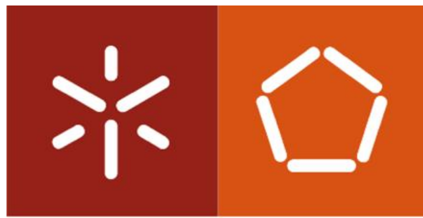
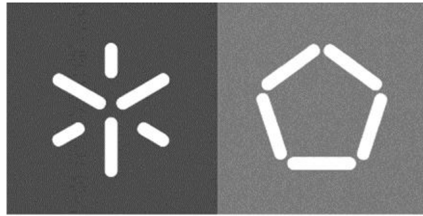


Universidade do Minho
Escola de Engenharia

Sofia Manuela Fevereiro de Azevedo

Refinement and Variability Techniques in Model Transformation of Software Requirements

Abril de 2014



Universidade do Minho
Escola de Engenharia

Sofia Manuela Fevereiro de Azevedo

Refinement and Variability Techniques in Model Transformation of Software Requirements

Tese de Doutoramento em
Tecnologias e Sistemas de Informação
Trabalho efectuado sob a orientação do
Professor Doutor Ricardo J. Machado
Departamento de Sistemas de Informação
e do
Professor Doutor Alexandre Bragança
Instituto Superior de Engenharia do Porto

Abril de 2014

DECLARAÇÃO

Nome: SOFIA MANUELA FEVEREIRO DE AZEVEDO

Endereço Electrónico: sofiaazo@gmail.com **Telefone:** +351 912 959 244

Bilhete de Identidade: 12450574

Título da Tese de Doutoramento: Refinement and Variability Techniques in Model Transformation of Software Requirements

Orientadores: Professor Doutor Ricardo J. Machado e Professor Doutor Alexandre Bragança

Data de Conclusão: Março de 2014

Designação do Programa Doutoral: Programa Doutoral em Tecnologias e Sistemas de Informação

É AUTORIZADA A REPRODUÇÃO INTEGRAL DESTA TESE, APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.

Universidade do Minho, _____ / _____ / __________

Assinatura: ____

A todos os que estavam ao meu lado à chegada desta expedição.

Abstract

This thesis begins with analyzing user functional requirements (as use cases) from the perspective of detail. In that sense, it investigates the applicability of the UML (Unified Modeling Language) *«include»* relationship to the representation of use case refinement and proposes another relationship for that purpose. It also clarifies the process of modeling use cases with UML when refinement is involved and provides for some guidelines in order to conduct that process. Afterwards, the work of this thesis on use case modeling is expanded to the field of SPLs (Software Product Lines) by means of exploring the UML *«extend»* relationship. It talks about alternative, specialization and option use cases as the representation of the three variability types this thesis proposes to be translated into stereotypes to mark use cases. Then, this thesis incorporates the refinement of logical architectures with variability support from use cases also with variability support in the 4SRS (Four Step Rule Set) transition method for model transformation of analysis artifacts (use cases) into design artifacts (logical architectures represented as UML component diagrams).

The model transformation the 4SRS guides in a stepwise way, from use cases into logical architectures, is based on a software development pattern that addresses architecture. This thesis yields a multilevel and multistage pattern classification that grounds the use of that pattern to generate system functional requirements (as logical architectures).

Lastly, the 4SRS transition method is modeled with the SPEM (Software & Systems Process Engineering Metamodel) and formalized as a small software development process dedicated at transitioning from the analysis to the design of software. After that, this thesis presents a case study on the automation of the 4SRS and thoroughly elaborates on the transformation rules that support the model transformations of the 4SRS.

Resumo

Esta tese começa por analisar requisitos funcionais de utilizador (enquanto casos de utilização) sob a perspectiva do detalhe. Nesse sentido, esta tese investiga a aplicabilidade da relação UML (*Unified Modeling Language*) *«include»* para a representação do refinamento de casos de utilização e propõe outra relação para esse fim. Esta tese também clarifica o processo de modelação de casos de utilização com a UML quando esse processo envolve refinamento e fornece algumas diretrizes para a condução desse processo. De seguida, o trabalho desta tese em modelação de casos de utilização é expandido para o campo das linhas de produtos de software através da exploração da relação UML *«extend»*. Esse trabalho fala de casos de utilização alternativos, de especialização e opcionais como a representação dos três tipos de variabilidade que esta tese propõe que sejam traduzidos em estereótipos para a marcação de casos de utilização. Depois, esta tese incorpora o refinamento de arquitecturas lógicas com suporte à variabilidade a partir de casos de utilização também com suporte à variabilidade no método de transição 4SRS (*Four Step Rule Set*) para a tranformação de modelos de artefatos de análise (casos de utilização) em modelos de artefatos de design (arquitecturas lógicas representadas como diagramas de components UML).

A transformação de modelos que o 4SRS guia por passos, de casos de utilização em arquitecturas lógicas, baseia-se num padrão de desenvolvimento de software que visa arquitetura. Esta tese produz uma classificação multinível e multietapa de padrões, que sustenta a utilização desse padrão na geração de requisitos funcionais de sistema (enquanto arquitecturas lógicas).

Por fim, o método de transição 4SRS é modelado com o SPEM (*Software & Systems Process Engineering Metamodel*) e formalizado como um pequeno processo de desenvolvimento de software dedicado a transitar da análise para o design the software. Depois disso, esta tese apresenta um estudo de caso sobre a automatização do 4SRS e elabora minuciosamente acerca das regras de transformação que apoiam as transformações de modelos do 4SRS.

Acknowledgements

Einstein said we cannot solve our problems at the same level of thinking we were when we created them. This means this thesis is the proof of a journey of growth from a lower level of thinking to a higher level of thinking with regards to the problems it solved. However, this thesis also proclaims the beginning of a new journey of knowledge development caused by new problems to solve.

I would like to express special gratitude to my (not supervisor but) mentor, Professor Doutor Ricardo J. Machado. Thank you, Ricardo, for allowing me to work with you. I strongly hope our enthusiastic research discussions with white boards last a long time from now. Thank you for involving me in applications to research project funding, paper reviewing, conference organization and conducting this thesis with a paper-oriented approach. Thank you for choosing me to work with Professora Doutora Rita Maciel, from the Federal University of Bahia (Brazil).

I would like to address gratitude to my co-supervisor Professor Doutor Alexandre Bragança, whose Ph.D. work inspired and set the context for this thesis. I would also like to address gratitude to my former co-supervisor Dr. Dirk Muthig for the experienced revisions of this thesis' work.

I would like to express kind gratitude to Professora Doutora Rita Maciel, who contributed with rich knowledge and resources for the elaboration of a chapter. I would also like to express gratitude to my colleagues from the Distributed Systems Laboratory of Computer Science Department at Federal University of Bahia for the kind reception and work developed in the context of this thesis.

I would like to thank the conference and workshop programme committees and reviewers, as well as the book and journal editors for the publication of this thesis' work.

I would also like to thank Algoritmi Research Center from the University of Minho for supporting my research in Brazil and the conferences where I presented the work of this thesis.

I am deeply grateful to my father for wishing the best of the best for me, for supporting me and for walking alongside me throughout all my scholar drive. I am as deeply grateful to my grandmother for teaching me to read, write and count. I am also deeply grateful to my uncle and my aunt for all the guidance, incentive and demand throughout the years since my first grade.

At last I would like to express my appreciation to all those who contributed somehow to the execution of this thesis, whose names I do not mention above.

Contents

Abstract ... v

Resumo ... vii

Acknowledgements ... ix

1. Introduction ... 1
   - 1.1. Research Problem ... 1
   - 1.2. Research Goals ... 4
   - 1.3. Research Method ... 4
   - 1.4. Thesis Roadmap ... 5

2. Related Work ... 7
   - 2.1. Refinement and Variability Modeling in Requirements ... 7
   - 2.2. Software Development Patterns ... 16
   - 2.3. Transformation of Requirements ... 22
   - 2.4. Conclusions ... 31

3. Transforming Use Case Models into Logical Architectures ... 33
   - 3.1. Introduction ... 33
   - 3.2. Refining Use Cases with the *Include* Relationship ... 37
   - 3.3. Modeling Variability with the *Extend* Relationship ... 46
   - 3.4. The 4SRS Method with Variability Support ... 60
   - 3.5. Conclusions ... 73

4. Pattern Classification for Model Transformation ... 77
   - 4.1. Introduction ... 77
   - 4.2. Multilevel and Multistage Classification ... 83
   - 4.3. Pattern Classification Types ... 90
   - 4.4. Conclusions ... 105

5. Automating Model Transformations ... 109
   - 5.1. Introduction ... 109
   - 5.2. Extending the SPEM Metamodel ... 112
   - 5.3. Automating the 4SRS Transition Method ... 123
   - 5.4. Variability Support with ATL Rules ... 129
   - 5.5. Conclusions ... 138

6. Conclusions ... 141
   - 6.1. Discussion ... 141
   - 6.2. Future Work ... 145

References ... 147

Appendix I. Tabular Transformations over the GoPhone Messaging Domain ... 155

List of Figures

Figure 1 – Refinement by decomposition according to criterion A and by decomposition according to criterion B. 39
Figure 2 – The proposed extension to the UML metamodel for representing the refinement of use cases....................41
Figure 3 – The multiple refines constraint....................41
Figure 4 – The coexistence constraint. 41
Figure 5 – The refinement process....................42
Figure 6 – Possibilities for the refinement of both an including use case and an included use case....................43
Figure 7 – Non-stepwise textual description of the use case Send Message....................44
Figure 8 – Non-stepwise textual description of the use case Compose Message....................44
Figure 9 – Non-detailed non-stepwise textual description of the use case Insert Object. 44
Figure 10 – Detailed non-stepwise textual description of the use case Insert Object....................44
Figure 11 – Non-stepwise textual description of the use case Browse Directory. 44
Figure 12 – Non-stepwise textual description of the use case Display Object in Message Area....................44
Figure 13 – The use case diagrams of the Send Message functionality from the GoPhone....45
Figure 14 – The use case variability types....................46
Figure 15 – Use case diagram from the GoPhone case study (highest abstraction level). 48
Figure 16 – The specialization of the variant use case Borrow Book with a single actor. 51
Figure 17 – The specialization of the use case Borrow Book with two different actors. 51
Figure 18 – The specialization of the variant use case Borrow Book with two different actors. 51
Figure 19 – The specialization of the variant use case Borrow Object. 51
Figure 20 – The proposed extension to the UML metamodel (figure 16.2 from [1]) for modeling variability in use case diagrams....................52
Figure 21 – The specialization of Insert Picture and Insert Picture or Draft Text....................54
Figure 22 – Use cases positioned according to the perspectives of detail*variability............55
Figure 23 – Non-stepwise textual descriptions from the GoPhone use case Send Message and some of its related use cases. 56
Figure 24 – Use case diagram from the GoPhone case study (two detail levels)....................58
Figure 25 – An example of refinement of the specialization type of variability from the GoPhone....................59
Figure 26 – An example of refinement of alternative variability from the GoPhone.............60
Figure 27 – Schematic representation of the recursive execution of the 4SRS method..........62
Figure 28 – Component diagram that resulted from the first execution of the 4SRS method over the use cases from the messaging domain of the GoPhone case study, while being filtered....................67
Figure 29 – Filtered component diagram with regards to the object insertion and object attaching functionalities of the Send Message use case from the GoPhone case study. . 69
Figure 30 – Filtered and collapsed diagram for object insertion and attaching functionalities from the GoPhone's messaging domain. 69
Figure 31 – Use case diagram for the first recursive execution of the 4SRS method over the GoPhone's messaging domain....................70
Figure 32 – Some descriptions of components that will be refined with the first recursive execution of the 4SRS method over the GoPhone's messaging domain....................71

Figure 33 – Non-stepwise textual descriptions of the use cases Insert Picture and Attach Business Card or Calendar Entry for the first recursive execution of the 4SRS method over the GoPhone's messaging domain. 72
Figure 34 – Detailed non-stepwise textual descriptions of the use cases Insert Picture and Attach Business Card or Calendar Entry for the first recursive execution of the 4SRS method over the GoPhone's messaging domain. 72
Figure 35 – Component diagram resulting from the first recursive execution of the 4SRS method over the GoPhone's messaging domain. 74
Figure 36 – The OMG modeling infrastructure or Four-Layer Architecture. 78
Figure 37 – Orthonormal referential with the dimensions of the multilevel and multistage classification on the axes plus the pattern categorization three-dimensional space (on the left). The projections of a pattern's positioning in a two-dimensional area (on the right). 85
Figure 38 – The business patterns' positioning according to the Stage and the Discipline dimensions (on the left). The Domain Model pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right). 92
Figure 39 – The analysis patterns' positioning according to the Stage and the Discipline dimensions (on the left). The Posting pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right). 94
Figure 40 – The enterprise patterns' positioning according to the Stage and the Discipline dimensions (on the left). The Service Layer pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right). 97
Figure 41 – The architectural patterns' positioning according to the Stage and the Discipline dimensions (on the left). The MVC pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right). 99
Figure 42 – The positioning of design patterns according to the Stage and the Discipline dimensions (on the top left). The difference between the design patterns of the classification this thesis presents and the GoF's according to the Stage and the Discipline dimensions (on the bottom left). The Adapter pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right). 102
Figure 43 – The implementation patterns' positioning according to the stage and the discipline dimensions. 104
Figure 44 – Metamodel that defines the visual language for modeling transition methods and formalizing them as microprocesses. 116
Figure 45 – The use of method content elements represented in the SPEM. 119
Figure 46 – The extension of the UML metamodel for modeling the method content of transition methods. 120
Figure 47 – The method content model for the 4SRS. 121
Figure 48 – The process model for the 4SRS. 121
Figure 49 – An activity detail model of the 4SRS (micro)process. 122
Figure 50 – A workflow model of the 4SRS (micro)process. 123
Figure 51 – The 4SRS transition method modeled with the SPEM for automation purposes. 124
Figure 52 – A use case diagram from the GoPhone. 125
Figure 53 – Part of the ATL rule that determines the leaf use cases of a use case diagram. 127
Figure 54 – The component diagram automatically generated from the use case diagram in Figure 52. 127
Figure 55 – The OCL code for constraints on the relation between transition tasks and work products. 128
Figure 56 – An example of a validation error in the constraints on the relation between transition tasks and work products. 128

Figure 57 – The OCL code for constraint on the relation between intermediate tasks and work products. 128
Figure 58 – An example of a validation error in the constraint on the relation between intermediate tasks and work products. 128
Figure 59 – The OCL code for constraints on the relation between tasks and steps. 129
Figure 60 – An example of the impossibility of a composition between a transition task and an intermediate step. 129
Figure 61 – Part of the ATL rule that applies to a use case diagram: definition of the subset of source use cases in contexts of variability. 130
Figure 62 – Part of the ATL rule that applies to a use case diagram: definition of leaf use cases regardless of variability. 130
Figure 63 – Part of the ATL rule that applies to a use case diagram: generation of components from leaf use cases regardless of variability. 131
Figure 64 – Part of the ATL rule that applies to a use case diagram. 133
Figure 65 – Part of the ATL rule that applies to a use case diagram: the `hasExtend()` function. 134
Figure 66 – Part of the ATL rule that applies to a use case diagram: the `getExtends()` function. 134
Figure 67 – Part of the ATL rule that applies to a use case diagram: the `associations()` function. 135
Figure 68 – Part of the ATL rule that applies to a use case diagram: generation of associations between interface components and actors in contexts of alternative variability (variability related to alternative relationships, which are stereotyped as «alternative»). 135
Figure 69 – Part of the ATL rule that applies to a use case diagram: generation of associations between actors and interface components generated from leaf use cases not involved in Extend relationships, and option use cases simultaneously not extending and extended. 136
Figure 70 – Part of the ATL rule that applies to the component diagram resulting from microstep 2.v of the 4SRS. 137

List of Tables

Table 1 – Some use case stereotypes concerned with variability. 16
Table 2 – Analysis of the automation capability of the steps from the 4SRS. 126
Table 3 – Tabular transformations over the GoPhone's Send Message use case. 155
Table 4 – Tabular transformations over the GoPhone's object insertion and object attaching functionalities. 163

Acronyms

4SRS	*Four Step Rule Set*
ADL	*Architecture Description Language*
API	*Application Programming Interfaces*
ATL	*ATLAS Transformation Language*
GoF	*Gang of Four*
GRAS	*General Responsibility Assignment Software*
MDD	*Model-Driven Development*
MOF	*Meta-Object Facility*
MVC	*Model-View-Controller*
OCL	*Object Constraint Language*
OMG	*Object Management Group*
OO	*Object-Oriented*
PML	*Process Modeling Language*
POSA	*Pattern-Oriented Software Architecture*
QVT	*Query/View/Transformation*
RSEB	*Reuse-Driven Software Engineering Business*
RUP	*Rational Unified Process*
RUP SE	*RUP for Systems Engineering*
SPEM	*Software & Systems Process Engineering Metamodel*
SPL	*Software Product Line*
UML	*Unified Modeling Language*

1. Introduction

This chapter is targeted at introducing the three main research contribution topics of this thesis: UML modeling of functional requirements and logical architectures with support for software variability and functional refinement, software development patterns and the automation of SPEM process models dedicated at transitioning from software analysis to software design. This chapter also presents the goals of this thesis, the demonstration case and the roadmap of the document.

1.1. Research Problem

This thesis is targetd at solving some problems related to the following topics: (1) UML (Unified Modeling Language) [1] modeling of functional requirements and logical architectures with support for functional refinement and software variability; (2) software development pattern classification for model transformation; and (3) automation of SPEM process models dedicated at transitioning from software analysis to software design.

Developing software with model-driven approaches involves dealing with diverse modeling artifacts such as use case diagrams, component diagrams, class diagrams, activity diagrams, sequence diagrams and others. This thesis focuses on use cases for software development and analyzes them from the perspective of detail. In that context, the UML *«include»* relationship was explored. This thesis allows understanding the use case modeling activity with support for refinement and provides for specific guidelines on how to conduct such activity.

Modeling SPLs (Software Product Lines) [2, 3] shall imply modeling from different perspectives with different modeling artifacts such as those previously enumerated. This thesis elaborates on use cases for modeling product lines and explores them from the perspective of variability by working with the UML *«extend»* relationship. It also explores use cases for modeling product lines from the perspective of detail by (functionally) refining use cases with *«extend»* relationships between them. One of the intents of this thesis is to provide for comprehension about use case modeling with support for variability and with functional refinement when variability is present.

Modeling by means of specific methods is still a relevant concern in engineering software product lines. From user requirements to logical software architectures there is a long way to go. Currently modeling methods applicable for modeling logical architectures with variability support do not comprise refinement at the user requirements level (the use cases level) and in a stepwise, therefore guided way. Likewise approaches to functional decomposition of software systems do not contemplate a method for handling use cases to get to the design of those systems or a technique for refining use cases. These lacks imply dealing with a lot of complexity during the application of such methods to a high number of functional requirements. The detail degree of logical software architectures can be increased with the technique of refinement. To support the refinement of logical software architectures with variability support, this thesis suggests the extension of a modeling method applicable for modeling those architectures, which is the 4SRS (Four Step Rule Set) UML modeling method [4-6]. The GoPhone [7] was used as the case study to illustrate the approach and the recursion capability of the method has ben used as the solution to the challenges of modeling such architectures. A cohesive logical software architecture with variability support, without redundant requirements and without missed requirements was generated for a part of the GoPhone's messaging domain and refined with the 4SRS method. The strength of this thesis' approach resides in its stepwise nature and in allowing the modeler to work at the user requirements level without delving into lower-abstraction-level concerns. The 4SRS allows the methodic transition from user requirements to system requirements. In other words, the transformation of use cases (dealt with during the analysis of software) into logical architectures (dealt with during in the beginning of the design of software) is conducted with a method specifically elaborated for the purpose.

Software patterns are reusable solutions to problems that occur often throughout the software development process. This thesis formally states which sort of software patterns

shall be used in which particular moment of the software development process and in the context of which Software Engineering professionals, technologies and methodologies. The way to do that is to classify those patterns according to the proposed multilevel and multistage pattern classification based on the software development process. The pattern classification fundaments the (architectural) pattern 4SRS uses to transform user functional requirements (in the shape of use cases) into system functional refinements (in the shape of a logical architecture represented with a component diagram): the MVC (*Model-View-Controller*) pattern [8]. The classification is based on the OMG modeling infrastructure or Four-Layer Architecture and also on the RUP (Rational Unified Process) [9]. It considers that patterns can be represented at different levels of the OMG modeling infrastructure and that representing patterns as metamodels is a way of turning the decisions on their application more objective. Classifying patterns according to the proposed pattern classification allows for the preservation of the original advantages of those patterns and avoids that the patterns from a specific category are handled by the inadequate professionals, technologies and methodologies. This thesis illustrates the proposed approach with the classification of some patterns.

Software process modeling is a model-driven approach for defining new or formalizing existing software development processes. It benefits from the advantages of MDD (Model-Driven Development) [10, 11]. The SPEM (Software & Systems Process Engineering Metamodel) [12] is a process modeling language for the domain of software and systems. This thesis elaborates on the formalization of the 4SRS method as a small software development process that can be plugged into larger software development processes. It is a transition method because it is dedicated at transitioning from the analysis to the design of software. This thesis explores the particularities of formalizing a transition method as a small dedicated software development process. The formalization is conducted with the SPEM.

Automation is the essence of MDD. Transforming models into models following a set of rules is at the core of automation. It allows using tools to enliven previously defined processes. Transition methods are most likely the most important player in the engineering of software. This thesis exemplifies how a transition method like the 4SRS can be modeled with the SPEM as a way to study the benefits of the automatic execution of a transition method as a small dedicated software development process.

Various methods have been proposed over time to model variability in software product lines. The 4SRS is a transition method that generates design artifacts out of analysis artifacts. It is applicable for modeling both design models and analysis models with support for variability. Besides the formalization of the 4SRS with the SPEM as a small software development process dedicated at transitioning from the analysis to the design of software, this thesis presents the transformation rules specified to automate that transition and provide tool support for the execution of the 4SRS over models with variability.

1.2. Research Goals

The goals of this thesis are the following: (1) providing specific guidelines on how to conduct the activity of use case modeling with support for functional refinement; (2) providing specific guidelines on how to conduct the activity of use case modeling with support for both functional refinement and software variability; (3) supporting the refinement of logical software architectures with variability support by extending a UML modeling method applicable for modeling those architectures (the 4SRS); (4) classifying software patterns according to a multilevel and multistage pattern classification based on the software development process to justify the pattern used for the model transformation the 4SRS guides; (5) exploring the particularities of modeling transition methods (like the 4SRS) to formalize them as small dedicated software development processes; (6) exemplifying the SPEM modeling of a transition method like the 4SRS as a way to study the benefits of the automatic execution of transition methods as small dedicated software development processes; and (7) reflecting on the impact of variability over the automation of transition methods (like the 4SRS) modeled with SPEM.

1.3. Research Method

This thesis adopted two research approaches: the proof of concept, or concept implementation, and the formulative research approach [13].

The proof of concept research approach is about developing a system to demonstrate the feasibility of a solution to a problem. The question with feasibility in this thesis is whether it is possible to formalize the 4SRS as a transition method and benefit from the automatic execution of a transition method as a small dedicated software development process by modeling a transition method (like the 4SRS) with SPEM. The Moderne tool [14], which is a tool developed at the Federal University of Bahia (Brazil), was adapted to support the automated execution of the 4SRS.

The formulative research approach is concerned with the formulation of methods, among other kind of artifacts. This thesis extends a UML modeling method (the 4SRS) applicable for transforming user functional requirements into logical architectures, both with variability support, in order for the method to support the refinement of such architectures. The pattern classification can also be considered as a method for classifying patterns to be used in model transformation, from use cases to component diagrams, in the case of the 4SRS. The Fraunhofer IESE's GoPhone case study [7] (that presents a series of use cases for a part of a mobile phone product line particularly concerning the interaction between the user and the mobile phone software for the sending of messages) is used in order to demonstrate the feasibility of the proposed solution to the addressed problem, therefore the GoPhone is used as a means of validation of that solution.

1.4. Thesis Roadmap

The remainder of this thesis is organized as follows. Chapter 2 presents the work of other authors on the refinement of use cases, the refinement of logical architectures and variability modeling with the UML *«extend»* relationship. Chapter 2 also affords a state-of-the-art that suits the purpose of substantiating the strength of this thesis' approach on the use of software development patterns, including the one 4SRS uses. Chapter 2 also concentrates on the transition from software development analysis to design as a process and its modeling. At last, it concentrates on process automation and execution.

Chapter 3 introduces the process of refining use cases. It defines the *«refine»* relationship, and discusses the difference between the *«include»* and the *«refine»* relationships. Chapter 3 also elaborates on the different types of variability this thesis proposes. It provides for the analysis of the UML *«extend»* relationship in contexts of variability and also for the extension this thesis proposes to the UML metamodel. It also analyzes the process of handling variability in use cases in contexts of functional refinement. Lastly it elaborates on the refinement of logical architectures with variability support according to both the formalization of use case refinement and the systematization of use case variability modeling this thesis proposes.

Chapter 4 is devoted to exhibiting the proposed pattern classification in abstract terms before formalizing categories and positioning patterns at those categories. Chapter 4 is also targeted at demonstrating the feasibility of the proposed solution to the systematic use of software development patterns by using some concrete examples of patterns positioned at

distinct categories of the proposed classification to illustrate the different types of patterns formalized, including the pattern used by the 4SRS in the transformation it guides.

Finally, chapter 5 shows the extension of the SPEM this thesis proposes for defining a visual language to model transition (from the analysis to the design of software) methods and formalize small dedicated software development processes like the 4SRS. Chapter 5 also shows the preparation necessary for the automation of transition methods modeled with the SPEM, particularly the work undertaken to prepare the automation of the 4SRS. Chapter 5 also provides for an insight over the impact of automating transitions methods (like the 4SRS) in contexts of variability.

2. Related Work

Section 2.1 presents the work of other authors on the refinement of use cases, the refinement of logical architectures and variability modeling with the UML *«extend»* relationship.

Section 2.2 affords a state-of-the-art that suits the purpose of substantiating the strength of this thesis' approach on the use of software development patterns, including the one 4SRS uses.

Section 2.3 concentrates on the transition from software development analysis to design as a process and its modeling. It also concentrates on process automation and execution.

2.1. Refinement and Variability Modeling in Requirements

Functional Refinement

Refinement has been treated over the years. Paech and Rumpe provide in [15] for a formal approach to incrementally design types through refinement. Types represent the static part of a system captured through software models, and consist of attributes and operations. The approach in this thesis is not formal and relates to the refinement of external functionalities of software systems, which shall be taken into account before the static part of those systems. Quartel, *et al*. propose in [16] an approach for the refinement of actions. It consists of replacing an abstract action with a concrete activity (composition of actions) based on the application of rules to determine the conformance of the concrete activity to the abstract action. Again the approach in this thesis relates to a perspective that shall be taken into account before behavior is. Darimont and van Lamsweerde talk in [17] about goal

refinement. In their approach the refinement process is guided by refinement patterns used for pointing out missing elements in refinements. This time the approach of this thesis to refinement relates to a perspective that shall be taken into account after goals. Schrefl and Stumptner face in [18] refinement as the decomposition of states and activites into substates and subactivities though inheritance. The approach of this thesis to refinement considers that refinement shall not be treated through generalization as it will be stated later on in this thesis. Mikolajczak and Wang present in [19] an approach to vertical conceptual modeling of concurrent systems through stepwise refinement using Petri net morphisms. The approach of this thesis to refinement is not formal. Batory created a model (the AHEAD model [20]) for expressing the refinement of system representations as equations. Despite his approach being based on stepwise refinement he worked at a code-oriented level. The work this thesis reports allows refining (also in a stepwise manner) software models that shall be handled before code is handled during the software construction phase.

Cherfi, *et al*. [21] (in their work on quality-based use case modeling with refinement) describe the refinement process as the application of a set of decomposition and restructuring rules to the initial use case diagram. Their approach is iterative and incremental. It consists of decomposing the initial use case diagram into smaller and more cohesive ones to decrease the complexity of the diagram and increase its cohesion. In their approach a use case is a set of activities that varies according to scenarios, which are flows of actions belonging to those activities. In the first phase of the refinement process a use case is decomposed into other use cases according to one or more scenarios. The second phase of the refinement process is about eliminating the redundant activities that compose the use cases obtained from the first phase, which generates *«include»* relationships. Their approach allows defining *«include»* relationships based on the commonality among the system's activities performed for different scenarios. The approach in this thesis considers that the *«include»* relationship is defined based on the non-stepwise textual descriptions of use cases and that stepwise descriptions (like those considered by Cherfi, *et al*.) shall be treated separately (stepwise textual descriptions are structured textual descriptions in natural language that provide for a stepwise view of the use case as a sequence of steps, alert for the decisions that have to be made by the user and evidence the notion of use case actions temporarily dependent on each other; Cockburn presents in [22] different forms of writing textual descriptions for use cases). Also in the approach of Cherfi, *et al*. to refinement, use cases are not actually detailed (like in the approach of this thesis), rather they are decomposed without detail being added to the description of those use cases.

Pons and Kutsche [23] present the refinement activity as a way to trace code back to system requirements and system requirements back to business goals, which allows verifying whether the code meets the business goals and the system requirements as expected in the specification of the system. Although these authors do not formally extend the UML metamodel to incorporate a new kind of relationship between use cases, they use this new kind of relationship between diagrams. But Pons and Kutsche use the relationship to connect two use cases belonging to two different diagrams, whereas the vision in this thesis is that the refinement relationship shall be established between one use case (a diagram) and two or more use cases (another diagram) to distinguish the different levels of abstraction both diagrams are situated at. Despite that Pons and Kutsche distinguish between refinement by decomposition and refinement by specialization, they achieve refinement by specialization through a generalization relationship between use cases that belong to the same diagram. The position of this thesis towards refinement is that the refinement relationship may be defined *by decomposition* but it is established between different diagrams as the use cases connected through the refinement relationship are situated at different levels of abstraction. Besides this, the approach in this thesis considers that generalization is different from refinement, which implies that refinement cannot be represented through a generalization relationship (e.g. the use case *Borrow Book* can be specialized into *Borrow Book to Student* and *Borrow Book to Teacher*; the use case *Borrow Book* can be refined into *Request Book Borrowing* and *Return Borrowed Book*; despite the request and the return happening in different points in time, both are needed in order to fulfill a book borrowing, which means that a book cannot be borrowed without requesting it and without returning it).

Eriksson, *et al*. [24] treat refinement as a relation between features that are obtained from decomposing other features. Features at different levels of decomposition maintain relationships with use cases or parts of their textual descriptions. This thesis considers that refining use cases includes their decomposition as well as features do. It also considers that use cases can be decomposed without being refined: in the approach of this thesis, refining use cases includes their detailing (adding detail to the description of use cases) besides their decomposition. In order for the relationship between features and use cases to be considered at different levels of abstraction, those different levels of abstraction shall be defined based on both decomposition and detailing.

Working at the level of user requirements is the strength of this thesis when comparing its perception of refinement to the perception of refinement that also Greenfield

and Short [2], and Egyed, *et al*. [25] have. Greenfield and Short [2] refer to refinement as the inverse of abstraction or the process of turning a description more complex by adding information to it. They refer to the process of developing software through refinement as progressive refinement. The process starts with requirements and ends up with the more concrete description of the software (the executable). They consider refinement as a concatenation of interrelated transformations mapping a problem to a solution. The goal of refinement is to smoothly decrease the abstraction levels that separate the problem from the solution. In general terms, Greenfield and Short talk about refinement as the stepwise decomposition of features' granularity. In the context of use cases, refinement is their detailing. However this thesis defends that use cases can themselves be refined in order to facilitate the transformation of a problem (which can be modeled with use cases) to a solution (which shall be modeled with design artifacts e.g. logical architectures).

Gomaa [26] explored refinement in the context of feature modeling, where a feature can be a refinement of another. But in order to get to the features, use cases have to be modeled and mapped to features. The approach in this thesis eliminates this mapping activity. To Gomaa the refinement is expressed through *«extend»* relationships in the context of use cases. This thesis considers that the refinement shall be expressed through the *«refine»* relationship it proposes. Eriksson et al. [24] have an understanding of refinement similar to the Gomaa's.

Fowler made the following advice in his book "UML Distilled" [27]: "don't try to break down use cases into sub-use cases and subsub-use cases using functional decomposition. Such decomposition is a good way to waste a lot of time". The work in this thesis is not in agreement with Fowler's opinion at a certain extent. The pertinence of functional decomposition lies in the scale of the software system under development. The development of large software systems benefits from decomposing the functionality of those systems to a level that allows delivering less complex modeling artifacts to the teams implementing the software system. All the more, large software systems are frequently built from a series of components developed by different teams. A single team is not expected to develop the whole system, therefore it shall not be delivered the modeling artifacts concerning the whole system in order to guide the ellaboration of the component that is required to be developed by that team [5]. Fowler made another suggestion in his book: "The UML includes other relationships between use cases beyond the simple includes, such as *«extend»*. I strongly suggest that you ignore them. I've seen too many situations in which

teams can get terribly hung up on when to use different use case relationships, and such energy is wasted. Instead, concentrate on the textual description of a use case; that's where the real value of the technique lies". The work in this thesis is in complete agreement with Fowler when he says that the value of use case modeling lies in the textual descriptions of use cases. The approach of this thesis to use case refinement is based on those descriptions. But the work in this thesis is not in agreement with Fowler when he says that the relationships besides the *«include»* relationship shall be ignored when modeling use cases. The the *«refine»* relationship this thesis proposes cannot be ignored. It is needed in order to formalize at an early time (the use case modeling) where functional decomposition shall happen in order to decrease the complexity of the modeling artifacts delivered to the different development teams.

Variability Modeling

Despite use cases being sometimes used as drafts during the process of developing software and not as modeling artifacts that actively contribute to the development of software, use cases shall have mechanisms to deal with variability in order for them to have the ability to actively contribute to the process of developing product lines. Consider that the variability types this thesis proposes in the context of use cases can be represented by option, alternative and specialization use cases. For instance, modeling variability in use case diagrams is important to later model variability in activity diagrams [28]: option use cases map to alternative insertions in activity diagrams (alternative insertion is a type of sequences of actions in the context of activity diagrams), and both alternative and specialization use cases map to alternative fragments in activity diagrams (alternative fragment is another type of sequences of actions in the context of activity diagrams). This thesis does not elaborate further in this topic since it is out of its scope. This thesis talks thoroughly about option, alternative and specialization use cases as the representation of the three different types of variability in use cases it considers.

The work in this thesis is inspired on the approach of Bragança and Machado to variability modeling in use case diagrams [29]. Bragança and Machado represent variation points explicitly in use case diagrams through extension points. Their approach consists of commenting *«extend»* relationships with the name of the products from the product line on which the extension point shall be present. Their approach to product line modeling is bottom-up (rather than top-down), which means that all the product line's products are known *a priori*. A top-down approach would consider that the product line would support as many

products as possible within the given domain. In [30] Bayer, *et al*. refer that all variants do not have to be anticipated when modeling the product line. In [31, 32] John and Muthig refer to required and anticipated variations as well as to a planned set of products for the product line, which indicates that their approach to product line modeling is bottom-up. The approach in this thesis adopts the top-down approach for product line modeling, therefore discarding the comments to the *«extend»* relationships.

In [32] John and Muthig refer the benefits of representing variability in use cases, namely establishing a variability and product line mindset among all involved roles in a product line's engineering, supporting the derivation of models and instantiation in application engineering, and communicating the possible products to different stakeholders. Although this thesis is in total agreement with the position of these authors towards the benefits of representing variability in use cases, it is not in agreement when they state that information on whether certain use cases are optional or alternatives to other use cases shall only be in decision models as it would overload use case diagrams and make them less readable (decision models in this context are feature models [33]). John and Muthig use one variability stereotype in use cases (the *«variant»* stereotype) applicable for variant use cases (use cases that are not supported by some products of the product line, whether optional or alternative). The position in this thesis is that features as well as use cases shall be suited for treating variability in its different types. If a use case is an alternative to another use case then both use cases shall be modeled in the use case diagram, otherwise the use case diagram will only show a part of the possible products John and Muthig mention in [32]. Bachmann, *et al*. mention in [34] that variability shall be introduced at different phases of the development of product families. Bühne, *et al*. propose in [35] a metamodel for representing variability in product lines based on the metamodel of Bachmann, *et al* for representing variability in product lines [34].

Coplien, *et al*. defend in [36] the analysis of commonality and variability during the requirements analysis in order for the analysis decisions not to be taken during the implementation phase by the professionals who are not familiar with the implications and impact of decisions that shall be made much earlier during the development cycle. They refer that early decisions on commonality and variability contribute to large-scale reuse and the automated generation of family members.

Maßen and Lichter talk about three types of variability in [37]: optional, alternative and optional alternative (as opposite to alternatives that represent a "1 from n choice", optional alternatives represent a "0 or 1 from n choice"). In this context they propose to extend the UML metamodel to incorporate two new relationships for connecting use cases. The approach in this thesis considers options and alternatives as well but it introduces these concepts into the UML metamodel through stereotypes (it considers that the *«extend»* relationship is adequate for modeling alternatives and a stereotype applicable to use cases for modeling options).

Gomaa and Shin [38, 39] analyze variability in different modeling views of product lines. They mention the *«extend»* relationship models a variation of requirements through alternatives. They also model options in use case diagrams by using the stereotype *«optional»* in use cases. This thesis adopts these approaches to alternatives and options but it elaborates on another form of variability (specializations, which this thesis considers a special kind of alternatives; Gomaa and Shin refer specialization as a means to express variability in [38, 39]). Besides alternative and optional use cases, Gomaa and Shin consider kernel use cases (use cases common to all product line members). Gomaa, together with Olimpiew, talks again about kernel, optional and alternative use cases in [40]. Gomaa models in [26] kernel and optional use cases both with the *«extend»* as well as with the *«include»* relationships (the approach in this thesis is towards modeling kernel and optional use cases independently of their involvement in either *«extend»* or *«include»* relationships and with a stereotype in use cases). In [41] Webber and Gomaa propose the Variation Point Model to model variation points. In that context the variation point shall be treated from four different views, one of which is the requirements variation point view. This view captures requirements together with variation points during the product line's domain analysis phase. Variation points are considered to be mandatory or optional (the difference between both is that mandatory variation points do not supply a default variant, whether optional ones do). In the approach of this thesis to variability modeling more types of variability besides the optional one (alternative and specialization) are considered.

Halmans and Pohl propose in [42] use cases as the means to communicate variability relevant to the customer and they also propose extensions to use case diagrams to represent variability relevant to the customer. Halmans and Pohl consider that generalizations between use cases are adequate to represent use cases' variants. This is not the position expressed in this thesis. This thesis recommends using the *«extend»* relationship instead of the

generalization relationship. Although Halmans and Pohl consider that the *«extend»* relationship is suitable for modeling options to parts of the use cases to which those options refer, they do not recommend it because of not explicitly representing variation points (Halmans and Pohl consider that by not having the variation points explicitly represented in use case diagrams, it is not documented if the customer can or must select one or more variants or if all of them are already present in the system, which violates the principle of communicating variability). They consider that modeling mandatory and optional use cases with stereotypes in use cases is not adequate because the same use case can be mandatory for one use case and optional for another. Again this is not the position of this thesis. This thesis considers that a mandatory use case is not mandatory with regards to another use case, rather it is mandatory for all product line members. This thesis also considers that an optional use case is optional with regards to one or more product line members. Halmans and Pohl end up by introducing additional graphical elements to use case diagrams to represent variation points and variability cardinality explicitly in use case diagrams. The work reported in this thesis is not in agreement with this approach since it introduces more complexity to use case diagrams than modeling variability with stereotypes and use case relationships as well as it introduces a reasoning about variability that should be present in decision models (the selection of the variants to be present in the system and the system/product to which that selection applies according to the features). Pohl uses in [43] the graphical notation used by Halmans and himself in [42] to represent variability in use case diagrams. Salicki and Farcet talk about variation points and additionally in decision models in [44].

Fowler suggests in his book "UML Distilled" [27] that the UML relationships between use cases besides the *«include»* shall be ignored and the focus shall be on the textual descriptions of use cases. This thesis is in complete agreement with Fowler on the textual descriptions but it is not in agreement with the rest. The *«extend»* relationship is needed in order to formalize at an early time (the use case modeling) where variation will occur when instantiating the product line. Bosch, *et al*. mention in [45] the need for describing variability within different modeling levels such as the requirements one.

Bayer, *et al*. present in [30] the Consolidated Variability Metamodel. In that context they systematize different kinds of variability recurrently present in product line models. The work this thesis addresses is related to that systematization since it addresses some of those kinds of variability and realizes it in annotations to the UML, applicable to some model elements to which the selected variability kinds apply. Ziadi, *et al*. expose a UML profile for

software product lines in [46], however they do not talk about stereotypes to be applied to models of requirements.

Regarding use case semantics and notation, the position of Simons [47] and of Heldal [48] on the topic was analyzed. Simons argues that the insertion semantics of the *«extend»* relationship is inadequate to model alternatives. That is not the position of this thesis (as it is explained later on) since the UML semantics supports this thesis' notion of variability (alternative is one type of variability that the *«extend»* relationship supports). Heldal worked on the extraction of system operations (calls into the system or communication between actors and the system) by structuring use cases through the grouping of action steps (e.g. sentences with the structure subject+verb+object) from use cases into action blocks. These action blocks allow writing contracts for the system operations (contracts are system operations with pre and post conditions). Heldal refers to event-driven systems where system operations make more sense than use cases. For every action block a contract can be written. A use case has more than one action block. Input and output data shall be related to single action blocks and not to a single use case because a use case has more than one action block and a contract is written for a single action block. An incomplete use case contains only one action block. A complete use case has more than one action block and fulfills a goal for the actor(s). Heldal mentions that *«include»* and *«extend»* relationships do not refer to complete use cases on both ends of the relationship, therefore in his approach these use cases are contracts rather than a group of action blocks, which does not allow fulfilling (a) goal(s) for (an) actor(s). That is not the position of this thesis. In the approach of this thesis, use cases involved in *«include»* and *«extend»* relationships are still use cases that fulfill (a) goal(s) for (an) actor(s), representing external functionality of the system that can be performed by the actors (a use case still represents observable value to an actor, despite being more or less detailed, despite decomposing another use case or despite being an extension to another use case).

According to Gomaa [26], and John and Muthig [31, 32], use cases can be tagged with some stereotypes concerning variability. Table 1 shows the applicability of those stereotypes in the approach of this thesis.

Table 1 – Some use case stereotypes concerned with variability.

Stereotype	Applicability
«kernel»	Use cases
«alternative»	*«extend»* relationships
«optional»	Use cases
«variant»	Use cases

2.2. Software Development Patterns

Typically patterns are adopted at later stages of the software development process. The analysis and design stages of software development are disregarded. Most of the times analysis and design decisions are not documented and that originates missing knowledge on how the transition from previous stages to the implementation stage was performed. Knowing design decisions without design documentation as a helper of this activity is only possible if those decisions can be transmitted by the people who know them. When talking about patterns, design decisions have to be perfectly known so that an activity of pattern discovery can be applied to a software solution with the purpose of discovering the original pattern (the pattern in the catalogue) from the implementation. If the original pattern is successfully reengineered from the implementation, then it means that most likely the advantages of the original pattern are present in that software solution. It is pertinent to understand how patterns from catalogues, after being interpreted, adapted and applied, can be constrained in such a way that the advantages enclosed in the solution each of those patterns proposes cannot be observed. Buschmann, *et al*. [49] referred that patterns may be implemented in many different ways; still patterns are not vague in the solution structure they propose. The diversity in the instantiations of a pattern is due to the specificity of the concrete problems being addressed. What must be assured is the “spirit of the pattern’s message” as Buschmann, *et al*. called it. In the development of software it must be assured that not only the advantages of the original pattern are visible (directly or indirectly) in the software solution but also that patterns are adopted throughout all the process phases since patterns address all of them as it will be seen in chapter 4. Besides these two considerations it must be noted that the development of software is not performed exclusively based on patterns but it is a microprocess or nanoprocess when compared to the whole software development process as Buschmann, *et al*. stated.

Pattern classifications are useful for understanding pattern catalogues better and providing input for the discovery of new patterns that fit into the already existing pattern categories [50]. Patterns are classified into categories according to different classification criteria and are organized in pattern catalogues according to classification schemas that support the different classification criteria each particular schema contemplates. Classification schemas can be unidimensional or multidimensional depending on whether they obey to a single or more than one criterion. In this thesis the term pattern classification is used instead of the complete term pattern classification schema.

The pattern classifications of [50-55] were not explicitly defined within a procedural referential, thus it is not possible to know beforehand which software pattern shall be used at what moment during the process of developing software in general as well as in the context of which Software Engineering professionals, technologies and methodologies. These procedural concerns include also the adoption of a modeling infrastructure to prevent subjective pattern application decisions, and situations of misinterpretation and corruption of patterns from catalogues while interpreting and adapting the patterns respectively. At last the classifications that will be presented next have not elaborated on the nature of the domain to which patterns are most adequately applicable. Considering that nowadays families of software products are commonly developed with domain-specific artifacts, taking the adequacy of patterns to particular domain natures into account is relevant in order to choose between the patterns that are most applicable to a domain-specific software product or family of products.

The first pattern classification mentioned in this thesis is from the GoF (Gang of Four) [50]. They classified design patterns according to two criteria: purpose and scope. The purpose of a pattern states that pattern's function. According to the purpose, patterns can be *creational*, *structural* or *behavioral*. Creational patterns are concerned with the creation of objects. Structural patterns are targeted at the composition of classes or objects. Behavioral patterns have to do with the interaction between classes or objects and their responsibility's distribution. The scope of a pattern is its applicability either to classes or to objects. *Class patterns* are related to the relationships between classes. *Object patterns* are related to the relationships between objects. Despite the GoF's classification considering more than one criterion, it is not multidimensional as the criteria were not combined to determine pattern categories. The GoF's classification is concerned with the function of the pattern (what the pattern does) and its applicability to low level implementation elements (how the pattern will

be handled in the software construction). The classification does not refer to explicit procedural questions on the development of software with the use of patterns (when patterns shall be used, by whom, with what technologies and methodologies, and at which levels of abstraction) or to questions with the applicability of patterns to specific domain natures. The same is true for the classification about to be mentioned.

A classification of patterns according to their relationships was proposed by Zimmer [55]. Zimmer classified the relationships into three categories: *X uses Y in its solution* (the solution of X contains the solution of Y), *X is similar to Y* (both patterns address a similar type of problem) and *X can be combined with Y* (both patterns can be combined, in spite of the solution of X not containing the solution of Y). This classification may give hints on the selection and composition of patterns, nevertheless it does not provide for directives on the nature of the domain the patterns are more adequate to, on the right moment to adopt the patterns, within which Software Engineering discipline's context and on how to respect a modeling infrastructure when adopting the patterns.

A classification of general-purpose design patterns (patterns traversal to all application domains) was proposed by Tichy in [53]. Tichy proposed nine categories to organize design patterns. The categories were determined based on the problems solved by the patterns. The proposed categories were *decoupling* (which has to do with the division of a software system into independent parts), *variant management* (which is associated with the management of commonalities among objects), *state handling* (which is the handling of objects' states) and others. Again neither procedural concerns, nor concerns with the applicability of patterns to particular domain nature types were evidenced by this classification that relies on the types of problems patterns propose to solve.

