AARHUS UNIVERSITET

Master Thesis

Technical Information Technology / Software Engineering

Coupling Overture to MDA and UML

by

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Abstract

It is vital that critical software systems perform as intended. An effective way to minimize the risk of unforeseen surprises in a system is to create a model of the system's critical parts. VDM++ is an OO modeling language used to validate and verify the design of software systems at a desired level of abstraction. VDMTools is a toolset which offers various features to support software development based on VDM and its predecessor, VDM-SL. Among the features offered by VDMTools, is the Rose-VDM++ Link which enables going back and forth between VDM++ model and UML version 1.1. This M.Sc. thesis presents an analysis of the additional possibilities offered by UML version 2. The results of this are materialized as an extension of the Overture project which is a community-based project dedicated to the development of the next generation of tools supporting formal modeling and analysis in the design of software systems. We have developed a counterpart to the Rose-VDM++ Link, i.e. a tool for going back and forth between VDM++ models and UML 2.0 Class Diagrams and Sequence Diagrams.

Resumé

Det er afgørende, at kritiske software systemer fungerer som tilsigtet. En effektiv måde at minimere risikoen for uforudsete overraskelser i et system er at skabe en model af systemets kritiske dele. VDM++ er et OO modelingssprog, som bruges til at validere og verifikere designet af software systemer pået ønsket abstraktionsniveau. VDMTools er et sæt af værktøjer, der understøtter udvikling af software baseret påVDM++ og dets forgænger, VDM-SL. Blandt de funktioner, der tilbydes af VDMTools, er Rose-VDM++ Link, der giver mulighed for at transformere mellem VDM++ modeller og UML 1.1 klassediagrammer. Denne M.Sc. afhandling præsenterer en undersøgelse af de ekstra muligheder, som UML version 2 tilbyder. Resultaterne indgår som en udvidelse af projektet Overture, som er en community-baseret projekt dedikeret til udviklingen af den næste generation af værktøjer, der understøtter formel modellering og analyse af software systemer. Vi har udviklet et modstykke til Rose-VDM++ Link, mere præcist et værktøj, som kan transformere mellem VDM++ modeller og UML 2.0 klassediagrammer og sekvensdiagrammer.

Acknowledgements

First of all, we would like to thank our supervisor, Professor Peter Gorm Larsen, for the professional and personal support during this thesis work. His dedication is remarkable and has resulted in correspondence both day and night regarding this thesis. At no point during the writing of this thesis has Peter been absent when needed. His support and guidance is second to none, both personally and professionally. Secondly, a warm thank you goes to Nokia, Sony/FeliCa Networks and Shin Sahara who sponsored our travel expenses, which enabled both of us to participate in the fifth Overture Workshop in Braga, Portugal. Thank you very much for that. Thirdly, Marcel Verhoef deserves thanks for sharing his knowledge regarding the Overture project and its tools. Fourthly, we would like to express our appreciation to Nick Battle for his continuous interest in our thesis work regarding VDMJ. Nick was extremely quick to resolve the deficiencies we discovered. We have not had direct relations to the last person whom we want to thank, however, he has been a valuable help during the construction of our VDM++ model. When we encountered a bug in VDMTools, we submitted a bug-report. Shin Sahara heads the development of VDMTools and one of his staff members, *Dr. K*, is the person who has agreed to fix a number of the bugs encountered by us.

Prerequisites

It is expected that the reader is able to read basic formal models written in VDM++ and possess base knowledge about UML class diagrams and sequence diagrams. For simplicity, we refer to VDM++ as VDM in the rest of this thesis.

Chapter 1

Introduction

Between 1985 and 1987, the radiation therapy machine Therac-25 was responsible for at least six accidents in which patients were given massive overdoses of radiation, approximately 100 times the intended dose. Three of the six patients died [Therac25].

Such an accident highlights the danger of software control of safety-critical systems. Formal methods (FM) mitigate the risk of a system malfunction, like Therac-25, by increasing the confidence in a computer system by formal verification of the systems specification. Hence it is interesting to investigate how to spread the use of FM.

This thesis investigates the possibility of combining an FM with an informal graphical modeling language. The topic is well-known in the literature and is referred to as *model transformation* [Kim&05, Snook&06, Dascalu&02, Laleau00].

The use of FM stem from the fact that software is notorious for being late in delivery and unpredictable and unreliable in operation. The expectation is that proper mathematical analysis can contribute to the reliability and robustness of a design [Holloway97]. However, developers are reluctant to devote themselves to FM. Suggestions listed by Holloway regarding the antipathy against FM includes, but are not limited to, the following [Holloway97, p1]:

1. Lack of adequate tools [Knight&97, p1].
2. High costs, and over-selling by advocates [Meyer97, p1] [Saiedian96, p2].

It is the hope, that this thesis work will contribute to the spread of FM by mitigating the two causes mentioned above. In particular, the ambition is that tool support for a specific FM will be improved with reduced cost, as a result of this work.

1.1 The formal method

The FM chosen for this thesis is the Vienna Development Method extended with object-oriented capabilities (VDM++) [Fitzgerald&05]. VDM++ is one of the oldest and most mature formal languages available [Fitzgerald&08a, Plat&92]. VDM++ is an extension of the specification language VDM-SL, thus a VDM++ model can be formally validated and verified by using a set of tools [Fitzgerald&08a]. A VDM++ model specifies the behavior of a system by encapsulating system behavior in classes, as known from the object-oriented world. Recently, a new construct for improving model testing has been introduced. This new feature called *trace statements* makes it easier to specify regression tests [Santos08, LangManPPTraces]. The new traces feature, together with VDM++, are interesting to take into account when performing a transformation to and from an informal method.

1.2 The informal method

The chosen graphical modeling language is the Unified Modeling Language (UML) [UMLSuperstructure2.1.2]. UML is widely used in the industry [UMLSuccess].

UML is great for presenting and discussing models due to its visual capabilities, i.e. different structural and behavioral views of a system. Of the different views, Class Diagrams and Sequence Diagrams are of particular interest to our work. One of the main disadvantages, however, is the level of formalism that can be obtained, since UML has no commonly agreed mathematical basis. However, the reason for that is the significant complexity it would add with no clear benefit [UMLInfrastructure2.1.2, p33]. VDM++ has a level of mathematical precision but it is not great for presenting or discussing a model to computer science novices, e.g. management or customers, or to developers unfamiliar with FM. A link between VDM++ and UML yields the best of both worlds [Dascalu&02, Kim&05], i.e. the formal specification of VDM++ becomes easier to apply and the informal language UML becomes more precise [Dascalu&02, Kim&05].

UML is designed to model object-oriented systems [UMLFromWikipedia], hence overall similarities do exist between VDM++ and UML. A careful analysis of the languages will determine the mapping potential between them.

1.3 Model transformation

If a mapping potential exists between VDM++ and UML, detailed knowledge of the semantics of the languages involved must be obtained in order to know:

- On what semantic basis the transformation has occurred
- Whether semantics are preserved during a transformation (soundness), and
- whether the transformation is complete [Kim&05, Sendall&03].

[Sendall&03] identifies meta-modeling as a common technique for defining the abstract syntax of models and the relationships between model elements. This thesis adopts that approach. The abstract syntax for VDM++ was available by the open-source project

Overture [OvertureTool] at the time this thesis work began. The definition of an abstract syntax for UML is made as a part of this thesis.

Once the abstract syntaxes exist at the same level of abstraction, it is possible to define transformation rules for the meta-model constructs of each language. The rules are first formulated in natural language, and secondly specified in a formal language in order to be validated and verified. Ultimately, the rules must be implemented and compiled to some executable form in order to act as a tool.

In this regard, VDM++ is interesting because VDM++ models may be executed and debugged directly on the specification level [Fitzgerald&08a]. A VDM++ model of the model transformation will allow developers to abstract away parts not directly related to the core functionality. Also, a VDM++ model may be subject to syntax checking, type checking and integrity checking to increase confidence in the correctness of the model [Fitzgerald&08a].

1.4 Participation in the Overture Project

The Overture project is an open source project led by a core team, who discusses and plans development of the Overture project. The aim is to enable better tool support for VDM++. Currently, the most feature-rich tool available is a commercial tool, VDMTools, which include features like syntax- and type-check, code-generation etc.

A model has been created to enable transformation between the abstract syntax of VDM++ and the abstract syntax of UML. The model utilizes a variety of VDM++ constructs and due to the large amount of classes, VDMTools becomes significantly slow when interpreting the model. This brought to our attention VDMJ [Fujitsu] developed by Nick Battle at Fujitsu. VDMJ is a console-based type-checker and interpreter which is roughly twice as fast as VDMTools. During the project close cooperation with Nick Battle has been maintained to test and further develop VDMJ. Additionally, to the development of VDMJ, we participated in the Overture project by means of net-meetings and we attended the fifth Overture Workshop at the University of Minho in Braga, Portugal. One of the main topics at the workshop was integrating various existing tools into a single workspace and to discuss how to integrate these tools in a single Eclipse platform. The solution for arranging all existing tools was to use Maven. However, Maven did not know how VDMTools projects are structured, hence a VDMTools plug-in for Maven was required.

We contributed with a presentation of the challenges and expected outcome of this thesis and we started the development of a VDMTools plug-in for Maven, which provided a solid starting point for further development.

1.5 Thesis Goal

The primary goal of this thesis is to investigate the mapping potential between VDM++ and UML. More specifically, this thesis will uncover the mapping potential between:

- VDM++ models and UML 2 Class Diagrams, and
- VDM++ traces and UML 2 Sequence Diagrams

To accomplish the abovementioned, it is necessary to conduct a syntax and semantics analysis of both VDM++ and UML. The analysis will determine a number of language constructs which can be transformed with their semantics maintained. The second goal of this thesis is to formulate bidirectional transformation rules for each identified language construct. The rules must be stated in natural language and subsequently be defined formally using VDM++. Once the rules have been formally defined, the ambition is to develop a prototype of a transformation tool incorporating the formally defined rules.

The output of the prototype must comply with the concrete syntaxes of VDM++ and UML, to enable importing the output into existing tools (i.e. an existing UML tool should be able to import the output of a VDM++ to UML transformation). To accomplish that regarding UML, it is necessary to first investigate the existing standard for UML diagram exchange by the Object Management Group (OMG), and secondly to explore to which degree various UML tool vendors adhere to the standard. In addition, the concrete syntax of VDM++ must be examined to produce correctly formatted output.

To summarize, the subgoals of this thesis are:

UML 1 and UML 2: To investigate the UML specifications, i.e. syntax and semantics of UML 1 and UML 2.

VDM++: To examine the VDM++ syntax and semantics, including the new traces definitions [Santos08].

Mapping potential: To determine the mapping potential between VDM++ and UML in terms of language constructs which can maintain their semantics during a transformation.

Transformation rules: To formulate in natural language a collection of bidirectional transformation rules for each language construct, i.e. one rule for each direction (VDM++ and UML roundtrip). The rules must subsequently be formally specified in VDM++.

Diagram exchange standard: To investigate the OMG standard for diagram exchange in order to represent a UML model correctly.

Prototype: To develop a model of the model transformation using VDM++. The prototype will assist to ascertain the level of correctness of the transformation rules.

In addition, the prototype will assist in uncovering whether existing UML tools adhere to the diagram exchange standard.

1.6 Reading Guidelines

In order to ease the reading process commonly used illustration principles are shown below along with a short description of what they present. In addition, please notice that the *page numbers* given in citations of articles, correspond to pages

Below is a description of how different types of models and source code are displayed and how names or keywords from within this models /source illustrations are shown:

Keyword: **`bool`** are shown in boldface.

References to names in models /source code are shown without boldface `getValue`.

Representation box of a VDM model:

```
class SensorController
thread
while true do
  skip;
end SensorController
```

Listing 1.1: Example of VDM.

Representation box of an AST:

```
TemplateParameter ::
  name : seq of char;
```

Listing 1.2: Example of an AST

Representation box of a XML files:

```
<xmi:Extension extender="Enterprise Architect" extenderID="6.5">
</xmi:Extension>
```

Listing 1.3: Example of XMI/XML.

Representation of a transformation rule:

Transformation Rule 1
VDM classes are mapped as the UML meta-class `Class`

Connection between two items at different levels:

```
class SensorController
thread
while true do
  skip;
end SensorController
```

Listing 1.4: A VDM class with a thread definition.

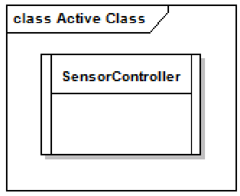

Figure 1.1: A UML Active class.

1.7 Related Work

The idea of combining formal and informal languages to exploit *the best of both worlds* [Dascalu&02, Kim&05, RoseMan] have been investigated by others before. Common to [Kim&05, Snook&06, Dascalu&02, Laleau00, RoseMan] is the mapping between a formal method (Alloy, Z, Z++, VDM++) an the UML Class Diagrams which provides a static view. Not only UML Class Diagrams have been considered for transforming between formal and informal models. UML Sequence diagrams [Dascalu&02] and state machines [Guelfi&08] have also been subject of model transformations.

A To enable such a transformation, rules must be stated in order to before a actual transformation can take place. The specification of such rules are critical and often not explicitly defined [Kim&05]. These rules can be specified in a formal way and proved as in [Laleau00], where they proved 80 % of the rules specified in B by isabelle/HOL.

[McUmber&01] have formalized UML in terms of Promela, the formal system description language for SPIN[1]. The mapping process from UML to a target language has been automated in a tool called Hydra, which is a prototype to demonstrate that the rules are sufficiently defined that formal language specifications can be generated automatically from UML diagrams.

[Konrad&05] describe a tool for specifying and analyzing natural language properties of UML models, resulting in generation of the corresponding formal specification language Promela, which can then be formally analyzed by the model checker Spin. Several tools for the behavioral analysis of UML models have been developed, where a user typically specifies properties in terms of formal specification languages. The aim of their tool is to ease the use of formal specification languages by being able to accept natural language as input. Natural language properties are derived using a grammar that supports certain specification patterns. Their grammar supports the natural language representation of these specification patterns. The grammar is used to specify linear-time temporal logic (LTL) properties, i.e. encode formulae about a condition which will eventually be true. The grammar can be customized according to vocabulary and speci-

[1] Used for formal verification of distributed software systems.

fication style of a domain. The approach does not require the user to know the specific syntax and semantics of the formal specification language used.