The Pree's and the Beck's classifications that are going to be exposed next do not also evidence hints on which moments of the software development process to adopt patterns, in the context of which Software Engineering discipline, respecting a modeling infrastructure and the applicability of patterns to domain natures in particular.

Wolfgang Pree [54] categorized design patterns by distinguishing between the purpose of the design pattern approach and its notation. Notation can be informal textual notation (plain text description in a natural language), formal textual notation (like a programming language) or graphical notation (like class diagrams). Purpose expresses the goal a design pattern pursues. The *Components* category indicates that design patterns are

concerned with the design of components rather than frameworks. The *Frameworks I* category indicates that design patterns are concerned with describing how to use a framework. The *Frameworks II* category indicates that design patterns represent reusable framework designs. Pree's classification scratches very superficially the question of modeling as it distinguishes between patterns represented with code (formal textual notation in the Pree's classification) and those represented with models (graphical notation in the Pree's classification) but it does not elaborate on how to work respecting different levels of abstraction throughout the process of developing software.

Kent Beck's [51] implementation patterns translate good Java programming practices whose adoption produces readable code. He claims these are patterns because they represent repeated decisions under repeated decision's constraints. Kent Beck's implementation patterns are divided into five categories: (1) class, with patterns describing how to create classes and how classes encode logic; (2) state, with patterns for storing and retrieving state; (3) behavior, with patterns for representing logic; (4) method, with patterns for writing methods (like method decomposition, method naming); and (5) collections, with patterns for using collections. Kent Beck claims his implementation patterns describe a style of programming. These implementation patterns address common problems of programming. For instance Kent Beck advises to use the pattern *Value Object* if the intention is to have an object that acts like a mathematical value, or the pattern *Initialization* for the proper initialization of variables, or the pattern *Exception* to appropriately express non-local exceptional flows, or the pattern *Method Visibility* to determine the visibility of methods while programming, or the pattern *Array* as the simplest and less flexible form of collection. Kent Beck uses Java in order to exemplify the pattern (as a different presentation of it) instead of a model or a structured text. Despite the programming practices having to be considered by the software development process, this classification does not care about the process of adopting patterns within the whole software development process.

Not only design patterns and implementation patterns are used when developing software. The classification of Eriksson and Penker [52] addresses business-level patterns like those going to be mentioned just now. The *Core-Representation* pattern dictates how to model the core objects of a business (the *business objects* e.g. customer, product, order) and their representations (e.g. the representation of a business object within the information system may be a window or another graphical user interface element as the representation of a debt is an invoice and the representation of a country may be the country code). The

Document pattern shows how to model documents (e.g. how to handle different versions and copies of a document). The *Geographic Location* pattern illustrates how to model addresses (which is of interest to mail-order companies, post offices, shipping companies). The *Organization and Party* pattern demonstrates how to model organizational charts. The *Product Data Management* pattern indicates the way to model the structure of the relationship between documents and products (the structure varies from one business to another). The *Thing Information* pattern (used in e-business systems) models the thing (resource in the business model) and the information about the thing (the information in the information system about that resource). The *Title-Item* pattern (used by stores and retail outlets) is to model items (e.g. a loan item) and their titles (e.g. a book title). The *Type-Object-Value* pattern (used by geographical systems) depicts how to model the relationship between a type (e.g. country), an object (e.g. Portugal) and a value (e.g. +351). Eriksson and Penker classified business-level patterns into three categories: *resource and rule patterns*, *goal patterns* and *process patterns*. The *resource and rule patterns* provide for guidelines on how to model the rules (used to define the structure of the resources and the relationships between them) and resources (people, material/information and products) from a business domain. The *goal patterns* are intimately related to goal modeling. The main idea is that the design and implementation of a system depends on the goals of the system (how it is used once built). At last the *process patterns* are related to process-oriented models (such as workflow diagrams). Process patterns prescribe ways to achieve specific goals for a set of resources, obeying to specific rules that express possible resource states.

The classification mentioned next is elaborated on the software development phases. Siemens' [8] two-dimensional pattern classification (from the book POSA ("Pattern-Oriented Software Architecture"), volume 1, or just POSA 1) was defined with two classification criteria (*pattern categories* and *problem categories*). Every pattern is classified according to both criteria. The *pattern categories* determined were *architectural patterns*, *design patterns* and *idioms*. They are related to phases and activities in the software development process. Architectural patterns are used at early stages of software design, particularly in the structure definition of software solutions. Design patterns are applicable to former stages of software design, particularly to the refinement or detailing of what Buschmann, *et al.* call the *fundamental architecture of a software system*. Idioms are adequate to implementation stages, during which software programs are written in specific languages. The *problem categories* determined were *from mud to structure*, *distributed systems*, *interactive systems*, *adaptable systems*, *structural decomposition*, *organization of work*, *access control*, *management*,

communication and *resource handling*. As an example *Structural Decomposition patterns* support the decomposition of subsystems into cooperating parts and *Organization of Work patterns* support the definition of collaborations for the purpose of providing complex services. These categories express typical problems that arise in the development of software. Placing some patterns in a specific category is a useful activity since it allows eliciting related problems in software development. However this pattern classification does not address the analysis phases (business modeling and requirements) of the software development process as the multilevel and multistage pattern classification does.

POSA 1 and POSA5 [49] are the most general POSA references. POSA 2 [56] contains a pattern language for concurrent and networked software systems. POSA 3 [57] contains a pattern language for resource management. POSA 4 [58] contains a pattern language for distributed computing. As referred in POSA 5 by its authors, the classifications in POSAs 2, 3 and 4 are intention-based, which is why they were not included in the literature review of this thesis. Chapter 4 is targeted at software development patterns in general, not intention-based software development patterns.

In POSA 5 Buschmann, *et al*. reflect on the terminology used in the pattern classification from POSA 1 and conclude that the pattern classification from POSA 1 has terminology problems. The terms used to distinguish disjoint categories (*architectural patterns*, *design patterns* and *idioms*) actually do not refer to pretty disjoint categories. These authors refer that architectural activities and the application of *idioms* can also be considered design activities. They also refer that since POSA 1 they have concluded that the term *design pattern* is to designate software development patterns in general and to distinguish them from patterns that have nothing to do with software. It does not mean that they have to do with design activities. For this reason they conclude that the term *design pattern* used in the pattern classification from POSA 1 should have been replaced with some other name to refer to the GoF patterns. Concerning the *architectural patterns* Buschmann, *et al*. conclude that all patterns are architectural in nature, so there cannot be a category called *architectural patterns*. To Buschmann, *et al*. design is the activity of making decisions on the structure or behavior of a software system and architecture is about the most significant design decisions for a system (and not all design decisions). Therefore although all patterns are intrinsically architectural, not all of them are applicable to architectural activities. Concerning the *idioms*, Buschmann, *et al*. conclude that the term *idiom* has some ambiguity since sometimes it refers to a solution for a problem specific to a given programming language and some other times it

refers to conventions for the use of a programming language. An *idiom* can even refer to both situations. Buschmann, *et al*. also conclude that *idioms* can refer to patterns used within the context of a specific domain, architectural partition or technology, thus they conclude that the term *idiom* should have been *programming language idiom* as a programming language is a specific solution domain. For instance the pattern *Iterator* is an *idiom* specific to C++ and Java, although it differs between these two specific languages.

The matter with *idioms* that Buschmann, *et al*. mention in POSA 5 was solved by Kent Beck in [51]. Kent Beck's implementation patterns express good programming practices (or the conventions for the use of programming languages). Kent Beck uses Java in order to exemplify his implementation patterns, which shall be applicable to other programming languages. Kent Beck's implementation patterns are not Java or other language-specific patterns that are just a different representation of design patterns [59, 60].

Since all architecture is design [61], the consideration of Buschmann, *et al*. that there cannot be a pattern category for architectural patterns makes sense (they are patterns of design). However not all design is architecture [61], which means that a distinction between patterns that address architecture and patterns that address design has to be made. Architectures do not define implementations. They rather constrain downstream activities of design and implementation. The architecture defines the system structure. The architect is more interested on the system structure than on the design decisions about architectural elements, or the structure of the subsystems of the system being designed. The software architect shall leave the implementation details veiled, as well as he/she shall not delve into design decisions about the structure of a system's subsystem. A good architect has to know when to stop making architectural decisions [61]. The approach of this thesis is contextualized within this distinction between architecture and design as the product line logical architecture originated from the execution of the 4SRS does not delve into structure or implementation details about the product line's architectural components, as well as the 4SRS uses a pattern that addresses architecture: the MVC. Design patterns shall address details of implementation (like the GoF patterns do).

2.3. Transformation of Requirements

Kruchten [62] defines development architecture in his "4+1" View Model of Software Architecture. The software system is structured in subsystems that shall be developed by one or a small number of developers (a team). That structure of subsystems is the development

architecture, which can be used to allocate work to teams. The development architecture is in fact a logical architecture. A logical software architecture can be faced as a view of a software system composed of a set of problem-specific abstractions from the system's functional requirements and it is represented as objects or object classes. Kruchten also referred that logical architectures suite the purpose of identifying common design elements across the different parts of a system [62]. Another definition of logical software architecture is a module view representing the static structure of the software system (the system's functional blocks, including traceability back to the use cases that express the system's functional requirements) [61]. The logical software architecture represents the functional decomposition of the software system. In the context of this thesis, a logical software architecture (represented as a component diagram) is a design artifact representing a functionality-based structure of the system being designed

As Sendall and Kozaczynski [63] state, transformations are "the heart and soul of model-driven software development". They refer to model transformation as being the process of transforming one or more source models into one or more target models following a set of transformation rules. Activities like reverse engineering, application of patterns or refactoring use model transformations. Transformations can be classified in some ways. Metzger [64] classifies transformations into endogenous and exogenous. On one hand an endogenous transformation takes place if the language of both the source and the target models is the same. On the other hand an exogenous transformation occurs if the language of the source model is not the same as the language of the target model. Brown, *et al*. [65] classify transformations into three possible kinds: refactoring transformations (which correspond to the reorganization of model elements), model-to-model transformations (if both the source(s) and the target of the transformation are models) and model-to-code transformations (if the source(s) of the transformation is(are) a model(s) and the target is code). Transformations are useful when transforming views between different levels of abstraction, but they are useful as well when transforming models at the same level of abstraction [65]. In the process of mapping a model (or more than one model) into another model, a mapping function is involved [66]. This function specifies the mapping rules that allow the transformations between source model(s) and target model to occur. The main characteristics of model mappings are construction and synchronization [66]. Mappings are used to construct models from other models (model derivation). This way, synchronization between models is assured. Mapping functions represent repeated design decisions which conduct to the reuse of those functions in models of similar design. The transformation of an

analysis model (model at the problem domain level, like a use case diagram targeted at the execution of the 4SRS) into a design model (model at the solution domain level, like a component diagram targeted at the execution of the 4SRS) is made by means of mapping functions [66].

The 4SRS is a method that allows the iterative and incremental model-based transformation of user functional requirements in the shape of use case diagrams into logical architectures in the shape of component diagrams. The method supports the modeling of logical architectures with variability support by considering the notion of variability [29]. The method also supports the functional refinement of those architectures. There are other approaches to functional decomposition of software systems besides the 4SRS method, such as KobrA or RSEB (Reuse-Driven Software Engineering Business) [67, 68]. However neither KobrA nor RSEB clearly contemplate a method for handling use cases to get to the design of software systems or a technique for refining logical architectures. These are the main strengths of the 4SRS method: an instrument to get to the design of software systems from their analysis and to refine design artifacts.

Smaragdakis and Batory [69] mention refinement in their work on collaboration-based design of large-scale software applications, which is applicable to the design of logical architectures with variability support. In their approach refinement is achieved through collaborations. The approach of this thesis uses a method that considers user requirements in the first place, before dealing with artifacts that would reside in product line design posterior to the logical architecture definition and refinement (artifacts like collaborations).

PuLSE comprises the refinement of already existing logical architectures with variability support [70], however the refinement is not conducted in a stepwise manner. The approach of PuLSE approach includes testing steps to assure that the architecture supports the requirements from which it was ellaborated. The approach of this thesis does not include such kind of steps, yet. Despite that, the approach of this thesis is stronger than the approach of PuLSE by allowing the refinement in a stepwise, thus guided mode.

Englebert and Vermaut present in [71] an ADL (Architecture Description Language) or software architecture modeling language, capable of handling multiple levels of abstraction. The levels of abstraction they consider are based on Kruchten's "4+1" View Model of Software Architecture [62] and are faced as the phases of an architecture refinement methodology. In [71] they propose transformations on the architecture to progressively fulfill

non-functional requirements (the refinement of a high-level architecture into a more concrete architecture). The methodology indicates how to transform requirements into design structures that consider those requirements. The approach of this thesis to the refinement of architectures is based on functional requirements. This thesis considers that non-functional ones shall be considered after designing the logical architecture and through pattern application.

According to Kaindl [72], 4SRS can be classified as a transition method. Kaindl argued that it is difficult to move from the analysis to the design of software. From the perspective of object-oriented software development the main reason is that analysis objects and design objects represent different kinds of concepts. Analysis objects are from the problem domain and represent objects from the real world. Design objects are from a solution domain and shall indicate how the system shall be developed. Design objects are abstractions of code or the implementation details needed in order to build a system with a solution to a problem. Design objects are both an abstraction of concepts from the problem domain and an abstraction of the implementation of the system to be built. When analyzing or designing a software system the focus is on drawing models. An analysis model is targeted at helping requirements engineers understand the problem domain. Implementation decisions shall not be expressed in analysis models. A design model models the system with objects that shall l on during the programming of the system implement that system’s external behavior. The requirements modeled with the analysis objects express the system’s external behavior. An analysis model can become part of a design model by influencing architectural decisions. Alternatively a direct mapping between objects from the problem domain and objects from a solution domain can originate a design model from an analysis model. The only thing left to do is to add detail and make further design decisions with impact on the design model. An analysis model cannot be a design model the same way a problem specification that represents requirements cannot be a solution specification that represents software internals. The 4SRS is a method that allows moving from the analysis to the design of software. In the case of the 4SRS, the analysis model (a UML use case diagram) influences architectural decisions that originate a design model (a UML component diagram).

The 4SRS is an instrument to get to the design artifacts of software systems from their analysis artifacts. As previously referred, Englebert and Vermaut present in [71] an ADL or software architecture modeling language that allows to transform requirements into design structures that consider those requirements. Both the 4SRS and the ADL of Englebert and

Vermaut can be considered as transition methods. In this thesis the 4SRS is used as the example.

From the perspective of the SPEM a process can be considered to be at least a method content (or shortly method) positioned within a development lifecycle. In the context of software and systems development, processes also define how to get from one milestone to the next one by defining sequences of tasks (and steps) that are performed by some roles to produce some output (work products) for that milestone to be declared. A process can be represented with workflows or work breakdown structures. Workflows are models of process behavior whereas work breakdown structures represent process structure. This thesis adopted workflows to represent process behavior and UML class diagrams to represent process structure. Processes can be modeled with process modeling languages like the SPEM. A process modeling language can be defined as the instrument to express software development processes through process models [73].

A short definition of process is the way activities are organized to reach a goal [74]. In the case of software development, a process (software process) can be defined as the set of activities (analysis, design, implementation, testing, among others) organized to deliver a software product (goal). A process model is an artifact that expresses a process to understand, communicate and automate that process. Process modeling is advantageous because it facilitates the transfer of know-how on the activities of an organization to newcomers, it facilitates the repeatability of those activities and is the basis for process improvement. A software process is targeted at the repeatability of software development activities. Those activities are performed on artifacts contextualized by the time frame of a software project. The repeatability of software development activities makes of these activities predictable, therefore *modelable* from the process modeling point of view. The goal of a metaprocess is to support software experts when changing a process model in order to adapt the process model to new methods and tools (process evolution) or to improve the process model (process improvement) or even to align the process model with the inconsistency found during the execution of that process (process instance evolution).

The goal of processes is to assure the quality of products and the productivity in developing them [75]. Process comprehension and process communication may be negatively affected by the lack of a standard and unified terminology [76]. In such conditions process enactment is far away from process definition, thus the quality of products and the

productivity in developing them may be compromised, and the goal of processes may not be achieved. Process modeling using a standard and unified terminology suits some purposes like process comprehension, process design, process training, process simulation, process support [77]. Tools support the execution of processes to consistently reach the goal (delivering a software product).

In 1995 Conradi and Liu [78] say that enactable process models are low-level process models in terms of abstraction. Process modeling languages suit the purpose of detailing process models to make them enactable. According to Henderson-Sellers [79] a process enactment is an instance of a process in a particular project with actual people playing roles, deadlines having real dates and so on. Different enactments have different people playing the same role and different dates for the same deadline. Bendraou, *et al*. [80] consider that process enactment shall contemplate support for automatic task assignments to roles, automatic routing of artifacts, automatic control on work product states, among others. In what process enactment is concerned, Feiler and Humphrey [81] define an enactable process as an instance of a process definition that shall have process inputs, assigned agents (people or machines that interpret the enactable process), an initial state, a final state and an initiation role. A process definition is a set of enactable process steps. Process definitions can be a composition of subprocess definitions as well as process steps can be a composition of process substeps. A process definition only fits for enactment when fully refined, which means that it cannot be more decomposed into subprocess definitions and into process substeps. The act of creating enactable processes from process definitions is defined by Feiler and Humphrey as process instantiation. They define process enactment as the execution of a process by a process agent following a process definition. Bendraou, *et al*. [80] consider that support for the execution of process models helps coordinating participants, routing artifacts, ensuring process constraints and process deadlines, simulating processes and testing processes. The use of machines in process enactment is called process automation and requires for a process definition to be embodied in a process program [81]. Gruhn [82] defines automatic activities as those executed without human interaction. He mentions that the automation of activities is one of the purposes of process modeling. Another purpose is to govern real processes on the basis of the underlying process models.

A process' capability can be assessed according to three criteria [83]: task customization, project customization and maturity customization. According to Henderson-Sellers, *et al*. [83], SPEM allows for task customization and for project customization, but not

for maturity customization. SPEM allows for task customization because it allows for the selection of techniques for each task according to the organization and the expertise of the professionals in those techniques. For instance various techniques can be used to elaborate a requirements specification depending on the organization and the project: questionnaires, workshops, storyboards, prototypes and others. SPEM allows for project customization since it allows for the selection of activities, tasks and techniques according to the project. The tasks required to be performed and the products to be developed (models and documents) vary from one project to another. Project customization is a matter of selecting or omitting portions of a process. SPEM does not allow for the addition/removal of activities and tasks to/from a process, and consequently work products depending on the capability or maturity level of the organization. Furthermore Henderson-Sellers, *et al*. [83] refer that SPEM allows for the definition of discrete activities and steps, therefore allowing for process fragment selection.

Software modeling can inspire the modeling of processes so as to communicate about those processes and help people to collaborate in the execution of those processes [75]. Different types of process models stand for different purposes. Different types of models concentrate on specific concerns and abstract away from other concerns that shall be responsibility of other types of models. The same way multiple software models need to be coordinated, so do multiple process models. In principle a process model is to represent a process that is considered to be effective in addressing certain process problems described in process requirements. Processes address both functional and nonfunctional requirements. Functional requirements are e.g. the software artifacts that shall be produced as the output of the process.

In the context of this thesis a logical architecture is product-based. In a higher level of abstraction a logical architecture may be process-based (according to the designation of this thesis) or a process architecture (according to Kruchten's designation [62]), consisting of a functionality-based structure of the process being designed. To this thesis' concern a product-based logical architecture or product architecture is an architecture that resides in a lower level of abstraction comparatively to a process-based or process architecture and consists of a functionality-based structure of the product being designed. Allocating work to teams developing subsystems (as the development architecture can be used to) presupposes that those subsystems can also represent process architecture components that consist of tasks (ultimately steps) that are performed by some roles to produce some output (work products).

In fact process architecture components are activities that compose a process structure. Activities are a (kind of) work breakdown element. It can be concluded that the 4SRS is not only a method dedicated at transitioning from analysis to design but can also be a method for defining a development architecture (or process architecture). This thesis focuses on the formalization of the 4SRS transition method as a small dedicated software development process that can be plugged into larger software development processes from the product development point of view (and not from the process architecture point of view). It also shows how to automate transition methods, particularly those modeled with the SPEM. The 4SRS previously modeled with the SPEM is used as the example of a transition method modeled with the SPEM. It transforms analysis artifacts into design artifacts (in the case of the 4SRS, use cases into component diagrams). Automated transition methods modeled with the SPEM can be automatically executed as small dedicated software development processes. This thesis focuses on transition methods from the product development point of view and not from the process architecture point of view.

A process modeling language may be part of an MDD infrastructure. An MDD infrastructure must provide for visual modeling and the means for defining visual modeling languages [11]. A visual language shall be composed of abstract syntax (metamodel), concrete syntax (notation), well-formedness rules (constraints on the abstract syntax) and semantics [11]. The SPEM is a process modeling language that in conjunction with the UML and the OCL (Object Constraint Language) [84] provides for the abstract syntax, the concrete syntax, well-formedness rules and semantics for visual modeling, and the means for defining visual modeling languages. An approach to extend UML is by using stereotypes, tagged values and constraints [85]. This thesis presents an extension to the SPEM for defining a visual language to model transition methods and formalizing small dedicated (at transitioning from analysis to design) software development processes (such as the 4SRS). Stereotypes are used as the extension mechanism along with the addition of elements to the metamodel through subclassing.

The SPEM is a process modeling language to define or formalize software and systems development processes. Its focus is on the structure of software and systems development processes. For all this the SPEM can be considered as a broad contribution. However the literature shows that it has been used in a summarized way. The paper [76] presents a slice of the SPEM. A metamodel slice is a part of the metamodel that is extended to ultimately ellaborate a hierarchy of stereotypes applicable to the (meta)classes of that

metamodel. The tools that allow modeling instances of the SPEM (for example the tool EPF [86], which allowed modeling e.g. the OpenUP [87] process) use slices of the SPEM. The consequences of summarizing the SPEM in slices are the popularization of the SPEM, a strict use of the language/metamodel and the need for a work of reverse engineering in order to fully understand the slices.

Software process modeling shall allow the comprehension [76, 77], communication, reuse, evolution and management [76] of processes. The goal of MDD is to raise the abstraction level at which software programs are written, which is achieved through the use of models in the development of those programs. One of the main characteristics of MDD is to make models accessible and useful (therefore understandable in the first place) by all stakeholders. This has to do with the easiness of understanding of models and is achieved through notation. Since a process modeling language is a visual language and may be part of an MDD infrastructure, it is relatively easy to understand and models drawn with that language are a good artifact to communicate with the stakeholders. Another main characteristic of MDD is the storage of models in formats that other tools can use, which is achieved through interoperability. This allows for the reuse of models (in this case, software process models) in different process modeling tools. Metamodeling techniques are used in this thesis to extend the SPEM for defining a visual language to model transition methods and formalizing small dedicated (at transitioning from analysis to design) software development processes (such as the 4SRS). The reuse is also achieved through metamodeling since several models can be derived from a single metamodel.

Processes can be executed through tools. In [75] Osterweil considers coding software processes (as part of programming them). Process modeling is one of the parts of programming a software process with a model-driven approach. Software process code is in a lower abstraction level when compared to software process models and it can be executed by computers. Software process code specifications require that software process models define (for new software processes) or formalize (for existing software processes) how software artifacts shall be input to or output from software process tools and how those artifacts are to be handled by the right roles at the right time of the process. Software process models can be analyzed to identify process steps that may be automated. The number of processes being followed to develop software is high. Some key software development processes like software requirements specification and software design lack definition (if they’re new ones) or formalization (if they’re existing ones). Software design for instance is a process that can

be modeled and coded. This thesis shows an approach to code a previously modeled software development process, which is the 4SRS transition method modeled with the SPEM as a small dedicated software development process. Software process models were analyzed to identify process steps that could be automated with the Moderne.

2.4. Conclusions

This chapter addressed the core concepts of this thesis' contribution: functional refinement of requirements represented as use case diagrams and of logical architectures represented as component diagamas, variability modeling in use case diagrams, software development patterns and transformation of user functional requirements (use cases) into system functional requirements (component diagrams).

Some authors produced previous contribution that differs from this thesis' in some senses. Regarding functional refinement, the approach of this thesis is not formal and does not deal with artifacts that shall be dealt with before or after use cases. It also considers that refining means decomposing as well as adding detail to the use cases, that a refinement relationship shall connect different abstraction levels and that refinement is not the same as specialization. The refinement of use cases was previously represented with the *Extend* relationship, whereas this thesis uses the *Refine* relationship it proposes for that purpose. This thesis considers functional decomposition, which is an advantage when developing large software systems. It also adopts a top-down approach for product line modeling, which allows the support for as many products as possible within a given domain at the level os use cases (as opposite to the bottom-up approach). This thesis is not in agreement with the authors that do not recommend modeling variability in use case diagrams as they would not represent all possible products of a product line. This thesis also considers the *Extend* relationship adequate for modeling variability and needed in order to perform that activity, and both the *Extend* and the *Include* relationships inadequate for modeling optional use cases. It considers as well the alternative and specialization variability types some authors do not consider. In opposition to other authors, this thesis does not adopt the generalization relationship to model variability, it does not model optional use cases in relation to other use caes, as well as it does not represent variability cardinality from decision models in use case diagrams and does not abandon the representation of system external functionality that can be performed by actors.

Some authors organized patterns into pattern classifications not explicitly defined with procedural concerns. Those who classified patterns according to software development phases, did not address the analysis phases (business modeling and requirements) of the software development process as the pattern classification proposed by this thesis does. This thesis also considers a pattern that addresses architecture in the model transformation from user functional requirements to systems functional requirements the 4SRS habilitates in a stepwise way, which is a kind of pattern some authors do not consider to address architecture, rather design.

When compared to other author's approach, the approach of this thesis to the refinement of logical architectures with variability support is more advantageous as it is stepwise. It is not focused on non-functional requirements as the approach of other authors is.

3. Transforming Use Case Models into Logical Architectures

Section 3.2 introduces the process of refining use cases. It defines the *«refine»* relationship, and discusses the difference between the *«include»* and the *«refine»* relationships.

Section 3.3 elaborates on the different types of variability this thesis proposes. It provides for the analysis of the UML *«extend»* relationship in contexts of variability and also for the extension this thesis proposes to the UML metamodel. It also analyzes the process of handling variability in use cases in contexts of functional refinement.

Section 3.4 elaborates on the refinement of logical architectures with variability support according to both the formalization of use case refinement and the systematization of use case variability modeling this thesis proposes.

3.1. Introduction

Use case diagrams are one of the modeling artifacts modelers have to deal with when developing software with a model-driven approach. This chapter envisions use cases according to the perspective of detail (which has to do with the abstraction level use cases may be situated at and implies refinement as it will be exposed).

Use cases can be more or less detailed, which means that they can be refined. The refinement of a use case results in lower-abstraction-level use cases. The lowering of the

abstraction level shall be represented in the diagrams with a new kind of relationship that will be presented ahead in this chapter: the *«refine»* relationship. In this chapter, refinement is considered from the functional perspective. It is explained why the *«include»* relationship is considered not adequate to support the refinement in use case diagrams. It shall be noted that in the approach of this thesis, use cases are still use cases, representing external functionality of the system that can be performed by the actors (a use case still represents observable value to an actor, despite being more or less detailed). Refining use cases is important to incrementally introduce user requirements in the design of the software system.

The *«refine»* relationship represents the refinement of use cases. The refinement of use cases is an approach to deal with the problem of complexity in the modeling activity. One of the chapter's contribution is on the understanding of the use case modeling activity with support for refinement, providing specific directives on how to conduct such activity in a systematic way. The approach of this thesis is illustrated with the GoPhone case study [7]. This thesis considers use cases in different abstraction levels according to the *«refine»* relationship. It also proposes an extension to the UML metamodel [1] in order to support both the concrete and abstract syntaxes of the refinement of use cases. In this chapter the focus is on the refinement support as well as on the process point of view with regards to the use case modeling activity.

A software product line can be faced as a family of software products developed with explicit concern about variability (and consequently commonality) during the development process. Use case diagrams are also one of the modeling artifacts modelers have to deal with when developing product lines with model-driven approaches. This chapter also envisions use cases according to the perspective of variability. The *«extend»* relationship plays a vital role in variability modeling in the context of use cases and allows for the use case modeling activity to be applicable to the product line software development approach. That is possible by determining the locations in use case diagrams where variation will occur when instantiating the product line. Another contribution of this chapter's is on the formalization and understanding of the use case modeling activity with support for variability. The approach of this thesis is illustrated with the GoPhone case study, which presents a series of use cases for a part of a mobile phone product line particularly concerning the interaction between the user and the mobile phone software. This thesis proposes an extension to the UML metamodel in order to formally provide for both the concrete and abstract syntaxes to represent different types of variability in use case diagrams. This thesis considers use cases in

different abstraction levels to elaborate on the (functional) refinement of use cases with *«extend»* relationships between them. The focus of this chapter is on the variability support as well as on the process point of view with regards to the use case modeling activity.

Another contribution of this chapter is on the formalization and understanding of the use case modeling activity with support for variability and functional refinement when variability is present. The approach of this thesis is again illustrated with the GoPhone case study. Throughout the chapter six different relationships are referred. Some are from the UML, which explicitly uses the terminology "relationship": the UML *«extend»* relationship, the UML *«include»* relationship and the UML generalization relationship. Some are introduced by this thesis to the UML metamodel by extending it according to an extensive related work analysis: the (UML) *«refine»* relationship, the (UML) *«alternative»* relationship and the (UML) *«specialization»* relationship.

Modeling variability in use case diagrams with the resources from the UML is a benefit of the approach in this thesis, since the UML is extensively used in the community (both academic and industrial) and a widely recognized standard. This thesis systematized variability modeling for use cases according to a model with explicit decisions modelers may follow to apply the approach (Figure 14 shows those decisions, which will be analyzed in section 3.3). This thesis considers the refinement of use cases connected through *«extend»* relationships, which is pertinent in the context of large-scale product lines. Both the variability modeling in use cases and the refinement of use cases are required at the time of requirements modeling to prepare the modeling artifacts for further handling in the product line development process. The complexity of a use case diagram with variability and refinement (an example of such use case diagram is in Figure 24, which will be analized in section 3.3) may be considered a limitation of the proposed approach but this thesis presents in section 3.3 some ways of decreasing that complexity.

This thesis defines the functional decomposition of a use case as the decomposition of an initial use case diagram into smaller and more cohesive ones. Its goal is to decrease the complexity of the use case diagram and increase its cohesion. The advantage of functional decomposition of use cases from the process point of view when developing large software systems is allowing the delivery of less complex modeling artifacts to the teams implementing the software system. The advantage of functional decomposition of use cases from the process point of view when developing software systems with variability is the

possibility of modeling later on an alternative to a part of the decomposed use case or modeling a part of the decomposed use case that is an optional part.

A lot of literature exists on variability modeling (some of it particularly related to requirements modeling). This thesis analyzed an extensive and significant set of references on the subject, and the need to systematize the modeling of variability according to the position of this thesis on the subject was found. A set of stereotypes are the solution concluded to be more adequate, efficient and effective for modeling variability in use case diagrams. This thesis also provides for comprehension on use case modeling with functional refinement when variability is present considering the variability modeling systematized with basis on that set of references and the position of this thesis on the subject (refer to the definition of functional decomposition in the paragraph above together with the notion of detailing the textual descriptions of use cases as the functional refinement of use cases).

In the context of this thesis, a logical software architecture (represented as a component diagram) provides for variability support and is a design artifact representing a functionality-based structure that embraces both a software product line’s reusable components and its member-specific components. The non-functional requirements are out of the scope of this thesis, although they will have to be considered (most likely through the application of patterns) in moments following the logical architecture’s design.

Logical software architectures with variability support can be obtained from functional requirements expressed in use cases with variability exposure [28, 29]. Since use cases can be more or less detailed, architectural components from logical software architectures can also be more or less detailed because in the approach of this thesis these components originate from use cases. Architectural components can be *refined* according to the detail level of the use cases they originate from. But the relation between use case and component is not one-to-one. A use case can originate more than one component. The refinement of architectural components is based on the stepwise refinement from old functional approaches like Cleanroom [88]. Cleanroom defines stepwise refinement as the expansion of the specification into the implementation via small steps (which includes the design of data and control constructs before implementing the details). Although this process’ activities are different from the 4SRS method’s, the principle of refinement is the same.

The refinement of logical software architectures with variability support may be due to two reasons: (1) the definition of subprojects for the product line development; and (2) the

partitioning of the product line into subsystems. The refinement is triggered by the identified need of detailing the architecture (although a subsystem is only confirmed as a subsystem that can be refined when the more detailed logical architecture generated from it is concluded to be cohesive).

Currently the modeling approaches that support the design of logical software architectures with variability support do not take refinement into consideration at the user requirements level (the use cases level) and in a stepwise way.

In order to motivate the product line modelers to the importance of refinement when modeling logical software architectures with variability support, this thesis argues that not considering refinement when modeling those architectures using a specific modeling method (in the case of this thesis, the 4SRS method) constitutes a problem of complexity in the modeling activity. The pertinence of refinement resides in large-scale contexts, even though the approach of this thesis to refinement is going to be demonstrated with the GoPhone [7], which is of small-scale. Nevertheless the GoPhone could end up as a subset of a bigger problem after refining that bigger problem. In order to circumvent the scale problem this thesis proposes to extend the 4SRS method to support the refinement of logical software architectures with variability support. The motivation for the extension of the 4SRS method is not restricted to addressing a limitation or weakness of the method, rather it is based on an unsolved problem or need in product line engineering as evidenced by the related work analysis presented earlier. This thesis will address the recursive character of the 4SRS method as the solution for refinement.

3.2. Refining Use Cases with the *Include* Relationship

Use Case Refinement

Detail in the context of this approach is intimately related to the activity of use case refinement. In this sense use cases can be more detailed if they are refined. This thesis considers that refining means decomposing and simultaneously detailing use cases. By refining use cases the artifacts resulting from the refinement process (the refining use cases) are situated in lower abstraction levels comparatively to the refined use cases (the use cases submitted to the refinement process). In order to represent in the use case diagram this decrease in the abstraction level when refining use cases the *«refine»* relationship is used (as a sort of traceability between use cases at different levels of detail). The refinement process of use cases can be represented by a tree-like form that in terms of detail presents use cases

hierarchically, being the more abstract ones at the top and the more concrete ones at the bottom.

Although use case diagrams are part of the UML (which follows the object-oriented paradigm) there is no restriction for the applicability of the approach of this thesis to the development of software according to other software development paradigms (e.g. the functional paradigm). For instance, data-flow diagrams can also be refined [89].

The *«include»* and the *«refine»* Relationships

The *«include»* relationship involves two types of use cases: the *including* use case (the use case that includes other use cases) and the *included* use case (the use case that is included by other use cases). In the context of the *«include»* relationship the UML Superstructure states that the including use case depends on the addition of the included use cases to be complete. Nevertheless, according to the position of this thesis, the functionality of the included use cases shall be described in the including use case. Since this thesis relies on non-stepwise textual descriptions of use cases to determine the *«include»* relationships, the including use case has to contain the description of the included use cases so that the modeler is able to define the parts that compose the including use case in order to decompose that use case (e.g. as can be seen from Figure 23, which will be analyzed in section 3.3, the functionality of the *Compose Message* use case is described in the *Send Message* use case). The included use case represents functionality common to various (including) use cases. But the *«include»* relationship may be used to partition the including use case into two or more use cases at the same level of abstraction instead of being used to evidence functionality common to various use cases. In that case the *«include»* relationship is used to decompose the including use case without detailing it, so the sum of the functionality represented by the non-stepwise textual descriptions of the included use cases shall be equal to the functionality represented by the non-stepwise textual description of the including use case (excluding glue logic), which implies having two or more included use cases for a single including use case.

Refinement can be defined *by decomposition according to criterion A* or *by decomposition according to criterion B*. *Refining* a use case *by decomposition according to criterion A* produces lower-abstraction-level use cases by detailing the use case and splitting it according to the parts that compose the object of that use case. In the example shown in Figure 1 the object (*chair*) is the whole and the objects *top*, *back* and *legs* are the parts of that

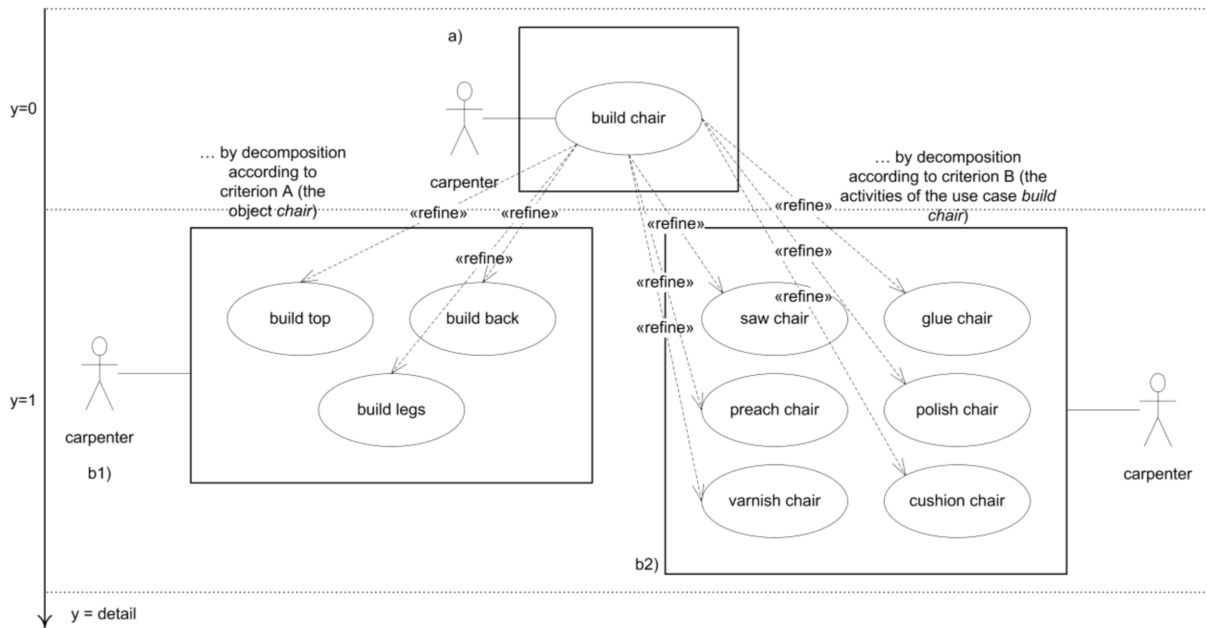


Figure 1 – Refinement by decomposition according to criterion A and by decomposition according to criterion B.

whole, therefore refining the use case *build chair* equaled splitting it into the use cases *build top*, *build back* and *build legs*. *Refining* a use case *by decomposition according to criterion B* equals splitting the use case into activities, which also results in lower-abstraction-level use cases by detailing the use case and splitting it according to the activities that compose the use case being split. Figure 1 illustrates the refinement of the use case *build chair* by decomposition according to criterion B by splitting it into the use cases *saw chair*, *glue chair*, *preach chair*, *polish chair*, *varnish chair* and *cushion chair* as the activity of building includes the activities of sawing, gluing, preaching, polishing, varnishing and cushioning. Although the use case under refinement is split into two or more use cases, resembling the decomposition of use cases through the *«include»* relationship (or even the (dis)aggregation/(de)composition of use cases; the generalization of use cases can also resemble refinement), the abstraction level decreases as the use cases that refine the use case under refinement are more detailed than it is. This is the distinction between the *«include»* relationship (and also the aggregation/composition association and the generalization relationship) and the refinement relationship (*«refine»*) that will be presented ahead in this section. The *«refine»* relationship implies that the result of executing the more detailed use cases together shall be equal to the result of executing the less detailed use case.

In the context of classes some stereotypes (which are part of the standard UML stereotypes [1]) deal with refinement. The stereotype *«refine»* (which is applicable to the *Abstraction* dependency) represents a unidirectional or bidirectional relationship between

diagram elements at different levels of abstraction (e.g. analysis and design levels). The *Abstraction* dependency represents a relationship that relates two elements representing the same concept at different levels of abstraction or from different viewpoints. It also represents a dependency in which there is a mapping between the supplier and the client. A class at the analysis level may map to more than one class at the design level, which means that a single supplier element can have a set of client elements. This thesis does not recommend using the *Abstraction* dependency to represent refinement of use cases because it can be bidirectional (and refinement is unidirectional).

In the UML Superstucture [1] (in the context of use cases, particularly in the description of the semantics) the *«include»* relationship is stated to be used for the purpose of extracting the common part of the functionality of two or more use cases to a separate use case to be included (or reused) by those two or more use cases. It may be the case that the modeler wants to replace (in a lower abstraction level) a use case by two or more detailed use cases. Figure 1 depicts such situation (1a is less detailed than 1b1 and than 1b2). In this case, the result will be two use case diagrams, the later more detailed than the previous one. For this argument this thesis considers that the use of the system represented by the use case in Figure 1a represents the uses of the system that the use cases in Figure 1b1 and that those in Figure 1b2 represent as well. The difference is that the use case in Figure 1a is less detailed than the use cases in Figure 1b1 together and the use cases in Figure 1b2 together as well. This thesis does not recommend using the *«include»* relationship to represent the lowering of use cases' abstraction level since it is not according to its semantics in the UML metamodel.

This thesis proposes an extension to the UML metamodel to make available a UML relationship to be used in the context of use cases for representing their refinement. Figure 2 illustrates a new UML metaclass (the *Refine* metaclass) created to satisfy the need for extension of the UML metamodel this thesis identified. As far as the unidirectional association is concerned, the end named *detail* references the more detailed use case (the refining use case) and the association means that one or more *Refine* relationships refer to one (more detailed) use case. Regarding the aggregation, the end named *refine* references the *Refine* relationships owned by the use case and the end named *refinedCase* references the use case that was detailed (the refined use case) and owns the *Refine* relationship. The metamodel shows that two or more *Refine* relationships are owned by one (refined) use case, and one (refined) use case may be detailed and own two or more *Refine* relationships. Summarily a refined use case shall be refined by more than one refining use case and a refining use case

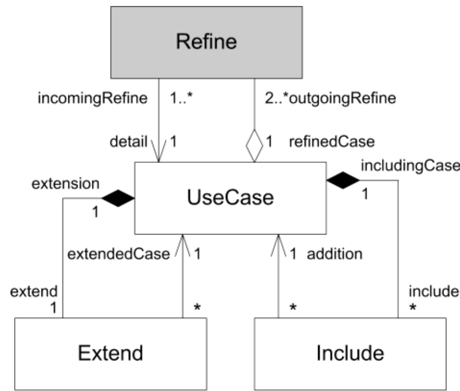


Figure 2 – The proposed extension to the UML metamodel for representing the refinement of use cases.

```
context UseCase inv:
        let refines : Set(Refine) = self.incomingRefine in
        if refines->size() >= 2
        then let includes : Integer = refines->iterate(nextElement : Refine; accumulator :
Integer = 0 | accumulator->nextElement.refinedCase.include->size()) in
                refines->size() - 1 = includes
        endif
```

Figure 3 – The multiple refines *constraint.*

```
context UseCase inv:
        if UseCase.include->size() >= 1
                and UseCase.refine->size() >= 1
        then UseCase.include->excludesAll(UseCase.refine)
        endif
```

Figure 4 – The coexistence *constraint.*

shall refine one or more refined use cases (more than one refined use case if the refined use cases are connected through *«include»* relationships; see Figure 3 for an OCL constraint on this). An OCL constraint (in Figure 4) was written for expressing the impossibility of having two use cases connected by both an *«include»* relationship and a *«refine»* relationship since the first does not imply increasing the detail level and the second does.

Figure 1 exemplifies the notation of the *«refine»* relationship. It is evident by the figure that two use cases connected through a *«refine»* relationship are situated at different levels of abstraction. For instance the use cases *build top*, *build back* and *build legs* (situated at the detail level 1) are more detailed than the use case *build chair* (situated at the detail level 0). A *«refine»* relationship is represented the same way the *«include»* relationship is and from the less detailed use case to the more detailed use case in order to evidence the lowering of the abstraction level. The only difference is that the arrow is labeled with the keyword *«refine»*.

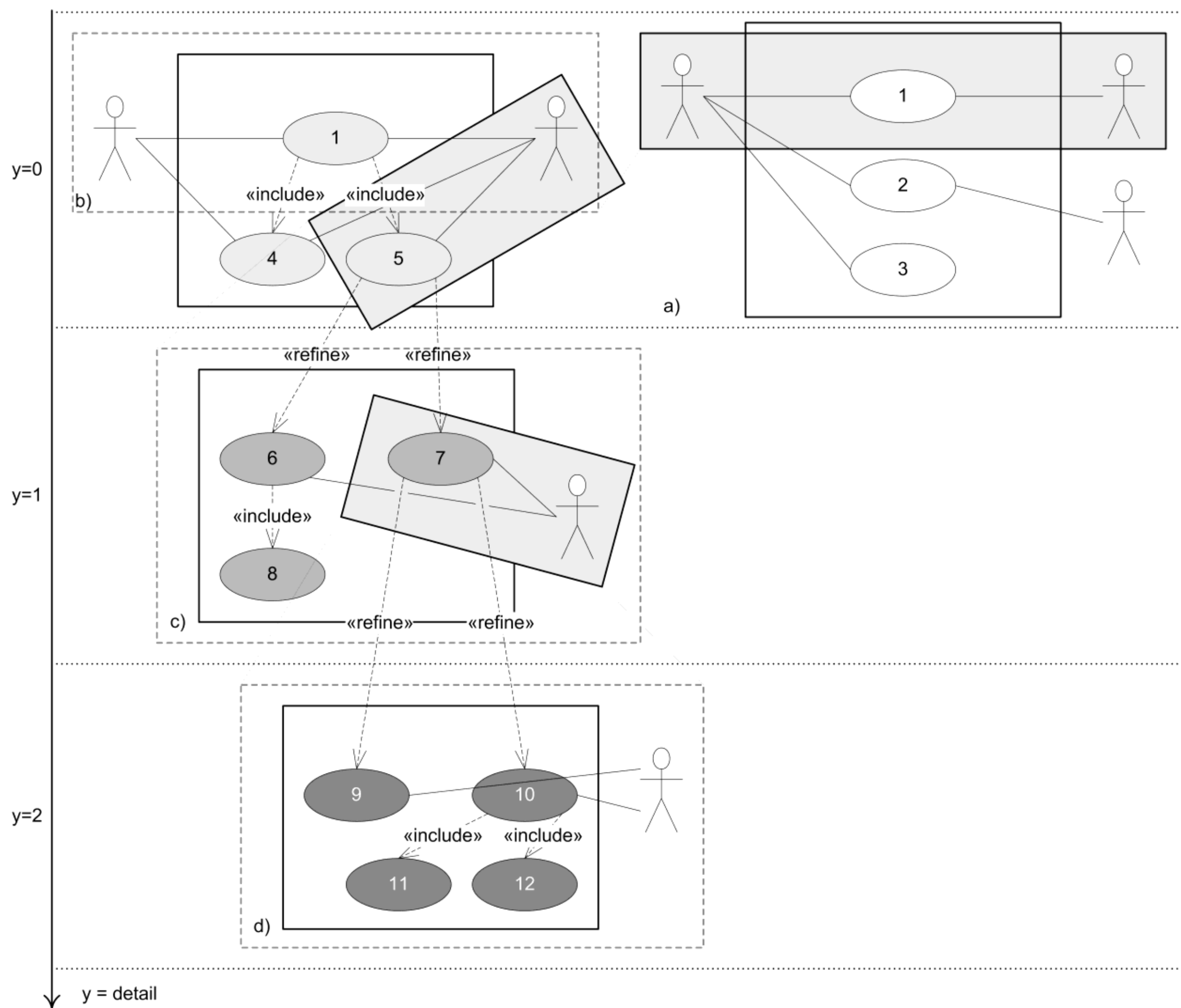


Figure 5 – The refinement process.

The Refinement Process

Figure 5 illustrates how the modeler shall go from the initial use case diagram (5a) to the detailed use case diagrams (5c and 5d). It is possible to consider more than three detail levels despite this thesis is exemplifying with three of them. The initial use case diagram (the more abstract one or less detailed one) must be analyzed independently for each of its use cases for simplicity reasons. Figure 5b shows how the partial use case diagram is elaborated from the use case 1 of the use case diagram in Figure 5a. Two *«include»* relationships were defined for that use case, which resulted in the use cases 4 and 5. The use cases 6 and 7 are a refinement of the use case 5. That is why the use case 5 is connected to the use cases 6 and 7 through a *«refine»* relationship. The use case 4 may be refined by use cases situated at the same level of abstraction as those in the use case diagram in Figure 5c but in a distinct diagram. The *«refine»* relationship is established between elements from two use case

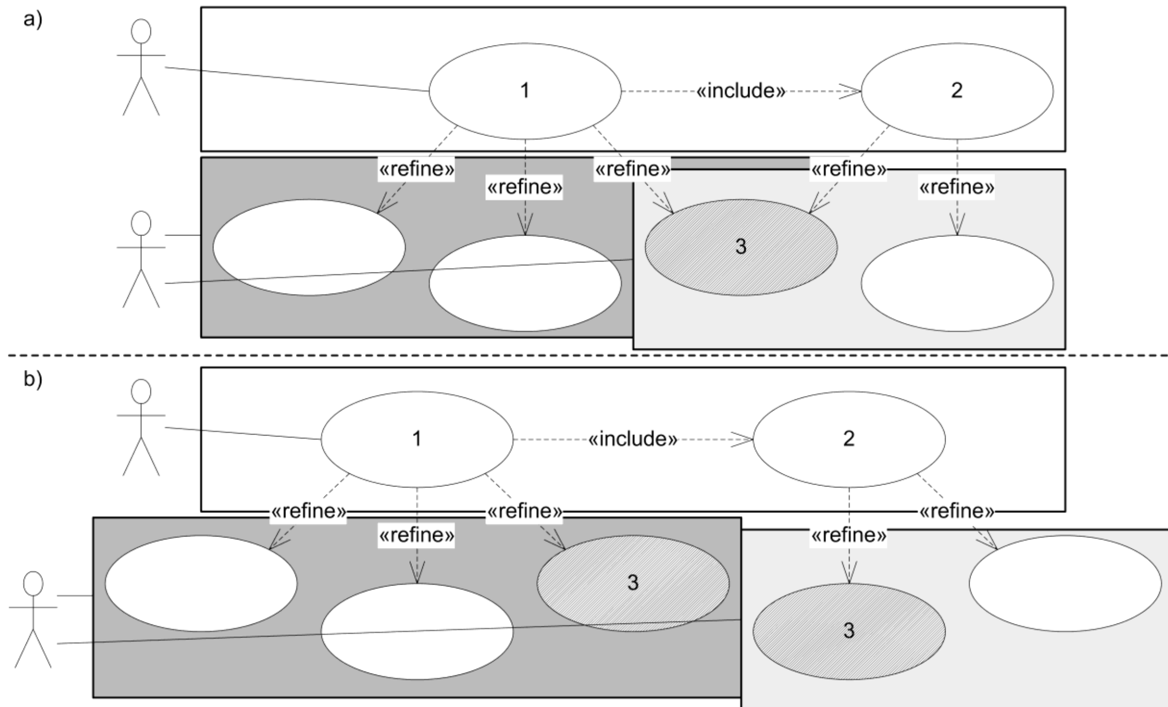


Figure 6 – Possibilities for the refinement of both an including use case and an included use case.

diagrams at different levels of detail (the partial use case diagram, the more abstract one, and the 5c use case diagram, the more detailed one). At this point it can be concluded that the *«refine»* relationship implies lowering the abstraction level (or increasing the detail level) as well as when the abstraction level decreases a new use case diagram has to be ellaborated. The refinement of the use case 7 (which gave origin to the use case diagram in Figure 5d) is used to show that not only included use cases or use cases that do not own any *«include»* relationship can be refined as exemplified in Figure 5. Including use cases can also be refined. When refining an including use case the included use cases are likely to be refined as well since their functionality is represented by the including use case as already explained in this chapter. Figure 5 is also to depict the impossibility of having two use cases connected by both an *«include»* relationship and a *«refine»* relationship.

Figure 6 depicts two possible cases for the refinement of both an including use case and an included use case connected through an *«include»* relationship. The most adequate modeling is the one in Figure 6a where the use case 3 refines two use cases (1 and 2) and is not repeated as it is in Figure 6b. That is possible because the refined use cases are connected through an *«include»* relationship, which implies that a complete use case is repeated in two use case diagrams at the same level of abstraction (the use case diagram that refines the including use case and the use case diagram that refines the included use case).

Use case name: Send Message
Use case description: The mobile user writes the message in a text editor. The mobile user sends some different kinds of messages through the GoPhone. When writing the message, the mobile user activates letter combination (T9). The mobile user inserts objects into a message. The mobile user attaches objects to a message. The GoPhone connects to the network to send the message. In order for the GoPhone to show an acknowledgement to the mobile user (stating that the message was successfully sent), it receives an acknowledgement from the network. Upon request from the GoPhone, the mobile user chooses to save the message into the sent messages folder.

Figure 7 – Non-stepwise textual description of the use case Send Message.

Use case name: Compose Message
Use case description: The mobile user writes the message in a text editor. The mobile user sends some different kinds of messages through the GoPhone. When writing the message, the mobile user activates letter combination (T9). The mobile user inserts objects into a message. The mobile user attaches objects to a message.

Figure 8 – Non-stepwise textual description of the use case Compose Message.

Use case name: Insert Object
Use case description: The mobile user inserts objects into a message. The mobile user may receive notifications on the violation of validation rules over the objects to be inserted into a message.

Figure 9 – Non-detailed non-stepwise textual description of the use case Insert Object.

Use case name: Insert Object
Use case description: The mobile user selects the objects from a repository of objects (eventually with folders), which he can browse. Upon selection of the objects from the repository, they are displayed to the mobile user in the message area of the message editor. The mobile user may receive notifications on the violation of validation rules over the objects to be inserted into a message. The violation of those rules prevents the display of the invalid objects to the mobile user.

Figure 10 – Detailed non-stepwise textual description of the use case Insert Object.

Use case name: Browse Repository
Use case description: The mobile user selects the objects from a repository of objects (eventually with folders), which he can browse.

Figure 11 – Non-stepwise textual description of the use case Browse Directory.

Use case name: Display Object in Message Area
Use case description: Upon selection of the objects from the repository, they are displayed to the mobile user in the message area of the message editor. The mobile user may receive notifications on the violation of validation rules over the objects to be inserted into a message. The violation of those rules prevents the display of the invalid objects to the mobile user.

Figure 12 – Non-stepwise textual description of the use case Display Object in Message Area.

The GoPhone Case Study

The non-stepwise textual descriptions in figures 7 through 12 were elaborated based on the functional requirements from the GoPhone. As previously stated in this chapter the *«include»* relationships are defined based on the non-stepwise textual descriptions of use cases. Figure 13 shows the graphical representation of the use cases textually described in figures 7 through 12. It can be seen that the textual descriptions of the included use cases are contained by the textual descriptions of the including use cases (e.g. the textual description of the *Compose Message* use case is contained by the textual description of the *Send Message* use case and the non-detailed textual description of the *Insert Object* use case is contained by the textual description of the *Compose Message* use case). This is an evidence of how *«include»* relationships imply decomposition but no detailing (of the including use cases' textual descriptions). The *«refine»* relationships imply that the textual descriptions of the refining use cases are more detailed than the textual descriptions of the refined use cases and

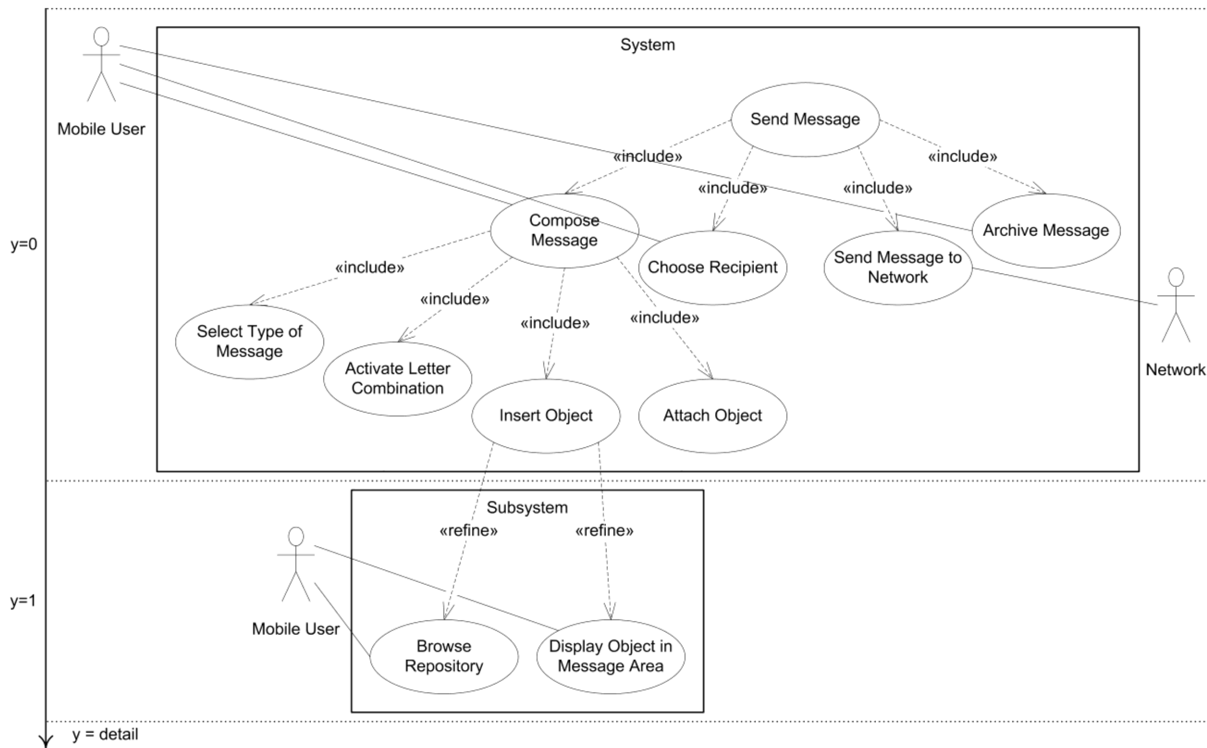


Figure 13 – The use case diagrams of the Send Message *functionality from the GoPhone.*

also that for a single refined use case there is more than one refining use case (which means that *«refine»* relationships imply decomposition besides detailing). For instance the textual description of the *Browse Directory* use case is contained by the detailed textual description of the *Insert Object* use case (note that this detailed textual description is not the description corresponding to the *Insert Object* use case in the use case diagram, rather the non-detailed textual description of the *Insert Object* use case is; the more detailed textual description was only used as an intermediary/auxiliary means to get to the descriptions of the refining use cases *Browse Directory* and *Display Object in Message Area*). This is evidence that the use cases at the detail level 1 in the figure are more detailed than the use cases at the detail level 0 in the figure.

The sum of the functionality represented by the non-stepwise textual descriptions of the included use cases shall be equal to the functionality represented by the non-stepwise textual description of the including use case. In the use case diagram at the detail level 0 in Figure 13 although the sum of the functionality represented by the non-stepwise textual descriptions of the use cases included by the *Send Message* use case is equal to the functionality represented by the non-stepwise textual description of the *Send Message* use case, the actor *Mobile User* was not associated with the *Send Message* use case but it could have been. This thesis did not associate the *Mobile User* with the *Send Message* use case

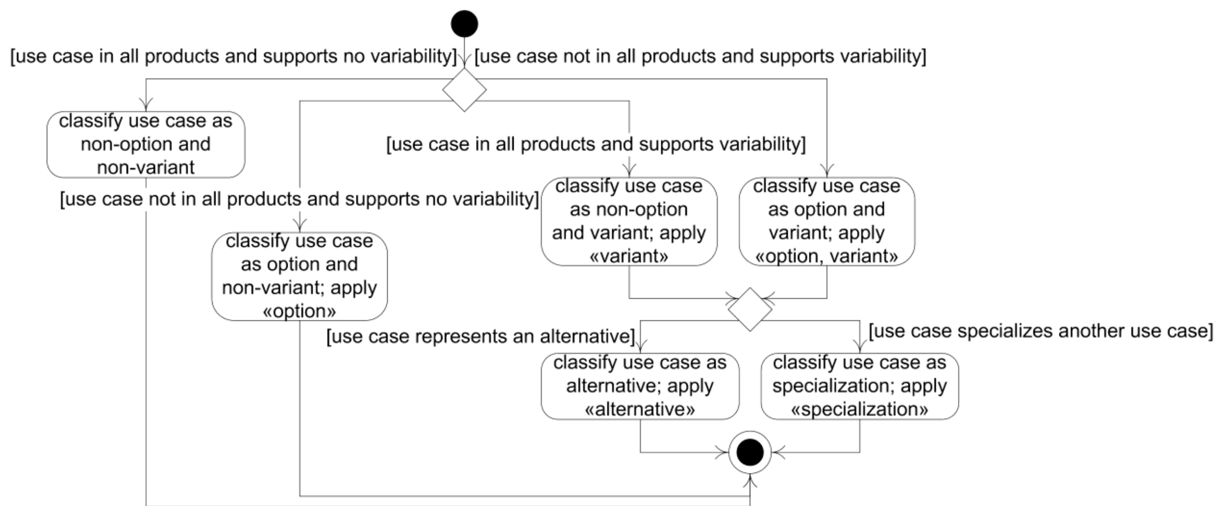


Figure 14 – The use case variability types.

because the purpose was to explicitly evidence the actor of each one of the included use cases in particular since there are two actors involved in the *Send Message* use case (the *Mobile User* and the *Network*). That is not what happens with the *Compose Message* use case as there is only one actor involved in the use case.

Regarding the use case diagram at the detail level 1 in Figure 13 the refining use cases are associated with an actor, which means that refining use cases have to be utilizations of the system by themselves (all use cases shall have an association with the exterior of the system they belong to whether they are including, included, refined or refining use cases, otherwise this thesis would not be talking about use cases).

3.3. Modeling Variability with the *Extend* Relationship

Variability in Use Case Modeling

Figure 14 illustrates the variability types this thesis considers and proposes to be applicable in the context of use cases. Use cases can be non-option or option. Non-option use cases are present in all product line members. Option use cases can be present in one product of the product line and not in another. It is not mandatory that option use cases are present in all products of the product line. Non-variant use cases are use cases that are present in all product line members but do not support variability. Variant use cases are use cases that are present in all product line members as well as they are use cases that support variability. This means that different products will support different alternatives for performing the same functionality or that different products will support different specializations of the same functionality. Later on during the modeling activity variant use cases are realized into

alternatives or specializations respectively. Alternative use cases represent alternatives for performing the same system's use in mutually exclusive products or sets of products from the product line. Specialization use cases represent a special kind of alternatives. A specialization use case is a use case that represents the specialization of another use case. Specialization use cases that specialize the same use case represent alternatives for performing the same system's use in mutually exclusive products or sets of products from the product line. Specialization use cases that specialize the same use case indeed represent alternatives to each other but they specialize a use case, which is not the case of alternative use cases. Option, alternative and specialization use cases are the representation of the three variability types that will be translated into stereotypes to be applicable to use cases. The use cases that do not represent options and are not variant (neither later alternatives nor specializations) are non-option and non-variant, and shall not be marked with any stereotype. Non-option and option use cases are mutually exclusive as well as non-variant and variant use cases. Figure 14 represents the activity of classifying use cases with variability types: either *non-option and non-variant* or *option and non-variant* or *non-option and variant* or *option and variant*. These last two variability types can be realized into the *alternative* or the *specialization* variability types (as already explained). The activity of classifying use cases with the variability types is important for applying the corresponding stereotypes to the use cases (except for the *non-option and non-variant* use cases, which shall not be marked with any stereotype). The conditions of the decision nodes express the semantics of each one of the variability types. This thesis would like to give emphasis to a particular variability type: the *option and variant* variability type. This variability type is applicable to a use case that is not present in all product line members but the different members in which it is present support different alternatives for performing that use case's functionality or different specializations of that use case's functionality. *Option and non-variant* use cases shall be marked as option use cases; *non-option and variant* as variant use cases; and *option and variant* use cases as both option and variant use cases.

Figure 15 depicts the use case diagram elaborated from the GoPhone concerning the messaging domain and the highest abstraction level (these use cases are the less detailed this chapter is presenting).

This thesis proposes an extension to the UML metamodel in order to formally provide for both the concrete and abstract syntaxes to represent the three variability types that are to be translated into stereotypes to be applicable to use cases. From now on this thesis either

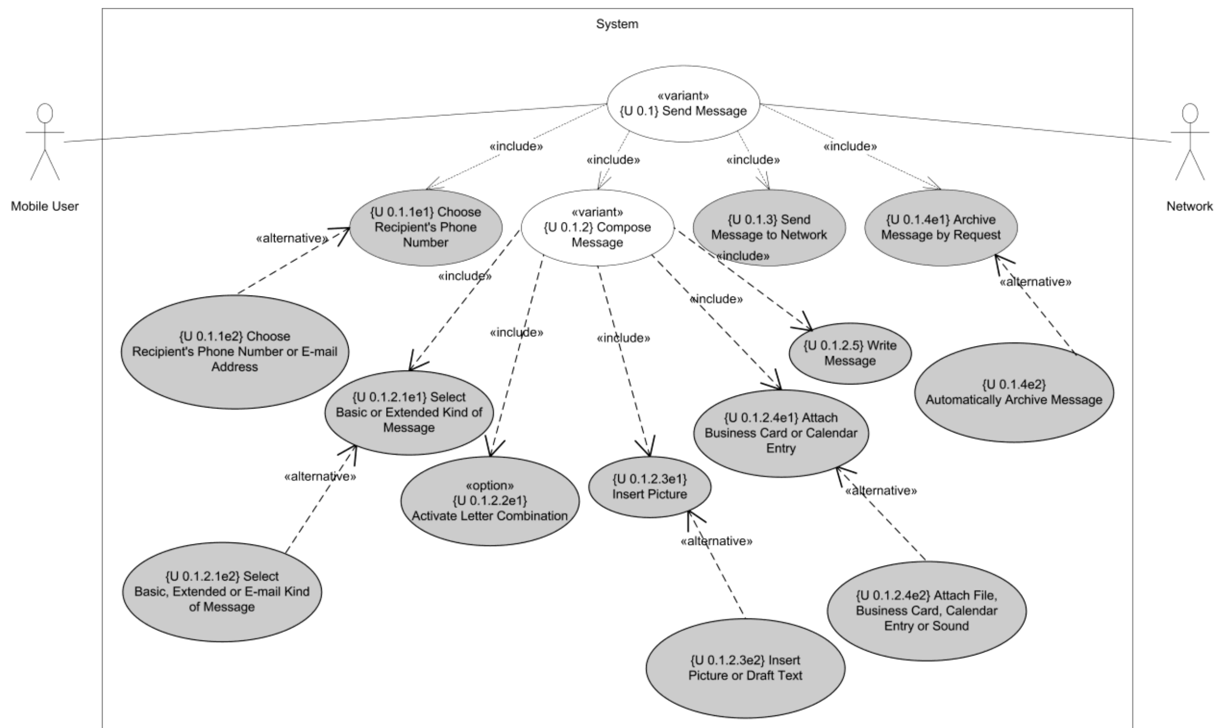


Figure 15 – Use case diagram from the GoPhone case study (highest abstraction level).

uses the *«extend»* relationship without stereotypes or with one of the two stereotypes applicable to this relationship from the proposed extension to the UML metamodel (depending on whether this thesis is modeling alternatives or specializations). Using no stereotypes on the *«extend»* relationship means that no variability is being modeled, otherwise the stereotypes applicable to the *«extend»* relationship from the proposed extension to the UML metamodel shall be used.

The *«extend»* Relationship

In order for use cases to be appropriate for product line modeling, they have to be equipped with variability mechanisms. These variability mechanisms must allow determining the locations in diagrams (in this case, use case diagrams) where variation will occur when instantiating the product line.

The *«extend»* relationship allows modeling alternative and specialization use cases in use case diagrams. Consider that an extending use case is a use case that extends another use case and that an extended use case is a use case that is extended by other use cases. As any other use case, an extending use case represents a given use of the system by a given actor or actors.

In the UML metamodel the extending use cases are considered to represent supplementary behavioral increments that have to be inserted into the appropriate insertion points between the extended use case's fragments. These fragments refer to parts of the textual descriptions of use cases. The position of this thesis is that both extending and extended use cases represent supplementary behavioral increments since in the context of product lines they represent functionality that is only essential for developing product lines (both represent alternatives). In principle the functionality represented by the extended use cases will be available for more advanced products in terms of functionality.

In the context of alternatives both extending and extended use cases represent supplementary functionality (or supplementary behavioral increments) since both represent alternatives, which are not essential for a product without variability to function. It shall be noted that alternatives are no longer supplementary when product line members are instantiated from the product line. Alternatives can be modeled with the generalization relationship in use case diagrams, but this thesis recommends to model alternatives with the *«extend»* relationship in order to evidence their supplementary character according to the UML semantics (when supplementary is mentioned in this thesis, supplementary behavioral increments from the UML semantics associated with the *«extend»* relationship are referred). Therefore the concept of alternative is semantically supported by the *«extend»* relationship. The *«extend»* relationship implies that alternatives are represented as binary and unidirectional dependencies. The alternative relationship is binary and unidirectional because the extending use case (just one or one from many) is an alternative to the extended use case. The extended use case is modeled as the extended one in order to evidence that it shall be present in products less robust in terms of functionality as opposite to all the others. A situation in which there is more than one alternative to a specific use case shall be represented with that specific use case as the extended use case and the other use cases as the extending ones relatively to that specific use case (the *«extend»* relationships shall be marked with the stereotype *«alternative»*). Situations with a high number of alternatives shall be modeled with different diagrams that shall have the extended use case in common.

If the intention is to use differential specification, specializations shall be modeled with the *«extend»* relationship in order to evidence their supplementary character according to the UML semantics, otherwise they shall be modeled with the generalization relationship. Differential specification of specializations means that specialization use cases represent supplementary functionality regarding the use case they specialize, therefore a product

without variability does not require the specialization use cases to function. Not requiring the specialization use cases implies the respective use case that is specialized is not required for a product without variability to function as well. Besides that, a specialization use case is an extending use case and the respective use case that is specialized is an extended use case, which according to the position of this thesis means both represent supplementary functionality as previously explained. It can be concluded that differential specification is related to supplementary functionality from the UML *«extend»* relationship's semantics. In the approach of this thesis, differential specification is used, therefore a specialization is represented as a relationship through a stereotype applicable to the *«extend»* relationship. A *«specialization»* relationship is an *«extend»* relationship marked with the stereotype *«specialization»*.

Options represent functionality that is only essential for a product with variability to function (when developing product lines), therefore options represent supplementary behavioral increments. However this thesis does not recommend modeling options with the *«extend»* relationship because if the stereotype was on the relationship, the relationship itself would be optional and that is not the case (the use case is not optional with regards to any other use case, rather it is optional by itself).

Options shall be modeled with a stereotype in use cases. The involvement of an option use case (classified with the *option and variant* variability type) in either *«extend»* or *«include»* relationships, or even in none of those does not imply the presence of that use case in all product line members (which makes of it optional).

In principle an extending use case is a use case that extends another use case both in the case of alternatives and in the case of specializations. In the case of specializations, this thesis considers that there is no multiple inheritance, therefore it is impossible for an extending use case to extend more than one use case. If there is more than one alternative use case for the same functionality, one of those use cases shall be the alternative to all the others and extended by them. That use case is the one to be present in the products less robust in terms of functionality. The extended use case is not aware of the functionality described in the extending use case.

As previously mentioned if the intention is not to use differential specification, generalization relationships shall be used because specializations are complementary under those circumstances. However it may be argued in a different way that the generalization

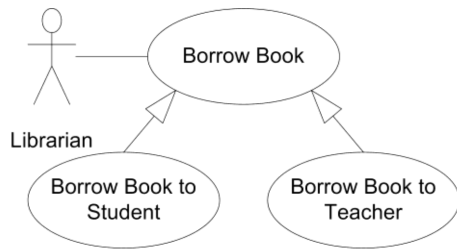


Figure 16 – The specialization of the variant use case Borrow Book *with a single actor.*

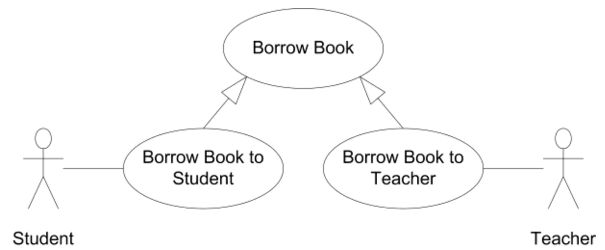


Figure 17 – The specialization of the use case Borrow Book *with two different actors.*

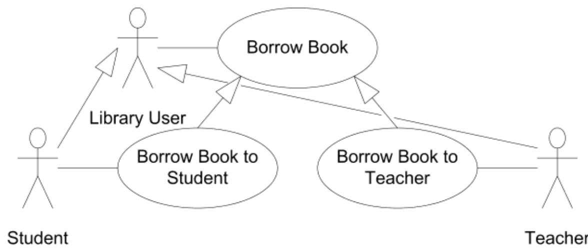


Figure 18 – The specialization of the variant use case Borrow Book *with two different actors.*

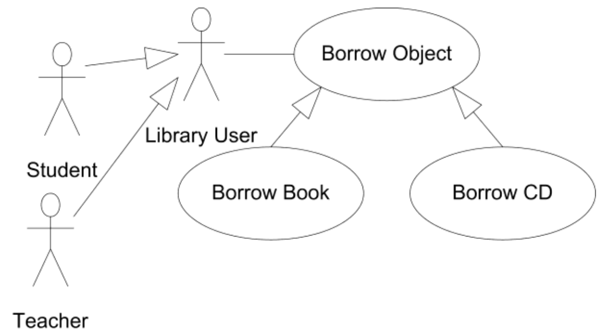


Figure 19 – The specialization of the variant use case Borrow Object.

relationship shall not be used to represent specializations in contexts of variability. Consider the examples depicted in figures 16 through 19. The examples are an exception in terms of the (GoPhone) case study that is used in this chapter. The figure shows that the use case *Borrow Book* can be specialized into *Borrow Book to Student* and *Borrow Book to Teacher*. If the actor is the same (the *Librarian*, who registers the borrowing), then the use cases that specialize the *Borrow Book* use case are alternatives to borrowing a book as both can be performed by the same actor. If the actor is not the same (the *Student*, in the case of the *Borrow Book to Student*, and the *Teacher*, in the case of the *Borrow Book to Teacher*), then the use cases that specialize the *Borrow Book* use case are not alternatives to borrowing a book as both cannot be performed by the same actor (the same actor does not have an alternative way of borrowing a book). Although the use case *Borrow Book* is connected to no actor, it is a use case that is in fact connected to the actors of the use cases that specialize it (*Student* and *Teacher*). If both of these actors were connected to the use case *Borrow Book*, it would not be explicit which part of the use case they would perform (either the one related to the book borrowing to student or the other related to the book borrowing to teacher). In this case, in order for the generalization to be considered as variability, the actor of *Borrow Book* has to be the *Library User* (connected to *Borrow Book*) specialized into the *Student* (connected to *Borrow Book to Student*) and into the *Teacher* (connected to *Borrow Book to Teacher*). Following the semantics of generalization in what actors in use case diagrams are

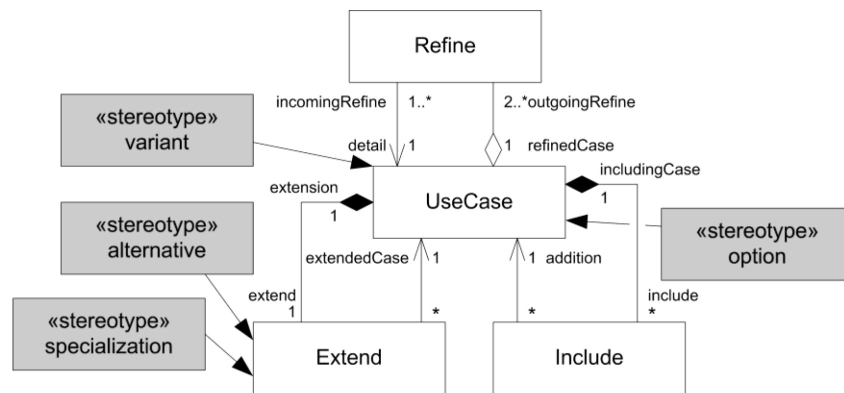


Figure 20 – The proposed extension to the UML metamodel (figure 16.2 from [1]) for modeling variability in use case diagrams.

concerned, being *Student* and *Teacher* subtypes of *Library User*, they both interact with the specific subuse case they are associated with as well as with the superuse case they are associated with via the superactor. Contrarily to the case of Figure 17, in Figure 18 it is explicitly known which part of the superuse case *Borrow Book* they perform (the *Student* performs the one related to the book borrowing to student and the *Teacher* performs the other related to the book borrowing to teacher). Another example: the use case *Borrow Object* can be specialized into *Borrow Book* and *Borrow CD*. In this case, the actor can be the same for all the use cases (the *Student* OR the *Teacher*). In order to support all the actors at the same time (the *Student* AND the *Teacher*), the *Library User* has to be specialized into them (the *Student* and the *Teacher*) and connected to the *Borrow Object* use case. This way the same actor (the *Library User*) can borrow an object (a *Book*) or alternatively another (a *CD*).

Figure 20 depicts the extension this thesis proposes to the UML metamodel concerning the *«extend»* relationship and use cases. This thesis adds the stereotypes *«alternative»*, *«specialization»* and *«option»* to the standard UML stereotypes in order to distinguish the three variability types that were to be translated into stereotypes to be applicable to use cases. This thesis has also added the stereotype *«variant»* to the standard UML stereotypes in order to mark use cases at higher levels of abstraction before they are realized into alternatives or specializations. A use case can include some use cases that are not marked with *«variant»* since they are alternatives (involved in *«alternative»* relationships), they are involved in *«specialization»* relationships or they are non-option and non-variant (if not marked with any stereotype and not involved in *«alternative»* or *«specialization»* relationships). For instance *Send Message* (Figure 15) is at the highest detail level and it is marked with *«variant»*. Some of the use cases it includes are not marked with *«variant»* since they were realized as alternatives (involved in *«alternative»* relationships), or

they are non-option and non-variant (if not marked with any stereotype and not involved in *«alternative»* relationships). Use cases could have been marked with *«variant»* in the approach of this thesis and related to variation points. Usually a variation point is associated with one or more variants (from [42]). This thesis did not adopt variation points to avoid additional graphical elements in use case diagrams, to avoid more complexity in use case diagrams and to avoid reasoning about variability that shall be present in decision models. This thesis proposes the stereotype *«option»* to be applicable to use cases that represent options. *«option»* is for marking use cases that are not mandatory for all product line members. It also proposes the stereotypes *«alternative»* and *«specialization»* to be applicable to the *«extend»* relationship for modeling alternatives and specializations respectively. Extending use cases involved in *«alternative»* relationships do not need to be marked with the stereotype *«alternative»* to evidence them as alternatives since they do not make sense without being involved in that kind of relationships (an alternative use case is always alternative to another use case). The same happens with the stereotype *«specialization»* (a use case involved in a specialization relationship always specializes another use case).

Regarding Figure 20 and the *Extend* metamodel element, as far as the unidirectional association is concerned, the end named *extendedCase* references the use case that is being extended (the extended use case) and the association means that many (zero or more) *«extend»* relationships refer to one extended use case. Regarding the aggregation, the end named *extend* references the *«extend»* relationships owned by the use case, and the end named *extension* references the use case that represents the extension (the extending use case) and owns the *«extend»* relationship. The metamodel means that one *«extend»* relationship is owned by one extending use case. Summarily a use case can be extended by many use cases and a use case can extend another use case. There can be zero or more alternatives (*«alternative»* relationships) to a use case. There can also be zero or more specializations (*«specialization»* relationships) for a use case. Although it can be argued that specializations are only worth the effort when there are two or more specialization use cases, this thesis does not want to take freedom away from the modeler.

It is important to distinguish alternatives from specializations in contexts of variability. In the case of alternatives, the extending use case is an alternative to the extended use case. In the case of specializations, the extending use cases are alternatives to each other. Figure 21 shows the specialization of two alternative use cases from Figure 15: *Insert Picture*

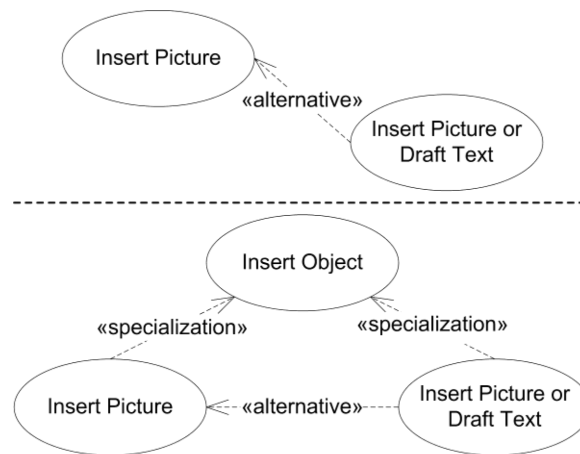


Figure 21 – The specialization of Insert Picture *and* Insert Picture or Draft Text.

and *Insert Picture or Draft Text*. It is possible to transform alternatives into specializations and the other way around. Again this thesis is not restrictive on this since it does not want to take freedom away from the modeler. *Insert Picture or Draft Text* is an alternative to *Insert Picture* because it extends the functionality represented by *Insert Picture* (which means that in this case and in the context of product lines, it is an alternative to *Insert Picture*).

Variability in Use Case Modeling with Refinement

Use cases can be decomposed with or without detailing their non-stepwise textual descriptions. Without detailing those descriptions this thesis proposes to represent the decomposition of use cases in use case diagrams with the *«include»* relationship (e.g. the decomposition of the *Send Message* use case from Figure 15). This decomposition suits the purpose of e.g. (1) modeling later on an alternative to a part of the decomposed use case; or (2) modeling a part of the decomposed use case that is an optional part (e.g. in Figure 15 *Insert Picture* is a part of *Compose Message* and has an alternative, which is *Insert Picture or Draft Text*; in Figure 15 *Activate Letter Combination* is a part of *Compose Message* and represents an option).

Figure 22 depicts use cases according to the perspectives of detail*variability to illustrate in abstract terms the approach of this thesis to use case modeling with support for variability. The detail perspective is intimately related to the activity of use case refinement. In this sense use cases can be more detailed if they are refined. The variability perspective is associated with the modeling of variability for product line support. The two perspectives (detail and variability) were converted into axes of the illustrated space: y=detail and z=variability. Each level of the z axis corresponds to a (parallel) plan, which means that this thesis positions use cases in variability plans. Thus variability plans are plans that contain use

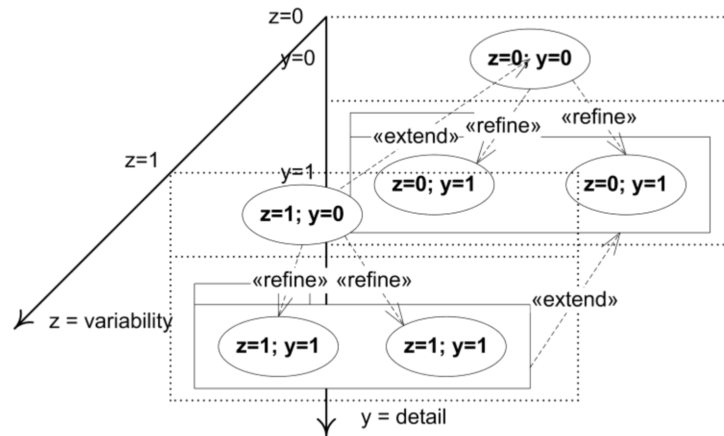


*Figure 22 – Use cases positioned according to the perspectives of detail*variability.*

cases representing variability in the three different types translated into stereotypes to be applicable to use cases. The plan z=0 contains none of these use cases that represent variability.

The figure clarifies that the *«refine»* relationships imply increasing the detail level, whereas the *«extend»* relationships do not imply increasing the detail level but rather changing from one variability plan (z plan) to another. Extending use cases represent alternative or specialization use cases, therefore they must be situated at the same level of detail but in different variability plans (z plans). Variabilities do not imply adding detail to the non-stepwise textual descriptions of the use cases like refinements do.

The figure shows the general case of the refinement of two use cases connected through an *«extend»* relationship. The refinement of a use case stereotyped as *«option»* is not relevant here, since it is not the case of an *«extend»* relationship connecting two use cases. The figure evidences that the refinement of two use cases connected through an *«extend»* relationship originates more detailed use cases organized in two packages that have also an *«extend»* relationship connecting them. That is not always the case. It is possible to have two use cases connected through a *«specialization»* relationship, which produces *«specialization»* relationships connecting more detailed individual use cases (and not packages) in different variability plans (an example of such case is in the next subsection).

The GoPhone Case Study

The non-stepwise textual descriptions in Figure 23 were elaborated based on the functional requirements for the GoPhone. This thesis relies on non-stepwise textual descriptions of use cases (the opposite of stepwise textual descriptions of use cases) to model

Use case name: {U 0.1} Send Message
Use case description: The mobile user writes the message in a text editor. The GoPhone connects to the network to send the message. In order for the GoPhone to show an acknowledgement to the mobile user (stating that the message was successfully sent), it receives an acknowledgement from the network. Upon request from the GoPhone, the mobile user chooses to save the message into the sent messages folder.
Alternatives:
The mobile user chooses the recipient's contact. [Use cases' name: *{U 0.1.1e1} Choose Recipient's Phone Number / {U 0.1.1e2} Choose Recipient's Phone Number or E-mail Address*]
The mobile user sends some different kinds of messages through the GoPhone. [Use cases' name: *{U 0.1.2.1e1} Select Basic or Extended Kind of Message / {U 0.1.2.1e2} Select Basic, Extended or E-mail Kind of Message*]
The mobile user inserts objects into a message. [Use cases' name: *{U 0.1.2.3e1} Insert Picture / {U 0.1.2.3e2} Insert Picture or Draft Text*]
The mobile user attaches objects to a message. [Use cases' name: *{U 0.1.2.4e1} Attach Business Card or Calendar Entry / {U 0.1.2.4e2} Attach File, Business Card, Calendar Entry or Sound*]
The message is saved into the sent messages folder. [Use cases' name: *{U 0.1.4e1} Archive Message by Request / {U 0.1.4e2} Automatically Archive Message*]
Specializations: -
Options: When writing the message, the mobile user activates letter combination (T9). [Use case's name: *{U 0.1.2.2e1} Activate Letter Combination*]

Use case name: {U 0.1.2} Compose Message
Use case description: The mobile user writes the message in a text editor.
Alternatives:
The mobile user sends some different kinds of messages through the GoPhone. [Use cases' name: *{U 0.1.2.1e1} Select Basic or Extended Kind of Message / {U 0.1.2.1e2} Select Basic, Extended or E-mail Kind of Message*]
The mobile user inserts objects into a message. [Use cases' name: *{U 0.1.2.3e1} Insert Picture / {U 0.1.2.3e2} Insert Picture or Draft Text*]
The mobile user attaches objects to a message. [Use cases' name: *{U 0.1.2.4e1} Attach Business Card or Calendar Entry / {U 0.1.2.4e2} Attach File, Business Card, Calendar Entry or Sound*]
Specializations: -
Options: When writing the message, the mobile user activates letter combination (T9). [Use case's name: *{U 0.1.2.2e1} Activate Letter Combination*]

Use case name: {U 0.1.4e1} Archive Message by Request
Use case description: Upon request from the GoPhone, the mobile user chooses to save the message into the sent messages folder.
Alternatives: The GoPhone automatically archives the message [Use cases' name: *{U 0.1.4e2} Automatically Archive Message*]
Specializations: -
Options: -

Use case name: {U 0.1.4e2} Automatically Archive Message
Use case description: The GoPhone saves the message into the sent messages folder and notifies the mobile user on the successful message saving into that folder.
Alternatives: -
Specializations: -
Options: -

Use case name: {U 0.1.2.3e1} Insert Picture
Use case description: The mobile user inserts pictures into the message. The mobile user may receive notifications on the violation of validation rules over the pictures to be inserted into the message.
Alternatives: The mobile user inserts pictures or draft texts into the message. [Use cases' name: *{U 0.1.2.3e2} Insert Picture or Draft Text*]
Specializations: -
Options: -

Use case name: {U 0.1.2.3e2} Insert Picture or Draft Text
Use case description: The mobile user inserts pictures and/or draft texts into the message. The mobile user may receive notifications on the violation of validation rules over the pictures and/or the draft texts to be inserted into the message.
Alternatives: -
Specializations: -
Options: -

Figure 23 – Non-stepwise textual descriptions from the GoPhone use case Send Message *and some of its related use cases.*

variability in use case diagrams. Stepwise textual descriptions are structured textual descriptions in natural language that provide for a stepwise view of the use case as a sequence of steps, alert for the decisions that have to be made by the user and evidence the notion of use case actions temporarily dependent on each other. Stepwise descriptions shall be treated after modeling the use cases. (Cockburn presents in [22] different forms of writing textual descriptions for use cases.)

In the context of the *«extend»* relationship the UML Superstructure states that an extending use case consists of one or more behavior fragment descriptions to be inserted into

the appropriate spots of the extended use case. This means that the functionality of the extending use case is not described in the extended use case. The extended use case is not aware of the functionality described in the extending use case (e.g. as can be seen from Figure 23 the functionality of the *Automatically Archive Message* use case is not described in the *Archive Message by Request* use case, as well as the functionality of *Insert Picture or Draft Text* is not described in *Insert Picture*, although they are very similar). This thesis would like to note that the statement of the UML Superstructure mentioning that the execution of an extended use case and its extending use cases is only one is not valid in the context of product lines, particularly for alternatives. As Figure 24 depicts, the use case *Automatically Archive Message* is an alternative to the use case *Archive Message by Request* (they are connected through a kind of *«extend»* relationship, tagged with the stereotype *«alternative»* in order to evidence that the use case *Automatically Archive Message* is an alternative to the use case *Archive Message by Request*). It must be noticed that *Archive Message by Request* is an (included) use case included by the including use case *Send Message*, which means that the functionality of the use case *Archive Message by Request* is described in the *Send Message* use case. For this reason this thesis could have extended the *Send Message* use case with the use case *Automatically Archive Message*, but then it would not be evidencing to which part of the functionality of the *Send Message* use case the use case *Automatically Archive Message* is an alternative to. Figure 24 also depicts that the *Browse Directory of Pictures* use case is a specialization of the use case *Browse Repository* (they are connected through another kind of *«extend»* relationship, tagged with the stereotype *«specialization»* in order to evidence that the use case *Browse Directory of Pictures* is a specialization of the use case *Browse Repository*). Option use cases shall be marked with the stereotype *«option»* (e.g. as Figure 24 evidences for the *Activate Letter Combination* use case).

Figure 24 shows some examples of variability modeled in use cases. The use cases in grey are those that do not represent variability. No borders containing use cases in the variability plans with $z>0$ were drawn because those borders are going to be needed during product derivation (or the generation of product models from the product line model, which is out of the scope of this thesis). All the use cases in the diagrams in this section have the values they take for both the perspectives of variability (z) and detail (y). These are not tagged values, rather just a help for the reader to visualize the use cases in the right place. Figure 24 seems complex but it ought to be noticed that the figure contains two diagrams and that the extensions to the use cases in the diagrams could have been modeled in different

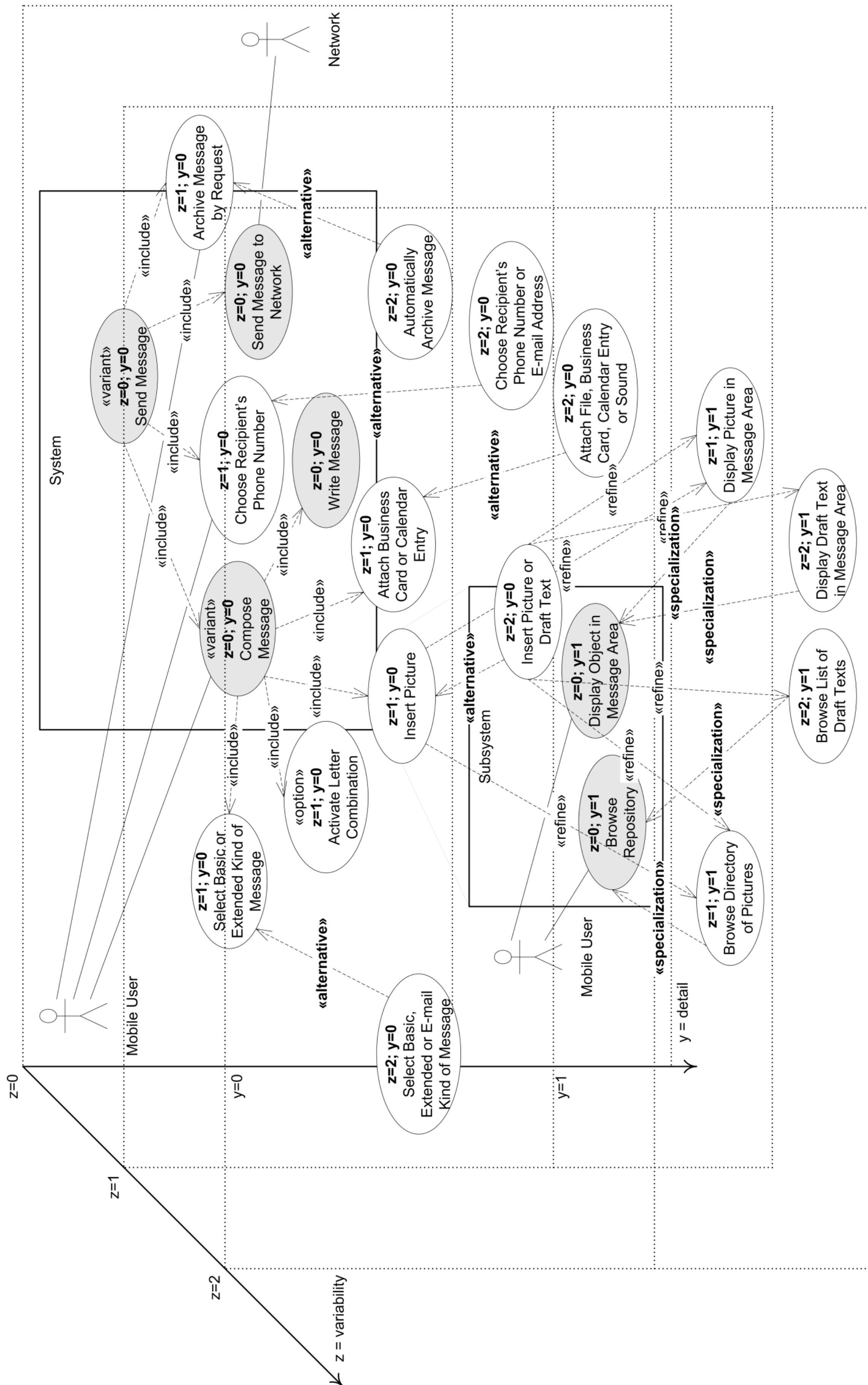


Figure 24 – Use case diagram from the GoPhone case study (two detail levels).