[Dascalu&02] propose an object-oriented specification approach based on the combined used of UML and Z++, aimed at the construction of real-time systems (Thus the use of Z++ has traits similar to the VICE extension of VDM++). They aim at developing a bidirectional link between the diagrammatic (i.e. shown by a diagram) and formal parts of a software system's model. They have devised what they call *translation algorithms* between a subset of the UML part of the model and its Z++ counterpart (presumably transformation rules). On the basis of the 4+1 view, they choose to pursue the user view, structural view and behavioral view, which is further narrowed down to use cases, scenarios, class diagrams, and state-charts diagrams. The environment, called Harmony, is designed to support the proposed specification approach, which is organized in stages and steps. It provides the methodological basis for a pragmatic and rigorous object-oriented modeling approach. The integration of formal and informal methods occur between UML classes/compounds[2] and Z++ classes.

[Kim&05] takes an MDA approach towards integrating a formal modeling language, Object-Z, with an informal modeling language, UML. Using the MDA model transformation approach, they define a meta-model of Object-Z using the MOF. Given the meta-models of UML and Object-Z, they then define transformation rules specifying how to convert an Object-Z element into a UML model element.

The UML meta-model is already available via the UML2-project as the file UML2.ecore. The Object-Z meta-model was automatically generated from Rational Rose using EMF. Thus, both meta-models are also MOF-models.

The transformation rules are defined using a transformation language, Tefkat, which is also a MOF model. The transformation language allows them to define a tracking model, which enables linking elements from both models together, i.e. by querying the tracking model, it can be decided which elements in one model are generated from elements in another model.

An actual transformation is then achieved automatically using a transformation tool that understands the transformation language. Tefkat is the transformation language used by [Kim&05] to define transformation rules.

1.8 Outline of the Thesis

This thesis is structured into 9 chapters, each covering a particular topic of the model transformation. The following section gives a quick overview of the thesis. The succeeding section gives a more elaborate account of the chapters of this thesis.

[2]A class with enhanced behavioral description.

1.8.1 Quick Overview of the Thesis

The first part of this thesis introduces the reader to UML and VDM++. The next two parts are concerned with the model transformations between VDM++ and UML Class Diagrams and VDM++ traces and UML Sequence Diagrams, in terms of transformation rules and how they are specified using VDM++. Then follows a discussion of the implementation of the transformation rules the use of various tools to achieve the model transformation. Finally we conclude on the work presented in this thesis.

1.8.2 Thorough Exposition of the Thesis

Chapter 2 gives an introduction of the informal language UML regarding its history and general usage. The chapter then focuses on the syntax and semantics of UML. It ends with an introduction of XML Metadata Interchange (XMI), which is the standard for diagram exchange advocated by OMG.

Chapter 3 introduces the formal language VDM++ and its uses in the industry. Next, a description of the syntax and semantics of VDM++ is given, supplemented with an account of current tool support. The chapter ends with a description of the new concept of VDM traces.

After the introduction of the two modeling languages, **Chapter 4** gives the reader a thorough explanation of the bidirectional transformation rules, which enable going back and forth between a VDM++ model and a UML model.

Chapter 5 follows up on the preceding chapter by giving a description of *how* the transformation rules from Chapter 4 are turned into a VDM model. The chapter also introduces the reader to Abstarct Syntax Trees, the Overture tool ASTGen and how to merge changes between VDM++ and UML models.

The thesis now turns the attention towards how to perform a model transformation between VDM++ and UML Sequence Diagrams. **Chapter 6** first discusses which combinations of VDM++ traces and UML Sequences Diagrams yield the greatest benefit. Then follows a description of how VDM++ traces are related to UML 2 Sequence Diagrams in terms of transformation rules.

Chapter 7 describes how the transformation rules from Chapter 6 are added to the existing model transformation described in Chapter 5.

At this point in time, the reader will have knowledge of the structure of both VDM++ and UML in addition to a complete set of transformation rules between the two languages. **Chapter 8** introduce the reader to the implementation of the model transformation. The implementation is facilitated tool-based code-generation to Java.

Finally, in **Chapter 9**, we conclude on the thesis work. Each subsection of the conclusion treat a certain angle of this thesis work. The thesis is ends with an overall conclusion which sum up relevant aspects of the thesis in its entirety.

Appendix A gives an outline important aspects regarding our participation in the Fifth Overture Workshop in Braga, Portugal.

Appendix B contains a description of omitted UML 1 constructs, i.e. the constructs which have no VDM++ counterpart.

Appendix C contains a description of omitted UML 2 constructs.

Appendix D contains a description of the changes to the UML meta-model from UML 1 to UML 2.

Appendix E contains the specification of the UML AST, i.e. the syntactical description of the UML abstract syntax.

Appendix F contains the model coverage, i.e. it shows which lines of the model are being used during a model transformation.

Appendix G contains the entire OML AST as provided by the Overture project [Overture07].

Appendix I presents an overview of the extent to which the model transformation is implemented.

A list of symbols and abbreviations can be found in the back thesis.

Chapter 2

UML

This chapter start by a short introduction to the history and general usage of the Unified Modeling Language (UML). Then a brief overview of the structure of UML follows to prepare the reader for the sections describing the constructs of UML 1.4.2 (denoted UML 1) and UML 2.1.2 (denoted UML 2) and the differences between the two versions. The chapter ends with a description of the XML Metadata Interchange (XMI) format by OMG to enable interchange of diagram instance data among different tool vendors.

2.1 History of UML

In the mid-1970s and the late 1980s various object-oriented (OO) modeling methodologies began to appear as a consequence of the emerging OO analysis and design. More than fifty different of modeling languages occurred in the period between 1989-1994 and developers had difficulties finding a methodology that satisfied their needs [UML1.4.2, p33-34]. In the mid-1990s the creators of two leading methods, the Object Modeling Technique (OMT) and the Booch Method by Rumbaugh and Booch, respectively, began to assimilate from other methods what they considered to be of interest [UMLDistilled, p7-8]. Together Rumbaugh and Booch attempted to reconcile their two approaches and started to work on a Unified Method [UMLDistilled, p7-8]. In 1993 they were accompanied by Jacobson who brought with him the object-oriented software engineering (OOSE) method which was a use-case oriented approach that provided excellent support for business engineering and requirements analysis [UMLDistilled, p7-8].

Rumbaugh, Booch and Jacobson was summoned in 1996 by Rational to head the development of a non-proprietary Unified Modeling Language that should be presented to the Object Management Group (OMG) for adoption [UMLDistilled, p7-8]. The rationale was that the abundance of methodologies was impeding the spreading of the OO approach and a unified language would help settle the differences [UMLDistilled, p7-8]. The efforts of Booch, Rumbaugh, and Jacobson resulted in the release of the UML 0.9

and 0.91 in June and October of 1996 [UML1.4.2, p33-34]. In 1997 Rational released version 1.0 of the UML documentation as their proposal to OMG. The proposal included suggestions from various organisations which was merged and the resulting version 1.1 was adopted by OMG [UMLDistilled, p8].

In January 2005 the International Standardization Organization (ISO) released version 1.4.2 of UML as an international standard (ISO/IEC 19501) and in July 2005 OMG released UML 2.0 which presented the most radical changes to the UML since version 1.1 [OMGUMLHomepage], [UMLDistilled, p157]. The present version of UML at the time of this writing is 2.1.2 [OMGUMLHomepage].

2.2 UML Usage

UML is a semi-formal visual modeling language used by developers to model a system at a desired level of abstraction. It allows developers to step back and look at a system, or a subpart hereof, from a more general point of view. The different views comprise thirteen kinds of diagrams distributed between two primary categories: structure and behavior [UMLSuperstructure2.1.2, p700]. This thesis focuses on Class Diagrams (static structure) and Sequence Diagrams (behavior). Several examples of the industrial use of UML exist [UMLSuccess], some of which are described below.

2.2.1 KLEIN+STEKL GmbH

The German software company KLEIN+STEKL GmbH provided a solution to the Operations Department of Zuercher Kantonalbank (ZKB), one of the three leading banks in Switzerland. The system serves about 60 NT-clients. The users are dealing with about 330 different data classes and about 220,000 objects saved in the database. The SDV Tool[1] consists of some 109,000 Java statements in 1,335 classes. The whole system was designed with UML (Rational Rose [RationalRose]). As UML is easy to understand, use cases, data models and interactions can be discussed even with the end users, thus ensuring a practical solution [ZurcherKantolbank].

2.2.2 Borland Together Control Center

The Charles Schwab Corporation provides securities brokerage and related financial services for 8 million active accounts with $837 billion in assets. Schwab senior technology management recognized the need to facilitate the consistency of architecture and development models across multiple projects, and get developers speaking the same language. After surveying its developers, and comparing features to features, Together Control Center was selected. One of the biggest benefits to the developers at Schwab is the Together Control Center reverse engineering feature, which takes existing code and allows the developer to visualize the model using UML. Another important feature

[1] Tool for Master Data Management (in-house product.)

to the developers is simultaneous round-trip engineering, which ensures instantaneous code and model matching allowing for fewer bugs and faster testing. [Schwab]

2.2.3 Telelogic Rhapsody

Telelogic Rhapsody is a commercial model-driven development tool targeted at the development of embedded and real-time systems. The Rhapsody modeling environment is based on the UML. The product has been used in a variety of industrial applications, implicitly spreading the use of UML [Thales, ThalesOptronics, ECITelecom, Trane, ZurcherKantolbank, Schwab, MotionControl, ObjectiveControl, Cytyc].

2.3 The UML Meta-model

Modelers use UML to model an abstraction of real world phenomena, e.g. business logic, prior to implementation. The runtime instances of an implementation and a corresponding UML model reside in two different layers of abstraction as shown in Figure 2.1. The lowest level, M0, represent the runtime instances (implementation) and the layer above, M1, represent the UML user-model. The rules by which the UML user-model is defined, i.e. the rules a modeler must obey when using UML for modeling some system, are defined in the M2 layer [UML1.4.2, p28]. The M2 layer is an abstraction of M1 and is called the meta-model of UML. The meaning of *meta* is data about other data and as a result the meta-model of UML is the model that describes the UML user-model. The meta-model prevents modelers from inventing their own constructs or interpretations of existing constructs at the user-model level. Above the UML meta-model level is the meta-meta-model (M3) called the Meta-Object Family (MOF), which is the language used to build meta-models, e.g. the UML meta-model.

Figure 2.1 is described in more detail in the following to allow a deeper understanding of the underpinnings of UML.

The boxes in layers M1-M3 are classes of that layer. The general concept of a *class* is applicable to all three layers, but with a twist: a class is a cohesive collection of data that specifies the structure and behavior of the classes created from the class (its instances). The subtlety of a class having classes as instances is a feature of meta-modeling. Only classes in the M1 layer has "real" objects as instances. The classes in layers M1-M3 comprise a model at each layer. The main idea of a model is also applicable to all three layers. A model is a description designed to show the main features of a concept. The concept of each layer varies: the concept of a M1 model is to model real-world phenomena. The concept of a M2 and M3 model is to model a model. In this thesis a M1 model is denoted a *model*. The prefix *meta* is used to distinguish, from a certain standpoint (i.e. M1), models at different layers. The meaning of meta-model in this context is data about a M1 model, i.e. a M2 model (UML meta-model). The same applies for a meta-meta-model, which translates to data about a M2 model, i.e. a M3 model (MOF). Hence, a *class* is a constituent of a M1 model (UML user-model), a

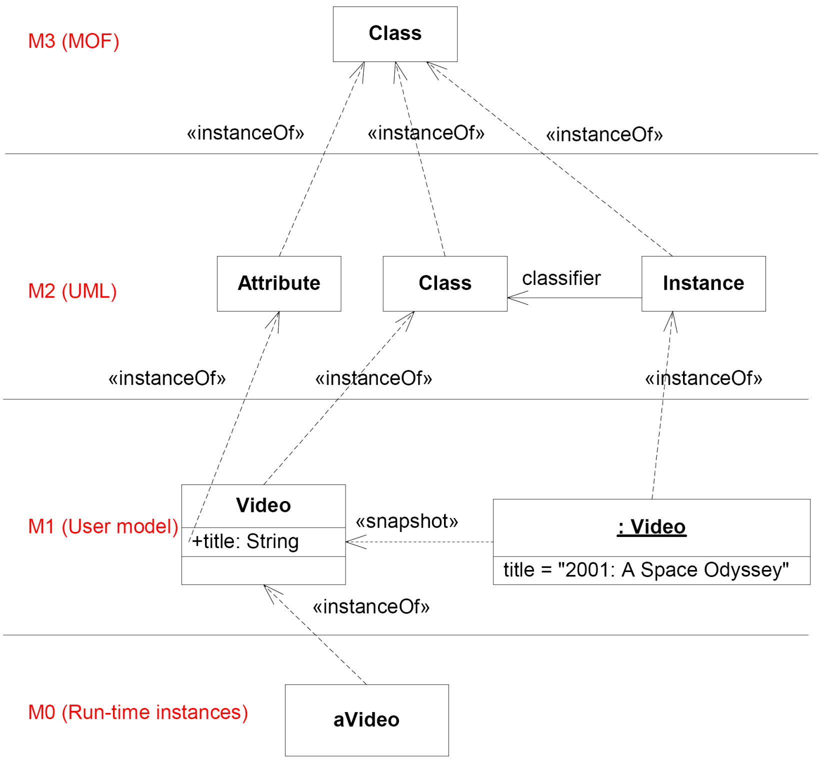

Figure 2.1: Example of the link between different layers of the UML Meta model

meta-class is a constituent of a M2 model (UML meta-model) and a *meta-meta-class* is a constituent of a M3 model (MOF).

The dashed arrows in Figure 2.1 are dependencies. A dependency in this context signifies a model element requiring another model element for its specification [UMLSuperstructure2.1.2, p79]. The model element at the tail of the arrow (the client) depends on the model element at the arrowhead (the supplier). The text enclosed in angle brackets is the dependency stereotype.

Beginning from the bottom up, the M0 instance `aVideo` is an instance of the M1 class `Video`. UML allows modelers to model instantiated classes. The class `:Video` is a model of an instance of `Video` as indicated by the dependency stereotype `<<snapshot>>` going from `:Video` to `Video`[2]. `:Video` is also an instance of the M2 class Instance. The M2 classes `Class` and `Instance` are connected by a M1 construct, the an association. The reason it is possible to use a M1 construct in a M2 context is that the UML 2 specification use a combination of three languages to describe the full UML [UMLInfrastructure2.1.2, p34]. One of those languages is a subset of UML[3]. The ori-

[2]The M2 class Instance is in fact the class InstanceSpecification [UMLSuperstructure2.1.2, p99] and it represents an entity at a point in time, i.e. a snapshot.