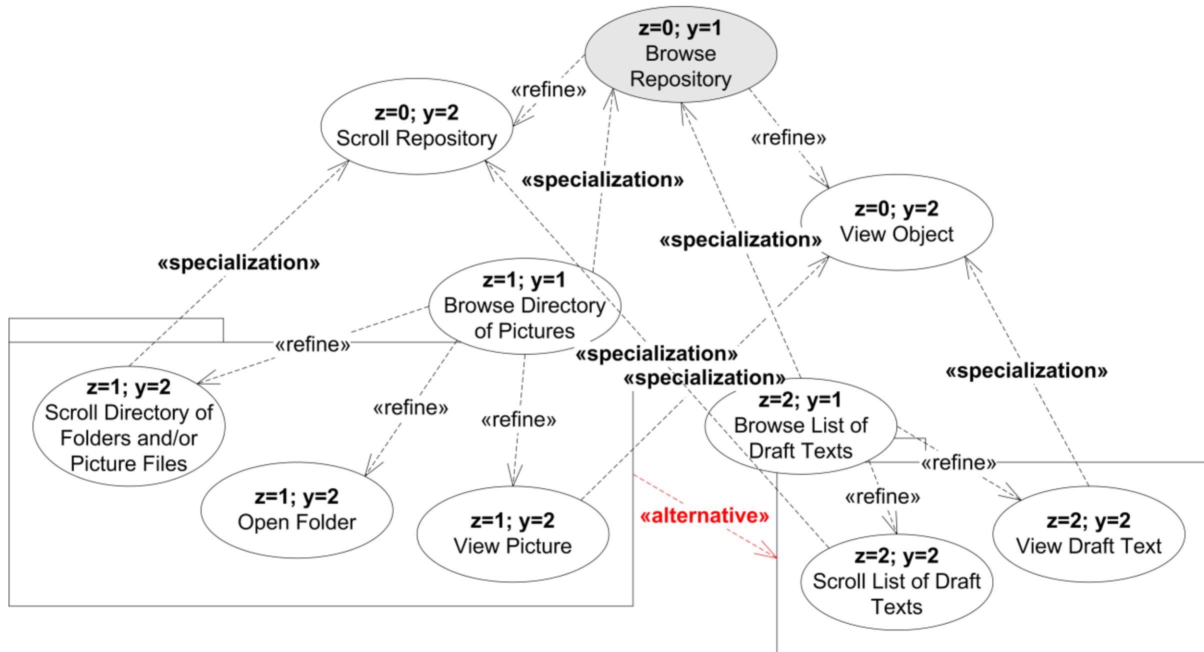


Figure 25 – An example of refinement of the specialization type of variability from the GoPhone.

artifacts. By stating this this thesis states that the diagram in Figure 24 could have been separated in some diagrams. Nevertheless this thesis cannot escape variability in its different types for the reasons already explained.

Figure 25 shows the refinement of the specialization type of variability. The figure shows that both the use case that is specialized (the *Browse Repository* use case) and the specialization use cases (the *Browse Directory* and *Browse List* use cases) were refined. Some use cases that refine the specialization use cases are specializations of the use cases that refine the use case that is specialized (e.g. the *View Picture* use case is a specialization of the *View Object* use case). The use case *Open Folder* represents functionality that is not common to both specialization use cases since it is only applicable to one of the objects the specialization use cases refer to (the *Directory of Pictures*). Having in mind that specializations are a special kind of alternatives, specialization use cases are alternatives to each other. Figure 25 illustrates that the use cases that refine the specialization use cases are alternatives to each other as packages.

Figure 26 depicts that the use cases that refine two use cases connected through an *«alternative»* relationship are alternatives to each other as packages.

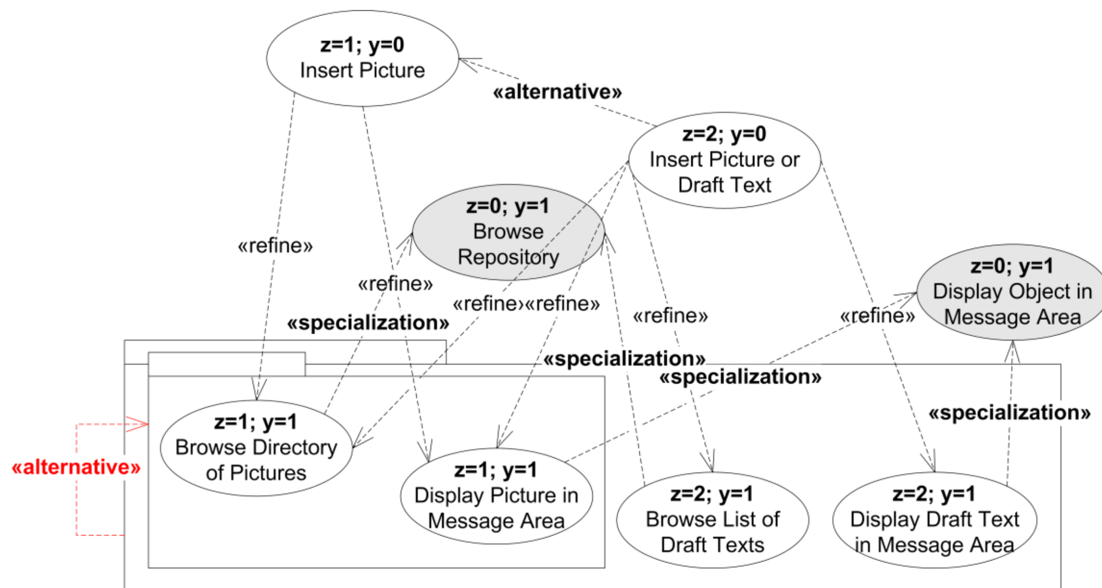


Figure 26 – An example of refinement of alternative variability from the GoPhone.

3.4. The 4SRS Method with Variability Support

Synopsis of the 4SRS Method

The 4SRS is a UML modeling method for obtaining system functional requirements from user functional requirements. Use cases model user functional requirements and logical architectures model system functional requirements. Use cases are problem-related, technology-independent and dealt with during the analysis of software. Logical architectures are solution-related, technology-independent and dealt with in the beginning of the design of software. The 4SRS is a transition method according to previous statements in this thesis.

Shortly the 4SRS method is composed of the following steps: (1) *Component Creation*, to create three kinds of components for each use case, based on the MVC (an interface component, a control component and a data component; other kinds of components could be created, so this is not a limitation of the method, rather an architectural decision); (2) *Component Elimination*, to remove redundant requirements and to find missing requirements (this step is vital in order to validate the components blindly created in the previous step and it includes eliminating the components whose requirements are already represented by other components; the finding of missing requirements means that components were inadequately eliminated or use cases are missing); (3) *Component Packaging and Aggregation*, to semantically group components in packages; and (4) *Component Association*, to define associations of components with each other in the component diagram.

In the past the 4SRS method was extended to support tabular transformations in the execution of its steps as well as some filtering and collapsing techniques to enable the refinement of logical architectures. After that the method was extended to support the modeling of logical architectures with variability support, which added the notion of variability to it [29]. The work in this section is both the conjunction and the prosecution of these previous works since it formalizes the filtering and collapsing as an intermediate step as well as it formalizes the transformation from components to use cases in order to finish preparing the recursive execution of the 4SRS method. The work of this thesis also contemplates the formalization of use case refinement and the systematization of use case variability modeling undertaken in this thesis. The formalization of use case refinement is relevant for the preparation of the recursive execution of the 4SRS method. The systematization of use case variability modeling is relevant for modeling use cases with variability support, for determining the use cases that will be the input for the method's execution (recursive or not) and has implications when executing the method itself.

The scale problem mentioned in section 2.1 is the reason for the 4SRS method to have included a technique to refine logical architectures. Handling a high number of use cases with the method implies a high number of resulting components and a consequent high number of possibilities for partitioning functionality into logical clusters. A high number of components in the component diagram that comes out of executing the 4SRS method imposes a greater amount of effort into some of method's steps. Step 2 involves eliminating the semantical redundancy of components. The more components, the more the probability of having components representing the same functionality as others, which complicates the task of comparing one to another. Step 4 becomes complex when there is a high number of components to compare with each other in order to guarantee that they can or cannot be connected since the possibility of associations to be established between components increases. The high number of possibilities to partition functionality implies a greater amount of effort into the execution of step 3. Comparing components to form packages of components becomes hard.

The modeling of logical architectures with variability support (see [62] for an example of a logical architecture's representation through models) may be conducted with specific instruments tailored to explicitly expose the variability of the product line like the 4SRS method with its extension to variability support. Architectural refinement is the approach the 4SRS method takes to increment a primary logical architecture with detail (by

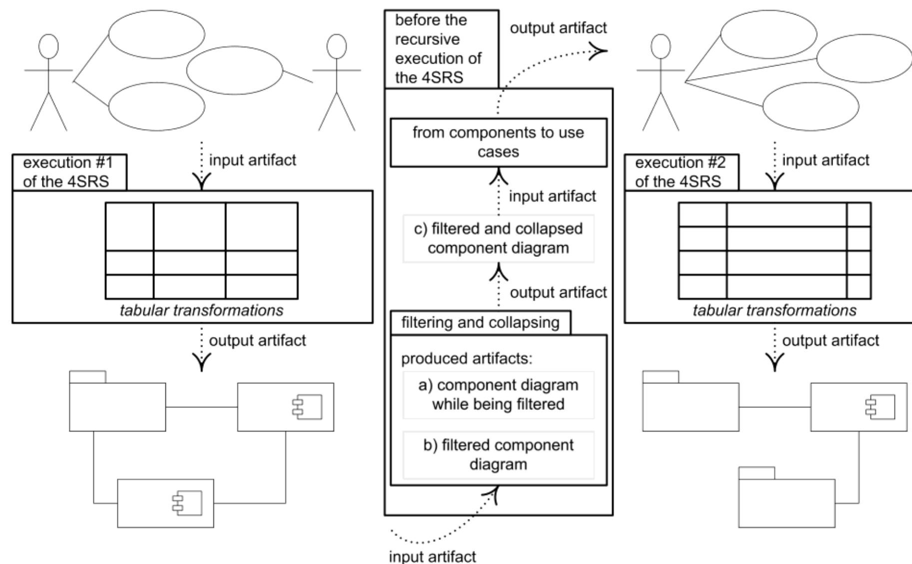


Figure 27 – Schematic representation of the recursive execution of the 4SRS method.

primary it is meant the architecture that is going to be detailed). In the context of this thesis, recursion is the ability of the modeling method to be executed over parts of the output artifact of a preceding execution after transformed into the input artifact for the current execution.

As depicted in Figure 27 the 4SRS method may be applied recursively, in several *executions*. In the context of each one of those executions various *iterations* can be performed. Although there is no stopping rule for iterating over the same use case diagram, it shall be performed until the results obtained generate a logical architecture that does not benefit from additional iterations in terms of the elimination of redundant requirements, the finding of missing requirements and the increasing of the logical architecture's cohesion. There cannot be components isolated from the rest of the architecture when the global architecture is composed from the various logical architectures generated by the different executions. In the case of refinement (by recursion), when one of the executions is considered to be finished by the modeler, the output of that execution's last iteration (a component diagram) is going to originate the input of a subsequent execution's first iteration (a use case diagram). The task flow of the new execution is exactly the same as the task flow of the preceding one. Again, in the case of refinement (by recursion), the logical architectures produced by the various executions are situated in lower levels of abstraction and cover less functionality than the logical architectures they refined.

Considering architectural refinement, the sequence of steps for the 4SRS method is the following: (1) *Component Creation*; (2) *Component Elimination*; (3) *Component Packaging and Nesting*; (4) *Component Association*; (4+1) *Filtering and Collapsing*; and (4+2) *From*

Components to Use Cases. The first four steps are the original steps and the other ones are what this thesis calls the *intermediate steps*, which are performed in between executions of the 4SRS method.

Step 2 is composed of seven microsteps. Microstep 2.i (*Use Case Classification*) is about determining the kinds of components that will originate from each use case according to the eight possible combinations. According to this classification, microstep 2.ii (*Local Elimination*) is about eliminating the components blindly created in step 1 by analyzing the textual description of the use cases and deciding on whether those components make sense in the problem domain. Microstep 2.iii (*Component Naming*) is about naming the components that were not eliminated in the previous microstep. Microstep 2.iv (*Component Description*) is about textually describing the components named in the previous microstep, based on the textual descriptions of the use cases they originated from, on nonfunctional requirements and on design decisions. Microstep 2.v (*Component Representation*) is about determining whether some components represent both their own system requirements and others'. Microstep 2.vi (*Global Elimination*) is about eliminating the components whose requirements are already represented by other components (elimination of functional redundancy). Finally, microstep 2.vii (*Component Renaming*) is about renaming the components that were not eliminated in the previous microstep and that represent additional components.

Generation of Logical Architectures with Variability Support

As already mentioned in this chapter, this thesis formalizes the techniques of filtering and collapsing as well as the transformation from components to use cases as intermediate steps of the 4SRS method to support the refinement of logical architectures. The following is the new sequence of steps for the 4SRS method: (1) *Component Creation*; (2) *Component Elimination*; (3) *Component Packaging and Aggregation*; (4) *Component Association*; (4+1) *Filtering and Collapsing*; and (4+2) *From Components to Use Cases*. The first four steps are the original steps and the other ones are what this thesis calls the *intermediate steps*, which are performed in between executions of the 4SRS method.

As also already mentioned in this chapter, the systematization of use case variability modeling is relevant for modeling use cases with variability support, for determining the use cases that will be the input for the method's execution and has implications when executing the method itself. The remainder of this section discusses these three topics.

Modeling use cases with variability support implies some considerations related to the variability types and the extension to the UML metamodel proposed in section 3.3. As any other use case, use cases involved in alternative relationships, in specialization relationships and those that stand for options represent a given use of the system by a given actor or actors. Next the particularities of modeling alternative relationships, specialization relationships and use cases that stand for options are going to be discussed. Since this thesis considers that the *«extend»* relationship is adequate for modeling alternatives and specializations, and a stereotype applicable to use cases for modeling options, it is important to discuss the *«extend»* relationship thoroughly.

In the case of alternatives, a use case can extend another use case that is included by two other use cases. It could be argued that the extending use case is an alternative to those two other use cases but this is not the most accurate argument since the extending use case is only alternative to a part of those two other use cases (a part that they share).

Consider that an extending use case is a use case that extends another use case and that an extended use case is a use case that is extended by other use cases. In the context of the *«extend»* relationship, extending use cases and extended use cases represent supplementary functionality. In the context of product lines this means that they represent functionality that is only essential for developing product lines.

Specializations can be modeled with the generalization relationship in use case diagrams but as specialization use cases represent a special kind of alternatives, this thesis recommends to model specializations with the *«extend»* relationship.

The relationship is optional if the use case is optional and not optional if the use case is not optional (the relationship shall not exist for the products in which the use case shall not exist as well). Furthermore the use case is not optional with regards to any other use case. Rather it is optional by itself. Options shall be modeled with a stereotype in the use cases. The stereotype is applicable to use cases independently of their involvement in either *«extend»* or *«include»* relationships. As previously stated in this chapter, a use case classified with the *option and variant* variability type (which corresponds to marking that use case with the stereotypes *«option»* and *«variant»*, or just *«option»* if the use case is an alternative use case or a specialization use case) is not present in all product line members but the different members in which it is present support different alternatives for performing that use case's functionality or different specializations of that use case's functionality.

Consider that a use case is shared by two use cases that include it. One of those two use cases is non-option and the other one is option. The use case that is included is non-option or option? The answer is non-option. The use case is going to be present in the product line members in which the non-option use case is going to be present and is also going to be present in the product line members in which the option use case is going to be present. This means that the use case is going to be present in all product line members. If the stereotype *«option»* is on use cases rather than on relationships, both the situation just described is solved as well as the situation of a use case that is not included by any other use case.

This thesis approached option use cases from the perspective of the product line but it could have approached them from the perspective of the members of the product line. This thesis considers that variability no longer exists when moving from compile-time (during which the work is around a product line) to runtime (during which the work is around products from that product line). This thesis considers that after a build the work is around binaries that are products from the product line that can only be changed during setup or post-setup (runtime). Therefore at this point in time a use case is in a product and not in another if it is in the binary of a product and not in the binary of another. However this thesis acknowledges that variability exists at the level of product line members if use cases are present in product line members after instantiation from the product line but during setup or post-setup the use case is no longer available for the respective actor(s).

Determining the use cases that will be the input for the execution of the 4SRS method depends on the support for variability in use case modeling. The 4SRS method shall only consider leaf use cases as input. Figure 15 has the leaf use cases for the first execution of the 4SRS method highlighted in grey (in what concerns the messaging domain of the GoPhone case study). Without variability support leaf use cases are the more detailed ones. With variability support things change. This thesis proposes the following rules to be applied to the determination of leaf use cases when variability is supported. Alternative use cases are leaf use cases (they are involved in *«alternative»* relationships). Specialization use cases are leaf use cases as well as the use case they are a specialization of (specialization use cases are specializations of another use case). Option use cases are leaf use cases. This thesis has discarded the possibility of using the *«include»* relationship to turn only a part of the including use case public to be included by other use cases because that would not guarantee the coherence of the use case diagram to generate logical architectures. Including use cases are not leaf use cases (with or without variability support). If this thesis allowed including use

cases to include only one use case, then the included use cases (in this case, only one) would not represent the totality of the functionality of the including use case and consequently the logical architecture would not be coherent with the user requirements (some would be missing in the architecture).

The execution of the 4SRS method has some implications when use cases are modeled with variability support. This thesis proposes to extend step 2 of the 4SRS method with a rule for the representation of alternatives and specializations. It is required that interface components originated from alternative and specialization use cases (together with the interface components originated from the use cases they specialize) are not represented by any other component, otherwise the essence of a logical architecture with variability support would be lost: the representation of commonalities (shared, reusable components) and variabilities (instance-specific components) among the product members [70]. This thesis also proposes to extend step 4 of the 4SRS method with a rule for the association of components originated from specialization use cases and the use cases they specialize. The components originated from specialization use cases shall be associated with those originated from the use cases they specialize.

The presence of alternatives and specializations in use case diagrams has some impacts on the execution of the 4SRS method. Due to the proposed extension of step 2 with a rule for the representation of alternatives and specializations, the presence of alternatives and specializations has impacts on that step regarding the global elimination of components. The global elimination is about eliminating the components whose system requirements are already represented by other components. It is required that interface components originated from alternative and specialization use cases (together with the interface components originated from the use cases they specialize) are not represented by any other component, which implies they cannot be globally eliminated. Interface components originated from option use cases cannot be represented by any other component.

Finally by executing the 4SRS method over the leaf use cases from Figure 15, the component diagram in Figure 28 was obtained (apart from the crosses and the grey area, which will be explained in the next subsection). The associations between actors and components are usually defined based on the descriptions of components elaborated during the execution of the 4SRS method (this thesis always tries to mention the actors in the description of interface components). But this is not mandatory. The traceability between use

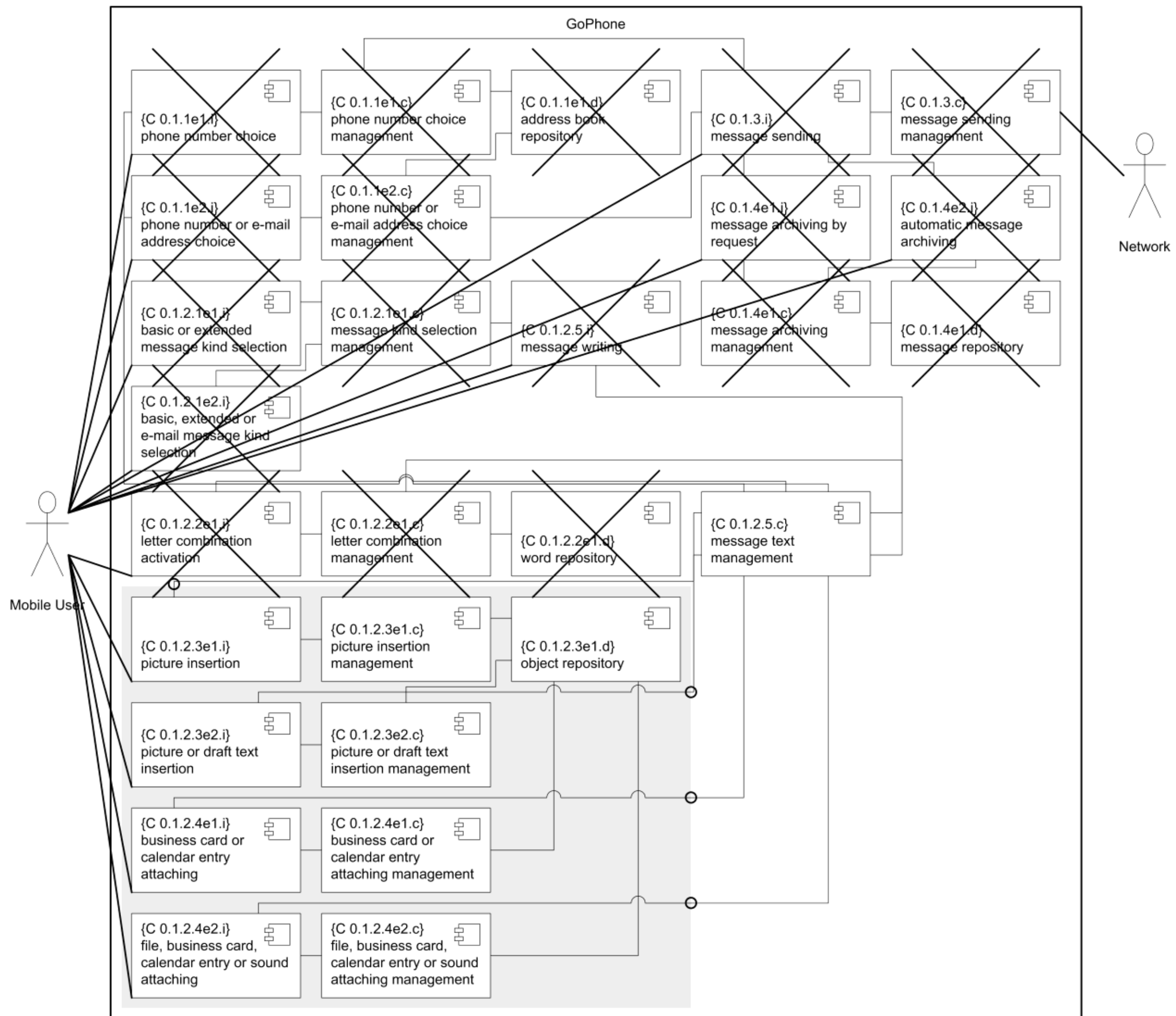


Figure 28 – Component diagram that resulted from the first execution of the 4SRS method over the use cases from the messaging domain of the GoPhone case study, while being filtered.

cases and components allows establishing those associations if they are not evident in the descriptions of the components.

Refinement of Logical Architectures with Variability Support

The refinement of logical architectures (with variability support or not) in the context of the 4SRS method requires its recursive execution. In order to prepare the recursive execution of the 4SRS method, the formalization of use case refinement plays a relevant role. This subsection first elaborates on the techniques of filtering and collapsing that have to be conducted before the recursive execution of the 4SRS method (which this thesis has formalized as an intermediate step of this method). Then the transformation from components to use cases (which this thesis has also formalized as an intermediate step of the 4SRS method) is discussed. In this last discussion this thesis talks about the difference between

decomposing use cases with and without detailing them, and it uses the *«include»* UML relationship to model the decomposition of use cases without detailing them and a UML relationship (the *«refine»* relationship) to model the decomposition of use cases with their detailing.

Filtering and Collapsing

This thesis uses techniques of filtering and collapsing in between executions of the 4SRS method. The filtering consists of considering some components as the subsystem for refinement and discarding those that are not associated with them. The collapsing consists of hiding the details of the subsystem whose components are going to be refined. Later on those components are replaced inside the limits of the subsystem's border by others of lower abstraction level.

This thesis has formalized the filtering and collapsing as an intermediate step of the 4SRS method: 4+1 (*Filtering and Collapsing*). This step produces three artifacts: (a) a component diagram while being filtered; (b) a filtered component diagram; and (c) a filtered and collapsed component diagram.

Figure 28 is the component diagram while being filtered (concerning the GoPhone's messaging domain). The components with a cross are those that are not associated with the components from the subsystem to refine, which are the ones from the grey area in the diagram. There is only one component left (*{C 0.1.2.5.c} message text management*) and that is the only one associated with the subsystem besides the *Mobile User* actor.

Figure 29 is the filtered component diagram (concerning the object insertion and object attaching functionalities from the GoPhone's messaging domain). It only contains the components from the subsystem to refine, the only component that is associated with them and the only actor that is also associated with them.

Figure 30 is the filtered and collapsed component diagram (concerning the object insertion and object attaching functionalities from the GoPhone's messaging domain). It is an evolution of the filtered component diagram. It presents a subsystem in place of the components that will be replaced by refined ones. The associations between the component *{C 0.1.2.5.c} message text management* and those components were removed and replaced by four interfaces, one for each of those associations. The components that will be placed inside

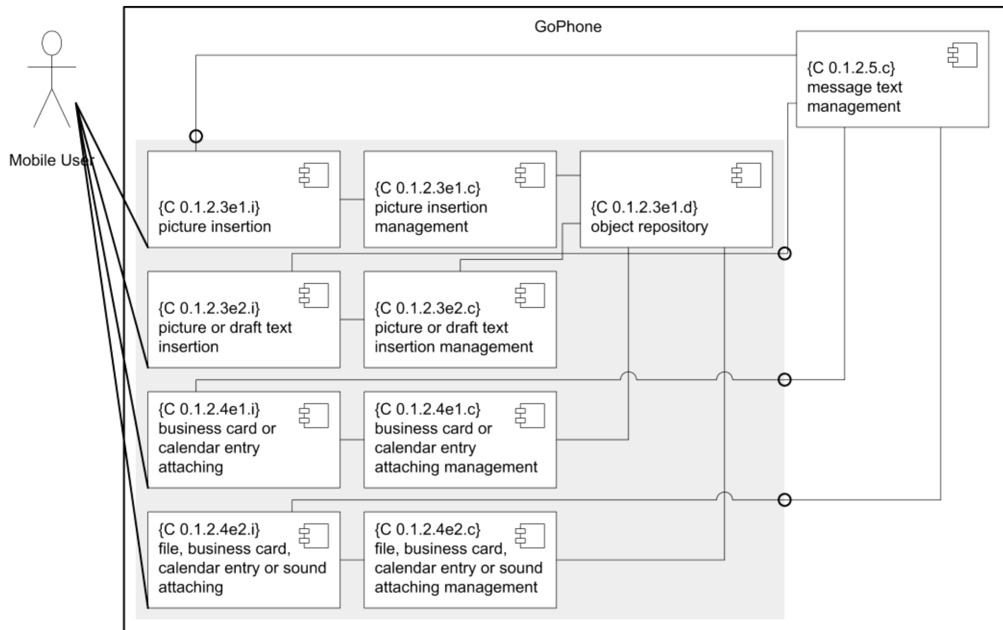


Figure 29 – Filtered component diagram with regards to the object insertion and object attaching functionalities of the Send Message *use case from the GoPhone case study.*

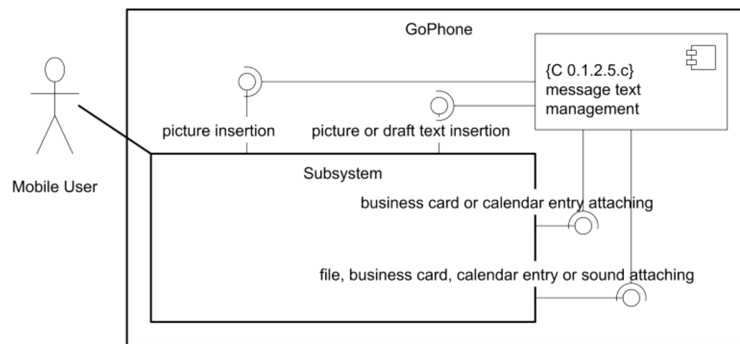


Figure 30 – Filtered and collapsed diagram for object insertion and attaching functionalities from the GoPhone's messaging domain.

the borders of the subsystem (the more detailed components that will be obtained from the recursive execution of the 4SRS method) will have to comply with those interfaces.

Deriving Use Cases from Components

The intermediate step 4+2 (*From Components to Use Cases*) of the 4SRS method is composed of two intermediate substeps: (4+2.i) *Deriving Use Cases from Components* and (4+2.ii) *Detailing Use Cases*. The goal of intermediate substep 4+2.i (*Deriving Use Cases from Components*) is to derive the use cases to hand out as input for the succeeding recursive execution of the 4SRS method from the components to refine. The goal of intermediate substep 4+2.ii (*Detailing Use Cases*) is to refine those use cases. The use case diagram at the detail level (y) 0 in Figure 31 depicts the use cases based on the descriptions of the components that will be refined. Those descriptions were elaborated during the execution of

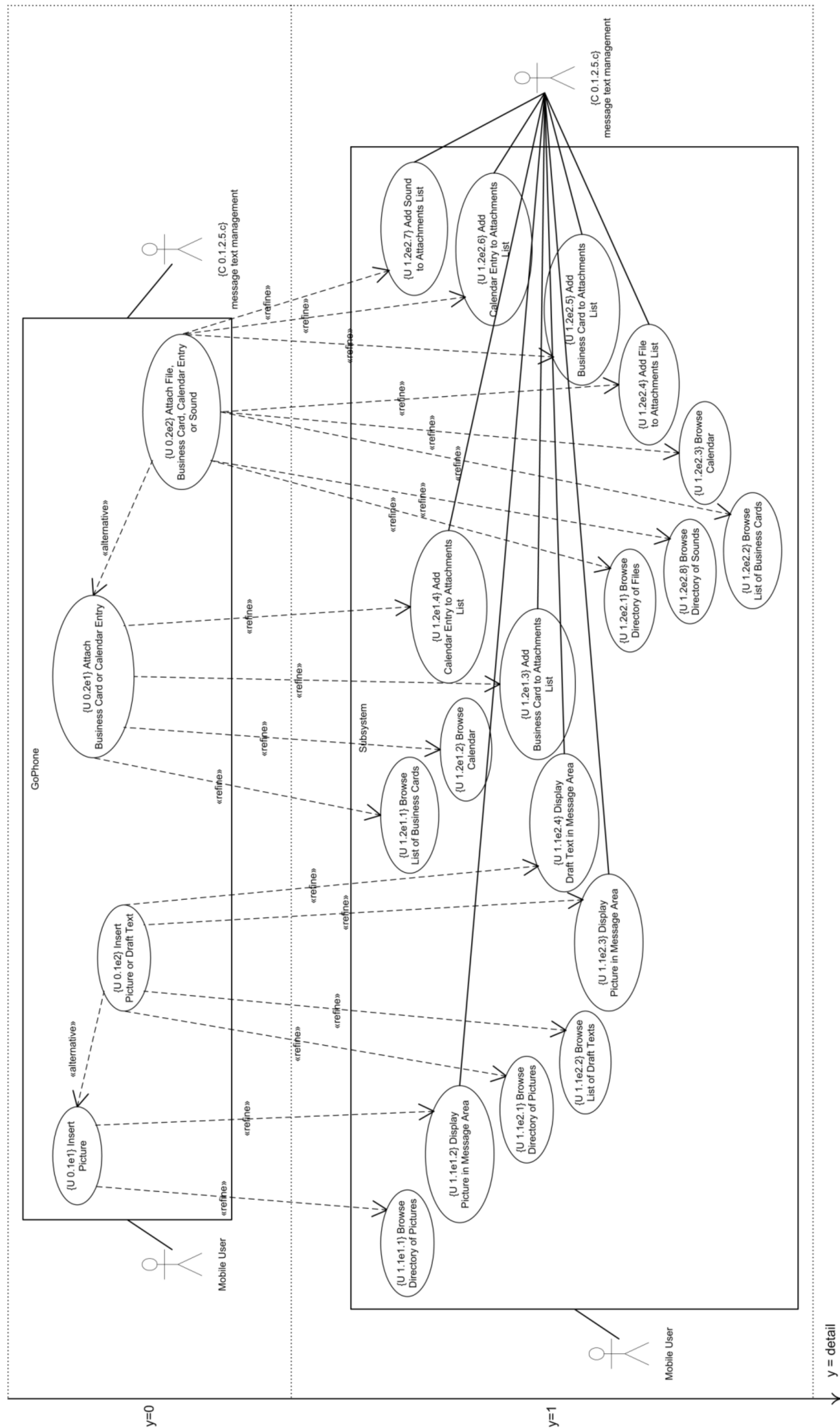


Figure 31 – Use case diagram for the first recursive execution of the 4SRS method over the GoPhone's messaging domain.

Component name: {C 0.1.2.3e1.i} picture insertion
Component description: This component provides for a user interface to allow the mobile user to insert pictures into a message. The mobile user shall be able to use this interface to insert multiple pictures. This component is responsible for notifying the mobile user on the violation of validation rules over the pictures. This component receives requests for picture insertion from the message writing functionality.

Component name: {C 0.1.2.3e1.c} picture insertion management
Component description: This component is actually responsible for inserting pictures into a message. It provides for the validation of the pictures to be inserted into a message. It is also responsible for retrieving pictures from the picture repository.

Component name: {C 0.1.2.3e1.d} object repository
Component description: This component provides for a repository of pictures.

Figure 32 – Some descriptions of components that will be refined with the first recursive execution of the 4SRS method over the GoPhone's messaging domain.

the prior step 2 from the 4SRS method and some examples are depicted in Figure 32. The component which was associated with the subsystem in the filtered and collapsed diagram of Figure 30 becomes an actor in the use case diagram at the detail level (y) 0 in Figure 31 together with the *Mobile User* actor. Although use case diagrams model user requirements and component diagrams model system requirements, the use cases from the use case diagram at the detail level (y) 0 in Figure 31 represent the system requirements from the components to refine. This is because from the perspective of the actors in Figure 31 those system requirements represent user requirements.

Detailing Use Cases

In the context of product lines the non-stepwise textual descriptions of included use cases simultaneously alternative or option cannot be considered more detailed than the non-stepwise textual descriptions of their corresponding including use cases because including use cases only contain pointers to those alternative or option use cases (e.g. in Figure 23 *Compose Message* has a pointer to *Insert Picture* that says "The mobile user inserts objects into a message"). The description of the including use cases would get chaotic with all the descriptions of all the alternatives for performing the same functionality. The other reason is that alternatives and options represent variability with regards to the including use cases and it may be the case to build a system with no variability (that system shall include neither alternatives nor options).

Consider the including use case as the use case that includes other use cases and the included use case as the use case that is included by other use cases (the UML Superstructure states that an included use case can be included by many other use cases and that an including use case can include many other use cases). As already stated in the previous subsection, this thesis has discarded the possibility of using the *«include»* relationship to turn only a part of the including use case public to be included by other use cases because that would not guarantee the coherence of the use case diagram to generate logical architectures. Therefore the sum of the functionality represented by the included use cases shall be equal to the

Use case name: {U 0.1e1} Insert Picture
Use case description: The mobile user inserts pictures into a message. The mobile user may receive notifications on the violation of validation rules over the pictures to be inserted into a message.
Alternatives: The mobile user inserts pictures or draft texts into a message. [Use cases' name: *{U 0.1.2.3e2} Insert Picture or Draft Text*]
Specializations: -
Options: -

Use case name: {U 0.2e1} Attach Business Card or Calendar Entry
Use case description: The mobile user attaches business cards and/or calendar entries to the message.
Alternatives: The mobile user attaches files and/or business cards and/or calendar entries and/or sounds to the message. [Use cases' name: *{U 0.1.2.4e2} Attach File, Business Card, Calendar Entry or Sound*]
Specializations: -
Options: -

Figure 33 – Non-stepwise textual descriptions of the use cases Insert Picture *and* Attach Business Card or Calendar Entry *for the first recursive execution of the 4SRS method over the GoPhone's messaging domain.*

Use case name: {U 0.1e1} Insert Picture
Use case description: The mobile user selects the pictures from a directory of pictures (eventually with folders), which he can browse. Upon selection of the pictures from the directory, they are displayed to the mobile user in the message area of the message editor. The mobile user may receive notifications on the violation of validation rules over the pictures to be inserted into a message. The violation of those rules prevents the display of the invalid pictures to the mobile user.
Alternatives: The mobile user inserts pictures or draft texts into a message. [Use cases' name: *{U 0.1e2} Insert Picture or Draft Text*]
Specializations: -
Options: -

Use case name: {U 0.2e1} Attach Business Card or Calendar Entry
Use case description: The mobile user selects the business cards or the calendar entries respectively from the list of business cards or from the calendar, which he can both browse. Upon selection of the business cards or the calendar entries respectively from the list of business cards or from the calendar, the business cards or the calendar entries are respectively added to the attachments list in the message editor.
Alternatives: The mobile user attaches files and/or business cards and/or calendar entries and/or sounds to the message. [Use cases' name: *{U 0.2e2} Attach File, Business Card, Calendar Entry or Sound*]
Specializations: -
Options: -

Figure 34 – Detailed non-stepwise textual descriptions of the use cases Insert Picture *and* Attach Business Card or Calendar Entry *for the first recursive execution of the 4SRS method over the GoPhone's messaging domain.*

functionality represent by the including use case (apart from glue logic). This means that this thesis forces the decomposition of use cases when using the *«include»* relationship. Nevertheless an included use case can be shared by two or more use cases.

In the context of the *«include»* relationship, the UML Superstructure states that the including use case depends on the addition of the included use cases to be complete.

The goal of intermediate substep 4+2.ii (*Detailing Use Cases*) is to refine the use cases from the use case diagram at the detail level (y) 0 in Figure 31. The refinement of those use cases begins with elaborating non-stepwise textual descriptions for them based on the descriptions of the components to be refined. Figure 33 shows those non-stepwise textual descriptions of two of those use cases. Figure 34 shows other non-stepwise textual descriptions of the same two use cases but these descriptions are auxiliary, more detailed descriptions to get to the use cases at the detail level (y) 1 in Figure 31. These last more detailed use cases are the input for the recursive execution of the 4SRS method. They are all leaf use cases as they are the most detailed ones from the use cases in the figure. Although in

Figure 31 only two detail levels were considered, that is not a rule (this thesis could have considered more detail levels if more detailing was concluded to be needed).

The Recursive Execution of the 4SRS Method

The goal of the recursive execution of the 4SRS method is to apply the method after one or more of its executions have occurred beforehand. This process is about applying the tabular transformations the 4SRS method is composed of to the target use cases (as already explained in [6]). The result will be a list of components that shall be associated with each other. The associations of components with each other are determined during the execution of the 4SRS method. The definition of these associations is not necessarily based on the descriptions of the components. This thesis tries always mentioning the interaction of components with each other in their descriptions.

The resulting artifact from the recursive execution of the 4SRS method to a subsystem of the GoPhone case study (concerning the object insertion and attaching functionalities from the messaging domain) is the component diagram in Figure 35. This diagram has then to be integrated into the logical architecture the preceding execution of the 4SRS method originated to provide for a global logical architecture.

The integration is possible because the components in Figure 35 provide for the interfaces required by the component from Figure 30.

3.5. Conclusions

This chapter elaborated on how the UML does not support refinement of use cases at the moment and how it can be extended in order to support that formally. As a result this thesis proposed to extend the UML metamodel with a new kind of relationship in the context of use cases (the *«refine»* relationship). The support of use case refinement is pertinent in large software systems development in order to deliver less complex modeling artifacts to the teams implementing those systems. Use cases shall be delivered to the different teams with responsibility for further designing and implementing the different sets of functionalities (a single team is not expected to develop the whole system). According to what was clarified in this chapter, the *«include»* relationship is not appropriate to model the refinement of use cases since the refinement activity implies lowering the abstraction level of use cases (particularly of their non-stepwise textual descriptions). Despite this, the *«include»* relationship shall not be discarded and shall live along with the *«refine»* relationship as this

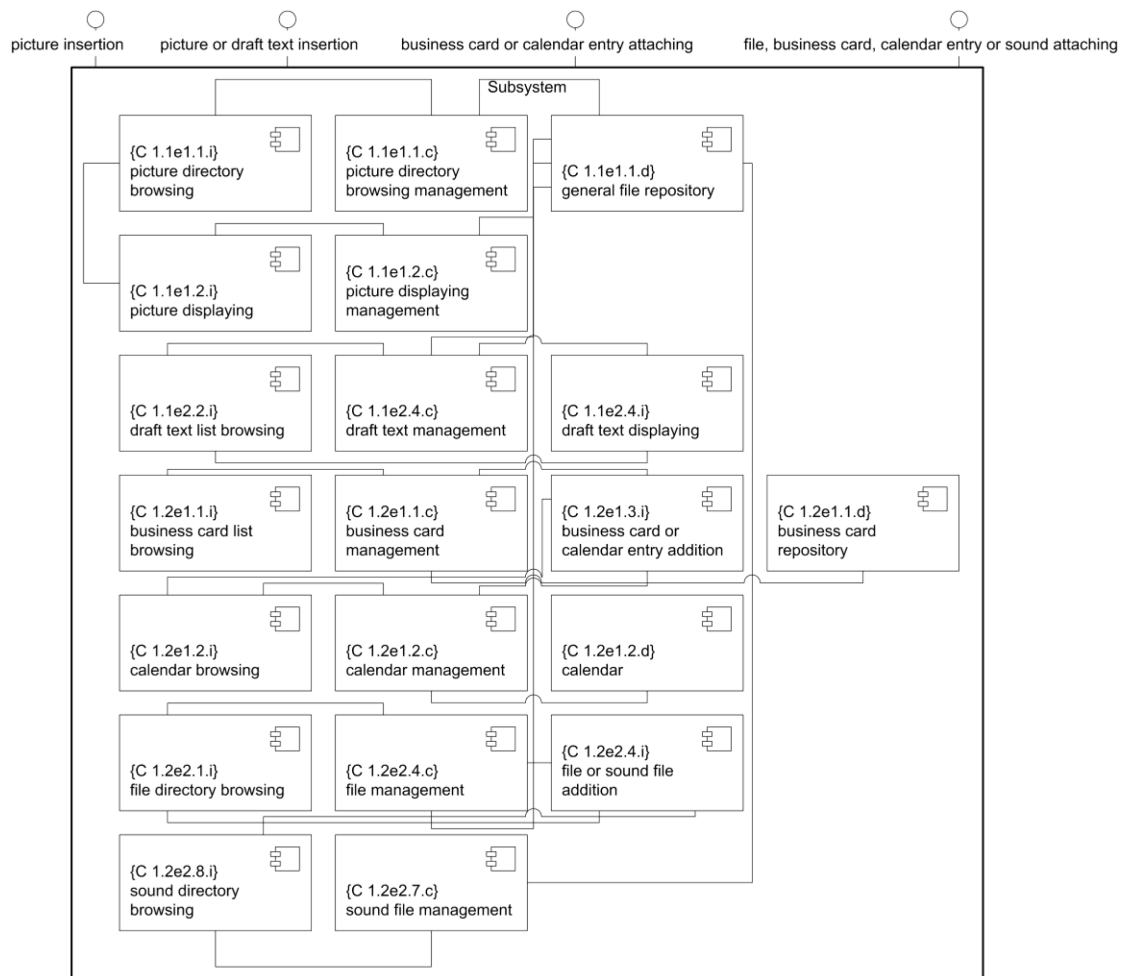


Figure 35 – Component diagram resulting from the first recursive execution of the 4SRS method over the GoPhone's messaging domain.

chapter elucidated.

This chapter has elaborated on the representation of variability in use case diagrams and the implications of functionally refining use cases when variability is represented in this kind of diagrams. It began by providing an in depth analysis of the state-of-the-art concerned with both of these topics. Based on the position of this thesis towards the related work, an extension to the UML metamodel to represent the three types of variability that were synthesized was proposed: alternatives, specializations and options. This thesis concluded that alternatives and specializations shall be adequately modeled with the *«extend»* relationship, and that options shall be adequately modeled with a stereotype on use cases. This conclusion was based on the UML metamodel's semantics associated with the relationships for connecting use cases in use case diagrams: alternatives, specializations and options represent supplementary functionality. This thesis has also introduced the functional

refinement of use cases connected through *«extend»* relationships due to its pertinence in large-scale product line contexts.

This chapter presented the capabilities of the 4SRS method for refining logical software architectures with variability support. This approach to the functional decomposition of families of software systems is an important instrument for moving from the analysis to the design of software in a guided way. The stepwise transformation of use cases into logical software architectures provides for that guidance.

The model-based transformation of user functional requirements in the shape of use cases (from the analysis of software) into system functional requirements in the shape of component diagrams (logical software architectures, which are from the design of software) is the most valuable contribution of the 4SRS method. This method is an instrument to get to the design of families of software systems from their analysis, which shall be the most important value for Software Engineering to bring into the software development process.

The second most valuable contribution of the 4SRS method is its ability to refine design artifacts (logical software architectures). The refinement of logical software architectures is relevant for defining subprojects for the software systems development and for partitioning software systems into subsystems. Hence the 4SRS method is appropriate for multiproject and/or multiteam contexts. The refinement of logical software architectures is also relevant for reducing the complexity in the modeling activity of large-scale software systems. The notion of variability allows for the method to be applicable for the modeling of software product lines.

Another important contribution of the 4SRS method to Software Engineering is the ability to demand for the removal of redundant requirements and the finding of missing requirements (this last one both at the level of logical architectural components and also at the level of use cases).

The 4SRS method was not automated with a tool for that purpose prior to this thesis. Some steps can be perfectly automated with tool-support. Some other steps rely on the Software Engineer to be executed. This means that some subjectiveness is in the process of modeling logical software architectures with the 4SRS method but it does not mean that the steps that rely on the Software Engineer to be executed cannot be executed with tool-support

in order to prevent unnecessary subjectiveness. Although the 4SRS method is subjective to some extent, that can be reduced with tool-support.