[3]The practice of defining a language by means of a subset of the language being defined yields a semi-circular description. Understanding the UML specification is possible for two reasons: (1) only a small subset of UML constructs are needed to describe its semantics and (2) additional two languages - the

entation and end-name of the association shows that `Instance` has an attribute named *classifier* of type `Class`. According to the UML specification, the attribute *classifier* is of type `Classifier` [UMLSuperstructure2.1.2, p99], and the M2 class `Class` inherits `Classifier` [UMLSuperstructure2.1.2, p66]. The association shows how `Instance` can be instantiated as `:Video`. It is possible because it has been modeled with an attribute of type `Classifier`.

The UML meta-model can be extended through Profiles or first-class extensions handled through MOF. With Profiles, the UML meta-model can be adapted to include (not remove nor alter) constructs not part of UML released by OMG [UMLInfrastructure2.1.2, p189]. It is a generic extension mechanism for customizing the UML meta-classes for particular domains and platforms. Profiles are defined using stereotypes, which define how an existing meta-class, e.g. `Class`, `Property` or `Operation`, may be extended. A Profile is a collection of such stereotypes that collectively customize UML for a particular domain. Profiles suffice if the existing properties of the UML meta-classes makes sense to the domain. If, however, some properties are misplaced or unaligned or if entire meta-classes are missing, first-class extensibility through MOF is an option. First-class extensibility handled through MOF impose no restrictions on what is allowed to do with the UML meta-model, e.g. add or remove meta-classes.

2.4 Choosing versions of UML for comparison

The Rose-VDM++ Link is based on UML 1.1 [UMLMan] and the model transformation developed as part of this thesis is based on UML 2.1.2. Consequently, both specifications of UML must be investigated to uncover differences that may influence the design of the model transformation rules. UML 1.4.2 has been chosen to represent UML 1.x. The rationale for choosing version 1.4.2 is that it is the only UML specification by OMG certified as an international standard by ISO and thus the version recognized by most developers. UML 2.1.2 has been chosen to represent UML 2.x because it is the latest published version of UML by OMG.

UML 1.4.2 is denoted UML 1 and UML 2.1.2 is denoted UML 2.

2.5 UML 1

This section presents the notion of UML 1 Class Diagram (CD) and Sequence Diagram (SD) followed by a description of the model constructs constituting each diagram type. Constructs not applicable to the model transformation between VDM and UML are not described in this section. Interested readers are referred to Appendix B for more information on excluded UML 1 constructs.

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declarative language Object Constraint Language (OCL) and precise natural language - are used to define UML.

2.5.1 Class Diagram

A CD consists of inter-connected classes and interfaces. A class is a definition of behavior, structure and relationships shared by multiple instances of the class, denoted objects. A class can be concrete or abstract. A concrete class can be instantiated as opposed to an abstract class which can only be inherited from, even if it contains implementation code. Connections among classes constitute relationships that can take the form of associations or generalizations.

Class

A class in an UML 1 CD is an instance of the meta-class `Class`. Figure 2.2 depicts a condensed CD from the UML 1 specification and shows the meta-attributes of class `Class` [UML1.4.2, p44,45,47]. It has the following meta-attributes:

isActive: Specifies whether an instance of a class maintain its own thread of control.

isAbstract: Specifies whether a class can have a direct instance or not.

ownerScope: Specifies whether the attributes or operations (see Figure 2.2) of a class are accessible directly via the class or via an instance of the class. Possibilities are `instance` or `class` [UML1.4.2, p106].

feature: Specifies an ordered list of attributes and operations, owned by the class (instances of `Attribute` and `Operation`.

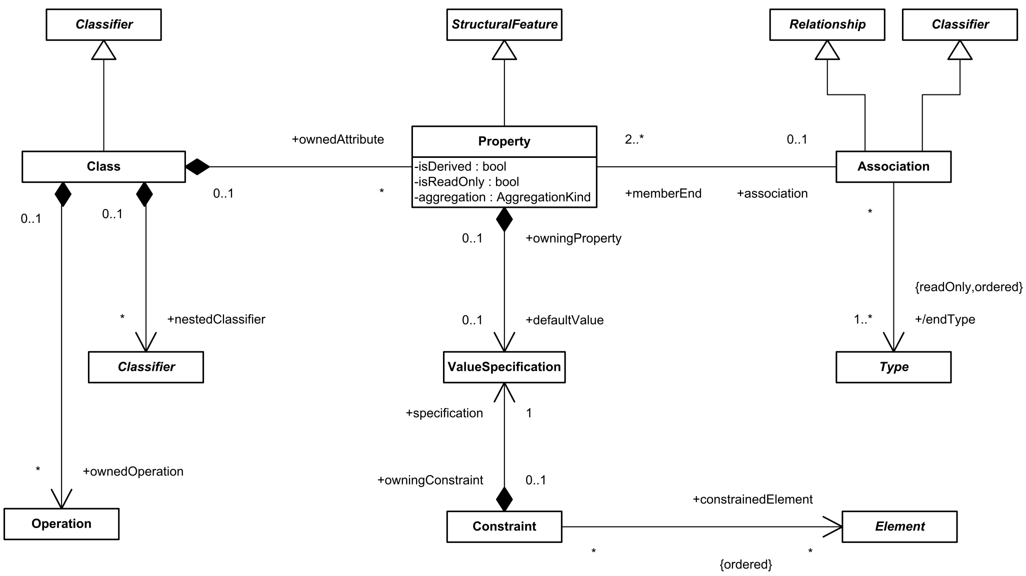


Figure 2.2: A condensed CD showing the attributes of meta-classes `Class`, `Attribute` and `Operation` [UML1.4.2, p44,45]

As mentioned above, an `Operation` is an owned meta-attribute of `Class` [UML1.4.2, p56], and it too has meta-attributes, as described below.

ownerScope, **isAbstract:** Have the same semantic meaning as described above for `Class`.

visibility: Denotes how the class to which it refers is seen outside the enclosing name space. Possibilities are `public`, `protected` and `private`.

isQuery: Specifies whether execution leaves the state of the system unchanged. A value of `false` indicates that side-effects may occur.

Parameterized class

A parameterized class is a generic class with one or more unbound formal parameters. The parameter can be of any type and can be used in the operations of the class. To be a meaningful constituent of a CD, the unbound parameters of a generic class must be bound to some types [UML1.4.2, p54].

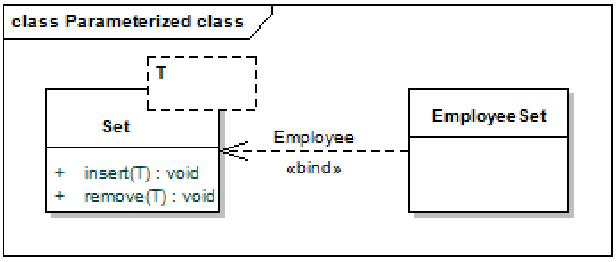


Figure 2.3: An example of a parameterized class

Figure 2.3 shows a generic class `Set` with one unspecified parameter `T`. The class `EmployeeSet` has `T` bound as type `Employeee` as specified by the `<<bind>>` dependency to `Set`.

Nested Class Declarations

A class declared within another class belongs to the namespace of the other class and may only be used within it. This construct is primarily used for implementation reasons and for information hiding [UML1.4.2, p234].

Association

An association defines a semantic relationship between classes. It consist of two or more ends, each specifying a connected class and may optionally have a name [UML1.4.2, p251]. A binary association connects exactly two classes and a n-ary association may connect several classes. Figure 2.9 shows the relevant meta-classes to understand the definition of an `Association`.

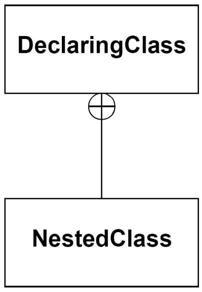
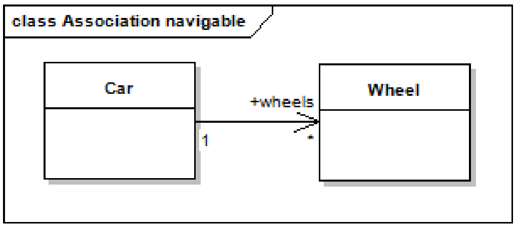
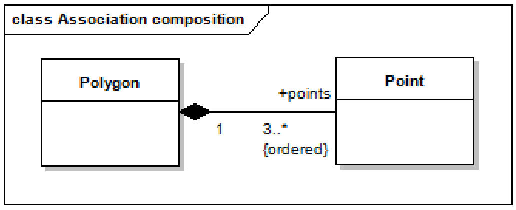


Figure 2.4: The class `NestedClass` is declared within the `DeclaringClass`, hence it is restricted to the namespace of the `DeclaringClass` [UML1.4.2, p239].



(a) Showing a navigable association.



(b) Showing a composite association with a ordered set.

Figure 2.5: Association examples both navigable, composite and ordered.

Figure 2.5a shows how a navigable association is visualized in a diagram. Each `Wheel` may belong to one `Car`, and one `Car` may have multiple wheels. Figure 2.5b shows a `Polygon` which has a composite association to three or more ordered `Point`. Class `Polygon` is the only class with knowledge of class `Point`, hence instances of `Point` are constructed and destructed by `Polygon` alone. Options for enhancing the power of expression of associations are described in the following text.

Xor association: Denotes that only one of a set of possible associations may be instantiated [UML1.4.2, p50]. See Figure 2.6 for an example.

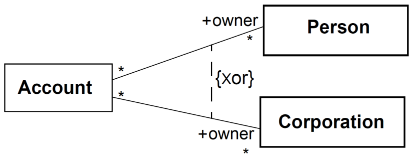


Figure 2.6: Xor Association. The dotted line annotated with {`xor`} denotes only one of the two classes may be instantiated by an instance of `Account` [UML1.4.2, p252]

N-ary association: An n-ary association is an association which spans three or more classes, see Figure 2.7. The lines connecting the owner of the association to multiple targets are joint through a diamond-shape. Although an n-ary association is composed of several lines, it is semantically one association. Multiplicity (explained further below) may be annotated to an n-ary association, but with less rigor compared to a binary association (i.e. between exactly two classes) [UML1.4.2, p259]. Figure 2.7 shows a simple n-ary association with little semantics. It could, however, be further annotated to show the navigability and multiplicity.

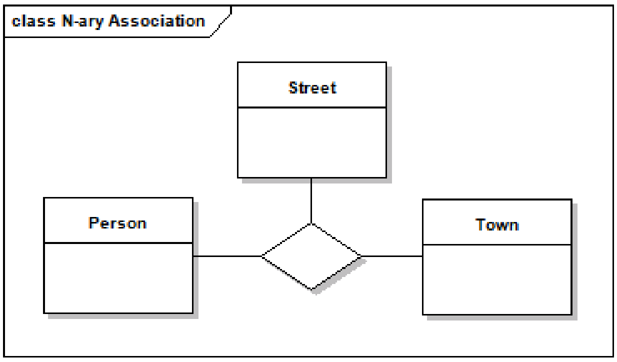


Figure 2.7: An N-ary association. The semantics of the depicted n-ary association is merely that an association of some kind exist among the three classes

Most of the interesting details about an association are attached to its ends. The meta-class `AssociationEnd` is represented The following additions can elevate the level of precision to an association-end.

Multiplicity: The multiplicity of an association-end specify the number of allowed instances the class located at the opposite end of the association may have knowledge of [UML1.4.2, p256]. A multiplicity is a range of non-negative integers. An example can be seen in Figure 2.5a and 2.5b.

Ordering: If the multiplicity is greater than one, the set of related instances may be either ordered or unordered. Default is unordered (duplicates are prohibited) [UML1.4.2, p253]. It is in effect a constraint on the association. An example can be seen in Figure 2.5b.

Qualifier: A qualifier is an attribute or list of attributes whose values serve to partition the set of instances associated with an instance across an association [UML1.4.2, p257]. See Figure 2.8 for an example.

ScopeKind: Is an enumeration that denotes whether an association belongs to individual instances or an entire classifier. Its values are {`class`} or {`instance`}, respectively.

Navigability: When placed on a target end, specifies whether traversal from a source instance to its associated target instances is possible. Specification of each direction across the association is independent. A value of `true` means that the association can be navigated by the source class and the target role-name can be used in navigation expressions [UML1.4.2, p52].

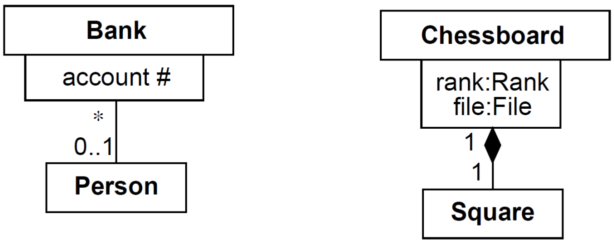


Figure 2.8: The qualifier `accountNo` designates that every instance of `Person` is identified by zero or more qualifier instances. It also shows that every instance of `Person` may be identified by an infinite number of `accountNo` instances.

Visibility: Specified by a visibility indicator (+, #, -, or explicit property name such as `public`) in front of the name of the association. Possibilities are:

- *public*, where other classes may navigate the association and use the name of it in expressions,
- *protected* where descendants of the source class may navigate the association and use name of it in expressions, and
- *private*, where only the source class may navigate the association and use the name of it in expressions.

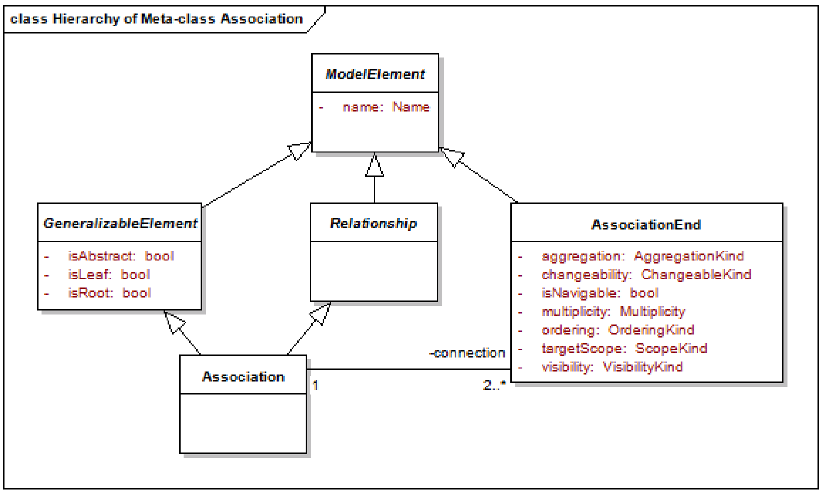


Figure 2.9: A condensed CD showing the class hierarchy of the meta-class `Association`.

Generalization

The terms child, subtype, and subclass are synonymous and mean that an instance of a class being a subtype of another class can always be used where an instance of the latter class is expected. The terms superclass and generalization and their counterparts subclass and specialization, are the preferred terms in this thesis. Generalization is used to classify classes. A class (abstract or concrete) is a superclass if it contains signatures of operations or implementation code common to one or more specializing classes, i.e. subclasses that inherit the superclass. See Figure 2.10 for an example. The superclass is thus a generalization of the subclasses and the subclasses are specializations of the superclass.

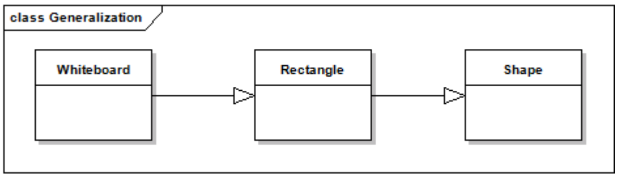


Figure 2.10: An example of generalization. A `Whiteboard` is both a `Rectangle` and a `Shape`, i.e. an instance of `Whiteboard` can be used where the former classifies are expected. Instances of `Shape` and `Rectangle`, however, can not be used where `Whiteboard` is expected.

Stereotype

Classes may be annotated with stereotypes. A number of built-in stereotypes exist that can be utilized to denote certain intentions of a stereotyped class, e.g. `control` or `semaphore`, and is in effect a new meta-class introduced at modeling time [UML1.4.2, p221] as it is possible to invent new stereotypes (Rose-VDM++ Link uses stereotypes. See section 2.5.3).

Constraint

In the UML meta-model, `Constraint` is used to restrict elements. The restriction can be stated in natural language, or in different kinds of languages with a well defined semantics. The meta-class `Constraint` has the attributes `constrainedElement` and `body`. The first specifies an element to constrain and the second a semantic condition or restriction on that element.

2.5.2 Sequence Diagram

A UML 1 SD is made up of the meta-classes `Collaboration` and `Interaction`[4] as shown in Figure 2.11. The former is the structural description of the participants, i.e. objects, and `Interaction` is the description of their communication patterns. The

[4] Or CollaborationInstanceSet and InteractionInstanceSet, due to the type-instance dichotomy: each element has a dual character, e.g. Class-Object, Association-Link, etc. [UML1.4.2, p206].

structure of the objects that participate in an SD is called a Collaboration. The *communication pattern* performed by the objects to accomplish a certain task is called an Interaction [UML1.4.2, p125].

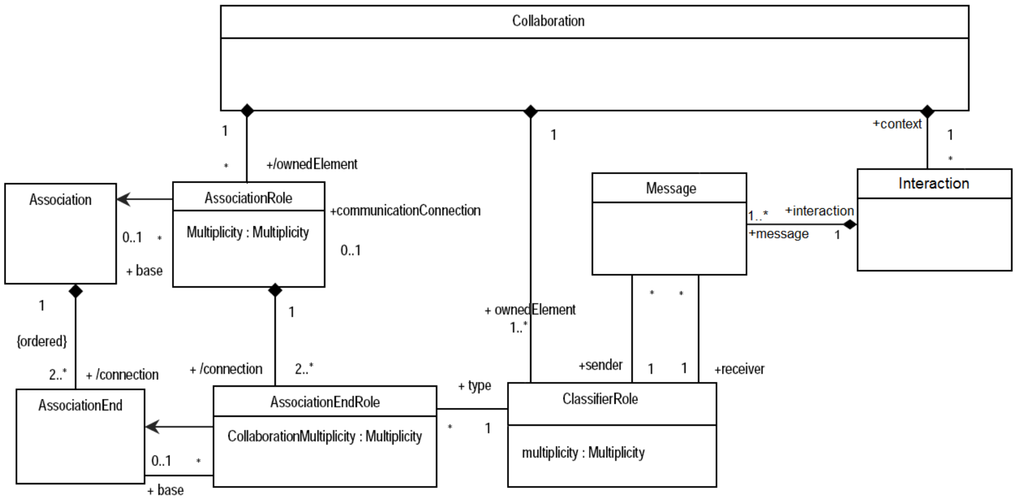


Figure 2.11: The meta-classes involved in a SD are shown. [UML1.4.2, p127]

As seen in Figure 2.11, the meta-class `Collaboration` includes a set of `ClassifierRole`s and `AssociationRole`s that defines the objects of the SD. `ClassifierRole` and `AssociationRole` defines usage of an instance of `Classifier` and `Association`, respectively. That is, `ClassifierRole` represents the classes and attributes involved in a particular SD [UML1.4.2, p137]. The meta-class `Interaction` is defined in the context of a `Collaboration` and it contains a set of partially ordered messages, each specifying one communication, e.g. which operation to be invoked [UML1.4.2, p139].

Each object is called an lifeline and is represented by a box with a vertical dashed line stemming from the lower center of the box. An example is shown in Figure 2.13. The interaction between objects is facilitated by messages between lifelines. The message is drawn as arrows between and is a communication that conveys information, e.g. about an operation to invoke or an instance to create.

An arrow may also be labeled with a sequence number to show the sequence of the message in the overall interaction or for identifying concurrent threads of control. An arrow may also be labeled with a condition and/or iteration expression [UML1.4.2, p283].

A connected set of arrows may be enclosed in a separate diagram and marked as an iteration. The continuation condition for the iteration may be specified at the bottom of the iteration. If there is concurrency, some arrows in the diagram may be part of the iteration and others may be single execution.
Various labels (such as timing constraints) can be shown either in the margin or near the transitions or activations that they label. Figure 2.12 shows how the lifeline may be split

into two or more concurrent lifelines to show conditionality or concurrency. The latter may be the case if the conditions are not mutually exclusive. The lifelines may merge together at some subsequent point.

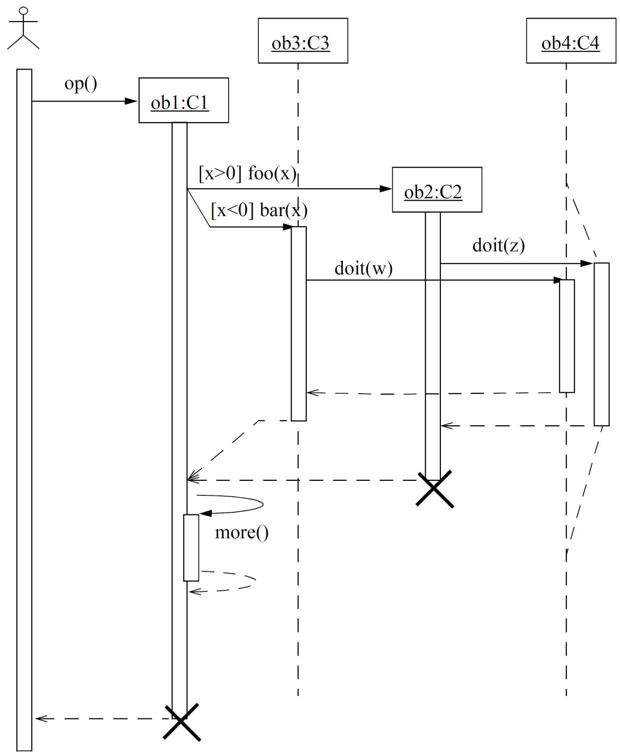


Figure 2.12: Sequence diagram showing creation of objects along with parallelism.

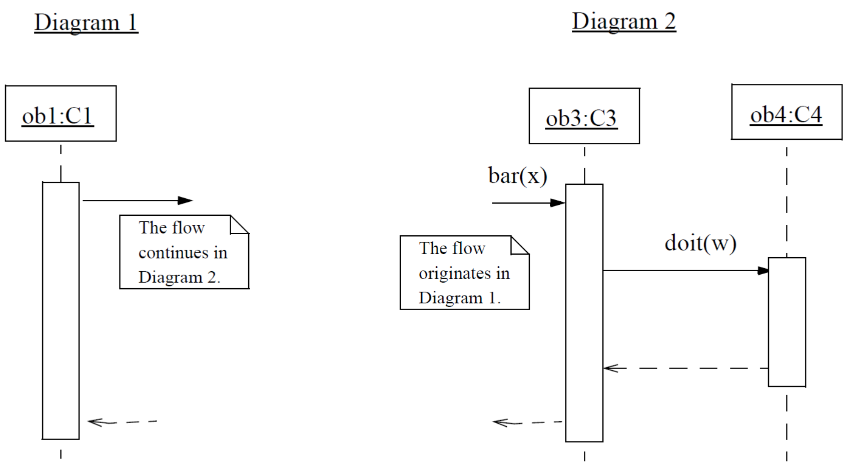
Four objects and one actor[5] are shown in Figure 2.12. The collaboration is triggered by a call to `op()` on `ob1` and results in numerous calls as time progresses according to an unknown metric. `ob4` splits its lifeline, suggesting multi-threaded execution. `ob1` and `ob2` is destroyed at different points in time and the method-calls `foo(x)` and `bar(x)` have conditions to be satisfied prior to execution.

If a diagram loses its clarity due to information overhead (e.g. it exceeds a sheet of paper) it can be split up as seen in Figure 2.13 for an example. In such cases, the cut between the diagrams can be expressed in one of the diagrams with a dangling arrow leaving a lifeline but not arriving at another lifeline, and in the other diagram it is expressed with a dangling arrow arriving at a lifeline from nowhere.

2.5.3 Rose-VDM++ Link

This section addresses the extent to which model transformation from VDM to UML is possible using the Rose-VDM++ Link (RVL) tool. RVL allegedly omits VDM and UML

[5] An intervening entity; a Use Case concept [UML1.4.2, p273].



(a) SD showing a message pointing to nowhere with a comment describing the *where*.

(b) SD showing a message origin from nowhere with a comment describing the *where*.

Figure 2.13: Shows how to connect SDs by the use of pointing to and from nowhere [UML1.4.2, 284].

constructs that can only be described in one of the two languages [UMLMan, p27]. This is not entirely true, however, since RVL *does* omit UML 1 construct that are expressible in VDM. This section first present UML 1 constructs that RVL supports. Second, the UML 1 constructs omitted by RVL are presented. In this section, UML 1 is referred to simply as UML.

Rose-VDM++ Link Included UML 1 constructs

VDM classes are equivalent to UML classes and can be mapped directly to and from VDM.

Values and instance variables are represented as attributes of a class in UML. RVL use the stereotypes `<<instance variable>>` and `<<value>>` to distinguish between instance variables and values, respectively. The need for such a distinction exist because values are read-only and instance variables are not [UMLMan, p27].

Operations and functions map into the operations section of the UML class. They are distinguished by the stereotypes `<<operation>>` and `<<function>>` because functions are constrained from interaction with values or instances variables. Operations on the other hand are capable of altering the state of an instantiated class by manipulating instances variables [UMLMan, p28].

Operations and functions may be explicit or implicit, i.e. implemented to some degree or not implemented at all. Both types map to the same syntax in UML, hence it is impossible to tell the difference between the two. RVL deals with this issue by saving the implementation of explicit functions or operations and apply the following rules when mapping functions or operation from UML to VDM [UMLMan, p28]:

Rose-Link Rule 1: If a function is already defined in VDM, it is mapped into the same kind (implicit or explicit) as defined in VDM.

Rose-Link Rule 2: If a function is not known in VDM (i.e. the function was defined at the UML level) it is mapped as explicit.

Objects (instances of VDM classes) may have relations to other objects through the object reference type [Fitzgerald&05, p78]. These relations correspond to UML associations and are represented by an arrow from the client class towards the class being referenced. The arrow indicates navigability towards the referenced instance. The ends of an association can be given a name which indicates the intended role of the association. Binary associations, i.e. an association among exactly two classes, renders the representation of the referenced object as an attribute in UML superfluous, because it is already given by the name of the association-end. Hence it is represented by the association alone.

In listing 2.1 a VDM model and its corresponding UML 1 Class Diagram generated by RVL is shown.

```
class Person
types
  day = nat;
instance variables
  name : seq1 of char :="My name";
  skills : set of Skill;
  favouriteDishes :
    seq of char := [];
  appointments : map day
    to Appointment;
end Person

class Appointment
end Appointment
class Skill
end Skill
```

Listing 2.1: VDM model of a Person

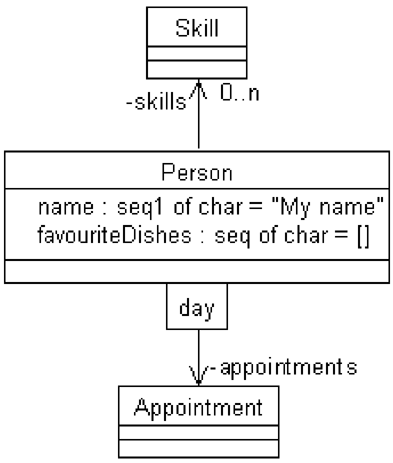


Figure 2.14: UML visualization of the VDM model generated by RVL

VDM:VDMPersonClassExample

It is possible to relate one instance to several other instances by using the following VDM constructs:

set of objref: A one-to-many association.

seq of objref: A one-to-many association of ordered elements.

seq1 of objref: The non empty sequence of object references is represented by the range `1..*` at the many-end of the association.

[objref]: The optional object reference is represented by the range 0..1 to the association.

Associations resulting from use of **seq** and **seq1** are decorated with the constraint {ordered} because sequences are ordered [Fitzgerald&05, p136].

Members of a class may be declared static. A static member can be accessed directly from the class as opposed to a non-static member that requires an instance of the class. RVL distinguishes between the two cases by prepending the character $ to the name of an value and underscores the name of an operation, as shown in listing 2.2 and Figure 2.5.3.

```
class Owner

values
  nonStaticValue : nat = 0;
  static staticValue : nat = 1;

instance variables
 private  nonStaticVar : Owned;
 private static
staticVar : Owned;

end Owner

class Owned
end Owned
```

Listing 2.2: Owner

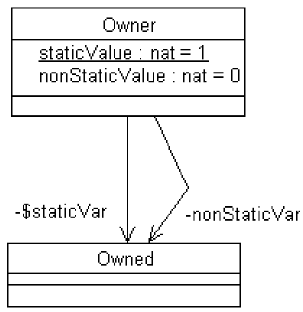


Figure 2.15: UML visualization of the VDM model generated by RVL

Mappings in VDM are used to model relationships between the values of one set, referred to as the domain, and the values of another set, referred to as the range [Fitzgerald&05, p167]. A mapping is expressed by the constructs **map** and **inmap**. The first denotes the type of all finite mappings between any two types, the mapping operates on, i.e. many-to-one. The latter denotes the injective version of the first, i.e. a one-to-one mapping between two types. The constructs **map** or **inmap** result in a qualified association in UML. The qualified association can be assigned a name, which will be the type of the domain of the map. See Figure 2.5.3 for an example of **map**.