The 4SRS method considered refinement in past works, yet so far there was not any formalization of use case refinement, which is relevant for the preparation of the recursive method's execution. Besides that formalization this thesis has systematized use case variability modeling, which is relevant for modeling use cases with variability support, for determining the use cases that will be the input for the method's execution (recursive or not) and has implications when executing the method itself. The relevance of the exercise this thesis presented in this chapter resides on the demonstration that a modeling method is capable of dealing with the refinement of logical architectures with variability support, which gains acute significance in the context of a high number of user functional requirements. The GoPhone case study and its message sending functionality were used to demonstrate the approach of this thesis. The extension of the 4SRS method this thesis proposes in this chapter includes the formalization of filtering and collapsing techniques applicable to the artifacts delivered by the method's execution (recursive or not) and the formalization of the transformation from components to use cases in order to prepare the recursive execution of the method. Taking refinement into account in stepwise methods for the modeling of logical architectures has a noteworthy impact on the execution effort of some of their steps.

Chapter 4 will address the classification of patterns that supports the use of the MVC by the 4SRS. Chapter 5 will present the work undertaken to automate the model transformation the 4SRS allows modelers to conduct.

4. Pattern Classification for Model Transformation

Section 4.2 is devoted to exhibiting the proposed pattern classification in abstract terms before formalizing categories and positioning patterns at those categories.

Section 4.3 is targeted at demonstrating the feasibility of the proposed solution to the systematic use of software development patterns by using some concrete examples of patterns positioned at distinct categories of the proposed classification to illustrate the different types of patterns formalized, including the pattern used by the 4SRS in the transformation it guides.

4.1. Introduction

In the context of software development, patterns are provided as reusable solutions to recurrent problems. In other words, software patterns are reusable solutions to problems that occur often throughout the software development process. Pattern classifications emerged as a way to organize the many patterns that have been synthesized. *Pattern classification* is the activity of organizing patterns into groups of patterns that share a common set of characteristics. The simple fact of organizing patterns into classifications is a way of building a stronger knowledge on patterns, which allows understanding their purpose, the relations between them and the best moments for their adoption [50].

Despite their use within the software development process, the use of patterns may not be systematic. In the context of this chapter, the systematic use of software development

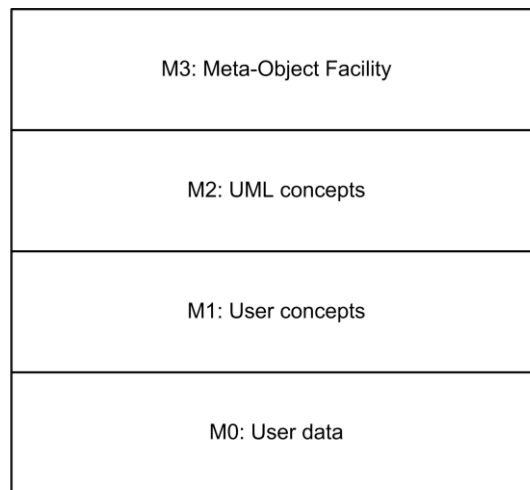


Figure 36 – The OMG modeling infrastructure or Four-Layer Architecture.

patterns means that decisions on the application of patterns are less subjective and more objective. Besides that, a lot of pattern classifications were ellaborated until the present day, yet none of them formally stated which sort of patterns shall be used in which particular moment of the software development process. This chapter will provide for specific directives on how to systematically adopt patterns within a multilevel and multistage software development process. A multilevel and multistage classification of patterns will be the foundation of such systematic use of patterns. It will also justify the pattern used by the 4SRS to transform analysis artifacts into design artifacts.

A multistage software development process can be defined as a software development process composed of some stages organized in a consecutive temporal order. Each stage is separated from the contiguous ones by well defined borders. Moreover each particular stage is composed of a flow of well defined activities. Each stage's activities are conducted by specific professionals, using specific technologies (frameworks, languages, tools), under the directives of specific methodologies (processes, notations and methods) to achieve specific goals. Borders are well defined if the shift in the professionals, technologies, methodologies and goals that takes place when moving from one stage to another is identified in terms of the development process. A multilevel software development process can be defined as a software development process concerned with the levels of abstraction in which the different artifacts involved in the development of software are handled. In the context of this chapter, those levels are the levels of the OMG (Object Management Group) [90] modeling infrastructure or Four-Layer Architecture [11], depicted in Figure 36. The OMG modeling infrastructure comprises a hierarchy of model levels just in compliance with the foundations of MDD [11]. Each model in the Four-Layer Architecture (except for the one at the highest level) is an instance of the one at the higher level. The first level (*user data*) refers to the data manipulated by software. Models of user data are called *user concepts models* and are one

level above the user data level. Models of user concepts models are *language concepts models*. These are models of models and so are called metamodels. A metamodel is a model of a modeling language. It is also a model whose elements are types in another model. An example of a metamodel is the UML metamodel. It describes the structure of the different models that are part of it, the elements that are part of those models and their respective properties. The *language concepts metamodels* are at the highest level of the modeling infrastructure. The objects at the user concepts level are the model elements that represent objects residing at the user data level. At the user data level, data objects may be the representation of real-world items.

Patterns are provided by pattern catalogues such as [8, 50-52, 54, 91-94]. Pattern languages are more than pattern catalogues (collections of patterns). A pattern language is composed of patterns for a particular (small and well-known) domain. Those patterns must cover the development of software systems down to their implementation. A pattern language must also determine the relationships between the patterns the language is composed of. The language's patterns are its vocabulary, and the rules for their implementation and combination are its grammar [8].

The *adoption* of a pattern (pattern adoption) is composed by the set of activities that consist of using the pattern somehow when producing software artifacts. Namely those activities are: (1) pattern interpretation; (2) pattern adaptation; and (3) pattern application. Patterns have to be interpreted in order to be applied. For the reason that usually patterns are not documented by those who apply them, they have to be interpreted prior to their application. The *interpretation* of a pattern is the activity that consists of reading the pattern from the pattern catalogue and reasoning about the solution the pattern is proposing for that problem in that given context. Following the interpretation activity, the adoption process may require the patterns to be adapted somehow [51, 95]. The *adaptation* of a pattern is the activity of modifying the pattern from the catalogue without corrupting it (corrupting the pattern includes corrupting the pattern's semantics and the pattern's abstract syntax). Finally the *application* of a pattern is its actual use in the development of software, whether to develop software products or families of software products, or to inspire the ellaboration of design artifacts since some patterns are not identifiable in the source code as they are not meant to give origin to code directly [96].

Habitually pattern catalogues represent patterns at the M1-level of the OMG modeling infrastructure or Four-Layer Architecture. This thesis considers that leveraging patterns to the M2-level is a way of turning the decisions on their application more objective as well as of reducing the misinterpretation of patterns from catalogues and the corruption of patterns during the pattern adaptation process. Misinterpretation and corruption of patterns can lead to the irremediable loss of the advantages of adopting those patterns. Considering the OMG modeling infrastructure as a multilevel architecture, *multilevel instantiation* (or the instantiation of M2-level patterns at the M1-level) shall occur during the adoption of patterns.

This chapter is an original contribution to the improvement of the software products' quality given that it provides for some directives on how to adopt software patterns in such a way that the original advantages of the adopted pattern are preserved. The originality of the contribution is due to the novelty character of the pattern classification, which relies on the fact that it is based on the software development process. The classification this thesis proposes represents a benefit in terms of the process of developing software as it allows knowing (by classifying the patterns according to it) in which moment of the software development process to use the patterns and in the context of which Software Engineering professionals, technologies and methodologies. This chapter contributes for MDD since it addresses the OMG modeling infrastructure through the multilevel character of the proposed classification. The classification considers that patterns can be represented at different levels of the OMG modeling infrastructure, which influences their interpretation. The usefulness of a multilevel and multistage pattern classification resides in avoiding that the patterns from a specific category are handled by the inadequate professionals, technologies and methodologies. By classifying the patterns (in this case, the software development patterns) this thesis assures that the professionals with the right skills (who use the technologies and methodologies adequate to their profile) use the right pattern categories. For instance it would be inadequate for a product manager to use a pattern from the GoF book. That would not produce the desired effects of using such kind of pattern.

Atkinson and Kühne discuss the foundations of MDD in [11]. The goal of MDD is to raise the abstraction level at which software programs are written by reducing the software development effort needed to produce a software product or set of software products. That effort is reduced by allowing modeling artifacts to actually deliver more to the software product or set of software products under development than they do when used just for documentation purposes. Automated code generation from visual models is one of the main

characteristics of MDD and the ultimate goal of the model transformation cycle. The other main characteristic of MDD is the reduction of models' sensitivity to change by (1) making them accessible and useful (therefore understandable in the first place) by all stakeholders; (2) changing models while the systems that rely on them are running; (3) storing the models in formats that other tools can use; and (4) automating the process of translating platform-independent models to platform-specific models and the former to code. Point 1 is achieved through notation, point 2 through dynamic language extension (through the runtime extension of the set of types available for modeling, which are the *language concepts* previously mentioned in this chapter), point 3 through interoperability and point 4 through user-definable mappings. An MDD infrastructure must provide for visual modeling and the means for defining visual modeling languages, which are abstract syntax, concrete syntax, well-formedness rules (constraints on the abstract syntax) and semantics. Such infrastructure must also provide for the use of OO (Object-Oriented) languages that allow extending the set of types available by those languages' APIs (Application Programming Interfaces) despite in a static way (not at runtime as MDD actually requires). Describing the previously mentioned concepts from the *language concepts metamodel* level, the concepts from the *language concepts* level and the also previously mentioned *user concepts* in a metalevel way (e.g. with the OMG modeling infrastructure) allows adding new *language concepts* dynamically at runtime. Finally an MDD infrastructure must provide for the means to define model transformations by the user in order to translate models ultimately into code of a specific implementation platform. A means to define model transformations is to use the model transformation languages QVT (Query/View/Transformation) [97] or ATL (ATLAS Transformation Language) [98].

MDD relies on models that can be used as input to automated transformations [99]. In [100] it is stated that the transformation of models into code can be facilitated by using software development patterns. The means to obtain that is to pack patterns as reusable assets with encapsulated implementation. This thesis considers that a packed pattern can contain either the (pattern's) model and the code or just the model since not all patterns are to be directly converted into programming code. Depending on the type of pattern, it can be translated into code that can be directly included in the software solution under development in the programming environment for further manipulation or it can be imported in the modeling environment to be used in the modeling of the software solution by customizing the pattern's model elements and relating them with the remaining model elements. If the packed pattern contains the model and the code, then both the inclusion of the code in the software

solution in the programming environment and the import of the model in the modeling environment can be performed. These ways patterns can be involved in the visual modeling of software systems and/or the automated code generation from visual models used in the development of those software systems just like MDD requires. According to [2] a code template can be attached to the pattern to generate code from the model to which the pattern was applied. Finally this thesis considers that there is no point in using implementation patterns as packed patterns that can be imported in the programming environment as most of the times they depend on modeled elements parameters to be instantiated. In fact some of those patterns are already available in the programming environment through context menus of source code elements generated from models.

The models used to develop a software product or family of products evolve along the software development lifecycle and according to MDD end up in code. Pattern classifications help the actors involved in MDD software development processes to choose the most convenient patterns (in the form of models) to be incorporated into the models that are later transformed into code. By dividing patterns into categories all pattern classifications contribute to the use of patterns to develop software according to the MDD directives as the effort to select patterns without them would be higher, which would not contribute to the goal of MDD (raising the abstraction level at which software programs are written by reducing the software development effort). Patterns in the form of models also help raising the abstraction level at which software programs are written. Those that are not represented as models because they are to be only in code contribute to MDD by being considered in the process of automating code generation from visual models, during which the structure of code is thoroughly defined for the code that is generated from the visual models. For instance if the model from which to generate code incorporates the *Getter/Setter* pattern, the implementation patterns like those in [51] applicable to the target platform have to be considered in order to generate source code for the getters/setters (operations) [99].

Especially the pattern classifications that reveal some kind of software development procedural notion contribute to MDD given that it is more likely that the most adequate patterns are selected. That is because those classifications avoid the wrong patterns to be handled by the wrong professionals, technologies and methodologies that make more sense in the context of a specific process' phase(s). Specific professionals, technologies and methodologies are more skilled to handle specific kinds of models that address specific kinds of problems in specific moments of MDD software development processes. This means that

specific professionals, technologies and methodologies are more skilled to handle specific kinds of patterns (in the form of models) to be applied to the specific kinds of models they handle as input to the automatic generation of code. Those patterns address specific kinds of problems, which can be better understood by those professionals due to their skills and profile. The pattern classification this thesis proposes in this chapter is particularly based on a software development process, which is the RUP. The proposed pattern classification is also related to the OMG modeling infrastructure in the sense that it demands for the patterns to be classified according to the abstraction level at which they are represented (the OMG modeling infrastructure's levels M2, M1 or M0) for the reasons this thesis will expose later on in this chapter.

4.2. Multilevel and Multistage Classification

The multilevel and multistage pattern classification in this thesis has three dimensions: the level (from the OMG modeling infrastructure), the Software Engineering discipline (based on the RUP) and the stage of the software development process (also based on the RUP). The classification includes an attribute, besides the three dimensions: the nature of the domain.

The Classification Explained

Domains can be of horizontal nature or of vertical nature. The vertical domains represent particular business domains and correspond to activity sectors (e.g. banking, insurance, trading, industry). The horizontal domains are traversal to the vertical domains, which means that they represent areas of knowledge common to every business domain (e.g. accounting, human resources, stock, project management). This does not mean that business applications (banking applications for example) shall contemplate all horizontal domains but it means that horizontal applications (for instance accounting applications) shall be usable by all the businesses possible, although there is a part of each horizontal domain that is only applicable to each business domain (e.g. there are accounting rules specific to the banking sector).

The multilevel character of the classification in this chapter lies on the different levels of the OMG modeling infrastructure, which provides for a multilevel, four-layer modeling architecture. The classification's RUP-based Software Engineering discipline dimension provides for clear hints on the professionals who shall handle specific types of patterns, with particular technologies and methodologies. At last the classification's multistage character is

given by the dimension associated with the RUP-based phases of the software development process. The hypothesis of this thesis is that the development of software can take more advantage of patterns and their proposed solutions if their adoption occurs at the right moment of the process of developing a software solution and within the context of the right Software Engineering professionals, technologies and methodologies, respecting the levels patterns shall follow throughout the adoption process, which involves dealing with models at different levels of abstraction as well. This thesis considers that the positioning of patterns at the wrong category of any process-based classification leads to a misinterpretation of those same patterns, resulting in an unsuccessful adoption. By unsuccessful adoption it is meant a constriction of the original patterns' advantages. Although the effort of this thesis is towards minimizing the effects of pattern misinterpretation, pattern adaptation can still and will most likely occur over the pattern models going to be exposed in this chapter. The classification in this thesis (especially due to its multilevel character) reduces the chances of pattern misinterpretation since it reaches the metamodeling level (M2-level from the OMG modeling infrastructure). Unsuccessful pattern adoptions can lead to software solutions where the adopted patterns are unrecognizable.

Patterns vary in their abstraction level. Actually the same pattern may be positioned at different abstraction levels according to its representation. Normally the interpretation of a pattern is performed directly from the catalogue to the particular context of the product or the family of products. This way both the representation of the pattern in the catalogue and the interpretation of that same pattern are situated at the M1-level, which may not be adequate if the goal is to systematically use patterns and reduce the unsuccessful pattern adoptions during software production. Thinking about software families the matter with software product lines and software patterns may lie on the instantiation of M2 artifacts at the M1 layer, which again indicates the relevance of the abstraction level concerning the adoption of software patterns.

This thesis adopted the geometrical terminology to represent the pattern classification. Patterns can be positioned at the *pattern positioning geometrical space* placed in the first octant of the orthonormal referential like Figure 37 (on the left) shows. Actually that space may be partitioned into cubes. As patterns can be classified with three possible values according to two of the three axes of the referential and with four possible values according to the other axis, the pattern positioning geometrical space can be divided into 3×3×4 cubes as can also be seen from Figure 37 (on the left). The fourth criterion is the domain nature and, in the case of the pattern positioned at the pattern positioning geometrical space in the figure,

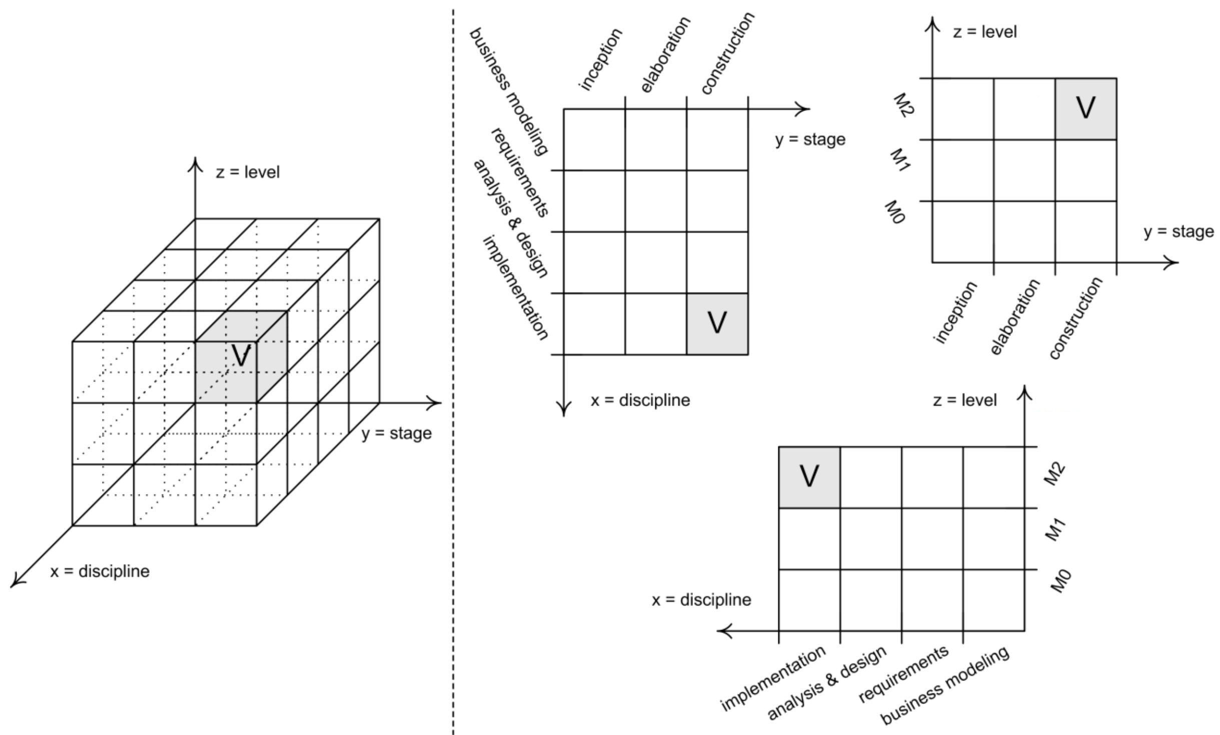


Figure 37 – Orthonormal referential with the dimensions of the multilevel and multistage classification on the axes plus the pattern categorization three-dimensional space (on the left). The projections of a pattern's positioning in a two-dimensional area (on the right).

it takes the value vertical (V). That is why the grey cube representing the pattern is tagged with a *V* (the domain nature is not a dimension, it is an attribute so it does not correspond to an axis). Figure 37 (on the right) presents the projections of the pattern's positioning represented in a three-dimensional space on the left of the figure, this time in a two-dimensional area. The possible values of each dimension are attached to the axes. They will be detailed later on in this section of the chapter.

As this thesis already argued, leveraging patterns to the M2-level is a way of turning the decisions on the application of patterns more objective as well as of reducing the misinterpretation of patterns at the M1-level with all the disadvantages that subjective decisions and misinterpretation bring into the software development process and the quality of the software product itself. Multilevel instantiation shall occur during the adoption of patterns in order to systematize their use. Patterns are positioned at the pattern positioning geometrical space (according to the axes representing the Software Engineering disciplines and the OMG modeling infrastructure levels) with regards to their representations: the M2 model (pattern M2), the M1 model (pattern M1) and the M1 code. As it will be seen later on in this chapter, the pattern in the M1 representation is an instance of the pattern in the M2 representation, whereas the code is a transformation of the pattern's M1 model into a specific

programming language code. The abstraction level decreases when moving from models at the M2-level to the code. Pattern catalogues represent patterns with M1 models and M1 code (source code). They do not propose patterns using their M2 representation (or metamodels). That is not the approach of this thesis as it will be detailed in the next section of this chapter. The course of the artifacts inside the pattern positioning geometrical space as well as the course's projection on the discipline×level plan indicates that a small process within the whole software development process must occur when systematically dealing with patterns, which includes multilevel instantiation and transformation of models into code.

The reason for representing patterns in catalogues in their M1 representation is due to the willing of not compromising the applicability of patterns to a broader domain coverage. This is the risk of rising the abstraction level from M1 to M2. Naturally every risk has some potential for success and the risk of rising the abstraction level carries with it the advantage of turning the pattern adoptable by more domains. In order to adapt a pattern from a catalogue to a different domain than the one considered for representing the pattern in the catalogue it is necessary to know in which areas to change it and for that the pattern's structure has to be known as well. To know the structure of the pattern, the pattern has to be represented at the M2-level.

Although the pattern may assume various representations according to the level it is positioned at, it is the same pattern since the diverse representations of the pattern answer to the same problem, within the same context, with the same solution, driven by the same recurrent and predictable forces [50, 51, 101]. Having various representations for the same pattern implies that the M2 representation of a pattern covers more functionality, therefore reaching higher levels of functional completeness than the M1 representation.

The Dimensions and the Attribute of the Classification

Next each criterion (the dimensions and the attribute) of the multilevel and multistage classification are described. As already stated, the multilevel and multistage classification considers the moment of the software development process during which specific kinds of patterns, what this thesis calls pattern types (see section 4.3 for more information on the multilevel and multistage pattern types), shall be used. The *Discipline* dimension represents these different moments in the process of developing software. The multilevel and multistage classification considers as well the context in which patterns shall be used in terms of Software Engineering professionals, technologies and methodologies. Stages of software

development are defined by different profiles of Software Engineering professionals who work with different kinds of technologies and methodologies tailored to their profiles. The *Stage* dimension represents these different stage-related professionals, technologies and methodologies in the process of developing software. The classification in this thesis also considers a modeling infrastructure that was adopted to avoid subjective decisions on the application of patterns, and situations of misinterpretation and corruption of patterns from catalogues while interpreting and adapting them respectively. The modeling infrastructure considered is the OMG modeling infrastructure. The *Level* dimension represents the different levels of the OMG modeling infrastructure. Finally the multilevel and multistage classification takes into account that domain-specific artifacts for the development of families of software products are common these days, which means that the applicability of patterns to particular domain natures allows to choose between the patterns that are most adequate to a domain of a software product or family of products. The *Domain Nature* attribute represents the different (both) domain natures to which patterns are most applicable (or the applicability of patterns to both domain natures).

As the subtitles indicate, the *Discipline* dimension can take the values {*business modeling*, *requirements*, *analysis & design*, *implementation*} and the *Stage* dimension can take the values {*inception*, *elaboration*, *construction*}. The *Level* dimension corresponds to the levels of the OMG modeling infrastructure {M1, M2}. For now M3 is not being considered. M3 is not being represented in the figures because M3 can be represented with (UML) models and the classification in this chapter was not yet worked at that level. Despite that, M0 is represented in the figures to remember that after M1 code (compile-time code) there is M0 code (runtime code) but runtime code is not relevant to the classification in this chapter. The *Domain Nature* attribute which was already explained earlier in this section of the chapter can take the values {*vertical*, *horizontal*, *agnostic*}.

In order to use this classification do the following: (1) analyze the pattern you want to classify according to the dimensions *Discipline* and *Stage*, and give a value to each of those dimensions for that pattern you are classifying; (2) conclude on the pattern type (see section 4.3 for more information on the multilevel and multistage pattern types and how the dimensions *Discipline* and *Stage* determine the pattern type); (3) determine the pattern's level, which corresponds to giving a value to the *Level* dimension; (4) if the pattern is not represented in its M2 representation, draw an M2 model of the pattern; (5) by looking at the M2 representation of the pattern describe its semantics in textual form; and finally (6) by

looking at the pattern's M2-level textual description and at the pattern's description in the catalogue classify the pattern in what its domain nature is concerned, which is equivalent to tagging the pattern with one of the three possible values for the *Domain Nature* attribute.

The assignment of patterns to particular chunks of the classification is dependent on the pattern type, therefore on the RUP's textual descriptions of its disciplines and phases (to conduct step 1). In order to determine the pattern's level the classifier (the subject who classifies) must be familiarized with the Four-Layer Architecture since he has to understand if the concepts the pattern presents are situated at the M2 or at the M1 levels. The classifier has to know the notion of multilevel instantiation. The classification process is dependent on the subject who conducts the process. Determining the pattern type is subjective as it implies looking at the textual descriptions of the RUP's disciplines and phases. Analyzing textual descriptions is subjective (at least in this approach). Determining the pattern's level is also subjective (at least in this approach) because it depends on the classifier's knowledge.

The Discipline Dimension

The RUP's Business Modeling Software Engineering Discipline

The RUP's *Business Modeling* discipline shall comprise activities of derivation of the software requirements the system to be developed must support in order to be adequate to the target organization and of analyzing how that system fits into the organization. The goal of the *Business Modeling* discipline is to model an organizational context for the system.

The RUP's Requirements Software Engineering Discipline

The RUP's *Requirements* discipline shall comprise activities of stakeholder request elicitation and of transformation of those requests into requirements on the system to be developed. Those requirements shall span the complete scope of the system. The requirements on what the system shall do have to be agreed with the stakeholders (customer and others). The goal of the *Requirements* discipline is to provide developers with a better understanding of the requirements the system must fulfill based on the customer's (or other stakeholder's) requests. It is also the goal of this discipline to delimit the boundaries of the system to be developed.

The RUP's Analysis & Design Software Engineering Discipline

The RUP's *Analysis & Design* discipline shall comprise activities of transformation of the requirements elicited with the stakeholders into a design of the system to be deployed.

The design of the system shall contemplate an architecture for the system. The goal of this discipline is to specify the design of the system to be developed.

The RUP's Implementation Software Engineering Discipline

The RUP's *Implementation* discipline shall comprise activities of development, unit testing of the developed components and integration of the software components that will allow the system requested by the stakeholders to be deployed based on the design specifications elaborated in the context of the *Analysis & Design* discipline. When developing the system, the organization of the code shall be defined according to the layers of the subsystems to implement. Developing the system through components implies that all the components produced by different teams are integrated into an executable system. The goal of this discipline is to translate the design elements that came up in the context of the *Analysis & Design* discipline into implementation elements (source files, binaries, executable programs and others).

The Stage Dimension

The RUP's Inception Software Development Stage

The RUP's *Inception* stage shall comprise activities of discrimination of the critical use cases of the system and the primary operation scenarios vital to the design tradeoffs that will have to be made later on during the process. At least one candidate architecture shall be exhibited (and maybe demonstrated) and shall support the primary scenarios (or at least some of them) in order for the stakeholders to agree upon the fulfillment of the requests they exposed to the Software Engineers responsible for the requirements elicitation. The goal of this stage is to ensure that the software development project is both worth doing and possible to execute.

The RUP's Elaboration Software Development Stage

The RUP's *Elaboration* stage shall comprise activities of architecture handling like ellaborating a baseline architecture of the system, thus providing a stable basis for further design and implementation work which will take place during the *Construction* stage. This architecture shall contemplate and reflect the most significant requirements for the architecture of the system. Architectural prototypes shall be used to evaluate the stability of the architecture. The goal of this stage is to elaborate an architectural foundation for the upcoming detailed design and implementation efforts.

The RUP's Construction Software Development Stage

The RUP's *Construction* stage shall comprise activities of development of deployable software products from the baseline architecture of the system elaborated during the prior stage. The design, development and testing of all the requested functionality for the system shall be completed during this stage. The construction of the software system shall be conducted in an iterative and incremental way. It is during the construction of that software system that remaining use cases and other requirements are described, others are further detailed, the design built during the previous stage is enlivened and the implemented software is tested. The goal of this stage is to develop a complete software product ready to transition to the users.

The Level Dimension

The *Level* dimension of the classification corresponds to the abstraction levels of the Four-Layer Architecture. Each model in the Four-Layer Architecture except for the one at the highest level is an instance of the one at the higher level. The M0-level refers to the data manipulated by software. The M1-level refers to models of user concepts. The M2-level refers to UML concepts models. These are models of models and so are called metamodels. A metamodel is a model whose elements are types in another model (an example of a metamodel is the UML metamodel). It describes the structure of the models, the elements that are part of those models and their properties. The meta-metamodels are at the highest level of the modeling infrastructure, the MOF (Meta-Object Facility) [102] or M3-level.

The Domain Nature Attribute

The *Domain Nature* attribute indicates whether the pattern is more adequate to vertical domains (industry, commerce, services and others) or to horizontal domains (accounting, stock, project management and others). Some patterns as it will be evidenced later in this chapter are domain nature agnostic, which means that they are applicable both to vertical and to horizontal domains.

4.3. Pattern Classification Types

Following are the pattern types from the multilevel and multistage classification. A pattern type represents a kind of pattern that is classified with the same *Discipline* dimension's value and the same *Stage* dimension's value. A description is provided for each of the pattern types as well as the classification according to the *Discipline* and *Stage* dimensions. The classification of pattern types according to the *Level* dimension does not

make sense as it depends on the representation of the pattern and has no influence on the definition of the pattern types themselves. The pattern types are: business patterns, analysis patterns, enterprise patterns, architectural patterns, design patterns and implementation patterns. These names were chosen because they are the most common pattern names in the literature and make the most sense in this thesis' definitions of the pattern types.

This section will expose some examples of patterns that were classified with different pattern types. The patterns in this section suit the purpose of demonstrating how this thesis has applied the multilevel and multistage classification of patterns. This thesis provides for a representation of the patterns as M2-level (meta)models and as M1-level models (when applicable).

Be aware that some of the patterns that are going to be analyzed in this section were not classified with the same pattern type name they were classified with using the classification in this chapter. For instance the *Posting* pattern was classified as a business pattern by Pavel Hruby in [103] but this thesis classifies it as an analysis pattern.

Business Patterns

The term *business pattern* is inspired on IBM's definition of business pattern [92].

Business patterns are more pertinent in the context of vertical domains. They make the most sense to be handled during the *Inception* stage by professionals, technologies and methodologies from the *Business Modeling* and *Requirements* disciplines.

Business patterns are used to describe a solution to accomplishing a business objective. They shall address the users of the solution, the organization's software systems the users interact with (or the organization itself) and the organization's information (available through those systems or the organization itself). Business patterns may refer to e-business solutions that convey an organizational framing, validity and conformance of the solution to the business problem the solution is trying to solve. Software solutions shall be sustained by the business and this is achieved with the adoption of business patterns.

Examples of business patterns can be seen in [92] and also in [52].

Figure 38 (on the left) illustrates the positioning of business patterns according to the *Stage* and the *Discipline* dimensions.

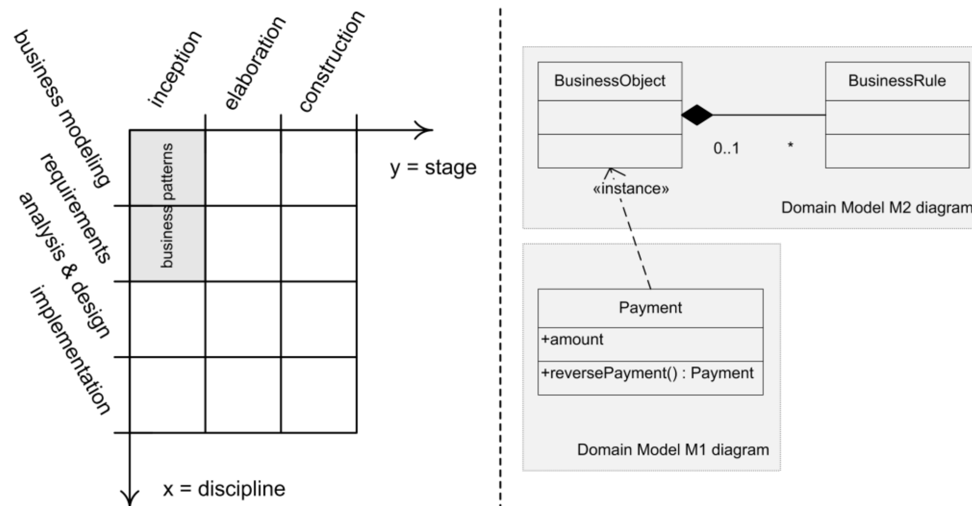


Figure 38 – The business patterns' positioning according to the Stage and the Discipline dimensions (on the left). The Domain Model pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right).

The Domain Model Pattern

The *Domain Model* pattern's goal is to produce an object model of the domain or business area. A domain model must distinguish between the data the business involves and the business rules (or the rules used by the business). The behavior expressed by these business rules shall be placed in the business object that really needs it. Figure 38 (on the right) shows a model with an example of the *Domain Model* pattern in the M1 representation as well as the M2 representation of the pattern. The *Domain Model* pattern is composed of two types of concepts: business objects (or domain objects) and business rules. This is evidenced by the *Domain Model* M2 model in Figure 38 (on the right).

The *Domain Model* pattern suits the modeling of every business domain possible as every business domain has business objects and business rules on those objects. Even though the pattern is applicable to all business domains it is not appropriate to the modeling of a horizontal domain or to the modeling of structural business domain commonalities, which makes of it applicable to domains of vertical nature.

The *Domain Model* pattern does not show how to model objects or rules for a specific business domain but the types of concepts the pattern handles are business-related and shall be instantiated in order to model business domains. Besides and more important than that, the *Domain Model* pattern allows to model objects and rules that shall be handled by the solution to the business problem the solution is trying to solve. The *Domain Model* pattern is a very atomic pattern as it does not address the users of the solution or the organization's software

systems the users interact with (or the organization itself); nonetheless it is adequate to reach the business domain model from the candidate architecture that shall be exhibited to the stakeholders. For all of these reasons this thesis considers that the *Domain Model* pattern shall be classified as a business pattern.

By looking at the RUP's textual descriptions of its disciplines and phases, this thesis concluded that the *Domain Model* pattern shall be used during the *Inception* software development stage and in the context of the *Business Modeling* and *Requirements* Software Engineering disciplines as seen in the previous section of this chapter. During the *Inception* stage a domain model must be built from a candidate architecture that translates the critical use cases and the primary operation scenarios. That domain model may be achieved with the application of the *Domain Model* pattern. The pattern shall help translating the requirements elicited with the stakeholders. Those requirements have to be adequate to the target organization, which is a concern of the *Requirements* discipline.

Analysis Patterns

The term *analysis pattern* is inspired on Fowler's definition of analysis pattern [94].

Analysis patterns are more applicable to horizontal domains. They shall be used during the *Inception* stage by professionals, technologies and methodologies from the *Business Modeling* and *Requirements* disciplines. In spite of being called analysis patterns it does not make sense to use them in the context of the *Analysis & Design* discipline. They were called so because *analysis pattern* is a terminology spread out the literature and also because Fowler's definition of analysis pattern inspired the definition of analysis pattern in this thesis. In an older informal terminology, the development of software is composed of three phases: analysis, design and implementation. With RUP formalizing the dimension of business modeling in the process of software development, analysis was divided into business modeling and requirements. The former design discipline corresponds to RUP's *Analysis & Design*.

Analysis patterns are solutions to recurrent problems in many (business) domains. They are composed of concepts that represent structural commonalities when modeling many different business domains.

Examples of analysis patterns can be seen in [94].

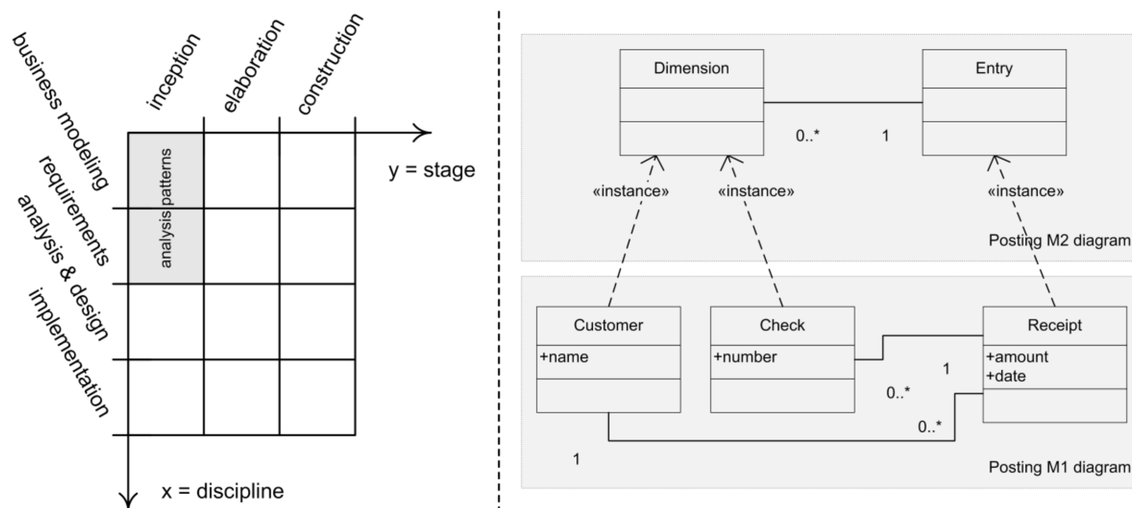


Figure 39 – The analysis patterns' positioning according to the Stage and the Discipline dimensions (on the left). The Posting pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right).

Figure 39 (on the left) shows the positioning of analysis patterns according to the *Stage* and the *Discipline* dimensions.

Business patterns and analysis patterns are *dual patterns* since they coexist in the context of the *Inception* stage and of both the *Business Modeling* and the *Requirements* disciplines. Business patterns are not necessarily about software but they have to give input on how the software requirements of a business domain are adequate to an organization. Analysis patterns have to consider its adequacy to the target organization. They both have to be used during the earliest period of the software solution's development, when requirements are elicited and agreed with the stakeholders.

The Posting Pattern

Previously in [103] the *Posting* pattern was classified as a business pattern by Pavel Hruby. According to the multilevel and multistage classification the *Posting* pattern is classified as an analysis pattern. It is applicable to horizontal domains.

The point of the *Posting* pattern is to keep the history of economic events (commitments, contracts or claims) or in other words the history of interactions between economic agents for the exchange of economic resources like the purchase of products, the sale of services, invoices and corresponding payments, among others. Some examples of posting types are inventory posting, finance posting, man-hours posting and distance posting. Figure 39 (on the right) exposes a model with an example of the *Posting* pattern in the M1 representation as well as the M2 representation of the pattern. The *Posting* pattern

contemplates two types of concepts: dimensions and entries. A posting dimension is either an economic agent or an economic resource. The purpose of the dimension is to provide additional information about the economic event or in other words provide descriptive information about the posting entries. A posting entry is an entry of a commitment, a contract or a claim. The purpose of the entry is to keep track of the history of economic events. In Figure 39 (on the right) it can be seen that `Customer` and `Check` are two posting dimensions of the posting entry `Receipt`. Most probably the `Customer` class represents the economic agent involved in the economic event represented by the entry class `Receipt` whereas the `Check` class represents the economic resource.

The *Posting* pattern is constituted by concepts belonging to a horizontal domain (the accounting domain). Nevertheless the *Posting* pattern has only the concept of posting entry in common with the *Accounting* pattern (in the *Accounting* pattern the concept of posting entry corresponds to the concept of agreement).

The arguments for classifying the *Posting* pattern as an analysis pattern as well as for its adequacy to the *Inception* software development stage, and the *Business Modeling* and *Requirements* Software Engineering disciplines are the same described beforehand for the *Accounting* pattern.

Enterprise Patterns

The term *enterprise pattern* is inspired on Fowler's considerations about enterprise patterns and enterprise software in [104].

Enterprise patterns are most adequate to vertical domains. They are more relevant in the context of the *Elaboration* stage by professionals, technologies and methodologies from the *Analysis & Design* discipline.

Enterprise patterns are used in the development of software systems on which various businesses rely on and run (the so called enterprise software systems). Normally the architecture of such systems is a layered architecture. Ellaboration decisions on layered architectures are design decisions that have to be taken inside a logical layer or between different logical layers. Often single enterprise applications need to interact so enterprise patterns have also to propose solutions to the integration of enterprise applications problem. Validations, calculations and business rules on the data an information system manipulates

vary according to the domain and change as the business conditions change. Enterprise applications must respond to ever changing business requirements.

Enterprise patterns address architectural concerns as well as the architecture patterns this thesis will be talking next but whereas enterprise patterns are mainly concerned with topological architecture, architectural patterns are mainly concerned with logical architecture.

This chapter does not consider the notion of *enterprise* as the RUP does not consider it. The RUP is a Software Engineering process framework. IBM has delivered a RUP plug-in called RUP SE (RUP for Systems Engineering) [105]. The RUP SE has enlarged the RUP with the consideration that the development of large-scale systems must be concerned with software, hardware, workers and information. The RUP SE considers different perspectives on the system (logical, physical, informational, and others). The RUP SE is shortly a framework for addressing the overall system's issues. The RUP SE addresses behavioral requirements (the way the system shall behave in order to fulfill its role in the enterprise). The RUP does not express such concern with the enterprise in which the system will play its role. In fact this kind of concern is more from the field of Systems Engineering than from the field of Software Engineering. System requirements in the context of Software Engineering are specifically software system requirements. The system requirements are derived from an understanding of the enterprise, its services and the role that the system (software-based or not) plays in the enterprise. For instance the RUP SE suggests that the enterprise shall be partitioned into the system and its actors in order to derive the system requirements. In the RUP SE an enterprise is faced as a set of collaborating systems that collaborate to realize enterprise services, mission and others. The system attributes are obtained from an analysis of the enterprise needs. As this chapter talks about software system development patterns in the context of RUP (not RUP SE), this chapter is related to Software Engineering, not to Systems Engineering, which means that this chapter's *enterprise patterns* have nothing to do with the concept of *enterprise* from the Systems Engineering field. The term *enterprise pattern* comes from the term *enterprise application architectural pattern* from Folwer's book "Patterns of Enterprise Application Architecture" [91].

Examples of enterprise patterns can be seen in [91].

Figure 40 (on the left) depicts the positioning of enterprise patterns according to the *Stage* and the *Discipline* dimensions.

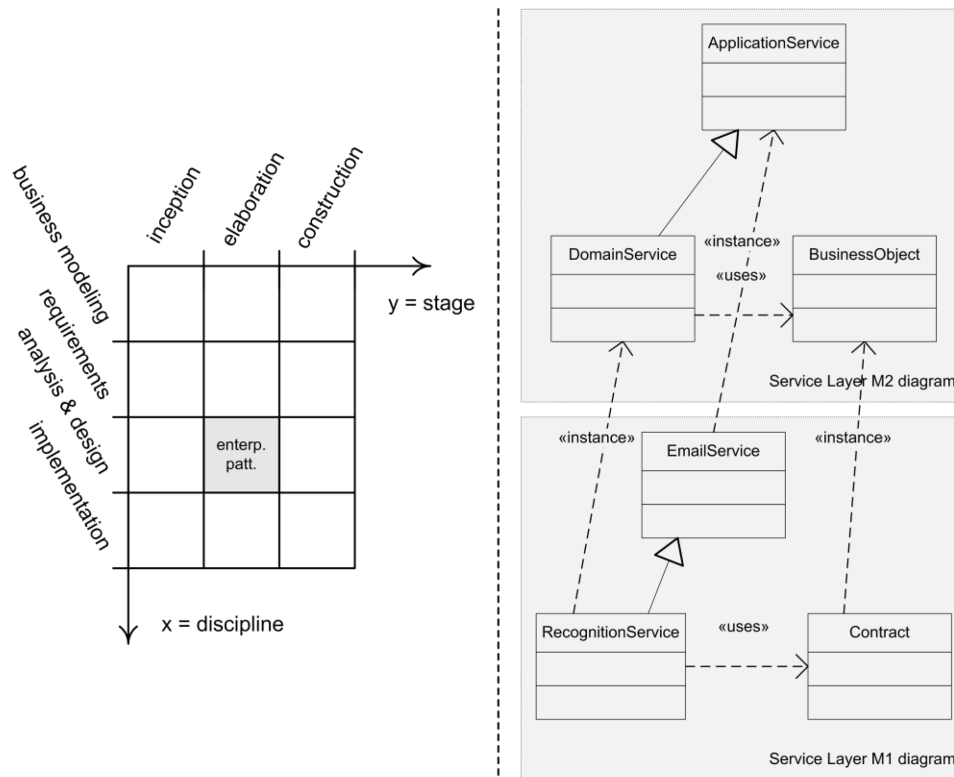


Figure 40 – The enterprise patterns' positioning according to the Stage and the Discipline dimensions (on the left). The Service Layer pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right).

The Service Layer Pattern

In [91] Fowler classified the *Service Layer* pattern as an enterprise application architectural pattern. According to the multilevel and multistage classification the *Service Layer* pattern is classified as an enterprise pattern.

The purpose of the *Service Layer* pattern is to provide for operations to access the enterprise application's stored data and business logic. The *Service Layer* pattern can be implemented with a set of facades over a domain model. The classes implementing the facades do not implement any business logic, which is implemented by the business object's rules from the domain model. The facades gather the operations the application has available for interaction with client layers. The Service Layer can also be implemented with classes directly implementing the application logic and delegating on business object classes for domain logic processing. Application logic is grouped into classes of related application logic. These classes are application service classes. Figure 40 (on the right) depicts an example of this second strategy for implementing the *Service Layer* pattern at the modeling level. The figure shows a model with an example of the *Service Layer* pattern in the M1 representation as well as the M2 representation of the pattern. As it may be concluded from

the figure, the *Service Layer* pattern is composed of two types of concepts: application services and domain services. Business objects are also represented in the models as the domain services rely on them for business logic. The domain services act as intermediates between the application services and the business objects since they provide for calls to application logic in application services and for calls to business logic residing on business objects. These last calls are made inside the service operations the domain services provide for, which correspond to the use cases the actors want to perform with the application.

As the main focus of the *Service Layer* is the domain service acting as a bridge between the application logic and the business logic, and not implementing any business domain logic (just accessing it) this thesis has tagged this particular enterprise pattern as domain nature agnostic.

The *Service Layer* pattern is classified in this chapter as an enterprise pattern because it is used to develop enterprise software systems for specific business domains. When developing enterprise applications, logical layers are essential and the concern of the *Service Layer* pattern (to separate application logic from business logic) proves that it is an enterprise pattern.

By looking at the RUP's textual descriptions of its disciplines and phases this thesis concluded that the *Service Layer* pattern shall be used during the *Elaboration* software development stage and in the context of the *Analysis & Design* Software Engineering discipline. Since splitting application logic from business logic is an architectural decision with impacts at the level of the baseline software system architecture it makes sense to adopt the *Service Layer* pattern during the *Elaboration* stage and by the professionals, technologies and methodologies responsible for the software design.

Architectural Patterns

The term *architectural pattern* is inspired on Buschmann, *et al*. and Zdun [8, 106].

Architectural patterns are more appropriate to horizontal domains. They shall be picked up from catalogues for usage during the ***Elaboration*** stage by professionals, technologies and methodologies from the *Analysis & Design* discipline.

Architectural patterns are used in the definition of the structure of software solutions. The architecture of a system is the design artifact that represents the functionality-based

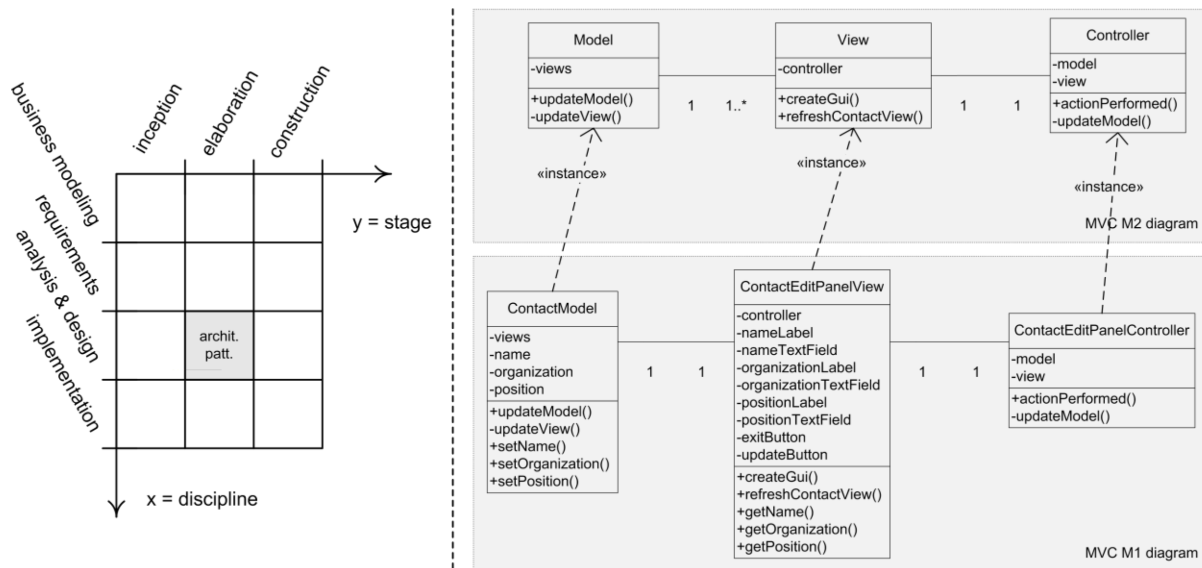


Figure 41 – The architectural patterns' positioning according to the Stage and the Discipline dimensions (on the left). The MVC pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right).

structure of that system and shall address quality or non-functional attributes wished-for the system. Architectural patterns shall help improving both the functional and the quality attributes of software systems.

Examples of architectural patterns can be seen in [8].

Figure 41 (on the left) shows the positioning of architectural patterns according to the *Stage* and the *Discipline* dimensions.

Enterprise patterns and architectural patterns are *dual patterns* since they coexist in the context of the *Elaboration* stage and of the *Analysis & Design* discipline.

The Model-View-Controller Pattern

Originally in [8] the MVC pattern was classified by Buschmann, *et al*. as an architectural pattern. According to the multilevel and multistage classification the MVC pattern is classified as an architectural pattern. It is adequate to both horizontal and vertical domains, so it is agnostic relatively to the domain nature.

The purpose of the MVC pattern is to ensure the consistency between the user interface and the business information of a software system. The separation of the user interface from the business information of a software system provides for user interface flexibility. Figure 41 (on the right) depicts an example of a model of the MVC pattern in the M1-level and also the MVC pattern represented in the M2-level. The MVC pattern is

composed of three types of classes: a model, a view and a controller. The model contains the business information that is to be presented to the user. The view obtains the information from the model and displays it to the user. The controller is responsible for requesting the business information updating on the model upon user action (event) on the graphical interface (view). It takes the business information from the view and requests for the model's updating with that information.

Although the model component contains business information the MVC pattern is adequate to both horizontal and vertical domains, which makes of it agnostic in what its domain nature is concerned. The pattern can either be adopted if the business information is relative to horizontal business objects or to vertical business objects.

The MVC pattern is classified as an architectural pattern according to the multilevel and multistage classification since it is used to define the structure of the software system, namely the structure of the client-side of the system. The pattern allows for the software system to be flexible concerning its user interface, which is a quality attribute wished-for that system. Mainly the MVC pattern is responsible for the structure of the client-side of the software system in order for it to be able to update business information upon events triggered by the user on the user interface (which allows the system to provide for the update functionality to the user).

By looking at the RUP's textual descriptions of its disciplines and phases this thesis concluded that the MVC pattern shall be used during the *Elaboration* software development stage and in the context of the *Analysis & Design* Software Engineering discipline. As the MVC pattern is used to define the structure of the client-side of the system, addressing both the update functionality and the user interface flexibility (non-functional requirement), it shall be part of the system's architecture, which shall be part of the system's design specification. The system's baseline architecture shall contemplate the most significant architectural requirements, and the MVC pattern addresses the consistency between the user interface and the business information of the software system (which is a requirement vital to interactive software systems).

Design Patterns

The term *design pattern* is inspired on the GoF's patterns.

Design patterns are domain nature agnostic, which means that they are both applicable to vertical and to horizontal domains. They shall be manipulated during the *Construction* stage by professionals, technologies and methodologies from the *Analysis & Design* discipline.

Although the GoF described design patterns as OO software patterns, this thesis considers design patterns as those that are applicable to the refinement or detailing of the software system architecture. For instance Larman's GRAS (General Responsibility Assignment Software) [93] patterns are design patterns since they have to do with behavioral aspects that only come up during a mechanistic design of the software solution's development (by mechanistic it is meant structural or behavioral mechanisms more refined than components from logical architectures) [93].

The presence of code in design patterns is only to give examples. Design patterns are independent of the language, as can be seen from the GoF catalogue (they only talk about OO concepts, not language features). The sample code section provides for code to illustrate the example given in the motivation section, where the reader is given a scenario to illustrate a design problem in order for him to better understand the more abstract description of the pattern that follows the motivation section. Again the code is an illustration of the pattern's applicability.

Figure 42 (on the top left) depicts the positioning of design patterns according to the *Stage* and the *Discipline* dimensions.

Figure 42 (on the bottom left) illustrates the difference between the definition of design pattern in this thesis and GoF's. The lighter grey area corresponds to the pattern positioning space of the GoF catalogue. The darker grey area corresponds to the pattern categorization area of the classification in this chapter where the design patterns of this classification are positioned. These areas were drawn taking only the *Discipline* and the *Stage* dimensions into consideration as the *Level* dimension does not allow demonstrating the difference between both definitions. This thesis considers that design patterns shall only be used during the *Construction* stage of the software development process as the Software Engineering professionals, technologies and methodologies of the *Analysis & Design* are the most adequate to handle these patterns due to their professional profile and adequacy to the *Construction* stage's activities and goals. It also considers that if design patterns are handled throughout the whole software development stages and by the people and tools (technologies

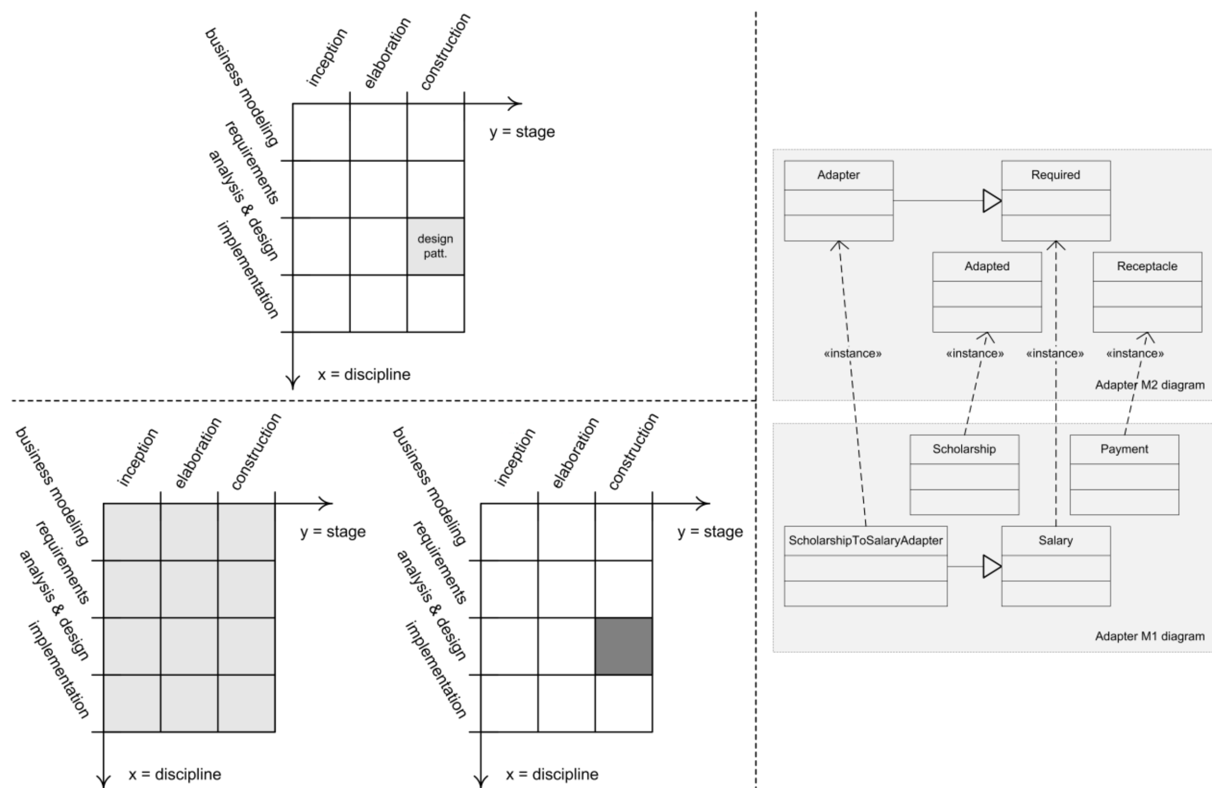


Figure 42 – The positioning of design patterns according to the Stage and the Discipline dimensions (on the top left). The difference between the design patterns of the classification this thesis presents and the GoF's according to the Stage and the Discipline dimensions (on the bottom left). The Adapter pattern modeled at both the M2 and the M1 levels of the OMG modeling infrastructure (on the right).

and methodologies) of every Software Engineering discipline, the advantages predicted in pattern catalogues of the adopted design patterns are not going to be preserved and that the design patterns in the catalogues are not going to be used in their full potential by the people most skilled to handle them.

The Adapter Pattern

In the past in [50] the *Adapter* pattern was classified as a design pattern by the GoF but in the sense of OO software pattern. According to the multilevel and multistage classification the *Adapter* pattern is classified as a design pattern. It is applicable to both horizontal and vertical domains, which makes of it a domain nature agnostic pattern.

The *Adapter* pattern (also known as *Wrapper*) has to do with a class converting the interface of one class to be what another class expects. Figure 42 (on the right) shows a model exemplifying the *Adapter* pattern in its M1 representation as well as the M2 representation of the pattern. This is what the *Adapter*'s implementation described at the M2-level should look like: "The `Adapter` must have an input parameter of the `Adapted`'s type in its constructor <u>and</u> extend the `Required` <u>and</u> call the `Adapted`'s appropriate operation

inside the operation required by the `Receptacle`". The *Adapter*'s description at the M2-level in terms of semantics is the following: "The `Receptacle` requires the `Adapted` to be adapted to the `Required` through the `Adapter` (the process is called *adaptation*). The goal is for the `Receptacle` to be able to call the `Required`'s operation from an instance of the `Adapted`".

The *Adapter* pattern is independent from any domain (or domain nature agnostic) because the adapter, the adapted, the required and the receptacle objects can belong to every domain possible. As long as the semantics or business logic (at the M1-level) specific of a certain domain complies to the M2 semantics described in the previous paragraph, the *Adapter* pattern is applicable to that domain no matter what the business is.

The *Adapter* pattern deals with classes and their operations that implement the interface operations those classes are expected to implement. Essentially the contents of those operations that are of relevance to the *Adapter* pattern are calls to other operations. As can be seen, this thesis is not arguing about business logic implemented by the class' operations, rather about the structure of the classes targeted by the adaptation, which means this thesis is discussing structural aspects rather than behavioral. Nevertheless and once again, the *Adapter* pattern shall be applied during the mechanistic design of the system's development when classes shall be derived from architectural components. The *Adapter* pattern in its semantics shall be used to detail the baseline software system architecture and be part of a design specification containing the interface design of the classes involved in the *adaptation* process. For all these reasons this thesis classified the *Adapter* pattern as a design pattern.

By looking at the RUP's textual descriptions of its disciplines and phases this thesis concluded that the *Adapter* pattern shall be used during the *Construction* software development stage and in the context of the *Analysis & Design* Software Engineering discipline as already argued in this chapter. The adequacy of such stage and discipline to the *Adapter* pattern is intimately related to the reasons that were just exposed for classifying the *Adapter* pattern as a design pattern.

Implementation Patterns

The term *implementation pattern* is inspired on Beck's definition of implementation pattern [51].

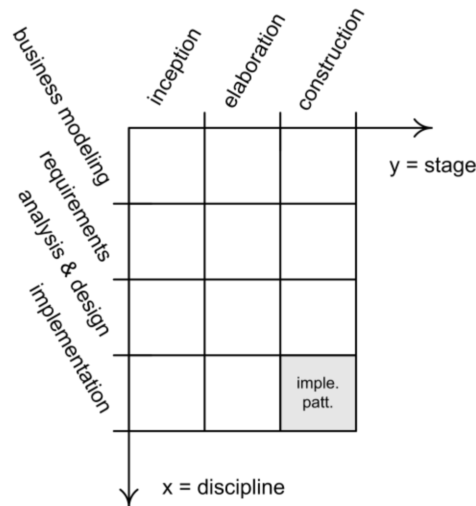


Figure 43 – The implementation patterns' positioning according to the stage and the discipline dimensions.

Implementation patterns are domain nature agnostic. They shall be considered during the *Construction* stage by professionals, technologies and methodologies from the *Implementation* discipline.

Implementation patterns are in fact the patterns in Kent Beck's catalogue [51] for instance and not Java or other language-specific patterns. The difference between design patterns and implementation patterns is that as Kent Beck claimed [51] design patterns are applicable a few times in the day of a programmer whereas his implementation patterns are applicable every few seconds in the day of a programmer. He also claimed that his implementation patterns teach readers how to use certain OO language constructs regardless of the language (despite him using a trivial subset of Java to exemplify the patterns). Java patterns or other language-specific patterns are just a different representation of design patterns [59, 60] (e.g. in [60] Java is *applied* to the GoF patterns and other patterns). A different representation changes the pattern's level in the classification (e.g. in the case of the patterns from [60], they had to be situated at the M1 (code) level in order for them to be called *Java* patterns). Kent Beck refers his patterns are applicable when all domain-specific questions are solved and developers are left with solely technical issues.

Figure 43 illustrates the positioning of implementation patterns according to the stage and the discipline dimensions.

The Value Object Pattern

In [51] the *Value Object* pattern was classified as a class pattern. In the context of the multilevel and multistage classification the *Value Object* pattern is classified as an implementation pattern. It is adequate to both horizontal and vertical domains, which means that it is domain nature agnostic.

The purpose of the *Value Object* pattern is to create objects that once created cannot have the values of the variables they handle changed. The solution is to set the value of those variables when the object is created through its constructor. No other assignments shall be made to those variables elsewhere in the object's class. Operations on the object shall always return new objects that shall be stored by the requester of the operation. Shortly value objects are objects representing mathematical values, which are values that do not change over time (have no state). For instance a transaction (value object) shall not change over time, rather an account changes over time (a transaction implies a change of state in the account). It does not make sense to model implementation patterns as they are only to exist in code, not in models, which implies that they are always represented at the M1-level (compile-time code).

The *Value Object* pattern shall be involved in the coding of both horizontal and vertical domain software systems since it is about the construction of objects that shall not change over time, the assignment of values to those objects' variables and the operations on those (value) objects.

The *Value Object* pattern is classified as an implementation pattern because it is about the technical details of using classes (an OO language construct), to create objects that shall have no state (whose variables' values shall not change over time), in this case.

By looking at the RUP's textual descriptions of its disciplines and phases this thesis concluded that the *Value Object* pattern shall be used during the *Implementation* software development stage and in the context of the *Construction* Software Engineering discipline as previously mentioned in this chapter. The *Value Object* is related to the development of software systems, particularly to the development of implementation elements (source code).

4.4. Conclusions

Some lessons were learned on the application of the multilevel and multistage pattern classification to some patterns from the literature. After looking at the RUP's textual descriptions of its disciplines and phases, some patterns were not classified with the expected

pattern type. This means that a procedural referential such as the RUP is important to classify patterns, mainly because it gives the classification a notion of software development process. It also means that the awareness of the adequacy of a pattern in a catalogue to a specific discipline and stage changed after the multilevel and multistage pattern classification was elaborated. Initially before an in depth analysis of the RUP's textual descriptions and the definitions of the various pattern types it was expected that (1) analysis patterns did not make sense in the context of the RUP's *Business Modeling* discipline; (2) design patterns made sense in the context of both the RUP's disciplines of *Analysis & Design* and *Implementation*, and of both the RUP's *Elaboration* and *Construction* stages; and (3) patterns that could be contextualized in the RUP's *Implementation* discipline and in the RUP's *Construction* phase were language-specific patterns. After analyzing RUP's textual descriptions and the pattern type definitions, this thesis concluded that (1) analysis patterns do make sense in the context of the RUP's *Business Modeling* discipline; (2) design patterns make only sense in the context of the RUP's *Analysis & Design* discipline and the RUP's *Construction* stage; and (3) language-specific patterns are a translation of design patterns into some language, not implementation patterns.

One of the reasons in the genesis of the multilevel and multistage classification's creation was to provide for some guidance on the adoption of software development patterns in order to avoid loosing the original advantages of the pattern throughout the adoption process. For this reason this thesis considered the pattern classification had to rely on the software development process. The benefits of such an approach to pattern classification are: (1) the knowledge of the moment from the software development process in which to use specific kinds of patterns; and (2) the knowledge of who the Software Engineering professionals most skilled to handle those specific kinds of patterns in each stage of the software development process are, considering their instruments (technologies and methodologies).

The systematic character of the multilevel and multistage classification is based on the objectiveness of the decisions on the application of software development patterns, which may be assured with the adoption of a modeling infrastructure. A systematic use of software development patterns is likely to also prevent the misinterpretation and corruption of patterns from catalogues when interpreting and adapting them, respectively.

Besides being concerned with the stages and the Software Engineering professional's skills and the instruments they handle to conduct Software Engineering activities, and besides translating concerns with the systematic use of software development patterns the multilevel and multistage classification is also concerned with the nature of the domain, which is one of the criteria that composes the classification. Therefore the multilevel and multistage classification is focused on domain-based software development. The classification also focuses on model-driven software development since it incorporates (through its multilevel character) the OMG modeling infrastructure by considering that patterns can be represented at different levels of that infrastructure, which influences their interpretation.

The multilevel and multistage pattern classification is innovative in some ways relatively to the existing literature. Most pattern classifications do not classify patterns based on the software development process. The only classification that does, disregarded the analysis phases (business modeling and requirements) of the software development process. The multilevel and multistage classification, though, addresses business modeling and requirements.

The architectural patterns (like the MVC pattern the 4SRS uses to transform user functional requirements dealt with during the analysis of software into systems functional requirements dealt with in the beginning of software design) were concluded to be adequate for the *Elaboration* software development stage and in the context of the *Analysis & Design* Software Engineering discipline. The incorporation of the MVC in the structure of the logical architectures the 4SRS generates is supported by this conclusion. The formulation of the method to refine logical architectures with variability support yield by chapter 3 is also supported by the pattern classification presented in this chapter.

5. Automating Model Transformations

> Section 5.2 shows the extension of the SPEM this thesis proposes for defining a visual language to model transition (from the analysis to the design of software) methods and formalize small dedicated software development processes like the 4SRS.
>
> Section 5.3 shows the preparation necessary for the automation of transition methods modeled with the SPEM, particularly the work undertaken to prepare the automation of the 4SRS.
>
> Section 5.4 provides for an insight over the impact of automating transitions methods (like the 4SRS) in contexts of variability.

5.1. Introduction

A method can be defined as a general description of how to develop software and systems. Method modeling is also essential when it comes to process modeling. The same method can be used by many different processes and more than once in the same process.

The definition of a software process may be time-consuming and labor-intensive, which means that defining a new process for each software development project may be unfeasible. In order to promote software processes and the reuse of methods, various PMLs (Process Modeling Languages) such as the SPEM have been proposed. PMLs shall be used to convey better comprehension [76, 77], communication, reuse, evolution and management

[76] of processes, besides used to define or formalize methods and processes, and reuse those definitions or formalizations in several and different process enactments.

The SPEM (2.0) is a standard metamodel based on the MOF that reuses some concepts from the UML (2.x) Infrastructure (e.g. Classifier and Package). The SPEM is a modeling language that contains the minimal elements to define or formalize software and systems development processes. The SPEM is not aimed at being a generic process modeling language, rather a software and systems development process modeling language.

The 4SRS method allows the iterative and incremental model-based transition from user functional requirements (represented as use case diagrams) to system functional requirements (or logical architectures represented as component diagrams). In other words the transformation of use cases (dealt with during the analysis of software) into logical architectures (dealt with in the beginning of the design of software) is conducted with a method specifically elaborated for the purpose. The main concerns of the method are: (1) guaranteeing that no user requirement is lost when moving from analysis to design; and (2) assuring that no user requirement that was not elicited with the customer is considered.

The 4SRS method was not formalized with process positioning concerns prior to this thesis. In order to plug the 4SRS method into larger software development processes it had to be formalized as a small dedicated software development process. In this sense the method had to be formalized with a PML. The SPEM is a PML that uses the UML (an OMG standard with worldwide impact, therefore handled by professionals worldwide to design their applications and communicate their design decisions), however it does not possess concepts that sharply express the needs of the 4SRS method with regards to process positioning concerns. The challenge was to maintain the interoperability the SPEM offers for being a standard that tools support and simultaneously express the 4SRS transition method in order to automate it.

Consider a methodology as a composition of methods (composed of techniques), process and notation. Within an effort to turn the 4SRS a methodology, this chapter shows how this thesis uses a PML (the SPEM) to model a method (the 4SRS) as a process. UML is the notation used in the 4SRS method to represent the necessary diagrams. The 4SRS is a transition method that can be defined as a method that generally describes how to transform analysis artifacts into design artifacts to develop software (in the case of the 4SRS, use cases into component diagrams). Therefore this chapter shows how to model transition methods (in

this case, the 4SRS) as processes with a process modeling language (the SPEM). Some other transition methods may for instance describe how to transform design artifacts into implementation artifacts, or how to generate test artifacts, or how to transform business modeling artifacts. Since the 4SRS is a method, it can be the basis for formalizing a small dedicated (at transitioning from analysis to design) software development process that can be plugged into larger software development processes. One of the goals of this chapter is to show the extensions that had to be performed to the SPEM in order to habilitate it for the expression of the 4SRS method's characteristics.

The general description of how to develop software and systems (a method) shall be the basis for defining or formalizing software and systems development processes. Software and systems development processes can be described as sequences of phases and milestones. The sequence of phases and milestones represents the development lifecycle of the product, so processes may represent product development lifecycles. In this sense, methods are only contextualized in a development lifecycle when positioned within a process.

The automation of software processes may be facilitated by process modeling. The problem this chapter addresses is the automation of transition methods, particularly those modeled with the SPEM. The 4SRS was modeled with the SPEM in order to formalize it as a software process. It had to be automated so that it could be enlivened by means of a tool. The SPEM was chosen because it is standard, in order to benefit from the advantages of using a standard that is available to every professional of process modeling. Assuming that disciplines are sets of tasks that can be grouped according to their particular relevance in (a) specific phase(s) from large software development processes into which small dedicated software development processes can be plugged, transition methods are methods that describe how to transform artifacts from one discipline of a large software development process into artifacts from another discipline of such a process. Transition methods have particularities regarding other methods. They realize a change in the perspective on the system, consequently in the artifacts that represent the system from different perspectives, as well as they mark a change in the discipline of the large software development process. In this chapter, the 4SRS is used as the example of a transition method modeled with the SPEM to illustrate the automation of transition methods modeled with the SPEM (in this case, a transition method that transforms analysis artifacts into design artifacts). The goal of the automation of transition methods modeled with the SPEM (in this case, the 4SRS) is the automatic execution of those methods as small dedicated software development processes.

The intent is to decrease the cost of introducing the method into large software development processes, facilitating its use. The (semi)automatic execution of the 4SRS transition method is based on the Moderne. The Moderne is a model-driven tool for process modeling and execution. The Moderne tool allows the execution of the 4SRS in a model-driven approach, which implies generating logical architectures through model transformations using a model-to-model transformation language [65, 98].

Previously this thesis addressed contribution on the representation of variability in use case diagrams. That contribution is relevant for providing variability support to the 4SRS transition method. This thesis also addressed contribution on the formalization of the use case modeling activity with support for variability since it proposed an extension to the UML metamodel in order to formally provide for both the concrete and abstract syntaxes to represent the three different types of variability in use case diagrams it has synthesized.

Transformation rules shall be considered as part of process automation tools that involve model transformations. This chapter presents transformation rules specified with the ATL model-to-model transformation language [98]. These transformation rules are part of a process automation tool adapted to perform the model transformations of the 4SRS transition method: the Moderne [14].

5.2. Extending the SPEM Metamodel

Synopsis of the SPEM

The explicit purpose of the SPEM is to be as simple as to contain the minimal elements to define or formalize software and systems development processes. Thus it shall not be considered a generic process modeling language. The SPEM focuses on the structure of development processes for software and systems. The behavior of those processes is modeled with UML 2.0 activity diagrams, so the SPEM does not provide elements for behavior modeling.

The SPEM distinguishes between the concept of process and the concept of method content. It considers that the concept of process can be divided into process structure and process behavior. A process structure is a composition of activities. An activity is a (kind of) work breakdown element. It represents a list of tasks and/or roles and/or work products in use by a process, and/or even other activities. The breakdown elements that activities may contain (tasks and/or roles and/or work products in use by the process) can be nested and

logically grouped. Activities represent work that can be assigned to roles that intervene on the process, and require inputs and/or outputs (work products) to be performed. The process structure is the representation of the process as a static composition of activities that have temporal dependencies between them. Although temporal dependency is a behavioral concept, structural diagrams drawn with the icons or stereotypes of the SPEM UML profile [12] can have tagged values indicating temporal dependency of activities on each other. Activities are relevant for modeling phases of a development lifecycle (waterfall, iterative and incremental are three types of development lifecycles). The same role can be used in an early phase of a development lifecycle and in a later phase of the same development lifecycle, which may mean that e.g. that role handles different work products in those two different phases. The process behavior is not the focus of the SPEM, rather of the UML for instance.

A method content can be considered as the set of concepts (tasks, roles and work products) that allows representing software and systems development methods and techniques independently of their positioning within a specific software and systems development lifecycle (consider that a method is composed of many techniques and that a development lifecycle can be composed of a sequence of phases and milestones for example). Processes shall use method content elements and organize them into sequences. Ad-hoc development processes that are not based on reusable methods or techniques can be formalized with elements from the Process Structure package of the SPEM. Development processes that are based on reusable methods or techniques shall be formalized with elements from the Process with Methods package of the SPEM. The same method or technique may need to be performed in different ways according to the point in the process where it is positioned. For instance requirements management methods shall be performed differently depending on whether they are performed early in the development lifecycle or later (e.g. requirements elicitation in early phases of the development lifecycle requires different concerns with respect to the management of requirements when compared with requirements updated in later phases of the development lifecycle). Requirements management methods may also be performed differently depending on whether the software or system to be developed is new or an existing one that needs to be maintained, depending on whether it is a single co-localized team or a global software or systems development process. Hence method contents are independent from the development lifecycle. In fact method contents are stepwise definitions of tasks that shall be performed by roles to originate work products. They may consume work products as well. A task from a method content may have its steps,

inputs or outputs (work products) changed depending on the development lifecycle they are positioned.

The main difference between a method content and a process is that a method content defines methods and techniques for software and systems development processes, whereas a process defines the positioning of those methods and techniques within a development lifecycle composed of e.g. a sequence of phases and milestones. When a specific composition of tasks, roles and work products (a specific method content) is positioned within a development lifecycle, it means that the method content is applied to that part of the process where it is positioned. It also means that the method content is used by that process. A method content use defines which parts of the method or technique will be performed in that point of the process. Shortly a method content definition (a composition of tasks, roles and work products) is different from the application of a method content to a software and systems development process. For instance the difference between a Task Definition (element from the Method Content package of the SPEM) and a Task Use (element from the Process with Methods package of the SPEM) is that the first one can be reused in many processes and the second one allows that reuse. In a task use a task can be customized (e.g. steps can be selected, inputs can be added, outputs can be added, roles can be related).

Earlier in this section, this thesis discussed activities in the context of process structure. These activities (which will from now on be referred to as SPEM activities) are not the activities from the UML. Whereas the UML activities are adequate for modeling behavior as a sequence of actions that may require decisions to be taken and are temporarily dependent on each other, the SPEM activities are adequately modeled with UML class diagrams (using the SPEM UML profile, eventually with its own icons, otherwise with its class-applicable stereotypes) and tagged values for temporal dependency representation. The SPEM activities model process structure as well as UML class diagrams model structure. If a process is represented with a workflow diagram (UML activity diagram with actions and object nodes), the notion of roles associated to tasks (actions in UML activity diagrams) shall be represented with swimlanes. A workflow diagram that models a process also represents the notion of work products (object nodes in UML activity diagrams) associated to tasks. As the SPEM activities modeled with UML class diagrams suggest, the notion of roles associated to tasks shall also be represented in diagrams that model structure (such as UML class diagrams). The process diagrams that model the process structure (the SPEM activities modeled with UML class diagrams) may also include the association between work products and tasks. In

workflow diagrams work products are represented as inputs and outputs for actions. Process diagrams contain instances of method content elements and those instances represent the use of tasks, roles and work products within the development lifecycle. As mentioned before in this chapter, this thesis adopted workflows since UML class diagrams were adopted to represent the process structure (instead of work breakdown structures, which are not appropriate for representing process behavior).

Metamodeling Transition Methods

If the goal is to represent software development processes with models drawn with a process modeling language, those software development processes will have to be metamodeled. Metamodelling is an approach to model complex systems by using abstraction as a means that facilitates that task [107]. Metamodels are models of models. A metamodel is a model of a modeling language. It is also a model whose elements are types in another model. An example of a metamodel is the UML metamodel. It describes the structure of the different models that are part of it, the elements that are part of those models and their respective properties.

As already stated in this chapter, this thesis extended the SPEM for defining a visual language to model transition methods and formalize small dedicated (at transitioning from analysis to design) software development processes (such as the 4SRS) that can be plugged into larger software development processes. According to the SPEM, the 4SRS method (which is a transition method) can be the basis for formalizing a small dedicated software development process that can be plugged into larger software development processes. This is possible by formalizing the 4SRS method as a method content with the SPEM.

Regarding language definition Atkinson and Kühne [11] divided the concept in four associated concepts: abstract syntax, concrete syntax, well-formedness and semantics. Abstract syntax is equivalent to metamodels. Concrete syntax is equivalent to UML notation. Well-formedness is equivalent to constraints on the abstract syntax (in OCL for instance). Finally semantics is the description of the meaning of a model in natural language. The abstract syntax of the visual language this thesis defined by extending the SPEM consists of the SPEM metamodel with some subclassing and profiling. The language's concrete syntax is the SPEM's notation. This thesis subclasses the SPEM because it did not support the semantics of transition methods both from the method content and from the process point of view.

Figure 44 – Metamodel that defines the visual language for modeling transition methods and formalizing them as microprocesses.

This chapter has already defined a transition method as a method that generally describes how to transform analysis artifacts into design artifacts to develop software (in the case of the 4SRS, use cases into component diagrams). However it was not yet defined what a small dedicated software development process is. It was already stated in this chapter that it can be plugged into larger software development processes. This kind of process is what this thesis calls a microprocess. The 4SRS modeled as a method content can be formalized as a microprocess, or a process from the SPEM’s perspective. The execution of a macroprocess may call the execution of microprocesses as much times as needed and in the context of the necessary phases of that macroprocess. For example the 4SRS microprocess can be executed in the phases of Inception, Elaboration and Construction of the RUP macroprocess, although with distinct weight in different phases. This distinct weight of the execution of the 4SRS microprocess in different RUP phases is due to the weight of the execution of the activities or tasks from the RUP disciplines involved in the transition the 4SRS allows (Requirements and Analysis & Design) in the context of each one of those phases.

Figure 44 depicts the metamodel that defines the visual language for modeling transition methods and formalize them as microprocesses. The 4SRS is the example of the

method in the source of both this definition and formalization. Although some particularities of the 4SRS method are metamodeled in the process package called *4SRSProcessMetamodel* (which contains the process structure metamodel for the 4SRS microprocess), in general the metamodel allows for the modeling of transition methods with the elements from the method content package (which contains the method content metamodel for transition methods) called *4SRSMethodContentMetamodel*.

The elements in dark grey represent the extension this thesis proposes to the SPEM. The elements in bright grey represent elements this thesis added to the SPEM that are a simplification of the SPEM itself. The elements *MethodContent* and *Process* are needed for the automation of the 4SRS microprocess and are represented here to emphasize that the elements from the *4SRSMethodContentMetamodel* define a visual language for modeling methods and the elements from the *4SRSProcessMetamodel* define a visual language for modeling processes. Those elements are tasks (*TaskDefinition*; and steps, represented by the metaclass *Step*), roles (*RoleDefinition*) and work products (*WorkProductDefinition*).

It must be noticed that this thesis simplified the SPEM metamodel, including the relations between the elements in white background. This thesis eliminated the elements in between those elements, the navigability, the compositions and aggregations, and explicitly specified the multiplicity of each association end. This thesis considers that the metamodel shall be flexible with regards to the multiplicities, therefore the multiplicities shall be 0..*, 0..1 or 0..x, x=ø. The metamodel shall be complemented with OCL constraints in order for the multiplicities to become more specific. A zero (0) in a multiplicity indicates optionallity. Also the multiplicity * is equivalent to 0..* [27].

Regarding the *4SRSMethodContentMetamodel* the element *Discipline* is a simplification of the SPEM metamodel. This thesis added a subtype of *Discipline* (*DisciplineFromMacroprocess*) to the metamodel in order to distinguish between microprocess and macroprocess. By doing so it is expected that *Discipline* is from the microprocess (although this thesis did not model it as *DisciplineFromMicroprocess*). The *MethodContent* shall contain the *Discipline* from the microprocess since this thesis extends the SPEM to model transition methods like the 4SRS that allows transitioning from analysis to design in the context of disciplines from a macroprocess such as the RUP as already elaborated in this section. In the case of transition methods, the disciplines from the

microprocess shall be the disciplines from the macroprocess involved in the transition the method allows.

The *4SRSMethodContentMetamodel* also shows that this thesis subclasses *TaskDefinition*, *Step* and *WorkProductDefinition*. A transition task (*TransitionTaskDefinition*) transforms an initial work product (*InitialWorkProduct*) or an intermediate work product (*IntermediateWorkProduct*) into an intermediate work product or a final work product (*FinalWorkProduct*). A transition task can transform an initial work product into an intermediate work product or an intermediate work product into an intermediate work product or even an intermediate work product into a final work product. An intermediate task (*IntermediateTaskDefinition*) transforms a final work product into an initial work product. The set of transition tasks of an execution of the 4SRS transforms an initial work product into a final work product. A transition step (*TransitionStep*) can only be contained by a transition task, whereas an intermediate step (*IntermediateStep*) can only be contained by an intermediate task.

One execution of the 4SRS has always 2..* work products associated with it, despite this thesis modeled this multiplicity as * in order to turn the metamodel more flexible. This multiplicity is represented in the metamodel in the composition between *MethodContent* and *WorkProductDefinition*.

Tasks and work products are linked in the metamodel through three associations with three different orders of reading: *in*, *out* and *inout*. An *in* work product is an input of a task. An *out* work product is an output of a task. An *inout* work product is both an input and an output of a task (it can be a version of a work product for instance).

Tasks and roles are also linked in the metamodel via two associations with two different orders of reading: *mandatorilyPerforms* and *optionallyPerforms*, which means that a role can (respectively) mandatorily perform a task or optionally perform a task.

This thesis already talked about execution, which is the execution of the 4SRS. In the metamodel that concept is represented through the element *Execution*. The element *Iteration* is a simplification of the SPEM metamodel just like the element *Discipline* is. This thesis adds a subtype of *Iteration* (*IterationFromMacroprocess*) to the metamodel in order to distinguish between microprocess and macroprocess. By doing so it is expected that *Iteration* is from the microprocess (although this thesis did not model it as

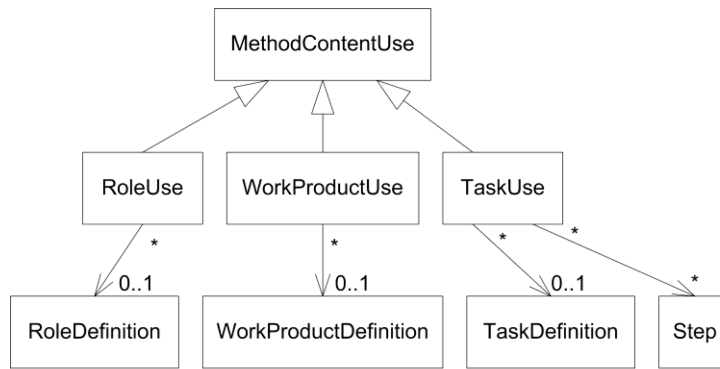


Figure 45 – The use of method content elements represented in the SPEM.

IterationFromMicroprocess). The *Process* shall contain *Iteration* from the microprocess since this thesis is extending the SPEM to model transition methods and they can be iterative like the 4SRS is.

As stated before in this thesis the 4SRS method may be applied recursively, in several *executions*, and in the context of each one of those executions various *iterations* can be performed. The same task can be performed several times in the same process. Tasks are the central element in the execution of the 4SRS microprocess since the tasks from the 4SRS are performed in the context of the executions of the 4SRS and ultimately in the context of the iterations that can occur for each one of those executions. The association class between *TaskDefinition* and *Iteration* (*TaskUse*) represents that in the metamodel. The *TaskUse* represents an instance of *TaskDefinition*, therefore the use of a specific task from the method content within the development lifecycle. Figure 45 shows that the use of method content elements (like *TaskDefinition*, *Step*, *RoleDefinition* and *WorkProductDefinition*) is contextualized within the development lifecycle through instances of *TaskUse*, *RoleUse* and *WorkProductUse*.

In the context of the 4SRS an execution transforms an initial work product into a final work product. An iteration (from the microprocess) also transforms an initial work product into a final work product. More accurately both an execution and an iteration take the same type of *in* work product and generate the same type of *out* work product. The difference between an execution and an iteration is that the execution ends a set of iterations (from the microprocess). Since no differences exist between execution and iteration in the context of the 4SRS in terms of work product manipulation and iterations are contained by executions, this thesis eliminates the association between execution and work product in the metamodel and gets to work product via task when necessary. That way the centrality of the task in the

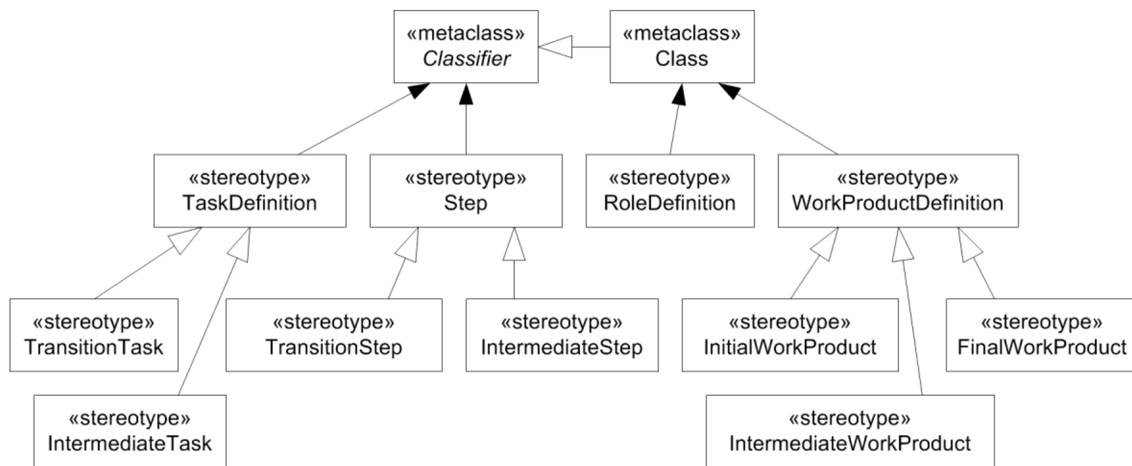


Figure 46 – The extension of the UML metamodel for modeling the method content of transition methods.

association between method content and process is maintained for the reasons already exposed.

The 4SRS microprocess is iterative and incremental but this thesis only models its iterations because increments have necessarily impact in the functionalities that are visible to the user and that is not what happens with the refinement in the 4SRS when the use cases are only visible to components originated by the previous execution of the 4SRS.

This thesis does not also add activity to the metamodel since activity is related to phases of process and the 4SRS microprocess needs only the concept of discipline for expressing the transition it allows.

The SPEM presents the metamodel for process modeling along with the profile it defines for the UML through extensions of the UML metamodel. Figure 46 presents the extension of the UML metamodel this thesis proposes in this chapter for modeling the method content of transition methods like the 4SRS. The stereotypes defined in the model in Figure 46 are all related to the method content of transition methods (except for the *RoleDefinition*, which is for methods in general). They are to be used in the method content model of the 4SRS, in the activity detail model of the 4SRS microprocess structure and in the workflow model of the 4SRS microprocess behavior. The next subsection of this chapter elaborates on these diagrams.

Modeling the 4SRS Transition Method

Figure 47 shows the method content model for the 4SRS. It represents a hierarchy of containments of tasks by the method content itself and of steps by the respective

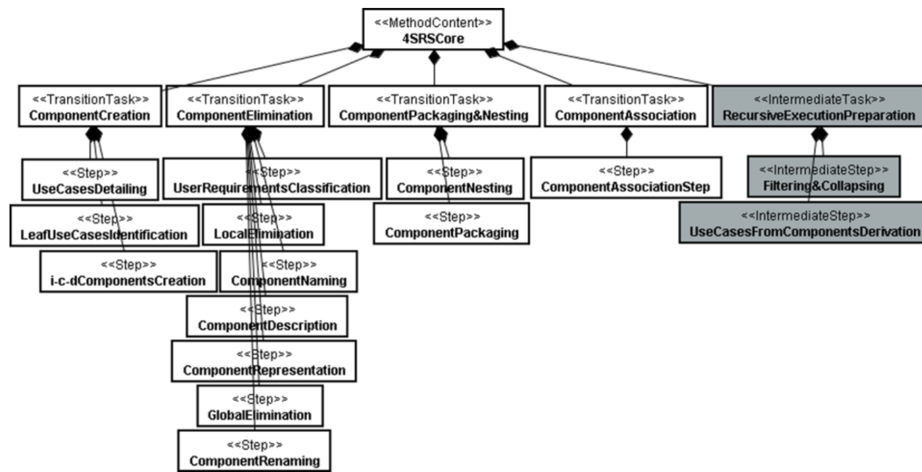


Figure 47 – The method content model for the 4SRS.

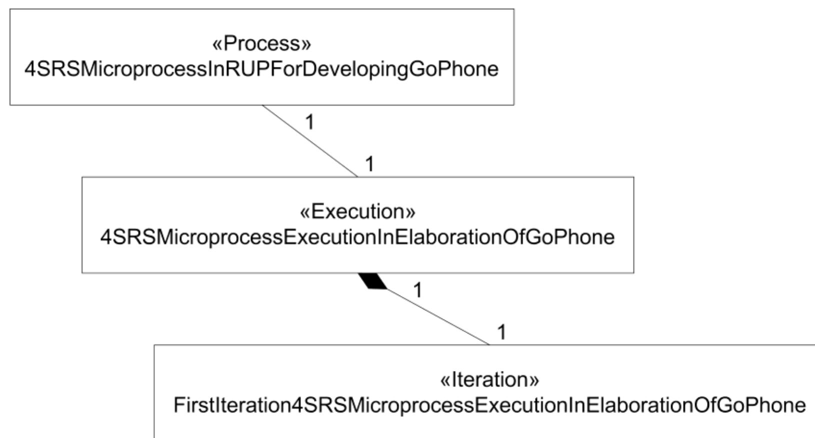


Figure 48 – The process model for the 4SRS.

tasks those *4SRSMicroprocessExecutionInEllaborationOfGoPhone*. That *Execution* is composed of one steps compose. The classes in white background are related to transition tasks, whereas the ones in grey background are related to intermediate tasks.

At the level of models, the concepts from the *4SRSProcessMetamodel* are more relevant when executing the process with a tool, therefore in the context of process automation. A process model with instances from a process structure metamodel may be like the one in Figure 48. The diagram depicts an instance of *Process*, an instance of *Execution* and an instance of *Iteration*. The diagram shows an instance of the 4SRS (micro)process called *4SRSMicroprocessInRUPForDevelopingGoPhone*. That particular instance of *Process* contains one *Execution* of the (micro)process in the context of a macroprocess (the RUP phase Elaboration) for the development of a software product line (the GoPhone) called *Iteration* called *FirstIteration4SRSMicroprocessExecutionInElaborationOfGoPhone*.

Figure 49 – An activity detail model of the 4SRS (micro)process.

Figure 49 illustrates what the SPEM calls an activity detail diagram. It is a model of the 4SRS (micro)process structure. It is called like that because in the context of the SPEM an activity represents a list of tasks and/or roles and/or work products in use by a process. The model has instances of tasks, a role and work products. The associations between the classes are instances of the associations between the metaclasses those classes are an instance of. Again the classes in white background are related to transition tasks, whereas the ones in grey background are related to intermediate tasks.

The model in Figure 50 is a workflow model that represents the 4SRS (micro)process behavior. The model is in fact a UML activity diagram with actions and object nodes. The actions are instances of tasks, whereas the object nodes are instances of work products. This thesis does not represent roles associated with tasks in the model because it considers a single role (the *SystemAnalyst* from the activity detail model in Figure 49), therefore only one swimlane would be considered.

As the figure evidences both an execution and an iteration (from the microprocess) transform an initial work product into a final work product. The figure also evidences that iterations are contained by executions. This chapter mentioned earlier that an execution ends a set of iterations (from the microprocess). The model in Figure 50 evidences that after an iteration is performed two guard constraints are evaluated to decide on the need for a new execution (or the ending of the current execution).