The keywords **is subclass responsibility** in VDM designates delegation of responsibility, i.e. inheritance relationship, which translates to an generalization arrow in UML. A VDM class containing a delegated operation of function is translated to an abstract class in UML, denoted by an italicized class name.

Rose-VDM++ Link Excluded UML 1 constructs

RVL omits UML 1 constructs that can in fact be represented in VDM. These constructs are presented in this section with a proposition of how to map them to UML 1. Each description contains a reference to section 4 on static model transformation, where explanations of the transformation rule for each VDM and UML construct can be found.

Constraints: Classes, operations or parameters cannot be constrained in RVL. Nevertheless, possibilities exist for specifying simple textual constraints in UML. The meta-class `Constraint` define such a semantic condition or restriction expressed in text. A number of textual constraints are defined as enumerations in the UML meta-model, e.g. $\{Xor\}$ for use with `Associations`, as showed in Figure 2.6 [UML1.4.2, p50,252]. Such an annotation can be mapped to VDM as an Union type [Fitzgerald&05, p74]. More complex constraints, such as invariant, should not be mapped to UML due to the overhead of textual information it will represent, thus bloating the UML diagram. See section 4.5.

N-ary association: An association may be binary or n-ary [UML1.4.2, p259]. The latter is not possible to map from VDM to UML using RVL, although it can be mapped as a product type [UML1.4.2, p75]. See section 4.6.

Active class: VDM classes may contain a **`thread`** section to enable modeling concurrent systems. The UML counterpart is an active class (`isActive=true`). RVL ignores VDM classes with a **`thread`** section, however, such a class can be mapped as an UML active class. See section 4.9.

Template class: A generic class has one or more unbound parameters. Such a construct is not part of VDMTools [Fitzgerald&05, vii]. However, the open source initiative named Overture Project develops a formal modeling method, Overture Modeling Language (OML), founded on VDM. In this context an extension of the VDM formal specification has been made as part of a master's thesis project to include generic classes [Christensen07], hence it is possible to represent generic classes in the Overture variant of VDM. See section 4.12.

Inner class: A UML class may have inner classes, i.e. nested classes confined to the name space of the host class. The idea of inner classes is to limit visibility of a class further than possible by use of name spaces. Currently, VDM does not have the concept of inner classes. Extending VDM to support inner classes requires access modifiers on classes, otherwise the concept of inner classes is lost. In listing 2.3 a suggestion to extended the VDM syntax is incorporate to enable the concept of inner classes.

```
public class Owner <-- added: access modifier on class declaration

classes  <-- added: classes compartment
  private class Inner
  end Inner

end Owner
```

Listing 2.3: Example of extended syntax for nested classes support.

In listing 2.3 a classes `Owner` is shown. The specification in extended by a visibility **`public`** and a inner class definition **`classes`** to support declaration of nested classes.

Another approach, that which is taken in this thesis, is to map definitions of VDM data types as UML nested classes. The **`types`** part of a VDM class definition contains any data types defined in the class. Such types can be considered inner classes; see section 4.3

2.6 UML 2

This section presents the differences between UML 1 and UML 2 in terms of new and deprecated constructs. Section 2.5 introduced a number of UML 1 constructs in order to explain the level of UML 1 support offered by RVL. The aim of this section is to prepare the reader for the sections describing the transformation rules.

2.6.1 Class Diagram

The basic building blocks of a CD have not changed from UML 1 to UML 2. It still consist of classes with relationships among them. Figure 2.16 gives an overview of the meta-classes constituting a UML 2 class diagram. The changes important to this thesis work are presented in the following.

Deprecated UML 1 meta-classes

Association: Binary associations and attributes now have different notations for the same concept, i.e. an attribute may represent the navigable ends of a binary association.

ChangeableKind: The enumeration has been revoked. It comprised the values {changeable}, {frozen} and {addOnly}, which denoted how an association-end was allowed to be modified. It has been replaced the meta-class `Constraint`, which allows textual constraints to be devised at a desired level of detail using natural language or more formal languages, e.g. OCL. [UMLSuperstructure2.1.2, p74].

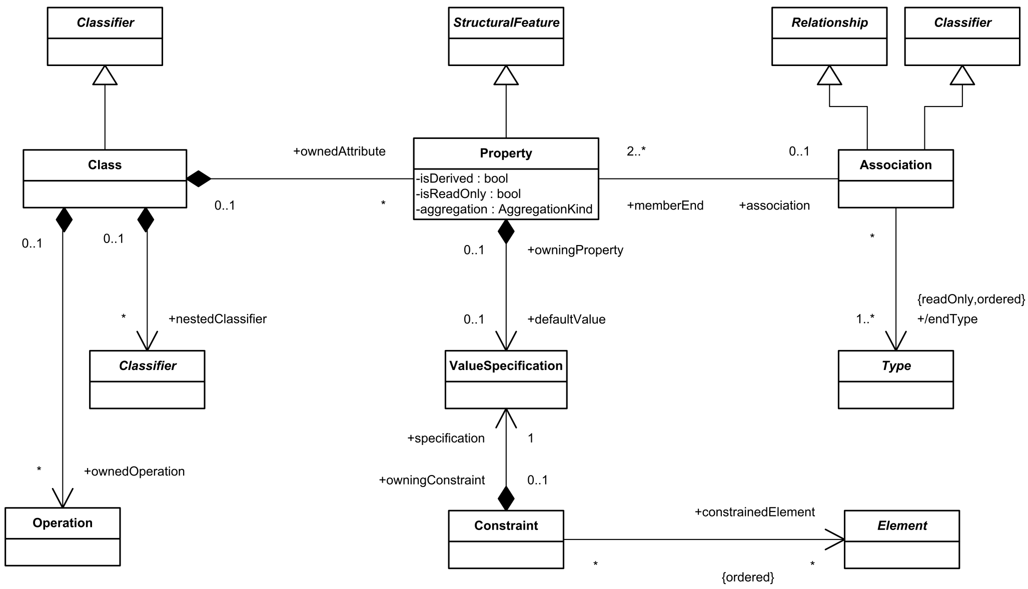


Figure 2.16: A condensed CD showing the attributes of meta-classes Class, Attribute and Operation [UMLSuperstructure2.1.2, p48]

Xor-association: The special kind of association has been replaced by the use of `Constraint`.

Nested class symbol: The nested class symbol shown in Figure 2.4 in section 2.5 have been deprecated. Normally, connections among classes are some kind of `Relationship` [UML1.4.2, 45] [UMLSuperstructure2.1.2, 148]. The nested class symbol in UML 1, however, are purely notational and has no supporting meta-class. No specialization of `Relationship` in UML 2 is used to model nested classes. The notation in UML 2 is simply to prepend the name of a nested class with its owning class (see Figure 4.3 in chapter 4 for an example).

2.6.2 Sequence Diagram

The basic building block of a UML 2 SD have not changed. It still consist of lifelines connected by messages. However, some of the underlying meta-classes have changed.

An interaction may be part of Sequence Diagrams, Interaction Overview Diagrams, and Communication Diagrams [UMLSuperstructure2.1.2, p473]. Figure 2.17 shows meta-class `Interaction` and other meta-classes related to it. Notice that every class, except those related to messages, inherit `InteractionFragment`. The idea in UML 2 SD is that everything is a piece of interaction and that pieces of interaction may be nested within each other to form more complex interactions.

The idea becomes apparent in Figure 2.18, where it is seen that `CombinedFragment` and `InteractionOperand` is also subclasses of `InteractionFragment` [UMLSuperstructure2.1.2, p488,501].

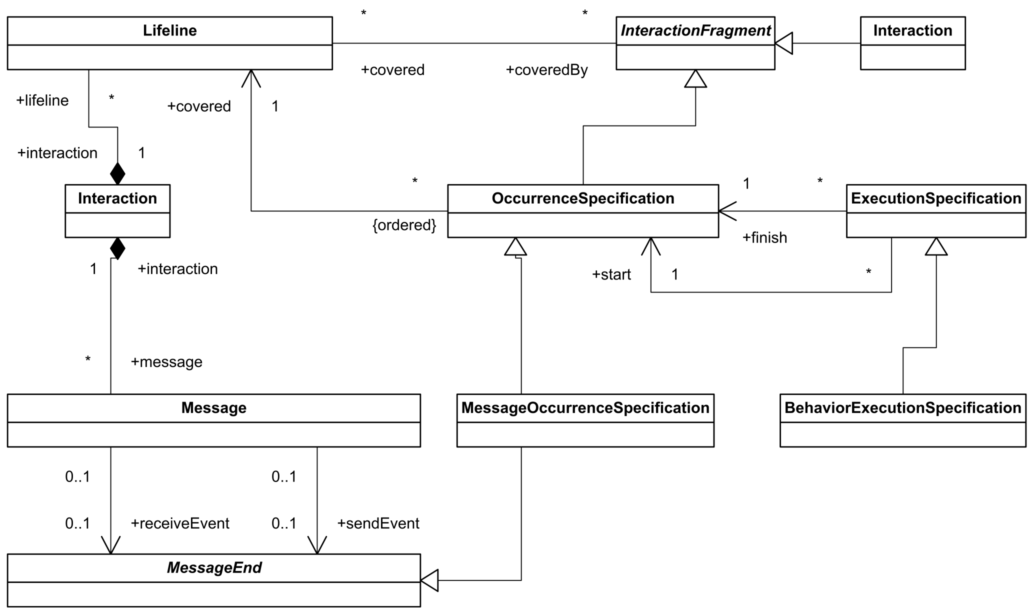


Figure 2.17: Condensed class diagram showing the meta-classes constituting the inner parts of a SD

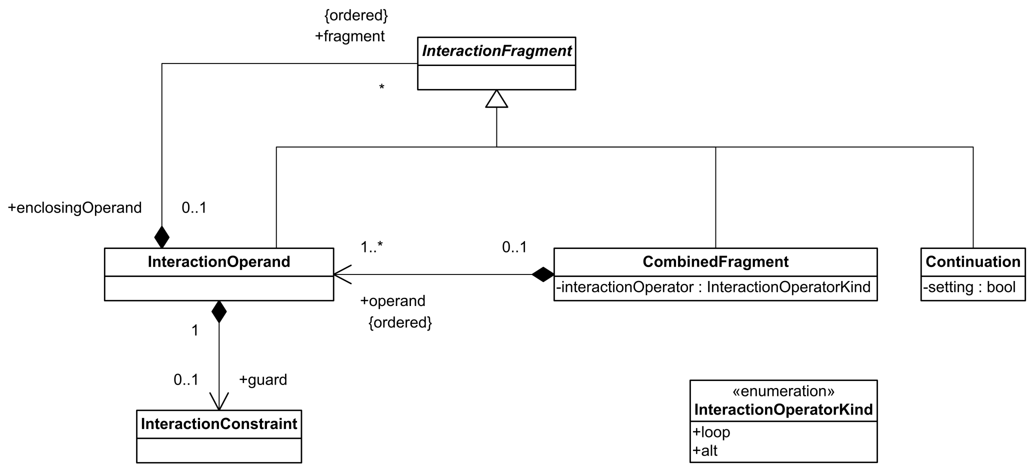


Figure 2.18: Condensed class diagram showing the meta-classes constituting the inner parts of a SD

In UML 2 the concept of `CombinedFragments` is introduced. The only valid option for describing procedural logic in UML 1 Sequence Diagrams is to separate a collection of messages in a separate diagram, e.g. for modeling an iteration with a condition (see section 2.5.2). In worst case the result is a multitude of different diagrams referencing each other. `CombinedFragment` mitigates this problem. A `CombinedFragment` is a piece of interaction, i.e. a part of a Sequence Diagram. At the same time it is a Sequence Diagram by itself. `CombinedFragments` can be nested within each other. They are used to increase clarity and keep Sequence Diagrams concise [UMLSuperstructure2.1.2, p483].

As seen in Figure 2.18, `CombinedFragment` has two attributes, `interaction-Operator` and `operand`. The first dictate the semantics of the CombinedFragment, i.e. how it should be interpreted by the reader. Depending on the kind of interaction operator zero, one or more operands separated by a dashed line can be used. The following operators have been selected for use in this thesis:

Alternative (alt): Denotes a choice of behavior akin to an if-then-else block. At most one operand must be chosen. It replaces the UML 1 notation of splitting a lifeline into concurrent lifelines to show conditionality. The syntactical way to define guards to test against is by `Continuation` [UMLSuperstructure2.1.2, p490]. Continuations have semantics only in connection with Alternative fragments.

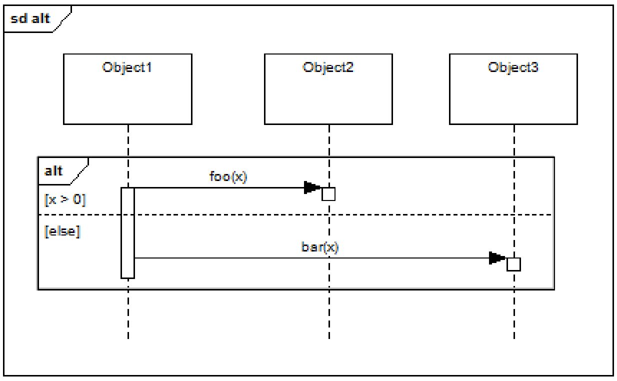


Figure 2.19: Example of a alternative region to denote a choice of behavior.

Loop (loop): Encloses a series of messages which are repeated. The number of iterations is defined by a pair (minint, maxint) of minimum and maximum repetitions or by a boolean expression.

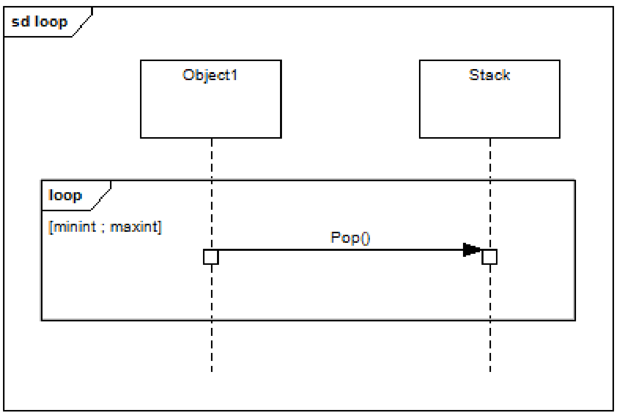


Figure 2.20: Example of a loop region to denote a loop of behavior.