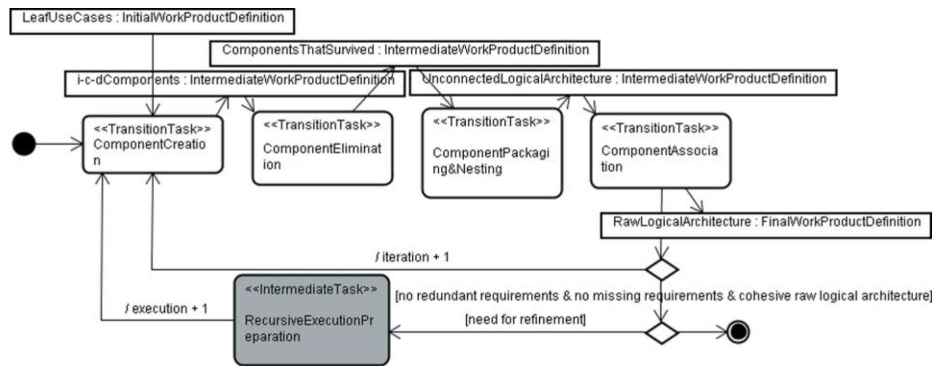


Figure 50 – A workflow model of the 4SRS (micro)process.

5.3. Automating the 4SRS Transition Method

The core topic of this section is model transformation. Some model-to-model transformations from one source model (a use case diagram) into a target model (a component diagram) are presented. Since the 4SRS moves from UML use cases to UML component diagrams, the Moderne tool allows endogenous transformations to occur in the context of this section. When generating a component diagram from a use case diagram, the move is from user functional requirements to system functional requirements and so the abstraction level decreases. This means the transformations in this chapter are useful to transform views between different levels of abstraction.

The goal of automated transition methods modeled with the SPEM is to automatically execute them as small dedicated software development processes. With regards to the 4SRS, that goal was achieved with the support of a tool. That tool is the Moderne. The Moderne is a model-driven tool of process modeling and execution. The Moderne tool allows the execution of the 4SRS in an explicit model-driven approach, which implies generating logical architectures through model transformations using a model-to-model transformation language. These model transformations can be executed with any ATL engine that uses UML, and not only with the Moderne.

This section exposes the way the 4SRS transition method modeled with the SPEM was automated according to this thesis' definition of goal for the automation of transition methods modeled with the SPEM: the automation allows the automatic or semiautomatic execution of these transition methods as small dedicated software development processes. By automatic it is meant that models (the artifacts) are transformed using a transformation language or based on some action the modeler (the tool user) performs with the tool (to which the tool is programmed to respond) or even based on rules the tool was programmed with to

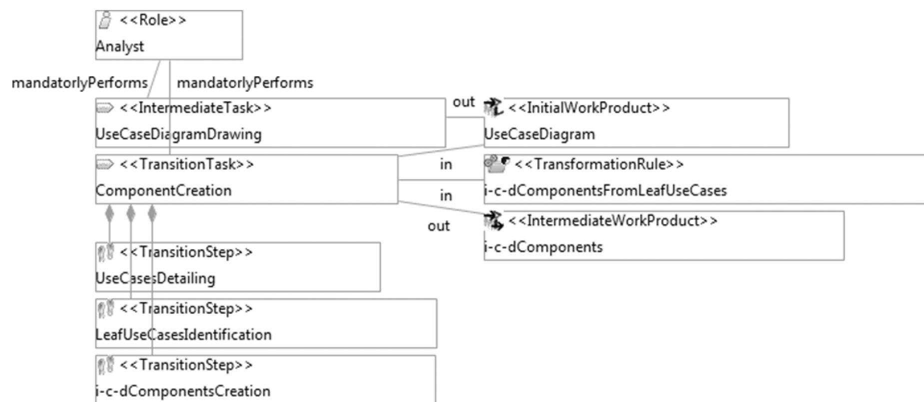


Figure 51 – The 4SRS transition method modeled with the SPEM for automation purposes.

respond to some particular event without any modeler's action. By semiautomatic it is meant that the tool supports decisions the modeler has to make by allowing him to represent them in the diagrams.

The modeling of the 4SRS transition method with the SPEM this thesis performed beforehand had to be adapted in order for the method to be automatically executed as a microprocess with the Moderne tool. In the context of this chapter, a microprocess is a small dedicated software development process dedicated at transitioning from analysis to design, which can be plugged into larger software development processes. In this chapter, a method defines tasks (composed of steps), roles and work products, therefore methods are modeled with the following elements: tasks (and steps), roles and work products. A process uses those tasks, roles and work products as many times as needed. In this thesis a process defines the use of a structure of tasks, roles and work products for software and systems development. This thesis subclasses tasks into transition tasks and intermediate tasks, steps into transition steps and intermediate steps, and finally work products into initial work products, intermediate work products and final work products. Figure 51 illustrates some examples of these elements. In the case of tasks, steps and work products, the stereotypes respectively indicate the type of task, step or work product according to the subclassing just mentioned.

The model of the 4SRS transition method with the SPEM (elaborated beforehand) was adapted by adding the transformation rule *i-c-dComponentsFromLeafUseCases* as an input to the transition task *ComponentCreation* and by adding the intermediate task *UseCaseDiagramDrawing* to the diagram. The transformation rule is an ATL rule that defines how to transform the use case diagram (the initial work product *UseCaseDiagram*) into the component diagram (the intermediate work product *i-c-dComponents*). The

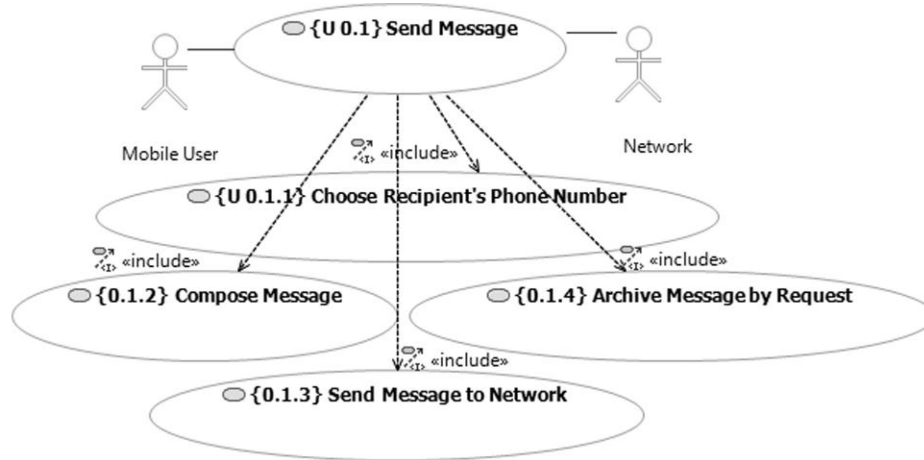


Figure 52 – A use case diagram from the GoPhone.

intermediate task had to be modeled to give the input (initial work product *UseCaseDiagram*) to the task that consumes the only initial work product in the model of the 4SRS transition method with the SPEM, which are the transition task *ComponentCreation* and the initial work product *UseCaseDiagram*. The intermediate task *UseCaseDiagramDrawing* was needed since the Moderne tool does not allow creating an input to a task in the context of the task itself, rather in the context of another task as output of that own task.

This thesis analyzed the model of the 4SRS transition method with the SPEM to identify the steps that could be automated with the Moderne tool. Table 2 shows that analysis. Some steps of the 4SRS transition method were concluded to be fully automated with the Moderne tool whereas others where concluded to be semiautomated or not automated at all. The automation capability is the ability of a method's step to be automated with a tool. The ones concluded to be fully automated with the tool were classified as "Automatic" in terms of their automation capability, the ones concluded to be semiautomated with the tool were classified as "Semiautomatic" and the ones concluded to be not automated with the tool where classified as "Not automatic". The automatic steps were automated using ATL model-to-model transformation rules. A semiautomatic step depends on some modeler's action in the models by means of the tool before the ATL model-to-model transformation rules concerning that particular step can be applied. The not automatic steps comprise actions that are fully performed by the modeler even that they consist of input for the models or for the information attached to the models, in the tool.

The use case diagram in Figure 52 is used to exemplify the model-to-model transformations the Moderne tool is able to perform in the context of the 4SRS. The diagram is based on the GoPhone case study.

Table 2 – Analysis of the automation capability of the steps from the 4SRS.

4SRS Step/Microstep	Automation Capability
Step 1: Component Creation	Automatic
Microstep 2.i: Use Case Classification	Not automatic (the modeler shall decide each use case's classification)
Microstep 2.ii: Local Elimination	Semiautomatic (the modeler shall tag in the component diagram the components to eliminate or maintain)
Microstep 2.iii: Component Naming	Not automatic
Microstep 2.iv: Component Description	Not automatic
Microstep 2.v: Component Representation	Not automatic (the modeler explicitly relates components in the diagram through *Dependency* relationships indicating which component represents others)
Microstep 2.vi: Global Elimination	Automatic (based on the *Dependency* relationships mentioned above in this table)
Microstep 2.vii: Component Renaming	Not automatic
Step 3: Component Packaging and Nesting	Not automatic
Step 4: Component Association	Semiautomatic (partially based on the rules for associating components and partially based on the modeler's decision)
Intermediate step 4+1: Filtering and Collapsing	Semiautomatic (the collapsing is automatic; the filtering is semiautomatic depending partially on the modeler's decision to perform refinement and with the automatic exclusion of the components not associated with any component from the region to refine determined by the modeler)
Intermediate microstep 4+2.i: Deriving Use Cases from Components	Not automatic
Intermediate microstep 4+2.ii: Detailing Use Cases	Not automatic

The transformation of the use case diagram in Figure 52 into the corresponding component diagram was defined in an ATL rule that mostly determines what leaf use cases are. Leaf use cases are those from which interface components, control components and data components are generated in step 1 of the 4SRS (*Component Creation*). The ATL rule defines that leaf use cases are those that are included by at least one use case and that do not include any other use case, and those that are not included by any use case and do not include any use case. The rule also defines some associations between components, and between components and actors (from the use case diagram). This anticipates part of step 4 (*Component Association*) to step 1 (*Component Creation*).

Figure 53 depicts part of the ATL rule that determines the leaf use cases of a use case diagram. The function `srcIncludes()` gets all *Include* relationships whose source is the

```
helper context UML!UseCase def : isLeaf() : Boolean =
	self.srcIncludes()->size() = 0;
```

Figure 53 – Part of the ATL rule that determines the leaf use cases of a use case diagram.

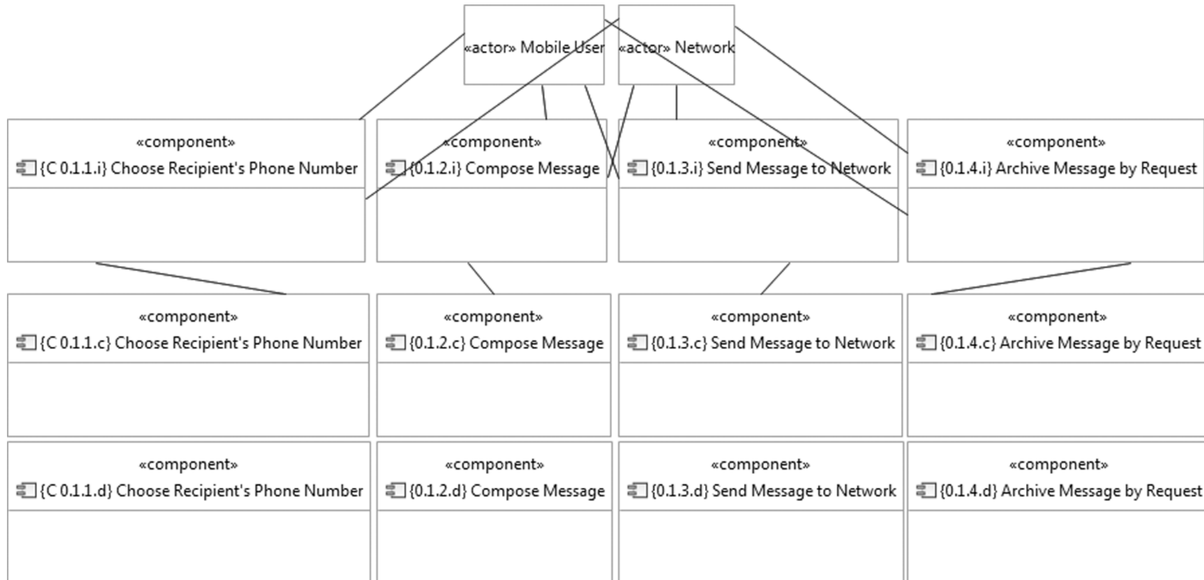


Figure 54 – The component diagram automatically generated from the use case diagram in Figure 52.

use case under evaluation. If the use case is not the source of any *Include* relationship, it means the use case under evaluation is a leaf use case. The component diagram generated from the use case diagram in Figure 52 through the ATL rule and the Moderne tool is in Figure 54.

This thesis defines some well-formedeness rules or constraints in OCL to do what the following figures illustrate.

A transition task can transform an initial work product into an intermediate work product or an intermediate work product into an intermediate work product or even an intermediate work product into a final work product. The OCL code for these constraints is in Figure 55. Figure 56 shows a validation error signaled with a cross in a transition task that transforms an intermediate work product into an initial work product.

An intermediate task transforms a final work product into an initial work product. The OCL code for this constraint is in Figure 57. Figure 58 illustrates a validation error signaled with a cross in an association between an intermediate task and an initial work product.

```
context TransitionTask
inv:
(self.in->forAll(wp | wp.oclIsTypeOf(InitialWorkProduct))
and
self.out->forAll(wp | wp.oclIsTypeOf(IntermediateWorkProduct)))
OR
(self.in->forAll(wp | wp.oclIsTypeOf(IntermediateWorkProduct))
and
self.out->forAll(wp | wp.oclIsTypeOf(IntermediateWorkProduct)))
OR
(self.in->forAll(wp | wp.oclIsTypeOf(IntermediateWorkProduct))
and
self.out->forAll(wp | wp.oclIsTypeOf(FinalWorkProduct)))
```

Figure 55 – The OCL code for constraints on the relation between transition tasks and work products.

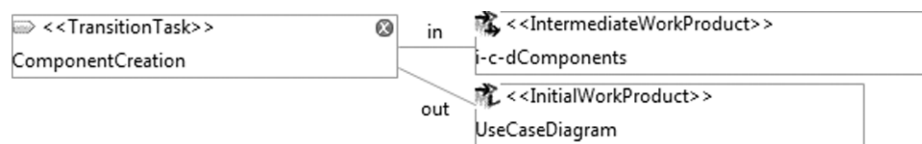


Figure 56 – An example of a validation error in the constraints on the relation between transition tasks and work products.

```
context IntermediateTask
inv:  self.in->forAll(wp | wp.oclIsTypeOf(FinalWorkProduct));
inv:  self.out->forAll(wp | wp.oclIsTypeOf(InitialWorkProduct));
```

Figure 57 – The OCL code for constraint on the relation between intermediate tasks and work products.

Figure 58 – An example of a validation error in the constraint on the relation between intermediate tasks and work products.

A transition step can only be contained by a transition task, whereas an intermediate step can only be contained by an intermediate task. The OCL code for these constraints is in Figure 59. Figure 60 depicts that a composition could not be drawn between a transition task and an intermediate step. In the case of the constraints above, a validation error is signaled with a cross in model elements because changing properties (the names) of the associations would eliminate that error. In this case, changing properties of the association would not eliminate the error since the association should not exist in the first place to obey the constraint.

```
context IntermediateTask
inv: steps->forAll(step | step.oclIsTypeOf(IntermediateStep))

context TransitionTask
inv: steps->forAll(step | step.oclIsTypeOf(TransitionStep)))
```

Figure 59 – The OCL code for constraints on the relation between tasks and steps.

Figure 60 – An example of the impossibility of a composition between a transition task and an intermediate step.

5.4. Variability Support with ATL Rules

The emphasis of this section is on the ATL rules for transforming an analysis model into a design model in the context of the 4SRS transition method with support for software variability. That model-to-model transformation generates a logical architecture out of a use case diagram. The UML profile related to the transformation rules is composed of the following stereotypes applicable to the following (respective) model elements: *«representedBy»* to the *Dependency* relationship, *«option»* to *UseCase* and *«alternative»* to the *Extend* relationship.

Previously, in this chapter, step 1 (*Component Creation*) of the 4SRS was considered to be automatic. This step is about creating an interface component, a control component and a data component for each use case. Microstep 2.vi (*Global Elimination*) was also concluded to be automatic. It is concerned with eliminating components based on some rules and the *Dependency* relationships the modeler explicitly relates components with in the diagram to indicate which component represents others. Step 4 (*Component Association*) of the 4SRS was identified as semiautomatic, since some rules were systematized for the association of components.

Figure 61 depicts part of the ATL rule that defines how to transform the use case diagram into the component diagram. The ATL rule targets a subset of the source model elements of type *UseCase*: leaf use cases (that are leaf regardless of variability being modeled in the use case diagram). Leaf use cases are those from which interface components, control components and data components are generated in step 1 (*Component Creation*) of the 4SRS. The ATL rule defines that leaf use cases are those that do not include any other use case. The

```
from u : UML!UseCase (if u.isLeaf() or u.name.startsWith('<<option>>') then u.extend-
>isEmpty() else false endif)
```

Figure 61 – Part of the ATL rule that applies to a use case diagram: definition of the subset of source use cases in contexts of variability.

```
helper context UML!UseCase def : isLeaf() : Boolean =
       self.srcIncludes()->size() = 0;

helper context UML!UseCase def : srcIncludes() : Sequence(UML!Include) =
       UML!Include.allInstancesFrom('IN')->select(c|c.getSrc()=self);

helper context UML!Include def : getSrc() : UML!UseCase =
       self.includingCase;
```

Figure 62 – Part of the ATL rule that applies to a use case diagram: definition of leaf use cases regardless of variability.

ATL rule also defines some associations between components, and between components and actors (from the use case diagram). This anticipates part of step 4 (*Component Association*) to step 1 (*Component Creation*). In the presence of variability, alternative use cases (connected to each other through *Extend* relationships stereotyped as *«alternative»*) are considered to be leaf use cases. Also, *«option»* use cases are considered to be leaf use cases. The ATL rule evaluates if a use case owns any *Include* relationship through the function `isLeaf()` and verifies if its name begins with «`option`». If the use case does not own any *Include* relationship or its name begins with «`option`», then the ATL rule verifies if the use case does not extend any other use case, which shall be the case. This means the subset of source use cases the ATL rule considers is composed of the ones returned from the function `isLeaf()` simultaneously not owning an *Extend* relationship (that can be an alternative or a specialization), as well as those marked with the stereotype *«option»* simultaneously not owning an *Extend* relationship.

Figure 62 shows the implementation of the function `isLeaf()`. In the context of the `srcIncludes()` function, the function `allInstancesFrom('IN')` gets all instances of *Include* relationships from the source model (in this case, the use case diagram). The function `getSrc()` gets all including use cases from the use case diagram. If `getSrc()` gets no use cases, it means the use case under evaluation is leaf (an including use case cannot be a leaf use case).

Figure 63 illustrates the part of the ATL rule that creates components, as well as the associations it defines between those components, both for use cases simultaneously neither including, nor extending and use cases marked with the stereotype *«option»* simultaneously not extending. As previously stated, interface components, control components and data

```
                ci.name <- u.name.regexReplaceAll('U ', 'C ');
                ci.name <- ci.name.regexReplaceAll('}', '.i}');
                cc.name <- u.name.regexReplaceAll('U ', 'C ');
                cc.name <- cc.name.regexReplaceAll('}', '.c}');
                cd.name <- u.name.regexReplaceAll('U ', 'C ');
                cd.name <- cd.name.regexReplaceAll('}', '.d}');

                ci.package.packagedElement <- ci.package.packagedElement.including(cc);
                ci.package.packagedElement <- ci.package.packagedElement.including(cd);
                ci.package.packagedElement <- thisModule.createAssociation(ci, cc);


lazy rule createAssociation {
    from ClassDst : UML!Component,
                ClassSrc : UML!Component
    to t : UML!"uml::Association"(
                ownedEnd <- dst,
                ownedEnd <- src
                ),
            dst : UML!Property
            (
                        name<-'dst',
                        type<-ClassDst
                ),
        src : UML!Property
                (
                        name<-'src',
                        type<-ClassSrc
                )
}
```

Figure 63 – Part of the ATL rule that applies to a use case diagram: generation of components from leaf use cases regardless of variability.

components are generated from leaf use cases and the use cases to which the part of the ATL rule illustrated in Figure 63 applies are leaf use cases regardless of variability consideration at the level of use cases. For each of these last mentioned use cases an interface component (`ci`), a control component (`cc`) and a data component (`cd`) are generated. After that, both the control component and the data component are packaged in the same package as the interface component.

This thesis also proposes to extend step 4 of the 4SRS with a rule for the association of components originated from use cases in general (regardless of variability consideration), from alternative use cases, and from specialization use cases and the use cases they specialize. An interface component shall be associated with the corresponding control component, both originated from the same use case. In presence of variability, components shall be associated with each other and with actors according to the following rules. An interface component generated from a specialization use case shall be associated with the interface component generated from the use case it specializes, as well as a control

```
                if(u.hasExtend() and u.isLeaf())
                {
                        for(e in u.getExtends())
                        {
                                usecase<-e.extension;
                                if(usecase.isLeaf())
                                {
                                        compi <- thisModule.createComp(usecase);
                                        compi.name <- compi.name.regexReplaceAll('U ', 'C ');
                                        compi.name <- compi.name.regexReplaceAll('}', '.i}');
                                        ci.package.packagedElement <-
ci.package.packagedElement.including(compi);

                                        compc <- thisModule.createComp(usecase);
                                        compc.name <- compc.name.regexReplaceAll('U ', 'C ');
                                        compc.name <- compc.name.regexReplaceAll('}', '.c}');
                                        ci.package.packagedElement <-
ci.package.packagedElement.including(compc);


                                        if(e.name <> '<<alternative>>')
                                        {
                                                ci.package.packagedElement <-
thisModule.createAssociation(ci, compi);
                                                ci.package.packagedElement <-
thisModule.createAssociation(cc, compc);
                                        }
                                        else
                                        {

                                                for(assoc in u.associations())
                                                {
                                                        if(assoc.getSrc().oclIsTypeOf(UML!Actor))
                                                        {

                                                                actor <- assoc.getSrc();
                                                                ci.package.packagedElement <-
thisModule.copyAssociation(actor, compi);
                                                }
                                                        if(assoc.getDst().oclIsTypeOf(UML!Actor))
                                                        {

                                                                actor <- assoc.getDst();
                                                                ci.package.packagedElement <-
thisModule.copyAssociation(actor, compi);
                                                        }
                                                }
                                        }

                                        ci.package.packagedElement <-
thisModule.createAssociation(compi, compc);

                                        compd <- thisModule.createComp(usecase);
                                        compd.name <- compd.name.regexReplaceAll('U ', 'C ');
                                        compd.name <- compd.name.regexReplaceAll('}', '.d}');
                                        ci.package.packagedElement <-
ci.package.packagedElement.including(compd);

                                }
                        }
                }
```

```
            else
            {
                    for( assoc in u.getParent())
                                    {
                                            if(assoc.getSrc().oclIsTypeOf(UML!Actor))
                                            {

                                                    actor <- assoc.getSrc();
                                                    ci.package.packagedElement <-
thisModule.copyAssociation(actor, ci);
                                            }
                                            if(assoc.getDst().oclIsTypeOf(UML!Actor))
                                            {

                                                    actor <- assoc.getDst();
                                                    ci.package.packagedElement <-
thisModule.copyAssociation(actor, ci);

                                            }
                                    }
            }
```

Figure 64 – Part of the ATL rule that applies to a use case diagram.

component generated from a specialization use case shall be associated with the control component generated from the use case it specializes. An interface component shall be associated with the actor of the use case that originated the component. An actor associated with a use case for which there is an alternative shall also be associated with the interface component generated from the use case that represents the alternative.

The function `createAssociation` in Figure 63 creates an association between the interface component and the control component. Considering the possibility of data components representing each other, the ATL rule does not generates a data component for every leaf use case regardless of variability being considered.

The part of the ATL rule that defines how to transform the use case diagram into the component diagram and considers the subset of source use cases simultaneously neither including, nor extending and source use cases marked with the stereotype *«option»* simultaneously not extending starts by evaluating that subset of source use cases with the first two functions in Figure 64: `hasExtend()` and `isLeaf()`.

For each of the source use cases in the just mentioned subset, the function `hasExtend()` in Figure 65 checks if it is an extended use case.

```
helper context UML!UseCase def : hasExtend() : Boolean =
       UML!Extend.allInstancesFrom('IN')-> exists(st| st.extendedCase = self);
```

Figure 65 – Part of the ATL rule that applies to a use case diagram: the `hasExtend()` *function.*

```
helper context UML!UseCase def : getExtends() : Sequence(UML!Extend) =
       UML!Extend.allInstancesFrom('IN')-> select(st| st.extendedCase = self);
```

Figure 66 – Part of the ATL rule that applies to a use case diagram: the `getExtends()` *function.*

The combination of the `hasExtend()` function with the `isLeaf()` function equals considering use cases simultaneously not including, not extending and extended. This means these use cases are leaf and have at least one alternative to them.

The ATL rule targets each of the leaf use cases from the use case diagram that have at least one alternative to them with the function `getExtends()`. In the context of that function, in Figure 66, the function `allInstancesFrom('IN')` gets all instances of *Extend* relationships from the use case diagram. The function `getExtends()` gets all *Extend* relationships from the use case diagram of which the targeted use case is the extended use case.

For every use case in the diagram that is leaf (not an including use case), not an extending use case and has at least one alternative to it, the ATL rule accesses each of the *Extend* relationships targeted at it. For each of those relationships, the ATL rule gets the extending use case and checks if that is not an including use case. If that is the case, then the ATL rule creates, from the extending use case, an interface component (`compi`) and a control component (`compc`) and packages them in the same package as the components previously created for the extended use case.

In the context of each *Extend* relationship just mentioned, the ATL rule verifies if it is an «`alternative`». If that is not the case, it means it is a specialization relationship (relationship stereotyped as *«specialization»*) and the ATL rule creates an association between the interface component generated from the extended use case and the interface component generated from the extending use case, as well as an association between the control component generated from the extended use case and the control component generated from the extending use case.

```
helper context UML!UseCase def : associations() : Sequence(UML!Association) =
	UML!Association.allInstancesFrom('IN')->select(c|c.getSrc()=self or c.getDst()=self);

helper context UML!Association def : getSrc() : UML!Element =
	self.ownedEnd->select(c | c.name = 'src')->first();

helper context UML!Association def : getDst() : UML!Element =
	self.ownedEnd->select(c | c.name = 'dst')->first();
```

Figure 67 – Part of the ATL rule that applies to a use case diagram: the `associations()` *function.*

```
lazy rule copyAssociation {
    from ClasseSrc : UML!Element,
               ClasseDst : UML!Component
    to t : UML!"uml::Association"(
               ownedEnd <- dst,
               ownedEnd <- src
               ),
           dst : UML!Property
           (
                       name<-'dst',
                       type<-ClasseDst
               ),
        src : UML!Property
               (
                       name<-'src',
                       type<-ClasseSrc
               )
}
```

Figure 68 – Part of the ATL rule that applies to a use case diagram: generation of associations between interface components and actors in contexts of alternative variability (variability related to alternative relationships, which are stereotyped as «alternative»*).*

Again in the context of each *Extend* relationship just mentioned, if it is an «`alternative`», the ATL rule gets all associations of which the leaf extended use case is the source or the destination, as Figure 67 demonstrates.

For each of those associations, the ATL rule checks if the source is an UML element of type *Actor*. If it is, then it creates an association between the actor and the interface component generated from the extending use case. After that, the ATL rule performs the same for the destination of each of those associations (it creates an association between the actor and the interface component generated from the extended use case). Figure 68 depicts the creation of these associations.

Still for every use case in the diagram that is leaf, not an extending use case and has at least one alternative to it, the ATL rule creates an association between the interface component generated from the extending use case and the control component generated from the extending use case. Then the ATL rule creates a data component for the extending use

```
helper context UML!UseCase def : getParent() : Sequence(UML!Association) =
	if not self.dstIncludes()->isEmpty() then
		self.firstDstInclude().getSrc().getParent()
	else
		self.actorAssociations()
	endif;

helper context UML!UseCase def : dstIncludes() : Sequence(UML!Include) =
	UML!Include.allInstancesFrom('IN')->select(c|c.getDst()=self);

helper context UML!UseCase def : firstDstInclude() : Sequence(UML!Include) =
	UML!Include.allInstancesFrom('IN')->select(c|c.getDst()=self)->first();

helper context UML!UseCase def : hasSrcExtend() : Boolean =
	UML!Extend.allInstancesFrom('IN')-> exists(st| st.extension = self);

helper context UML!UseCase def : getSrcExtend() : Sequence(UML!Extend) =
	UML!Extend.allInstancesFrom('IN')-> select(st| st.extension = self)->first();

helper context UML!UseCase def : actorAssociations() : Sequence(UML!Association) =
	UML!Association.allInstancesFrom('IN')->select(c|(c.getSrc()=self or c.getDst()=self)
and (c.getSrc().oclIsTypeOf(UML!Actor) or c.getDst().oclIsTypeOf(UML!Actor)));
```

Figure 69 – Part of the ATL rule that applies to a use case diagram: generation of associations between actors and interface components generated from leaf use cases not involved in Extend *relationships, and option use cases simultaneously not extending and extended.*

case and packages it in the same package that contains the interface component generated from the extended use case.

For every use case in the diagram that is leaf and not involved in *Extend* relationships, and is option simultaneously not extending and extended, the ATL rule evaluates if the use case is included by any other (through the function `dstIncludes()` in Figure 69). If that is the case, the ATL rule gets the including use case (through the function `getSrc()` over `firstDstInclude()` in Figure 69) and recursively looks for associations between the use case and an actor. Otherwise, the ATL rule gets the associations of which the use case is either source or destination and either the destination or the source is a UML element of type *Actor*.

For each of those associations, the ATL rule gets the actor and associates it with the interface component generated from the including use case on the top of the *Include* hierarchy.

Part of the ATL rule that applies to the component diagram resulting from microstep 2.v (*Component Representation*) (the diagram in which the modeler explicitly relates components in the diagram through *Dependency* relationships indicating which component

```
	from src : UML!Component(if thisModule.allModelElements('IN')->includes(src) then
	                                                        if
src.name.split('(?s)e(.+)[cd]}').size() = 1 then
	                                                        src.isRepresented()
	                                                        else
	                                                               true
	                                                        endif
	                                                else false endif)

helper context UML!Component def : isRepresented() : Boolean =
	self.clientDependency->exists(dep|dep.isStereotyped('«representedBy»'));

helper context UML!UseCase def : isStereotyped(stereotype : String) : Boolean =
	self.getAppliedStereotypes()->exists(c|c.name = stereotype);
```

Figure 70 – Part of the ATL rule that applies to the component diagram resulting from microstep 2.v of the 4SRS.

represents others) to generate the component diagram resulting from microstep 2.vi (*Global Elimination*) is going to be presented next.

Since UML2 Tools [108] (the editor of UML models the Moderne tool uses) does not allow forbidding the modeler from drawing a *«representedBy» Dependency* relationship from a component that cannot be represented by any other, the rules for the global elimination of components previously mentioned in this section can only be applied when applying the ATL rule just mentioned.

The next ATL rule automatically performs the transformation of 4SRS' microstep 2.vi (*Global Elimination*). Based on the *Dependency* relationships the modeler used to explicitly relate components in the diagram that represent others, this ATL rule (shown partly in Figure 70) takes the name of a component in the source component diagram and evaluates whether the component shall be copied to the target component diagram or not. If the component's name is from a control or data component involved in an *Extend* relationship, the ATL rule evaluates if the component is represented by any other (owning at least one *Dependency* relationship tagged with the stereotype *«representedBy»*). If that is the case, the ATL rule does not maintain the component in the component diagram resulting from this transformation. The component's name is evaluated with a split, which is determined by a regular expression (`(?s)e(.+)[cd]}`). `e` represents the character *e*, `(.+)` represents one or more characters (including line terminators, which is determined by the embedded flag `(?s)` that enables the DOTALL mode) and `[cd]}` represents either the characters *c}* or *d}*. If the source component is the client of at least one *Dependency* relationship stereotyped as *«representedBy»*, then the ATL rule considers it to be represented by at least another component (this is achieved through the function `isRepresented()`). Since UML2 Tools

does not allow the stereotype *«representedBy»* on *Dependency* relationships, the ATL rule looks for the stereotype in the component's name (`c.name = stereotype`).

5.5. Conclusions

The SPEM is a software and systems development process modeling language. Transition methods describe how to transform artifacts originally produced within a certain discipline of a large software development process into artifacts from another discipline of such a process. Some transition methods are targeted at moving from the analysis to the design of software. The 4SRS is a method that allows moving from the analysis to the design of software. In the case of the 4SRS, the analysis model (a UML use case diagram) influences architectural decisions that originate a design model (a UML component diagram, the first technical artifact to initiate the design of the system).

The work reported in this chapter was to formalize transition methods as small dedicated software development processes that can be plugged into larger software development processes. In that sense, the SPEM was extended through metamodeling techniques for defining a visual language to model transition methods and formalizing small dedicated (at transitioning from the analysis to the design of) software development processes (such as the 4SRS). The 4SRS modeled as a method content from the SPEM can be the basis for formalizing it as a small software development process dedicated at transitioning from the analysis to the design of software, which can be plugged into larger software development processes.

This chapter presents some models drawn (in the context of the 4SRS) with the visual language this thesis defined by extending the SPEM: the method content model for the 4SRS, a process model with instances from the process structure metamodel, an activity detail model of the 4SRS microprocess structure and a workflow model of the 4SRS microprocess behavior.

This chapter describes the automation of a transition method, using the 4SRS method modeled with the SPEM as the case study. This thesis reports the adaptation of the Moderne tool to automate the generation of logical architectures through model transformations defined with the ATL language. This thesis defines some well-formedeness rules or constraints in OCL to validate the models of the 4SRS transition method with the SPEM.

The SPEM model of the 4SRS transition method elaborated beforehand was adapted for automation purposes. For instance a transformation rule was added to the diagram.

The OCL constraints on the models of the 4SRS transition method with the SPEM established the well-formedeness of the relations between transition tasks and work products, between intermediate tasks and work products, and between tasks and steps (all of these are elements for the modeling of methods). The violation of the constraints on those relations is tagged in the model through validation errors.

This chapter also reported the transformation rules to automate some steps of the transition from use cases to a logical architecture, both diagrams supporting the representation of variability. The metamodel this thesis extended represents a metamodeling approach, which means the approach in this thesis is in concordance with the suggestion of Brown, *et al*. stating that if a metamodel is ellaborated, transformations between models using automation tools are facilitated [65].

The method to refine logical architectures with variability support prompted by chapter 3 has been automated with the work reported in this chapter.

6. Conclusions

This last chapter is devoted to showing the way the contributions of this thesis addressed the research goals pointed out in Chapter 1, to presenting the list of publications this thesis produced, and to providing suggestions to continue developing and applying this research.

6.1. Discussion

Research Contributions

Chapter 3 reflected upon the support of the UML metamodel for the functional refinement of use case diagrams. It concluded that the *«include»* relationship is not adequate for that purpose and proposed an extension to the UML metamodel to bridge that gap with a new relationship: the *«refine»* relationship. Chapter 3 also proposed a systematization of use case variability modeling, as well as an extension to the UML metamodel in order to model variability in use case diagrams according to that systematization. This chapter proposed to represent variability in use case diagrams through *«extend»* relationships and stereotypes. It considered that the *«extend»* relationship is adequate for modeling alternatives and specializations, and a stereotype applicable to use cases for modeling options. This chapter proposed the stereotypes *«alternative»*, *«specialization»* and *«option»* to distinguish the three variability types it proposed. It also proposed the stereotype *«variant»* to mark use cases at higher levels of abstraction before they are realized into alternatives or specializations. The stereotypes *«alternative»* and *«specialization»* were recommended to be applicable to the *«extend»* relationship for modeling alternatives and specializations, respectively, and the

stereotype *«option»* to mark use cases that represent options. Chapter 3 also argued about the implications of functionally refining use cases when variability is represented in use case diagrams with use cases connected through *«extend»* relationships. The approach of this chapter to use case modeling with support for refinement and variability was illustrated with the GoPhone case study. Chapter 3 provided for the following research contributions:

Research contribution 1: *an extension to the UML metamodel for the functional refinement of use case diagrams*.

Research contribution 2: *an extension to the UML metamodel for variability modeling in use case diagrams*.

These contributions addressed the following research goals, pointed out in Chapter 1:

Research goal 1: *providing specific guidelines on how to conduct the activity of use case modeling with support for functional refinement*.

Research goal 2: *providing specific guidelines on how to conduct the activity of use case modeling with support for both functional refinement and software variability*.

By representing variability in use case diagrams, chapter 3 provided for variability support in the logical architectures generated with the execution of the 4SRS transition method over those use case diagrams. Chapter 3 formalized use case refinement, which is relevant for the preparation of the recursive method's execution, as well as it provided for guidelines to determine the use cases that will be the input for the method's execution (recursive or not) and exposed the implications of executing the method itself when variability is considered in use cases. The extension of the 4SRS proposed in chapter 3 included the formalization of filtering and collapsing techniques applicable to the logical architectures delivered by the method's execution (recursive or not) and the formalization of the transformation from components to use cases in order to prepare the recursive execution of the method. Chapter 3 provided for the following research contributions:

Research contribution 3: *guidelines to determine the use cases that will be the input for the 4SRS' execution (recursive or not) when variability is considered in use cases*.

Research contribution 4: *guidelines for the execution of the 4SRS when variability is considered in use cases.*

Research contribution 5: *extension of the 4SRS with filtering and collapsing techniques applicable to the logical architectures delivered by the method's execution (recursive or not).*

Research contribution 6: *formalization of the transformation from components to use cases in order to prepare the recursive execution of the 4SRS.*

These contributions addressed the following research goal, pointed out in Chapter 1:

Research goal 3: *supporting the refinement of logical software architectures with variability support by extending a method applicable for modeling those architectures (the 4SRS).*

Chapter 4 concluded that a procedural referential such as the RUP is important to classify patterns, mainly because it gives the classification a notion of software development process, therefore, it proposed a multilevel and multistage pattern classification. That classification provides for the knowledge of the moment from the software development process in which to use specific kinds of patterns. The foundation for the model transformation the 4SRS conducts is given the classification chapter 4 reported of a specific pattern (the MVC) and its incorporation in the structure of the logical architectures the 4SRS generates. Chapter 4 provided for the following research contribution:

Research contribution 7: *multilevel and multistage software development pattern classification based on the RUP and the classification of some software development patterns.*

This contribution addressed the following research goal, pointed out in Chapter 1:

Research goal 4: *classifying software patterns according to a multilevel and multistage pattern classification based on the software development process to justify the pattern used for the model transformation the 4SRS guides.*

Chapter 5 formalized a transition method (the 4SRS) as a small dedicated (at transitioning from the analysis to the design of) software development process that can be plugged into larger software development processes. For that purpose, chapter 5 extended the SPEM through metamodeling techniques for defining a visual language to model transition methods. Then, it modeled the 4SRS as a method content from the SPEM. Chapter 5 also elaborated on the automation of transition methods by means of a case study with the 4SRS method modeled with the SPEM and automated with the Moderne tool, which was adapted for the purpose. In the context of the Moderne tool, the 4SRS model transformations were defined with the ATL language, as well as some well-formedeness rules or constraints were defined with OCL to validate the models of the 4SRS transition method with the SPEM. Finally, chapter 5 addressed the transformation rules the Moderne tool used to automate some steps of the 4SRS with support for variability. Chapter 5 provided for the following research contributions:

Research contribution 8: *visual language to model transition methods by means of an extension to the SPEM*.

Research contribution 9: *model of the 4SRS as a method content from the SPEM*.

Research contribution 10: *the Moderne tool adapted to automate the 4SRS transition method modeled with the SPEM, including ATL model transformation rules for the execution of the 4SRS with support for variability and OCL constraints to validate the models of the 4SRS with the SPEM*.

These contributions addressed the following research goals, pointed out in Chapter 1:

Research goal 5: *exploring the particularities of modeling transition methods (like the 4SRS) to formalize them as small dedicated software development processes*.

Research goal 6: *exemplifying the SPEM modeling of a transition method like the 4SRS as a way to study the benefits of the automatic execution of transition methods as small dedicated software development processes*.

Research goal 7: *reflecting on the impact of variability over the automation of transition methods (like the 4SRS) modeled with SPEM.*

Publications

This thesis produced some research publications, namely:

1) S. Azevedo*, et al.*, "On the Refinement of Use Case Models with Variability Support," *Innovations in Systems and Software Engineering,* vol. 8, pp. 51-64, 2012;

2) S. Azevedo*, et al.*, "On the Use of Model Transformations for the Automation of the 4SRS Transition Method " presented at the 10th International Workshop on System/Software Architectures (IWSSA 2012), Gdańsk, Poland, 2012;

3) S. Azevedo*, et al.*, "Systematic Use of Software Development Patterns through a Multilevel and Multistage Classification," in *Model-Driven Domain Analysis and Software Development: Architectures and Functions*, J. Osis and E. Asnina, Eds., ed Hershey: IGI Global, 2011, pp. 304-333;

4) S. Azevedo*, et al.*, "Support for Variability in Use Case Modeling with Refinement," presented at the 7th International Workshop on Model-Based Methodologies for Pervasive and Embedded Software (MOMPES 2010), Antwerp, Belgium, 2010;

5) S. Azevedo*, et al.*, "The UML «extend» Relationship as Support for Software Variability," presented at the 14th International Software Product Line Conference (SPLC 2010), Jeju Island, South Korea, 2010;

6) S. Azevedo*, et al.*, "The UML «include» Relationship and the Functional Refinement of Use Cases," presented at the 36th Euromicro Conference on Software Engineering and Advanced Applications (SEAA 2010), Lille, France, 2010;

7) S. Azevedo*, et al.*, "Refinement of Software Product Line Architectures through Recursive Modeling Techniques," presented at the 8th International Workshop on System/Software Architectures (IWSSA 2009), Vilamoura, Portugal, 2009;

8) S. Azevedo*, et al.*, "Multistage Model Transformations in Software Product Lines," presented at the Simpósio para Estudantes de Doutoramento em Engenharia de Software (SEDES 2009), Porto, Portugal, 2009.

6.2. Future Work

The most obvious work to conduct in the future as an extension of this thesis is to define or formalize the support for refinement and variability in other perspectives over software systems or families of software systems development.

Future work concerning the software patterns in the context of the software development process involves studying how patterns evolve over the time of that process. This evolution demands for the comprehension of the relationships between software patterns (especially those positioned at consecutive stages). It also demands for the analysis of how time implies that software patterns are associated with each other in a chain. The gap between patterns used at different stages shall be bridged in order to have a complete multistage

software development process that contemplates different artifacts (software patterns and other artifacts like use cases, component diagrams and others). In fact software patterns used at different stages solve the same problem at different levels of abstraction.

Software patterns may be used to detail logical software system architectures (expressed through component diagrams). As software patterns are normally presented in class diagrams, the detailing of those architectures requires knowing how to apply the concept of class to the concept of (logical) component.

The consideration of software patterns within the context of the software development process claims for the specialization of the actors who intervene in that process with specific roles during the adoption of those patterns. It is relevant to study the impacts of other software development processes (besides the RUP) in the proposed pattern classification.

Developing software product lines with software patterns (and other artifacts) may have some particular implications. Some variability mechanisms may have to be taken into account in software patterns. The use of those mechanisms may be constrained to a specific level of the OMG modeling infrastructure (the M2-level) and to specific pattern types. It may be necessary to define all the possible M2-level concepts (e.g. classes, attributes, operations) and/or the values of those concepts (e.g. class names, class attributes, class operations) as well as the application of all of them to all or some of the product line's members. The whole matter with software product lines and software patterns may mainly lie on the instantiation of M2-level artifacts at the M1-level.

Finally it is important to determine which software patterns may and shall be made available in modeling infrastructures (either through libraries of software pattern metamodels or models, or through domain-specific languages).

In terms of future work concerned with the automation of transition methods (like the 4SRS), it is planned to assess the efficiency of this thesis' approach by adopting the Moderne tool to apply the 4SRS transition method in a real industrial project. It is also planned to include the approach of this thesis to the refinement of logical architectures with the 4SRS transition method in the Moderne tool, as well as conducting a broader case study on the use of the Moderne for the same purpose and validating that approach with software metrics.

References

[1] OMG. (2009). *Unified Modeling Language: Superstructure - version 2.2*. Available: http://www.omg.org

[2] J. Greenfield and K. Short, *Software Factories: Assembling Applications with Patterns, Models, Frameworks, and Tools*. Hoboken, New Jersey: Wiley, 2004.

[3] J. Greenfield and K. Short, "Software Factories: Assembling Applications with Patterns, Models, Frameworks and Tools," presented at the 18th Annual ACM SIGPLAN Conference on Object-Oriented Programming, Systems, Languages and Applications (OOPSLA 2003), Anaheim, California, USA, 2003.

[4] J. M. Fernandes*, et al.*, "A Demonstration Case on the Transformation of Software Architectures for Service Specification," presented at the 5th IFIP Working Conference on Distributed and Parallel Embedded Systems (DIPES 2006), Braga, Portugal, 2006.

[5] R. J. Machado*, et al.*, "Refinement of Software Architectures by Recursive Model Transformations," presented at the 7th International Conference on Product Focused Software Process Improvement (PROFES 2006), Amsterdam, The Netherlands, 2006.

[6] R. J. Machado*, et al.*, "Transformation of UML Models for Service-Oriented Software Architectures," presented at the 12th IEEE International Conference and Workshops on the Engineering of Computer-Based Systems (ECBS 2005), Greenbelt, Maryland, USA, 2005.

[7] D. Muthig*, et al.*, "GoPhone - A Software Product Line in the Mobile Phone Domain," Fraunhofer IESE, IESE-Report No. 025.04/EMarch 5 2004.

[8] F. Buschmann*, et al.*, *Pattern-Oriented Software Architecture: A System of Patterns*. Hoboken, New Jersey: Wiley, 1996.

[9] P. Kruchten, *The Rational Unified Process: An Introduction*. Upper Saddle River, New Jersey: Addison-Wesley, 2000.

[10] L. Balmelli*, et al.*, "Model-Driven Systems Development," *IBM Systems Journal,* vol. 45, pp. 569-585, 2006.

[11] C. Atkinson and T. Kühne, "Model-Driven Development: A Metamodeling Foundation," *IEEE Software,* vol. 20, pp. 36-41, 2003.

[12] OMG. (2008). *Software & Systems Process Engineering Meta-Model Specification - version 2.0*. Available: http://www.omg.org

[13] I. Vessey*, et al.*, "Research in Information Systems: An Empirical Study of Diversity in the Discipline and Its Journals," *Journal of Management Information Systems,* vol. 9, pp. 129-174, 2002.

[14] R. A. Gomes*, et al.*, "Moderne: Model Driven Process Centered Software Engineering Environment," presented at the 2nd Congresso Brasileiro de Software: Teoria e Prática (CBSoft 2011), São Paulo, Brasil, 2011.

[15] B. Paech and B. Rumpe, "A New Concept of Refinement used for Behaviour Modelling with Automata," presented at the 2nd International Symposium of Formal Methods Europe (FME 1994), Barcelona, Spain, 1994.