2.7 Tool support for XML Metadata Interchange (XMI)

The XML Metadata Interchange (XMI) is a standard for exchanging meta data information via Extensible Markup Language (XML) it can be used for any meta model that can be expressed in Meta-Object Facility (MOF). XMI is standardized by the Object Management Group (OMG) [OMGUMLHomepage]. XMI is widely used to exchange UML models by UML modeling tools. The modeling of data in XMI is split into two parts on *abstract* model and one *concrete* model which is the vision of OMG. The abstract model represents the semantic information which in the case of UML would be e.g. class definitions, it is an instance of arbitrary MOF-based modeling languages such as UML. The concrete model represents visual diagrams such as Sequence diagrams in UML. For diagrams the Diagram Interchange [UMLDI] (XMI[DI]) which is a standard specifying how the actual diagram should be specified.

2.7.1 XMI incompatibilities between UML modeling tools

There are several incompatibilities between different tool vendors implementing XMI for UML. At the Diagram interchange level the standard are almost nonexistent and even between interchange of abstract models there are multiple incompatibilities. Unfortunately this means that the goal of XMI: Enable interchange of e.g. UML model are rarely possible or very limited. Moreover the new XMI 2.1 standard are even less widespread which as a result limit the interchange of models even more.

To give an impression of how this deviations from XMI influence the interchange of models a list of UML modeling tools is provided together with examples of limitations and deviations from the standard. All the tools listed have support for XMI version 2.1 which at the time of writing are the newest standard released by OMG. Common for all the tools are the widely use of the `extension` tag as shown in listing 2.4 which enables tool vendors to extend the XMI model with tool specific data. This feature is by no means intended to be used as a substitute for the *abstract* or *concrete* model.

```
<xmi:Extension extender="Enterprise Architect" extenderID="6.5">
</xmi:Extension>
```

Listing 2.4: Example of XMI extension tag.

Enterprise Architect (EA) [EA71]: They claim to have full support for UML 2.1.2 and XMI 2.1. This is partly true, but they do not use the XMI[DI]. All diagrams are placed inside a EA extension tag with all data serialized to EA specific elements. In addition to this they placed the information about navigable associations (see figure 2.5a) and placement of qualifiers of associations (see figure 2.8) etc. in `extension` tags as well. The above information in specified in the *abstract* model at export but ignored by EA itself at import.

Visual Paradigm for UML (VP-UML) [VP-UML]: They claim to have full support for UML 2.1.2 and XMI 2.1. This is not correct, but compared to EA they use the XMI[DI] to some extent. All diagrams are facilitated by `extension` tags. The tool is limited in the *abstract* model e.g. it does not support n-ary associations instead it creates binary associations between a class acting as the diamond of the n-ary which do not exist. This diamond class is represended in the *abstract* model as a class with no name and an extension.

```
<ownedMember name=""
             xmi:type="uml:Class"
             ...>
        <xmi:Extension xmi:Extender="Visual Paradigm for UML">
             <modelType value="NARY"/>
             <nary/>
        </xmi:Extension>
</ownedMember>
```

Listing 2.5: VP-UML n-ary association class

Eclipse UML2 Tools [UML2Tools], Topcased [TOPCASED-UML2], rCos [rCOS]: Supports UML 2 and XMI 2.1 but have their own name space for UML which reduce the interchange of models. Besides the limitation of n-ary associations like VP-UML and the fact that the UML type are missing from a subpart of elements in the *abstract* model, it has a good support. Both Topcased and rCos are build on top of Eclipse UML2.

2.7.2 Limitation of Sequence Diagrams in XMI

The XMI presentation of a Sequence Diagram (SD) is limited since there is no way a `Message` can be linked to a `CombinedFragment` in the *abstract* model of the sequence diagrams (see section 2.6.2). This missing link means that a connection between a message of SD and the `InteractionOperand` in which it may exist are missing from the *abstract* model, the link only exist in the diagram where most tool vendors use their own standard.

Limitation: From a transformations point of view the use of `CombinedFragment` in SD is restricted to none, since they do not contribute with any value if no `Message`s can be related to them.

To solve the problem without breaking the XMI standard a `extension` tag is inserted in the `operand` element representing a interaction operand. The new `extension` tag is provided with a `covered` element containing the id of the `MessageOccurrence-Specification` (`MOS`) at the message `sendEvent` and `receiveEvent` to link the message and operand together. This makes it possible through the *abstract* model to obtain enough information to reproduce the SD by taking the new extension and the ordering of messages into account. Instead of placing this link in an extension of the operand it should be included in the operand element but it will require the standard to be changed.

```
1  <ownedBehavior xmi:type="uml:Interaction" xmi:id="idInteraction"
2                 name="SD1Interaction">
3    <fragment xmi:type="uml:CombinedFragment" xmi:id="VDM.11" name="CF1"
4            covered="VDM.5 VDM.12" interactionOperator="loop">
5      <operand xmi:id="VDM.21">
6        <Extention extender="umltrans">
7          <covered>VDM.14 VDM.6</covered>
8        </Extention>
9        <guard xmi:id="VDM.22" constrainedElement="VDM.21">...</guard>
10     </operand>
11   </fragment>
12   <message xmi:id="VDM.20" name="" receiveEvent="VDM.14" sendEvent="VDM.6"/>
13 </ownedBehavior>
```

Listing 2.6: Setting multiplicity of properties

In listing 2.6 an example of the extension is shown in line 5-10. Where the message at line 12 is linked to the operand.

Chapter 3

VDM

The Vienna Development Method (VDM) is a *method* comprising a collection of techniques for the formal specification and development of software systems. It is based on the VDM Specification Language (VDM-SL), which is a model-oriented formal specification language. VDM-SL has an extended form, VDM++, which supports modeling of object-oriented systems (denoted VDM from this point). VDM is one of the oldest formal methods, and have been applied to a wide range of industrial projects [Fitzgerald&08a, Fitzgerald&08b].

3.1 History of VDM

In the period of 1964-69, IBM used the meta-language Vienna Development Language (VDL) to define the semantics of PL/1 (Programming Language One) [DinesBjornerPP, Plat&92, Fitzgerald&08b]. The descendant of VDL, Meta-IV, was used by IBM in 1973-75 to develop a PL/1 compiler [DinesBjornerPP]. The development approach taken by IBM became known as the Vienna Development Method, because it comprised several techniques, including, but not limited to, Meta-IV. During the 1970s, different specializations of Meta-IV began to emerge as a result of different application areas. As a consequence, the British Standards Institution (BSI) submitted a standardization proposal to ISO aiming at reconciling the strands into a unity. VDM-SL was ISO standardized in 1996 [ISOVDM96] and the standardization of Meta-IV was called VDM-SL. Extensions incorporating object oriented structuring and handling of concurrency were developed in 1992-94 by the Afrodite[1] project [Fitzgerald&05, p10]. The extended VDM-SL together with improved tool support is collectively denoted VDM++ [Fitzgerald&05, p10]. Further extensions have been made to VDM, most noticeably VDM In Constrained Environment (VICE) which support the modeling of distributed and real-time systems [VDMLangManVICE]. Available tool support for VDM include:

[1] Afrodite has been sponsored by the European Union under the ESPRIT programme (EP6500).

VDMTools: Constitutes the leading commercial tools for VDM-SL and VDM++. It is an industry-strength tool set owned, marketed, maintained and developed by CSK Systems, building on earlier versions developed by the Danish Company IFAD A/S [VDMFromWikipedia, IFAD].

Overture: An open-source project [OvertureTool] aiming at providing free tool support for VDM++ on top of the Eclipse platform and to develop a framework for interoperable tools that will be useful for industrial application, research and education [VDMFromWikipedia, OvertureTool]. Focus is also on making it easier to use VDM to test new ideas and concepts.

3.2 VDM Usage

The purpose of VDM is basically the same as that of UML, i.e. to let developers focus on the critical parts of a software system by abstracting parts of the system away. It is, like UML, designed to be independent of methodologies and programming languages. The great difference between the two is that VDM is a model-based formal method, while UML is visual semi-formal method. If a model is created in UML it is recommended to use a verification tool to ensure a certain degree of completeness and correctness. VDMTools can be used to validate a VDM model very easy. VDM requires that all constructs to be precisely specified and as a reward for the VDM language supports type check of the model, the ability to run the hole model and assistance of proof construction. The useful feature that enables code generation exists in many modeling tools for UML, the same is the case for VDM, where the model can be executed at the specification level and the final source that can be generated from the specification.

3.2.1 Banknote Processing

The SIC2000 project at the GAO [2] involved the development of a complex collection of mutually suspicious cooperating software components in a banknote processing system. The goal was to expedite the integration of sensor software and hardware into existing banknote processing systems. This was the first large project at the GAO in which formal methods played a central role. The analysis, design, and test phases of the development were supported by the IFAD VDM-SL Toolbox.

The use of VDM in the SIC2000 project can be considered lightweight in the sense that no formal refinement or proof has been performed. Instead, in the course of the project, the VDM technology became the focal point of the entire development process, providing a unified treatment of analysis, design, documentation, and testing. The development of the formal specification of the SIC2000 project was performed in 1 man-year. The implementation (in the SIC) of the specification was completed in 3 man-months.

[2] Sensor Integration Controller (SIC) project, which was undertaken at the GAO (Gesellschaft für Organisation und Automation).

Modular testing of the SIC was finished in 4 man-weeks: several errors were detected, all but one attributable to an imperfect translation of the specification into code.

The developers of the project believes, that the primary advantage of the VDM technology is the support it provides for the construction of precise and realistic software system models. For complex industrial projects, this is a capability whose value can hardly be overestimated. The price that must be paid for the capability of formulating design ideas in a formal notation, following the implications of design features to their logical conclusions, exposing and codifying all design assumptions in a collection of formal invariants is not excessively high, considering the alternatives.

If VDM had not been utilized in the project, the result would have been a different, a weaker, and eventually a more expensive final product than was produced by using lightweight formal methods [Smith&99].

3.2.2 VDMTools

Most components of the VDMTools tool suite are themselves developed using VDM. This development has been made at IFAD in Denmark and CSK in Japan [Fitzgerald&08a].

3.2.3 ISEPUMS

In a project from the space systems domain, VDM was used to develop a sub-system of the ground segment, which handled processing of messages communicated to the SPOT4 satellite, an earth observation satellite designed by CNES (French National Space Centre) and in service since March 1998. The aim of the project was to apply a knowledge acquisition method[3] in combination with a specification of a real-size application. The combination of a knowledge acquisition method and the use of VDM, with prototyping and multi-modules capabilities, enabled modeling the complicated system and build a first complete executable specification in a reasonable time (5 months). The direct use of the VDM method to build a model immediately revealed the complexity and level of details of the ground segment, leading to frequent meetings with the domain expert to clear up the ambiguous points. Furthermore, VDM helped to find the right choice in terms of abstractions, which results in a smaller system than the one obtained using classical techniques [Puccetti&99]

3.2.4 A Mission Critical Data Handling Subsystem

The data handling subsystem developed using VDM-SL technology is an input- and output service of a large data mining application. On the input side of the data handling subsystem, the arriving messages can be very complex, due to the richness of the message syntax and semantics. This leaves the opportunity for highly ambiguous messages to be send to the system's, analogous to natural language interpretation. Furthermore, the

[3] The identification and categorization of relevant domain knowledge.

format of the input messages evolves over time (and in practice, so will the data model of the data mining application), so the requirements with respect to the maintainability of the data handling subsystem were very high. Due to the clear need for a very expressive method for specification of the subsystem, VDM-SL was selected (and the IFAD VDM-SL toolkit) as means to implement the data handling subsystem. The system as a whole was developed under a fixed-price, fixed-date contract. About 4800 man-hours (which corresponds to about 10 per cent of the total available project resources) where spent on the development of the data handling component. From the start of the project, the data handling subsystem has been in the critical path of the project plan, mainly due to the sequential nature of the activities. Nevertheless, it was the first subproject to deliver results, on time, within the allocated budget and was accepted by the client without a single change. The application of VDM-SL was a major success and the client has continued to work on the data handling subsystem using VDM-SL and the IFAD tools [Berg&99b].

3.3 Tool support

To aide development in VDM a commercial tool called VDMTools exists, which provides a wide range of features like: extensive static semantics checking, automatic code generation, round-trip mapping to UML 1 class diagram, documentation support, test coverage analysis and debugging support. The tool is build on top of the IFAD VDM Toolbox and currently maintained and developed by CSK. The tool has a comprehensive code generator both to c++ and Java it supports up to 95 per ce of the VDM language [Fitzgerald&08a]. The integrity checker points out all places where potential runtime error could happen named proof obligation e.g. check that all operators are applied correctly. VDMTools enables a model to be split up into multiple files enable concurrent model development additional to this is includes a pretty printer that can format the model and used together with the interpreter for debugging and running the model it can color the model according to the part executed and collect coverage information. In the interpreter it has the ability to check invariants, pre and post conditions when execution the model. A VICE extension to VDMTools exist which enable future modeling of time and deployment of resources in a distributed architecture. A external plug-in for VICE exists to enable a graphical representation of the execution. The VDMTools has been used in many industrial projects: ConGorm, Dust-Expert, The development of VDMTools, TradeOne, Sony/FeliCa Networks etc. [Fitzgerald&08a]. The tool is available on multiple platforms, e.g. Windows, Linux and Mac. Another open source tool available is VDMJ, now part of Overture, which is currently being developed. It includes an parser, type check and an interpreter for debugging. VDMJ is an Java implementation of a subset of VDMTools and supports VDM-SL and VDM++.

3.4 VDM Classes

VDM models are structured into classes familiar from the object oriented world. A class is made up of different blocks that can be arranged arbitrarily and may be empty. Here follows a short introduction to the content of each block.

Value: Constant values. Instead of using a constant value directly in the model, a value can be defined. This enhances readability and makes changes effortless.

Types: There are two kinds of types, *basic types* and *constructed types* [Fitzgerald&05, p71]. The basic types refer to primitive data types such as integer, boolean, char, etc. as found in conventional programming languages. The constructed types, e.g. union or tuple, are made from primitive types using a *type constructor*.

Instance variables: Variables constitute the state of an instantiated class and are themselves instances of a type.

Functions: A function takes input parameters and produces a result, with no reference to the instance variables of the object.

Operations: Same as functions, but an operation can modify instance variables and are thus able to cause side-effects in the model.

Thread: An independent thread of execution for each instance of the class.

Sync: Access to shared data among parallel threads are synchronized using permission predicates and mutex constraints.

Inheritance in a class hierarchy is denoted by the keyword **`is subclass of`** after the name of the subclass.

Name conflicts occur if several class members with identical names are defined in a class. This can be resolved by prepending the respective class name to each class member.

Access modifiers govern the visibility of member declarations within a class and the scope of a class. Member declarations can be declared private, protected or public.

Private: The member is only reachable from within the class.

Protected: The member is reachable from subclasses in its class hierarchy.

Public: The member is reachable from all classes in the model.

Type	Values
bool	true, false
nat1	1, 2, 3, ...
nat	0, 1, 2, ...
int	..., -2, -1, 0, 1, ...
rat	..., -1/7, -1/356, ..., 1/3, ...
real	..., -12.78353, ..., 0, ..., 1322.2324, ...
char	$'a','b',...,'1','2',...,'+','-',...$
quote	$< RED >, < CAR >, < QuoteLit >, ...$
token	$mk\_token(...)$

Table 3.1: Basic types supported in VDM

3.5 Types

A *type definition* is used to define *data types* that can be used elsewhere in the model. It consists of a type name and the definition of the type.

An *invariant* is a boolean predicate on a data type restricting the values in a data type by means of an invariant. Thus, by means of a predicate the acceptable values of the defined type are limited to those where this expression is true [VDMLangMan, p32].

VDM provides the ability to structure data, such as records, collections and sequences. VDM uses *type constructors* to enable creation of new types from the basic types provided. Table 3.1 shows the basic types available in VDM.

As mentioned above, types representing structured values and collections are build from the basic types using a *type constructor*. The available constructors are described below.

Union types: A union type can be formed by several component types. The formed union type will contain all values from each of the components.

```
--NewUnionType : type1 | type2
NewUnionType : nat | bool
```

Listing 3.1: Example of a Union type.

Listing 3.1 shows a `NewUnionType` having the ability to reference a **`nat`** or a **`bool`** value.

Product types: The product type brings all values from the composed types together in composite structures called *tuples*, which is different from the union type where all the values are combined. A product type consists of combined types:

```
let
  address : seq of char * nat * PostalTown =
    mk_("Street",5,<Aarhus>) in skip;
```

Listing 3.2: Example of Product type. An address composed of three fields.

Listing 3.2 shows a product type, address. It consists of a street, number and a town. To create a product type the make constructor, **mk_**, is used.

Record types: A Record type is like a product type but with the ability of naming the different fields in the record as shown in Listing 3.3.

```
Address ::
        street: seq of char
        number: nat
        town  : PostalTown

let street = mk_Address("Street",5, <Aarhus>).street in ...
```

Listing 3.3: let expression creating an instance of the record using the **mk_** command.]Example of Record type. An Address composed of three types and a **let** expression creating an instance of the record using the **mk_** command.

Optional types: The optional type constructor takes any type as an argument and adds the special value **nil** to it. For example, the type **seq of char** may be extended with the special value **nil**, as shown in Listing 3.4.

```
Name : [seq of char]
```

Listing 3.4: Example of a optional type.

Object References types: Serves as a reference to objects of given class. Listing 3.5 shows a VDM a class B with an instance variable a whose value is an instance of class A. Hereby the instance variable a references an instance of the class A.

```
class B
instance variables
a : A := new A();
end B
```

Listing 3.5: Example of the creation of an object.

3.6 Test Trace

Test traces is a feature for expressing test-cases in a compact form for exhaustive testing of a model. By the use of repeat-patterns on traces, it is possible to express that sequences of operation-calls should be tested in all possible combinations. Since repeat-patterns may be nested within each other, the risk for combinatorial explosion exists, i.e. a trace may result in an excessive amount of test-cases. A test case resulting in an error is caught and if the erroneous test case appears as a subpart of another test case, the remaining execution of such a trace is cancelled. Traces are defined in the **traces** block of a VDM class. Each trace must have a name, but a single trace may define several execution paths separated by a semicolon in a sequential order.

traces definitions = 'traces', { named trace } ;

named trace = identifier, { '/', identifier }, ':', trace definition list ;

trace definition list = trace definition term, { ';', trace definition term } ;

trace definition term = trace definition
| trace definition term, '|', trace definition ;

trace definition = trace core definition
| trace bindings, trace core definition
| trace core definition, trace repeat pattern
| trace bindings, trace core definition, trace repeat pattern ;

trace core definition = trace apply expression
| trace bracketed expression ;

trace apply expression = identifier, '.', identifier, '(', expression list, ')' ;

trace repeat pattern = '*'
| '+'
| '?'
| '{', numeric literal, '}'
| '{', numeric literal, ',' numeric literal, '}' ;

trace bracketed expression = '(', trace definition list, ')' ;

trace bindings = trace binding, { trace binding } ;

trace binding = 'let', local definitions, { ',', local definition }, 'in'
| 'let', bind, 'in'
| 'let', bind, 'be', 'st', expression, 'in' ;

The traces syntax shown above is represented as an Abstract Syntax Tree (AST) to make it available for computational use. The following descriptions present each traces construct in the context of an AST, e.g. `named trace` which consist of at least one `identifier` followed by a `trace definition list`, is represented as the `NamedTrace` in the AST. It is seen, that `NamedTrace` defines a name, `name`, and a trace definition, `defs`, as a (**`seq of char`** and `TraceDefinition`, respectively, which corresponds to `identifier` and `trace definition list` in the traces syntax. Hence, the AST is merely a way to represent language syntax so that a computer can process it.

Named trace: A named trace consists of a name and a sequence of trace definitions, see Listing 3.6.

```
NamedTrace ::
  name : seq of char
  defs : TraceDefinition;
```

Listing 3.6: NamedTrace.

Trace definition: A trace definition consists of a sequence of **let** or **let be** expressions, a test which can be a `TraceMethodApply` expression of a bracket expression and a optional repeat pattern.

```
TraceDefinitionItem ::
  bind    : seq of TraceBinding
  test    : TraceCoreDefinition
  regexpr : [TraceRepeatPattern];
```

Listing 3.7: TraceDefinitionItem.

Method apply expression: The method apply expression consists of a variable name which is the name of an instance of a class whose operation is execute upon and lastly a sequence of parameters see listing 3.8.

```
TraceMethodApply ::
  variable_name : Identifier
  method_name : Identifier
  args : seq of Expression;
```

Listing 3.8: TraceMethodApply.

Repeat pattern:

Zero of more [a*]: Repeat expression a from 0 to a pre-defined maximum value. If the maximum value is 3, then a would have the trace nil,a, aa, aaa.

One of more [a+]: Repeat expression a from 1 to a pre-defined maximum value. If the maximum value is 3, then a would have the trace a, a a, a a a.

Zero of one [a?]: Repeat expression a from 0 to 1. The trace of a would then be nil, a.

Exactly n times [an]: Repeat expression a exactly n times. If n is equal to 4, then the trace of a would be a a a a.

From n to m times [an,m]: Repeat expression a between n and m times. If n is equal to 2 and m is equal to 4, the trace of a would be a a, a a a, a a a a.

3.7 Trace Example

A example of some of the possible trace statements is shown in listing 3.9 from line 9 in the class named `UseStack`. The trace statement at line 12 expanded in listing 3.10 to show how the interpretor in VDM Tools would execute the `trace` statement.

```
1  class Stack
2  operations
3  public Push3 : nat ==> ()
4  Push3(e) == ...
5  public Pop : () ==> nat
6  Pop() == ...
7  end Stack
8
9  class UseStack
10 instance variables
11 s : Stack := new Stack();
12 traces
13 trace1 : s.Push3(1)*
14 trace2 : s.Push3(1)+
15 trace3 : s.Push3(1)?
16 trace4 : s.Push3(1){2}
17 trace5 : s.Push3(1){0,4}; s.Pop()
18 end UseStack
```

Listing 3.9: Example of the definition of traces in a class.

```
s.Pop()
s.Push3(1); s.Pop()
s.Push3(1); s.Push3(1); s.Pop()
s.Push3(1); s.Push3(1); s.Push3(1); s.Pop()
s.Push3(1); s.Push3(1); s.Push3(1); s.Push3(1); s.Pop()
```

Listing 3.10: Trace statement expanded from listing 3.9 line 17.

Chapter 4

Static Model Transformation

This chapter describes the transformation rules for each VDM construct chosen to be part of the static model transformation. The rules are defined in order to enable a transformation between VDM and UML. Each rule use a VDM construct as a base to describe how the rule successfully transform the VDM construct to UML.

Not all VDM constructs have a concrete representation in UML, hence some VDM constructs are omitted from the model transformation, e.g. invariants and pre-conditions. The reason is the different intentions of VDM and UML: UML is a well-defined visual language, thus the structure and functionality of a system is expressed mainly by means of diagrams with a degree of rigour [UMLInfrastructure2.1.2, p33]. VDM, on the contrary, has a mathematical semantics for proving properties about a model [Fitzgerald&05, p4]. The detailed syntactical statements of a VDM model has little purpose in a visual representation and will only serve to bloat a UML diagram. The transformation rules for a static transformation describes how VDM class constructs are related to certain UML meta-classes comprising UML diagrams.

4.1 Classes

VDM classes have a one-to-one relationship to UML classes.

Transformation Rule 1
VDM classes are mapped as the UML meta-class `Class`

4.2 Visibility

The UML meta-class `VisibilityKind` is an enumeration of the different visibilities an element can have. Of those elements, `package` is left out because it does not have a VDM counterpart.

Transformation Rule 2
The visibility of VDM instance variables, values, functions and operations are mapped as a *subset* of the UML enumeration `VisibilityKind` comprising **`public`**, **`private`** and **`protected`**.

The VDM **`static`** keyword allowing access to classes, values, instance variables, functions or operations without having a specific instance, is mapped as the `isStatic` property of the UML meta-classes `Class`, `Property` or `Operation` respectively.

Transformation Rule 3
VDM **`static`** is mapped as the `isStatic` property of the UML meta-class `Class`, `Property` or `Operation` respectively.

4.3 Data types

Data types may be defined in a **`types`** block of a VDM class. The definition of a data type within a VDM class resembles the concept of a nested class in UML, except that instances of data types are identified only by their value in contrast to classes, which may also be identified by reference. See section 5.1.3 for the rationale behind the decision.

Transformation Rule 4
Data type definitions are mapped as the UML meta-class `Class` and are referenced, and thus nested, through the meta-attribute `nestedClassifier` of the owning class. Notice that this rule is not specified or implemented, hence Figure 4.3 is not generated by the tool made as part of this thesis.

```
class Car
types
 Manufacturer = <Mercedes> | <BMW>;
instance variables
  mfacturer : Manufacturer;
end Car
```

Listing 4.1: The VDM class with a value and an instance variable showed as UML attributes.

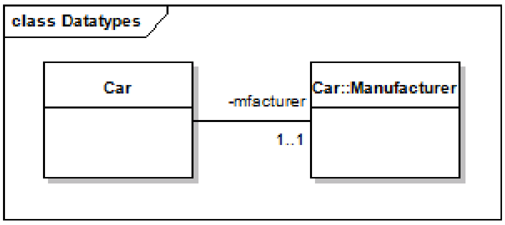


Figure 4.1: A UML attribute `mfacturer`. Nested class noted by `::` on the right.

Listing 4.1 shows a VDM class `Car` with a data type `Manufacturer`. Figure 4.3 shows how the instance variable `mfacturer` of type `Manufacturer` is mapped as the association between `Car` and `Car::Manufacturer` with the role name `mfacturer`. The figure also shows how the data type `Manufacturer` is mapped as the class `Car::Manufacturer`, i.e. as a nested class of class `Car`.

4.4 Instance variables and values

Instance variables and values are defined in the block **`instance variables`** and **`values`**, respectively, of a VDM class. They are the attributes (i.e. the properties) of a VDM class which hold the state of an object. In UML, the attributes of class may be represented as associations or as attributes.

> **Transformation Rule 5**
> Instance variable and value definitions are mapped as the UML meta-class `Association`, if:
>
> **5 a:** The type is an *object reference type*, or
>
> **5 b:** The type is *not* a basic *data type* [Fitzgerald&05, p64,71].

Listing 4.2 shows VDM classes `Order` and `Customer`. The instance variable `customer` is of type `Customer` and is thus identified from a class, i.e. its type is an object reference. Figure 4.4 shows the corresponding UML class diagram for `Order` and `Customer`. The association between `Order` and `Customer` is the instance variable `customer` (rule 5 a). The class `Order::OrderIdType` is the data type `OrderIdType` prefixed `Order` because it is a nested class. The association between `Order::OrderIdType` and `Order` is the value `id`, as indicated by the name and multiplicity at the `Order::OrderIdType` end of the association (rule 5 b).

```
class Order
types
  OrderIdType = seq of nat;
values
  id : OrderIdType = [1,2,3,4,5];

instance variables
  customer : Customer;

end Order

class Customer
instance variables
  name : seq of char;
end Customer
```

Listing 4.2: VDM classes with instance variables showing a UML association.

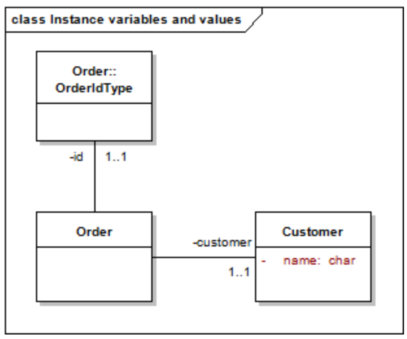


Figure 4.2: A UML association

Transformation Rule 6
Instance variable and value definitions are mapped as the UML meta-class `Property` [UMLSuperstructure2.1.2, p48,p139], if the type is a *basic data type* [Fitzgerald&05, p71]. Instance variables and values are distinguished by the meta-attribute `isReadOnly`. Notice: rules 9 and 12 is an exception to this rule.

VDM concept	`Property::isReadOnly`
Instance variables	`false`
Values	`true`

Table 4.1: The meta-attribute `isReadOnly` distinguishes instance variables and values

Transformation Rule 7
The initial value of instance variables and values definitions are mapped as the property `default` of the UML meta-class `Property`.