[16] D. A. C. Quartel, *et al.*, "An Engineering Approach towards Action Refinement," presented at the 5th IEEE Workshop on Future Trends of Distributed Computing Systems (FTDCS 1995), Chenju, Korea, 1995.

[17] R. Darimont and A. v. Lamsweerde, "Formal Refinement Patterns for Goal-Driven Requirements Elaboration," presented at the 4th Symposium on the Foundations of Software Engineering (FSE-4), San Francisco, California, USA, 1996.

[18] M. Schrefl and M. Stumptner, "Behavior Consistent Refinement of Object Life Cycles," presented at the 16th International Conference on Conceptual Modeling (ER 1997), Los Angeles, California, USA, 1997.

[19] B. Mikolajczak and Z. Wang, "Conceptual Modeling of Concurrent Systems through Stepwise Abstraction and Refinement Using Petri Net Morphisms," presented at the 22nd International Conference on Conceptual Modeling (ER 2003), Chicago, Illinois, USA, 2003.

[20] D. Batory, *et al.*, "Scaling Step-Wise Refinement," *IEEE Transactions on Software Engineering,* vol. 30, pp. 355-371, June 2004.

[21] S. S.-s. Cherfi, *et al.*, "Use Case Modeling and Refinement: A Quality-Based Approach," presented at the 25th International Conference on Conceptual Modeling (ER 2006), Tucson, Arizona, USA, 2006.

[22] A. Cockburn, *Writing Effective Use Cases*. Upper Saddle River, New Jersey: Addison-Wesley, 2000.

[23] C. Pons and R.-D. Kutsche, "Traceability Across Refinement Steps in UML Modeling," presented at the 3rd UML Workshop in Software Model Engineering (WiSME 2004), Lisbon, Portugal, 2004.

[24] M. Eriksson, *et al.*, "Software Product Line Modeling Made Practical," *Communications of the ACM,* vol. 49, pp. 49-53, 2006.

[25] A. Egyed, *et al.*, "Software Connectors and Refinement in Family Architectures," presented at the 3rd International Workshop on Development and Evolution of Software Architectures for Product Families (IWSAPF-3), Las Palmas de Gran Canaria, Spain, 2000.

[26] H. Gomaa, *Designing Software Product Lines with UML: From Use Cases to Pattern-Based Software Architectures*. Upper Saddle River, New Jersey: Addison-Wesley, 2004.

[27] M. Fowler, *UML Distilled: A Brief Guide to the Standard Object Modeling Language*. Upper Saddle River, New Jersey: Addison-Wesley, 2004.

[28] A. Bragança and R. J. Machado, "Extending UML 2.0 Metamodel for Complementary Usages of the «extend» Relationship within Use Case Variability Specification," presented at the 10th International Software Product Line Conference (SPLC 2006), Baltimore, Maryland, USA, 2006.

[29] A. Bragança and R. J. Machado, "Deriving Software Product Line's Architectural Requirements from Use Cases: An Experimental Approach," presented at the 2nd International Workshop on Model-Based Methodologies for Pervasive and Embedded Software (MOMPES 2005), Rennes, France, 2005.

[30] J. Bayer, *et al.*, "Consolidated Product Line Variability Modeling," in *Software Product Lines - Research Issues in Engineering and Management*, T. Käköla and J. C. Duenas, Eds., ed Berlin Heidelberg: Springer-Verlag, 2006, pp. 195-241.

[31] I. John and D. Muthig, "Tailoring Use Cases for Product Line Modeling," presented at the International Workshop on Requirements Engineering for Product Lines (REPL 2002), Essen, Germany, 2002.

[32] I. John and D. Muthig, "Product Line Modeling with Generic Use Cases," presented at the Workshop on Techniques for Exploiting Commonality Through Variability Management, San Diego, California, USA, 2002.

[33] K. Kang*, et al.*, "Feature-Oriented Domain Analysis (FODA) Feasibility Study," Software Engineering Institute, Carnegie Mellon University, Technical Report1990.

[34] F. Bachmann*, et al.*, "A Meta-model for Representing Variability in Product Family Development," presented at the 5th International Workshop on Product-Family Engineering (PFE-5), Siena, Italy, 2004.

[35] S. Bühne*, et al.*, "Modelling Requirements Variability across Product Lines," presented at the 13th IEEE International Conference on Requirements Engineering (RE 2005), Paris, France, 2005.

[36] J. Coplien*, et al.*, "Commonality and Variability in Software Engineering," *IEEE Software,* vol. 15, pp. 37-45, 1998.

[37] T. v. d. Maßen and H. Lichter, "Modeling Variability by UML Use Case Diagrams," presented at the International Workshop on Requirements Engineering for Product Lines (REPL 2002), Essen, Germany, 2002.

[38] H. Gomaa and M. E. Shin, "Multiple-View Modelling and Meta-Modelling of Software Product Lines," *Institution of Engineering and Technology Software,* vol. 2, pp. 94-122, 2008.

[39] H. Gomaa and M. E. Shin, "A Multiple-View Meta-modeling Approach for Variability Management in Software Product Lines," presented at the 8th International Conference on Software Reuse (ICSR-8), Madrid, Spain, 2004.

[40] H. Gomaa and E. M. Olimpiew, "Managing Variability in Reusable Requirement Models for Software Product Lines," presented at the 10th International Conference on Software Reuse (ICSR-10), Beijing, China, 2008.

[41] D. L. Webber and H. Gomaa, "Modeling Variability in Software Product Lines with the Variation Point Model," *Science of Computer Programming,* vol. 53, pp. 305-331, 2004.

[42] G. Halmans and K. Pohl, "Communicating the Variability of a Software-Product Family to Customers," *Software and Systems Modeling,* vol. 2, pp. 15-36, 2003.

[43] K. Pohl*, et al.*, *Software Product Line Engineering: Foundations, Principles, and Techniques*. Berlin Heidelberg: Springer-Verlag, 2005.

[44] S. Salicki and N. Farcet, "Expression and Usage of the Variability in the Software Product Lines," presented at the 4th International Workshop on Product Family Engineering (PFE-4), Bilbao, Spain, 2002.

[45] J. Bosch*, et al.*, "Variability Issues in Software Product Lines," presented at the 4th International Workshop on Product Family Engineering (PFE-4), Bilbao, Spain, 2002.

[46] T. Ziadi*, et al.*, "Towards a UML Profile for Software Product Lines," presented at the 5th International Workshop on Product-Family Engineering (PFE-5), Siena, Italy, 2004.

[47] A. J. H. Simons, "Use Cases Considered Harmful," presented at the 29th Conference on Technology of Object-Oriented Languages and Systems (TOOLS Europe 1999), Nancy, France, 1999.

[48] R. Heldal, "Use Cases are more than System Operations," presented at the 2nd International Workshop on Use Case Modeling (WUsCaM 2005), Montego Bay, Jamaica, 2005.

[49] F. Buschmann*, et al.*, *Pattern-Oriented Software Architecture: On Patterns and Pattern Languages*. Hoboken, New Jersey: Wiley, 2007.

[50] E. Gamma*, et al.*, *Design Patterns: Elements of Reusable Object-Oriented Software*. Upper Saddle River, New Jersey: Addison-Wesley, 1995.

[51] K. Beck, *Implementation Patterns*. Upper Saddle River, New Jersey: Addison-Wesley, 2008.

[52] H.-E. Eriksson and M. Penker, *Business Modeling With UML: Business Patterns at Work*. Hoboken, New Jersey: Wiley, 2000.

[53] W. F. Tichy, "A Catalogue of General-Purpose Software Design Patterns," presented at the 23rd Technology of Object-Oriented Languages and Systems (TOOLS-23), Santa Barbara, California, USA, 1997.

[54] W. Pree, *Design Patterns for Object-Oriented Software Development*. Upper Saddle River, New Jersey: Addison-Wesley, 1995.

[55] W. Zimmer, "Relationships between Design Patterns," in *Pattern Languages of Program Design*, J. O. Coplien and D. C. Schmidt, Eds., ed Upper Saddle River, New Jersey: Addison-Wesley, 1995, pp. 345-364.

[56] D. Schmidt*, et al.*, *Pattern-Oriented Software Architecture: Patterns for Concurrent and Networked Objects*. Hoboken, New Jersey: Wiley, 2000.

[57] M. Kircher and P. Jain, *Pattern-Oriented Software Architecture: Patterns for Resource Management*. Hoboken, New Jersey: Wiley, 2004.

[58] F. Buschmann*, et al.*, *Pattern-Oriented Software Architecture: A Pattern Language for Distributed Computing*. Hoboken, New Jersey: Wiley, 2007.

[59] M. Grand, *Patterns in Java: A Catalog of Reusable Design Patterns Illustrated with UML*. Hoboken, New Jersey: Wiley, 2002.

[60] S. Stelting, *Applied Java Patterns*. Upper Saddle River, New Jersey: Prentice Hall, 2002.

[61] P. Clements*, et al.*, *Documenting Software Architectures: Views and Beyond*. Upper Saddle River, New Jersey: Addison-Wesley, 2002.

[62] P. Kruchten, "Architectural Blueprints - The "4+1" View Model of Software Architecture," *IEEE Software,* vol. 12, pp. 42-50, November 1995.

[63] S. Sendall and W. Kozaczynski, "Model Transformation: The Heart and Soul of Model-Driven Software Development," *IEEE Software,* vol. 20, pp. 42-45, September/October 2003.

[64] A. Metzger, "A Systematic Look at Model Transformations," in *Model-Driven Software Development*, S. Beydeda*, et al.*, Eds., ed New York: Springer-Verlag, 2005, pp. 19-33.

[65] A. W. Brown, *et al.*, "Introduction: Models, Modeling, and Model-Driven Architecture (MDA)," in *Model-Driven Software Development*, S. Beydeda, *et al.*, Eds., ed New York: Springer-Verlag, 2005, pp. 1-16.

[66] S. J. Mellor, *et al.*, *MDA Distilled*. Boston: Addison-Wesley, 2004.

[67] C. Atkinson, *et al.*, "Component-Based Product Line Development: The KobrA Approach," presented at the 1st Software Product Line Conference (SPLC 2000), Denver, Colorado, USA, 2000.

[68] I. Jacobson, *et al.*, *Software Reuse: Architecture, Process and Organization for Business Success*. Upper Saddle River, New Jersey: Addison-Wesley, 1997.

[69] Y. Smaragdakis and D. Batory, "Mixin Layers: An Object-Oriented Implementation Technique for Refinements and Collaboration-Based Designs," *ACM Transactions on Software Engineering and Methodology,* vol. 11, pp. 215-255, 2002.

[70] J. Bayer, *et al.*, "Creating Product Line Architectures," presented at the 3rd International Workshop on Development and Evolution of Software Architectures for Product Families (IWSAPF-3), Las Palmas de Gran Canaria, Spain, 2000.

[71] V. Englebert and F. Vermaut, "Attribute-Based Refinement of Software Architectures," presented at the 4th Working IEEE/IFIP Conference on Software Architecture (WICSA 2004), Oslo, Norway, 2004.

[72] H. Kaindl, "Difficulties in the Transition from OO Analysis to Design," *IEEE Software,* vol. 16, pp. 94-102, 1999.

[73] R. Conradi and M. L. Jaccheri, "Process Modelling Languages," in *Software Process: Principles, Methodology, Technology*, J.-C. Derniame, *et al.*, Eds., ed Berlin Heidelberg: Springer-Verlag, 1999, pp. 27-52.

[74] J. Estublier, "Software Are Processes Too," presented at the International Software Process Workshop (SPW 2005), Beijing, China, 2005.

[75] L. J. Osterweil, "Software Processes Are Software Too, Revisited: An Invited Talk on the Most Influential Paper of ICSE 9," presented at the 1997 International Conference on Software Engineering (ICSE 97), Boston, Massachusetts, USA, 1997.

[76] R. S. P. Maciel, *et al.*, "An Integrated Approach for Model Driven Process Modeling and Enactment," presented at the XXIII Brazilian Symposium on Software Engineering (SBES'09), Fortaleza, Brazil, 2009.

[77] A. Fuggetta, "Software Process: A Roadmap," presented at the 22nd International Conference on on Software Engineering (ICSE 2000), Limerick, Ireland, 2000.

[78] R. Conradi and C. Liu, "Process Modelling Languages: One or Many?," presented at the 4th European Workshop on Software Process Technology (EWSPT 1995), Noordwijkerhout, The Netherlands, 1995.

[79] B. Henderson-Sellers, "Process Metamodelling and Process Construction: Examples Using the OPEN Process Framework (OPF)," *Annals of Software Engineering,* vol. 14, pp. 341-362, 2002.

[80] R. Bendraou, *et al.*, "A Comparison of Six UML-Based Languages for Software Process Modeling," *IEEE Transactions on Software Engineering,* vol. 36, pp. 662-675, 2010.

[81] P. H. Feiler and W. S. Humphrey, "Software Process Development and Enactment: Concepts and Definitions " presented at the 2nd International Conference on the Software Process (ICSP 1993), Berlin, Germany, 1993.

[82] V. Gruhn, "Process-Centered Software Engineering Environments, A Brief History and Future Challenges," *Annals of Software Engineering,* vol. 14, pp. 363-382, 2002.

[83] B. Henderson-Sellers*, et al.*, "Process Construction and Customization," *Journal of Universal Computer Science,* vol. 17, pp. 326-358, 2004.

[84] OMG. (2010). *Object Constraint Language: Specification - version 2.2*. Available: http://www.omg.org

[85] M. F. Fontoura*, et al.*, "UML-F: A Modeling Language for Object-Oriented Frameworks," presented at the 14th European Conference on Object Oriented Programming (ECOOP 2000), Cannes, France, 2000.

[86] The Eclipse Foundation. (2011). *Eclipse Process Framework Project (EPF)*. Available: http://www.eclipse.org/epf

[87] The Eclipse Foundation. (2011). *OpenUP*. Available: http://epf.eclipse.org/wikis/openup

[88] S. A. Becker and J. A. Whittaker, "An Overview of Cleanroom Software Engineering," in *Cleanroom Software Engineering Practices*, S. A. Becker and J. A. Whittaker, Eds., ed Hershey, Pennsylvania: IGI Global, 1996, p. 198.

[89] J. M. Fernandes*, et al.*, "Integration of DFDs into a UML-Based Model-Driven Engineering Approach," *Software and Systems Modeling,* vol. 5, pp. 403-428, 2006.

[90] OMG. (2009). *Object Management Group*. Available: http://www.omg.org

[91] M. Fowler, *Patterns of Enterprise Application Architecture*. Upper Saddle River, New Jersey: Addison-Wesley, 2003.

[92] J. Adams*, et al.*, *Patterns for e-Business: A Strategy for Reuse*. Indianapolis, Indiana: IBM Press, 2001.

[93] C. Larman, *Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design and the Unified Process*. Upper Saddle River, New Jersey: Prentice Hall, 2001.

[94] M. Fowler, *Analysis Patterns: Reusable Object Models*. Upper Saddle River, New Jersey: Addison-Wesley, 1997.

[95] M. Fowler, "Patterns," *IEEE Software,* vol. 20, pp. 56-57, 2003.

[96] J. Soukup, "Implementing Patterns," in *Pattern Languages of Program Design*, J. O. Coplien and D. C. Schmidt, Eds., ed Upper Saddle River, New Jersey: Addison-Wesley, 1995, pp. 395-412.

[97] OMG. (2008). *Meta Object Facility 2.0 Query/View/Transformation: Specification - version 1.0*. Available: http://www.omg.org

[98] The Eclipse Foundation. (2010). *ATL Project*. Available: http://www.eclipse.org/m2m/atl

[99] P. Swithinbank*, et al.*, *Patterns: Model-Driven Development Using IBM Rational Software Architect*. Indianapolis, Indiana: IBM Press, 2005.

[100] P. Ruben and S. Vjeran, "Framework for Using Patterns in Model-Driven Development," in *Information Systems Development: Towards a Service Provision Society*, G. A. Papadopoulos*, et al.*, Eds., ed Berlin Heidelberg: Springer-Verlag, 2009, pp. 309-317.

[101] G. Meszaros and J. Doble, "A Pattern Language for Pattern Writing," in *Pattern Languages of Program Design 3*, R. C. Martin*, et al.*, Eds., ed Upper Saddle River, New Jersey: Addison-Wesley, 1997, pp. 529-574.

[102] OMG. (2006). *Meta-Object Facility: Core Specification - version 2.0*. Available: http://www.omg.org

[103] P. Hruby, *Model-Driven Design Using Business Patterns*. Berlin Heidelberg: Springer-Verlag, 2006.

[104] M. Fowler. (2009). *Patterns in Enterprise Software*. Available: http://martinfowler.com/articles/enterprisePatterns.html

[105] M. Cantor. (2003). *Rational Unified Process for Systems Engineering - Part III: Requirements Analysis and Design*. Available: http://www.ibm.com/developerworks/rational/rationaledge

[106] U. Zdun and P. Avgeriou, "Modeling Architectural Patterns Using Architectural Primitives," presented at the 20th Annual ACM SIGPLAN International Conference on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA 2005), San Diego, California, USA, 2005.

[107] M.-N. Terrasse*, et al.*, "A UML-based Metamodeling Architecture for Database Design," presented at the 2001 International Symposium on Database Engineering and Applications (IDEAS 2001), Grenoble, France, 2001.

[108] The Eclipse Foundation. (2014). *MDT-UML2Tools*. Available: http://wiki.eclipse.org/MDT-UML2Tools

Appendix I. Tabular Transformations over the GoPhone Messaging Domain

Table 3 presents the tabular transformations from the first execution of the 4SRS method over the *Send Message* use case from the GoPhone case study.

Table 3 – Tabular transformations over the GoPhone's Send Message *use case.*

4SRS step nr.	**1.**	**2i.**	**2ii.**	**2iii.**	**2iv.**	**2v.**	**2vi.**	**2vii.**	**3**	**4**
column name	**compo. ref.**	**classify original use case**	**local killing [T/F]**	**name**	**description**	**representation**	**global killing [kill/alive]**	**renaming**	**packages/aggregations**	**related components**
{U 0.1.1e1} Choose Recipient's Phone Number		i-d								
	i		T	phone number choice	This component provides for a user interface to allow the mobile user to choose the phone numbers of one or multiple message recipients. The mobile user shall be able to use this interface to choose multiple phone numbers. This component shall also include a user interface to connect to the message sending functionality. It is responsible for forbidding the mobile user at the user interface level to insert more than the maximum number of digits possible for each phone number.	{C 0.1.1e1.i}	alive	phone number choice		{C 0.1.1e1.c}
	c		T	phone number choice management	This component is responsible for controlling the user interface flow from the phone number choice functionality to the message sending functionality. It is also responsible for controlling the maximum number of digits the mobile user can type for each phone number. It shall as well retrieve the phone numbers from the repository of contacts.	{C 0.1.1e1.c}	alive	phone number choice management		{C 0.1.1e1.i} {C 0.1.3.i} {C 0.1.1e1.d}
	d		T	address book repository	This component provides for a repository of contacts.	{C 0.1.1e1.d} {C 0.1.1e2.d}	alive	address book repository		{C 0.1.1e1.c} {C 0.1.1e2.c}

{U 0.1.1e2} Choose Recipient's Phone Number or E-mail Address		i-d								
	i		T	phone number or e-mail address choice	This component provides for a user interface to allow the mobile user to choose the phone numbers or the e-mail addresses of one or multiple message recipients. The mobile user shall be able to use this interface to choose multiple phone numbers or multiple e-mail addresses. This component shall include a user interface to connect to the message sending functionality. It is responsible for forbidding the mobile user at the user interface level to insert more than the maximum number of digits possible for each phone number or to insert invalid e-mail addresses.	{C 0.1.1e2.i}	alive	phone number or e-mail address choice		{C 0.1.1e2.c}
	c		T	phone number or e-mail address choice management	This component is responsible for controlling the user interface flow from the phone number/e-mail address choice functionality to the message sending functionality. It is also responsible for controlling the maximum number of digits the mobile user can type for each phone number or the validity of e-mail addresses. It shall as well retrieve the phone numbers or the e-mail addresses from the repository of contacts.	{C 0.1.1e2.c}	alive	phone number or e-mail address choice management		{C 0.1.1e2.i} {C 0.1.3.i} {C 0.1.1e1.d}
	d		T	address book repository	This component provides for a repository of contacts.	{C 0.1.1e2.d} {C 0.1.1e1.d}	kill			
{U 0.1.2.1e1} Select Basic or Extended Kind of Message		i								
	i		T	basic or extended message kind selection	This component provides for a user interface to allow the mobile user to choose the kind of message to send (basic SMS or extended SMS). It shall include a user interface to connect to the message writing functionality.	{C 0.1.2.1e1.i}	alive	basic or extended message kind selection		{C 0.1.2.1e1.c}
	c		T	message kind selection management	This component is responsible for controlling the user interface flow from the basic/extended kind of message selection functionality to the message	{C 0.1.2.1e1.c} {C 0.1.2.1e2.c}	alive	message kind selection management		{C 0.1.2.5.i}

					writing functionality.					
	d		F							
{U 0.1.2.1e2} Select Basic, Extended or E-mail Kind of Message		i								
	i		T	basic, extended or e-mail message kind selection	This component provides for a user interface to allow the mobile user to choose the kind of message to send (basic SMS, extended SMS or e-mail). It shall include a user interface to connect to the message writing functionality.	{C 0.1.2.1e2.i}	alive	basic, extended or e-mail message kind selection		{C 0.1.2.1e1.c}
	c		T	message kind selection management	This component is responsible for controlling the user interface flow from the basic/extended/e-mail kind of message selection functionality to the message writing functionality.	{C 0.1.2.1e2.c} {C 0.1.2.1e1.c}	kill			
	d		F							
{U 0.1.2.2e1} Activate Letter Combination		c-d								
	i		T	letter combination activation	This component provides for a user interface to allow the mobile user to activate the letter combination (into words from the word repository) according to the keys pressed by him when writing the message. It is responsible for notifying the mobile user on the activation/deactivation of the letter combination.	{C 0.1.2.2e1.i}	alive	letter combination activation		{C 0.1.2.2e1.c}
	c		T	letter combination management	This component is actually responsible for activating/deactivating the letter combination, therefore it shall keep record of letter combination's activation state. It is also responsible for getting the possible combinations of letters (words) from the word repository according to the keys pressed by the mobile user when writing the message. It is responsible as well for composing and sending an alphabetically ordered list with those combinations (words) to the message writing functionality upon request. This component shall notify the message writing functionality on the changes to the letter combination's activation state,	{C 0.1.2.2e1.c}	alive	letter combination management		{C 0.1.2.2e1.i} {C 0.1.2.2e1.d} {C 0.1.2.5.c}

					whenever that happens. It can also receive requests for updating the letter combination's activation state from the message writing functionality.					
	d		T	word repository	This component provides for a repository of possible combinations of letters (words) for the keys and language availables.	{C 0.1.2.2e1.d}	alive	word repository		{C 0.1.2.2e1.c}
{U 0.1.2.3e1} Insert Picture		i-c-d								
	i		T	picture insertion	This component provides for a user interface to allow the mobile user to insert pictures into a message. The mobile user shall be able to use this interface to insert multiple pictures. This component is responsible for notifying the mobile user on the violation of validation rules over the pictures. This component receives requests for picture insertion from the message writing functionality.	{C 0.1.2.3e1.i}	alive	picture insertion		{C 0.1.2.3e1.c} {C 0.1.2.5.c}
	c		T	picture insertion management	This component is actually responsible for inserting pictures into a message. It provides for the validation of the pictures to be inserted into the message. It is also responsible for retrieving pictures from the picture repository.	{C 0.1.2.3e1.c}	alive	picture insertion management		{C 0.1.2.3e1.i} {C 0.1.2.3e1.d}
	d		T	picture repository	This component provides for a repository of pictures.	{C 0.1.2.3e1.d} {C 0.1.2.3e2.d} {C 0.1.2.4e1.d} {C 0.1.2.4e2.d}	alive	object repository		{C 0.1.2.3e1.c} {C 0.1.2.3e2.c} {C 0.1.2.4e1.c} {C 0.1.2.4e2.c}
{U 0.1.2.3e2} Insert Picture or Draft Text		i-c-d								
	i		T	picture or draft text insertion	This component provides for a user interface to allow the mobile user to insert pictures and/or draft texts into a message. The mobile user shall be able to use this interface to insert multiple pictures and/or multiple draft texts. This component is responsible for notifying the	{C 0.1.2.3e2.i}	alive	picture or draft text insertion		{C 0.1.2.3e2.c} {C 0.1.2.5.c}

					mobile user on the violation of validation rules over the pictures and/or the draft texts. This component receives requests for picture or draft text insertion from the message writing functionality.					
	c		T	picture or draft text insertion management	This component is actually responsible for inserting pictures and/or draft texts into a message. It provides for the validation of the pictures and/or the draft texts to be inserted into the message. It is also responsible for retrieving pictures or draft texts from the picture and draft text repository.	{C 0.1.2.3e2.c}	alive	picture or draft text insertion management		{C 0.1.2.3e2.i} {C 0.1.2.3e1.d}
	d		T	picture and draft text repository	This component provides for a repository of pictures and draft texts.	{C 0.1.2.3e2.d} {C 0.1.2.3e1.d}	kill			
{U 0.1.2.4e1} Attach Business Card or Calendar Entry		i-c-d								
	i		T	business card or calendar entry attaching	This component provides for a user interface to allow the mobile user to attach business cards and/or calendar entries to a message. The mobile user shall be able to use this interface to insert multiple business cards and/or multiple calendar entries. This component receives requests for business card or calendar entry attaching from the message writing functionality.	{C 0.1.2.4e1.i}	alive	business card or calendar entry attaching		{C 0.1.2.4e1.c} {C 0.1.2.5.c}
	c		T	business card or calendar entry attaching management	This component is actually responsible for attaching business cards and/or calendar entries to a message. It is also responsible for retrieving business cards or calendar entries from the business card and calendar entry repository.	{C 0.1.2.4e1.c}	alive	business card or calendar entry attaching management		{C 0.1.2.4e1.i} {C 0.1.2.3e1.d}
	d		T	business card and calendar entry repository	This component provides for a repository of business cards and calendar entries.	{C 0.1.2.4e1.d} {C 0.1.2.3e1.d}	kill			
{U 0.1.2.4e2} Attach File, Business Card, Calendar Entry or Sound		i-c-d								
	i		T	file, business card, calendar entry or sound	This component provides for a user interface to allow the mobile user to attach files, business cards, calendar	{C 0.1.2.4e2.i}	alive	file, business card, calendar entry or sound		{C 0.1.2.4e2.c} {C 0.1.2.5.c}

				attaching	entries and/or sounds to a message. The mobile user shall be able to use this interface to insert multiple files, multiple business cards, multiple calendar entries and/or multiple sounds. This component is responsible for notifying the mobile user on the violation of validation rules over the files, the business cards, the calendar entries and/or the sounds. It receives requests for file, business card, calendar entry or sound attaching from the message writing functionality.			attaching		
	c		T	file, business card, calendar entry or sound attaching management	This component is actually responsible for attaching files, business cards, calendar entries and/or sounds to a message. It is also responsible for the validation of the files and/or the sounds to be introduced to the message. It is responsible as well for retrieving files, business cards, calendar entries or sounds from the file, business card, calendar entry and sound repository.	{C 0.1.2.4e2.c}	alive	file, business card, calendar entry or sound attaching management		{C 0.1.2.4e2.i} {C 0.1.2.3e1.d}
	d		T	file, business card, calendar entry and sound repository	This component provides for a repository of files, business cards, calendar entries and sounds.	{C 0.1.2.4e2.d} {C 0.1.2.3e1.d}	kill			
{U 0.1.3} Send Message to Network		i								
	i		T	message sending	This component provides for an interface that receives messages for sending through the network. It is responsible for notifying the mobile user on the sending operation's initialization (message being sent) and on the success of the sending operation. It receives requests for message sending from the phone number choice functionality, or from the phone number or e-mail address choice functionality. It is also responsible for calling the message archiving functionality.	{C 0.1.3.i}	alive	message sending		{C 0.1.3.c} {C 0.1.4e1.i} {C 0.1.4e2.i}
	c		T	message sending management	This component is responsible for actually sending the message through the network and controling the state of the message sending (message successfully sent or message not sent).	{C 0.1.3.c}	alive	message sending management		{C 0.1.3.i}

	d		F							
{U 0.1.4e1} Archive Message by Request		d								
	i		T	message archiving by request	This component provides for a user interface to ask the mobile user whether he wants to save the message into the sent messages folder or not. It is reponsible for notifying the mobile user on the success of the archiving operation. It receives requests for message archiving from the message sending functionality.	{C 0.1.4e1.i}	alive	message archiving by request		{C 0.1.4e1.c}
	c		T	message archiving management	This component is responsible for verifying the memory space for archiving messages into the sent messages folder. It is also responsible for controlling the state of the message archiving (message archived or message not archived). It is responsible as well for saving the sent messages into the message repository.	{C 0.1.4e1.c} {C 0.1.4e2.c}	alive	message archiving management		{C 0.1.4e1.i} {C 0.1.4e2.i} {C 0.1.4e1.d}
	d		T	message repository	This component provides for a repository of messages (sent messages folder).	{C 0.1.4e1.d} {C 0.1.4e2.d}	alive	message repository		{C 0.1.4e1.c}
{U 0.1.4e2} Automatically Archive Message		d								
	i		T	automatic message archiving	This component is responsible for notifying the mobile user on the success of the archiving operation. It receives requests for message archiving from the message sending functionality.	{C 0.1.4e2.i}	alive	automatic message archiving		{C 0.1.4e1.c}
	c		T	message archiving management	This component is responsible for verifying the memory space for archiving messages into the sent messages folder. It is also responsible for controlling the state of the message archiving (message archived or message not archived). It receives requests for message archiving from the message sending functionality.	{C 0.1.4e2.c} {C 0.1.4e1.c}	kill			
	d		T	message repository	This component provides for a repository of messages (sent messages folder).	{C 0.1.4e2.d} {C 0.1.4e1.d}	kill			
{U 0.1.2.5} Write Message		d								

	i		T	message writing	This component provides for a user interface to allow the mobile user to write a message in the message area of the message editor (which is a text editor). If the letter combination is supported and activated, the user interface shall display the first possible combination of letters (words) for the keys pressed by the mobile user and allow him to choose other combinations from the word repository. This component is responsible for displaying to the mobile user the alerts of maximum number of characters reached. It shall include a user interface to connect to the object insertion functionality (either pictures, or pictures or draft texts), to the object attaching functionality (either business cards or calendar entries, or files, business cards, calendar entries or sounds), to the recipient's contact choice functionality (either phone numbers, or phone numbers or e-mail addresses) and to the letter combination activation functionality. This component receives requests for message writing from the basic or extended kind of message selection functionality, or from the basic, extended or e-mail kind of message selection functionality.	{C 0.1.2.5.i}	alive	message writing		{C 0.1.2.5.c}

	c		T	message text management	This component is responsible for keeping a local record of the letter combination's activation state, which is updated upon initialization (by requesting it to the letter combination management) and whenever it changes (by notification from the letter combination management). It is also responsible for getting the list of possible combinations of letters (words) from the letter combination management for the keys pressed by the mobile user. It is responsible as well for controlling the number of characters in the message's text according to the kind of message. It shall generate alerts of maximum number of characters reached to be displayed to the mobile user. This component is responsible as well for controlling the user interface flow from the message writing functionality to the object insertion functionality (either pictures, or pictures or draft texts), to the object attaching functionality (either business cards or calendar entries, or files, business cards, calendar entries or sounds), to the recipient's contact choice functionality and to the letter combination activation functionality.	{C 0.1.2.5.c}	alive	message text management		{C 0.1.2.5.i} {C 0.1.2.2e1.c} {C 0.1.2.3e1.i} {C 0.1.2.3e2.i} {C 0.1.2.4e1.i} {C 0.1.2.4e2.i} {C 0.1.1e1.i} {C 0.1.1e2.i} {C 0.1.2.2e1.i}
	d		F							

Table 4 shows the tabular transformations from the first recursive execution of the 4SRS method over the object insertion and object attaching functionalities from the GoPhone's messaging domain.

Table 4 – Tabular transformations over the GoPhone's object insertion and object attaching functionalities.

4SRS step nr.	**1.**	**2i.**	**2ii.**	**2iii.**	**2iv.**	**2v.**	**2vi.**	**2vii.**	**3**	**4**
column name	**compo. ref.**	**classify original use case**	**local killing [T/F]**	**name**	**description**	**representation**	**global killing [kill/alive]**	**renaming**	**packages/aggregations**	**related components**
{U 1.1.2.3e1.1} Browse		i-c-d								

Directory of Pictures										
	i		T	picture directory browsing	This component provides for a user interface to show the picture files in a directory of picture files (eventually with folders). The directory can be browsed for selection of those picture files. The mobile user shall be able to use this interface to select multiple picture files. This component is responsible for showing the picture files in the directory with a small image of the picture (icon) next to them.	{C 1.1.2.3e1.1.i} {C 1.1.2.3e2.1.i}	alive	picture directory browsing		{C 1.1.2.3e1.1.c} {C 1.1.2.3e1.2.i}
	c		T	picture directory browsing management	This component is responsible for retrieving the picture files from the picture file repository and resizing them to the icon size.	{C 1.1.2.3e1.1.c} {C 1.1.2.3e2.1.c}	alive	picture directory browsing management		{C 1.1.2.3e1.1.i} {C 1.1.2.3e1.1.d}
	d		T	picture file repository	This component provides for a repository of files.	{C 1.1.2.3e1.1.d} {C 1.1.2.3e1.2.d} {C 1.1.2.3e2.1.d} {C 1.1.2.3e2.2.d} {C 1.1.2.3e2.3.d} {C 1.1.2.3e2.4.d} {C 1.1.2.4e2.1.d} {C 1.1.2.4e2.4.d} {C 1.1.2.4e2.7.d}	alive	general file repository		{C 1.1.2.3e1.1.c} {C 1.1.2.3e1.2.c} {C 1.1.2.3e2.4.c} {C 1.1.2.4e2.1.c} {C 1.1.2.4e2.8.c} {C 1.1.2.4e2.4.c} {C 1.1.2.4e2.7.c}
{U 1.1.2.3e1.2} Display Picture in Message Area		i-c-d								
	i		T	picture displaying	This component is responsible for displaying pictures in the message area of the message editor. It is also responsible for notifying the mobile user on the violation of size constraints over the picture files.	{C 1.1.2.3e1.2.i} {C 1.1.2.3e2.3.i}	alive	picture displaying		{C 1.1.2.3e1.2.c}
	c		T	picture displaying management	This component provides for the validation of size constraints over the picture files. It is also responsible for retrieving them from the picture file repository and resizing them to fit the message area.	{C 1.1.2.3e1.2.c} {C 1.1.2.3e2.3.c}	alive	picture displaying management		{C 1.1.2.3e1.2.i} {C 1.1.2.3e1.1.d}
	d		T	picture file repository	This component provides for a repository of files.	{C 1.1.2.3e1.2.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.3e2.1} Browse Directory of		i-c-d								

Pictures										
	i		T	picture directory browsing	This component provides for a user interface to show the picture files in a directory of picture files (eventually with folders). The directory can be browsed for selection of those picture files. The mobile user shall be able to use this interface to select multiple picture files. This component is responsible for showing the picture files in the directory with a small image of the picture (icon) next to them.	{C 1.1.2.3e2.1.i} {C 1.1.2.3e1.1.i}	kill			
	c		T	picture directory browsing management	This component is responsible for retrieving the picture files from the picture file repository and resizing them to the icon size.	{C 1.1.2.3e2.1.c} {C 1.1.2.3e1.1.c}	kill			
	d		T	picture file repository	This component provides for a repository of files.	{C 1.1.2.3e2.1.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.3e2.2} Browse List of Draft Texts		i-c-d								
	i		T	draft text list browsing	This component provides for a user interface to show the draft text files in a list. It can be browsed for selection of those draft text files. The mobile user shall be able to use this interface to select multiple draft text files. This component is responsible for presenting the draft text files in the list by showing the beginning of the text (fitting the user interface's length).	{C 1.1.2.3e2.2.i}	alive	draft text list browsing		{C 1.1.2.3e2.4.c} {C 1.1.2.3e2.4.i}
	c		T	draft text list browsing management	This component is responsible for retrieving the draft text files from the draft text file repository.	{C 1.1.2.3e2.2.c} {C 1.1.2.3e2.4.c}	kill			
	d		T	draft text file repository	This component provides for a repository of files.	{C 1.1.2.3e2.2.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.3e2.3} Display Picture in Message Area		i-c-d								
	i		T	picture displaying	This component is responsible for displaying pictures in the message area of the message editor. It is also responsible for notifying the mobile user on the violation of size constraints over the picture files.	{C 1.1.2.3e2.3.i} {C 1.1.2.3e1.2.i}	kill			

	c		T	picture displaying management	This component provides for the validation of size constraints over the picture files. It is also responsible for retrieving them from the picture file repository and resizing them to fit the message area.	{C 1.1.2.3e2.3.c} {C 1.1.2.3e1.2.c}	kill			
	d		T	picture file repository	This component provides for a repository of files.	{C 1.1.2.3e2.3.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.3e2.4} Display Draft Text in Message Area		i-c-d								
	i		T	draft text displaying	This component is responsible for displaying draft texts in the message area of the message editor. It is also responsible for notifying the mobile user on the violation of length constraints over the text files.	{C 1.1.2.3e2.4.i}	alive	draft text displaying		{C 1.1.2.3e2.4.c}
	c		T	draft text displaying management	This component provides for the validation of length constraints (character number) over the text files. It is also responsible for retrieving them from the draft text file repository.	{C 1.1.2.3e2.4.c} {C 1.1.2.3e2.2.c}	alive	draft text management		{C 1.1.2.3e2.4.i} {C 1.1.2.3e1.1.d} {C 1.1.2.3e2.2.i}
	d		T	draft text file repository	This component provides for a repository of files.	{C 1.1.2.3e2.4.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.4e1.1} Browse List of Business Cards		i-c-d								
	i		T	business card list browsing	This component provides for a user interface to show the business cards in a list. It can be browsed for selection of those business cards. The mobile user shall be able to use this interface to select multiple business cards.	{C 1.1.2.4e1.1.i} {C 1.1.2.4e2.2.i}	alive	business card list browsing		{C 1.1.2.4e1.1.c} {C 1.1.2.4e1.3.i}
	c		T	business card list browsing management	This component is responsible for retrieving business cards from the business card repository (by business card holder).	{C 1.1.2.4e1.1.c} {C 1.1.2.4e1.3.c} {C 1.1.2.4e2.2.c} {C 1.1.2.4e2.5.c}	alive	business card management		{C 1.1.2.4e1.1.i} {C 1.1.2.4e1.1.d} {C 1.1.2.4e1.3.i}
	d		T	business card repository	This component provides for a repository of business cards.	{C 1.1.2.4e1.1.d} {C 1.1.2.4e1.3.d} {C 1.1.2.4e2.2.d} {C 1.1.2.4e2.5.d}	alive	business card repository		{C 1.1.2.4e1.1.c}
{U 1.1.2.4e1.2} Browse Calendar		i-c-d								

	i		T	calendar browsing	This component provides for a user interface to show the calendar entries in a calendar. It can be browsed for selection of those calendar entries. The mobile user shall be able to use this interface to select multiple calendar entries. This component is responsible for showing the text of the calendar entries concerning each day while the mobile user browses the calendar.	{C 1.1.2.4e1.2.i} {C 1.1.2.4e2.3.i}	alive	calendar browsing		{C 1.1.2.4e1.2.c} {C 1.1.2.4e1.3.i}
	c		T	calendar browsing management	This component is responsible for retrieving calendar entries from the calendar (by date).	{C 1.1.2.4e1.2.c} {C 1.1.2.4e1.4.c} {C 1.1.2.4e2.3.c} {C 1.1.2.4e2.6.c}	alive	calendar management		{C 1.1.2.4e1.2.i} {C 1.1.2.4e1.2.d} {C 1.1.2.4e1.3.i}
	d		T	calendar	This component provides for a repository of calendar entries.	{C 1.1.2.4e1.2.d} {C 1.1.2.4e1.4.d} {C 1.1.2.4e2.3.d} {C 1.1.2.4e2.6.d}	alive	calendar		{C 1.1.2.4e1.2.c}
{U 1.1.2.4e1.3} Add Business Card to Attachments List		i-c-d								
	i		T	business card addition	This component is responsible for adding items to the attachments list in the message editor.	{C 1.1.2.4e1.3.i} {C 1.1.2.4e1.4.i}	alive	business card or calendar entry addition		{C 1.1.2.4e1.1.c} {C 1.1.2.4e1.2.c}
	c		T	business card addition management	This component is responsible for retrieving business cards from the business card repository (by business card holder).	{C 1.1.2.4e1.3.c} {C 1.1.2.4e1.1.c}	kill			
	d		T	business card repository	This component provides for a repository of business cards.	{C 1.1.2.4e1.3.d} {C 1.1.2.4e1.1.d}	kill			
{U 1.1.2.4e1.4} Add Calendar Entry to Attachments List		i-c-d								
	i		T	calendar entry addition	This component is responsible for adding items to the attachments list in the message editor.	{C 1.1.2.4e1.4.i} {C 1.1.2.4e1.3.i}	kill			
	c		T	calendar entry addition management	This component is responsible for retrieving calendar entries from the calendar (by date).	{C 1.1.2.4e1.4.c} {C 1.1.2.4e1.2.c}	kill			
	d		T	calendar	This component provides for a repository of calendar entries.	{C 1.1.2.4e1.4.d} {C 1.1.2.4e1.2.d}	kill			
{U 1.1.2.4e2.1} Browse		i-c-d								

Directory of Files										
	i		T	file directory browsing	This component provides for a user interface to show the files in a directory of files (eventually with folders). The directory can be browsed for selection of those files. The mobile user shall be able to use this interface to select multiple files.	{C 1.1.2.4e2.1.i}	alive	file directory browsing		{C 1.1.2.4e2.4.c} {C 1.1.2.4e2.4.i}
	c		T	file directory browsing management	This component is responsible for retrieving files from the file repository.	{C 1.1.2.4e2.1.c} {C 1.1.2.4e2.4.c}	kill			
	d		T	file repository	This component provides for a repository of files.	{C 1.1.2.4e2.1.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.4e2.8} Browse Directory of Sounds		i-c-d								
	i		T	sound directory browsing	This component provides for a user interface to show the sound files in a directory of sound files (eventually with folders). The directory can be browsed for selection of those sound files. The mobile user shall be able to use this interface to select multiple sound files.	{C 1.1.2.4e2.8.i}	alive	sound directory browsing		{C 1.1.2.4e2.7.c} {C 1.1.2.4e2.4.i}
	c		T	sound directory browsing management	This component is responsible for retrieving sound files from the sound file repository.	{C 1.1.2.4e2.8.c} {C 1.1.2.4e2.7.c}	kill			
	d		T	sound file repository	This component provides for a repository of files.	{C 1.1.2.4e2.8.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.4e2.2} Browse List of Business Cards		i-c-d								
	i		T	business card list browsing	This component provides for a user interface to show the business cards in a list. It can be browsed for selection of those business cards. The mobile user shall be able to use this interface to select multiple business cards.	{C 1.1.2.4e2.2.i} {C 1.1.2.4e1.1.i}	kill			
	c		T	business card list browsing management	This component is responsible for retrieving business cards from the business card repository (by business card holder).	{C 1.1.2.4e2.2.c} {C 1.1.2.4e1.1.c}	kill			
	d		T	business card	This component provides for a	{C 1.1.2.4e2.2.d}	kill			

				repository	repository of business cards.	{C 1.1.2.4e1.1.d}				
{U 1.1.2.4e2.3} Browse Calendar		i-c-d								
	i		T	calendar browsing	This component provides for a user interface to show the calendar entries in a calendar. It can be browsed for selection of those calendar entries. The mobile user shall be able to use this interface to select multiple calendar entries. This component is responsible for showing the text of the calendar entries concerning each day while the mobile user browses the calendar.	{C 1.1.2.4e2.3.i} {C 1.1.2.4e1.2.i}	kill			
	c		T	calendar browsing management	This component is responsible for retrieving calendar entries from the calendar (by date).	{C 1.1.2.4e2.3.c} {C 1.1.2.4e1.2.c}	kill			
	d		T	calendar	This component provides for a repository of calendar entries.	{C 1.1.2.4e2.3.d} {C 1.1.2.4e1.2.d}	kill			
{U 1.1.2.4e2.4} Add File to Attachments List		i-c-d								
	i		T	file addition	This component is responsible for adding files to the attachments list in the message editor. It is also responsible for notifying the mobile user on the violation of size constraints over the files.	{C 1.1.2.4e2.4.i} {C 1.1.2.4e2.7.i}	alive	file or sound file addition		{C 1.1.2.4e2.4.c}
	c		T	file addition management	This component provides for the validation of size constraints over the files. It is responsible for retrieving them from the file repository.	{C 1.1.2.4e2.4.c} {C 1.1.2.4e2.1.c}	alive	file management		{C 1.1.2.4e2.4.i} {C 1.1.2.3e1.1.d} {C 1.1.2.4e2.1.i}
	d		T	file repository	This component provides for a repository of files.	{C 1.1.2.4e2.4.d} {C 1.1.2.3e1.1.d}	kill			
{U 1.1.2.4e2.5} Add Business Card to Attachments List		i-c-d								
	i		T	business card addition	This component is responsible for adding items to the attachments list in the message editor.	{C 1.1.2.4e2.5.i} {C 1.1.2.4e1.3.i}	kill			
	c		T	business card addition management	This component is responsible for retrieving business cards from the business card repository (by business card holder).	{C 1.1.2.4e2.5.c} {C 1.1.2.4e1.1.c}	kill			

	d		T	business card repository	This component provides for a repository of business cards.	{C 1.1.2.4e2.5.d} {C 1.1.2.4e1.1.d}	kill			
{U 1.1.2.4e2.6} Add Calendar Entry to Attachments List		i-c-d								
	i		T	calendar entry addition	This component is responsible for adding items to the attachments list in the message editor.	{C 1.1.2.4e2.6.i} {C 1.1.2.4e1.3.i}	kill			
	c		T	calendar entry addition management	This component is responsible for retrieving calendar entries from the calendar (by date).	{C 1.1.2.4e2.6.c} {C 1.1.2.4e1.2.c}	kill			
	d		T	calendar	This component provides for a repository of calendar entries.	{C 1.1.2.4e2.6.d} {C 1.1.2.4e1.2.d}	kill			
{U 1.1.2.4e2.7} Add Sound to Attachments List		i-c-d								
	i		T	sound file addition	This component is responsible for adding sound files to the attachments list in the message editor. It is also responsible for notifying the mobile user on the violation of size constraints over the sound files.	{C 1.1.2.4e2.7.i} {C 1.1.2.4e2.4.i}	kill			
	c		T	sound file addition management	This component provides for the validation of size constraints over the sound files. It is responsible for retrieving them from the sound file repository.	{C 1.1.2.4e2.7.c} {C 1.1.2.4e2.8.c}	alive	sound file management		{C 1.1.2.4e2.8.i} {C 1.1.2.3e1.1.d}
	d		T	sound file repository	This component provides for a repository of files.	{C 1.1.2.4e2.7.d} {C 1.1.2.3e1.1.d}	kill			