Transformation Rule 8
The VDM optional type is mapped as the UML meta-class `MultiplicityElement` with the properties `lower = 0` and `upper = 1`.

Listing 4.3 shows a VDM class `Address` which have a value `zip` and an instance variable `houseNumber`, both of the *basic type* **nat**. Both `zip` and `houseNumber` are mapped as attributes of the corresponding UML class `Address`, as shown in Figure 4.4, because they are a basic type.

```
class Address
values
  zip          : int = 8000;
instance variables
  houseNumber : nat;
end Address
```

Listing 4.3: The VDM class with a value and an instance variable showed as UML attributes.

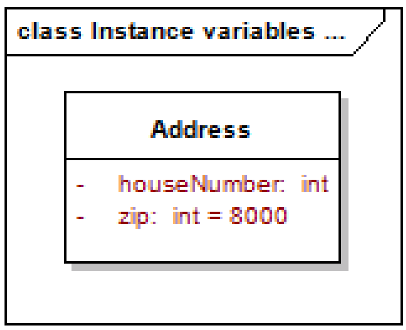


Figure 4.3: UML attributes.

4.5 Union Types

A union type is a union of values from different types [Fitzgerald&05, p74]. Listing 4.4 shows an example of a `Person` that may be either male, female or **`bool`**[1], as indicated by the union `gender`.

> **Transformation Rule 9**
> A union type is mapped as the meta-class `Association` between the owning class and the types specified in the union type. The resulting associations are decorated with a textual constraint {`xor`}. The constraint is an instance of the meta-class `Constraint`. Notice, that if a member of a union type is a *basic type*, it is mapped as a separate UML class. This is an exception to rule 6

Listing 4.4 shows a VDM classes `Person`, `Female` and `Male`. The instance variable `gender` is mapped as three associations each connecting `Person` to one of the possibilities of `gender`. The textual constraint {`xor`} spanning all associations will allow only one possibility to be chosen.

```
class Person
instance variables
  name : seq of char;
  age : nat;
  gender : Male | Female | bool;
end Person

class Male
end Male
class Female
end Female
```

Listing 4.4: Person with a union type on gender, Female, Male or **`bool`**.

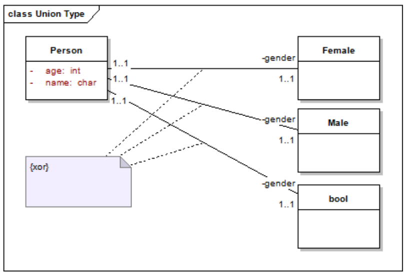


Figure 4.4: A textual constraint {`xor`} spanning three associations.

4.6 Product Types

A product type is a composite structure, which consists of tuples of values. Listing 4.5 shows three uses of product type and Figure 4.5 shows the UML counterpart: A product type declared as a data type will result in subfigure 4.5a. A product type declaration with more expressive power when visualized in UML is the VDM instance variable `addressWork` and `addressBook` of Listing 4.5, which result in subfigures 4.5b and 4.5c: a n-ary `Association` which makes it possible to have multiple participants in an association. Note that part **`set of`** `Name` in line 8 of Listing 4.5 is shown as the multiplicity of `0..*` in Figure 4.5c.

[1]For the sake of argument, a `Person` may be regarded `false` if the gender is indefinable.

```
class Person
types
Address = City * County * Street;

instance variables
addressHome : Address;
addressWork : City * County * Street;
addressBook : City * County * set of Name * Street;
age         : nat;
name        : Name;

end Person
```

Listing 4.5: Example of a Person where a product type are used to model the `addressWork` and `addressBook`. The `addressHome` is declared from a explicit type.

> **Transformation Rule 10**
> A VDM product type maps to:
>
> **10 a:** The UML meta-class `Class` if it is declared as a data type. See figure 4.5a.
>
> **10 b:** The UML meta-class `Association` if it is not defined as a type (i.e. it is anonymous). See figure 4.5b and 4.5c.
>
> Each association-end that represents an entry in the product type is named according to the product type. The types constituting the product type are sorted alphabetically according to the name of the types used in the product type.

4.7 Collections

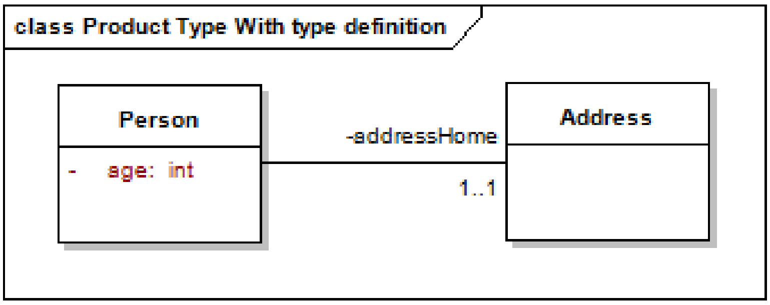
VDM define three constructs to model collections:

`set`: Repetition and order of elements are insignificant, i.e. multiple copies of an element and the order of elements are disregarded.

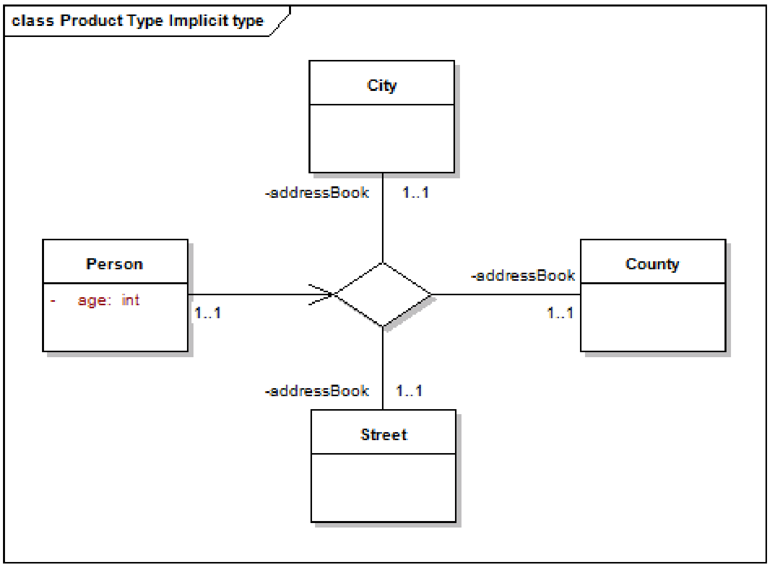
`seq`: Repetition and order of elements are significant, i.e. multiple copies of an element are distinguishable by the order in which they appear.

`seq1`: Equal to **`seq`**, except that an empty sequence is illegal.

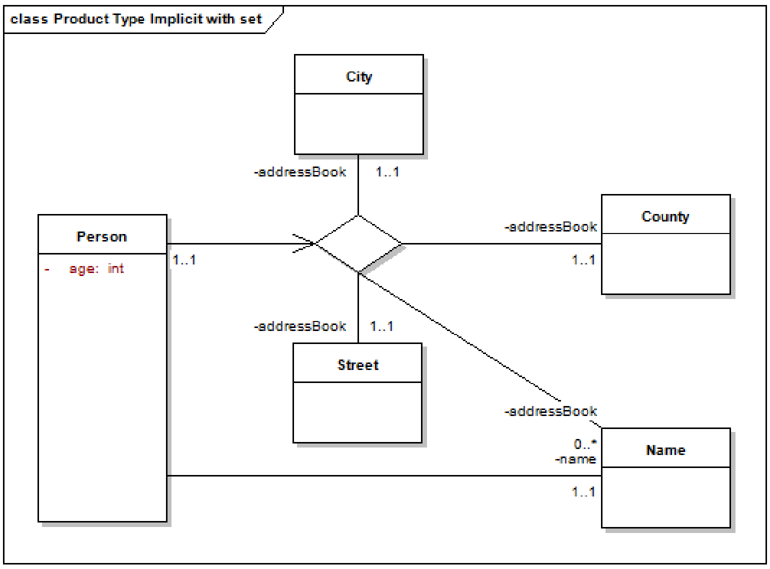
Listing 4.6 shows four VDM classes. Class `Order` models two sequences, `contacts` and `subOrders`, of which the former must contain at least one element. Class `SubOrder` models a set of `Product`. The two sequences, `contacts` and `subOrders`, are mapped as associations between `Order` and `Contact` and `Order` and `SubOrder`, respectively,



(a) VDM product type where the data type is explicitly declared.



(b) VDM product type where the type is implicit.



(c) VDM product type represented in UML where the type is both implicit (`addressBook`) and explicit (`Name`). stated

Figure 4.5: UML representation of constructs from Listing 4.5

as shown in Figure 4.7. The constraint {`ordered`} on the associations indicate that the type is **`seq`** and the different multiplicities further differentiates the types as **`seq`** and **`seq1`**. The set `products` are mapped as an association between classes `SubOrder` and `Product`.

```
class Order
instance variables
  contacts : seq1 of Contact;
  subOrders : seq of SubOrder;
end Order

class Contact
end Contact

class SubOrder
instance variables
  products : set of Product;
end SubOrder

class Product
end Product
```

Listing 4.6: VDM classes with collections.

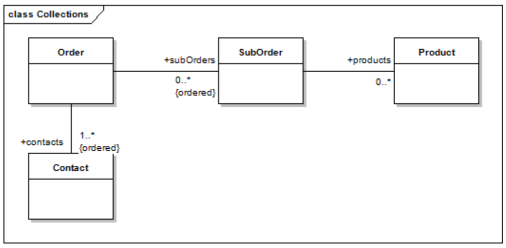


Figure 4.6: UML associations.

Transformation Rule 11

The VDM constructs **`set`**, **`seq`** and **`seq1`** is mapped as the UML meta-class `Association` which may be decorated with a textual constraint defined by the meta-attribute `isOrdered`[2] in addition to a multiplicity at both ends. Table 11 shows how the above-mentioned VDM constructs are mapped.

VDM construct	`Ordered`	Target `Multiplicity-Element`	`IsUnique`
`set`	`false`	`lower=0, upper=*`	`true`
`seq`	`true`	`lower=0, upper=*`	`false`
`seq1`	`true`	`lower=1, upper=*`	`false`

Table 4.2: Transformation rules for VDM constructs modeling collections

[2]The meta-class `Association` has two attributes of type `Property` which are the end of an association. Those ends may be ordered, indicated by meta-attribute `Property::isOrdered`.

4.8 Relationships

The VDM constructs **map** and **inmap** are used to model unique relationships between values of one set, the domain, and another set, the range. The order of elements in the domain and range are insignificant.

map: Denotes the type of all finite mappings between values of the domain and range. The relationship between values of the domain and range is many-to-one, i.e. one or more values of the domain map to exactly one value of the range.

inmap: Denotes the injective version of the first, i.e. a one-to-one relationship one value from the domain map uniquely to one value in the range.

```
class Order

instance variables

private charMap: map nat to char;
public products: map nat to Product;
public barcodes: inmap char to
                   seq of Barcode;

end Order

class Product
end Product
class Barcode
end Barcode
```

Listing 4.7: VDM class with a map showing a UML qualified association.

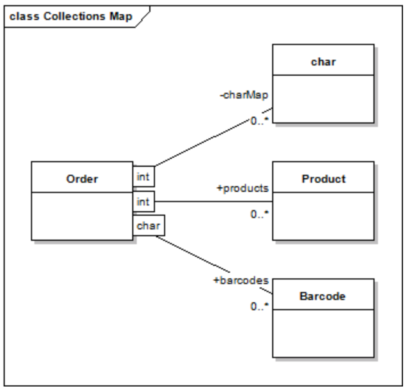
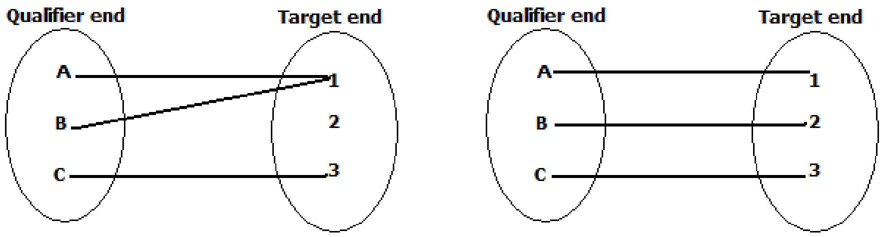


Figure 4.7: Qualified Associations with the qualifiers as `int` and `char`.

Listing 4.7 shows a VDM class `Order` with three mappings. Figure 4.8 shows that all ranges are mapped as separate classes, regardless of their type. In the case of `charMap`, this is an exception to rule 6. Observe that **nat** is mapped as `int`.



(a) Links from Qualifier end are not unique, Both links from A and B targets 1.

(b) Links from Qualifier end are unique, only a single link is allowed from a instance from left to right.

Figure 4.8: The unique property is used to distinguish **map** from **imap**. Additional information can be found on page 148.

Transformation Rule 12

The VDM constructs **map** and **inmap** are mapped as the UML meta-class `Association` with a qualifier. The domain is specified by the qualifier, which is located at the source class. The range is specified by the target class. Notice, that if the range is specified by a *basic type* it is mapped as a separate class. This is an exception to rule 6.

VDM construct	Qualifier end `isUnique`	Target class end `isUnique`
map	`false`	`true`
inmap	`true`	`true`

Table 4.3: Transformation rules for VDM constructs modeling relationships between two sets. See figure 4.8

4.9 Thread

A VDM class with a **thread** block has an independent thread of control. It corresponds to an active class in UML.

```
class SensorController
thread
while true do
  skip;
end SensorController
```

Listing 4.8: A VDM class with a thread definition.

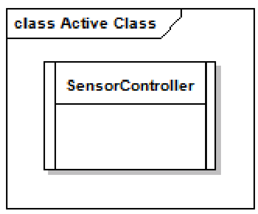


Figure 4.9: A UML Active class.

Listing 4.8 shows a VDM class with a thread section, which is mapped as a UML active class, as shown in Figure 4.9.

> **Transformation Rule 13**
> A VDM class with a **`thread`** compartment is mapped as the UML meta-class `Class` with the meta-attribute `isActive` set to `true`.

4.10 Generalization

A VDM class may inherit several classes using the keyword **`is subclass of`**. It is possible to model generalization in UML, including the notion of multiple inheritance.

```
class AmphibiousVehicle
    is subclass of Vechile,
                   MaritimeVessel

end AmphibiousVehicle

class Vechile
end Vechile

class MaritimeVessel
end MaritimeVessel
```

Listing 4.9: VDM class with an inheritance.

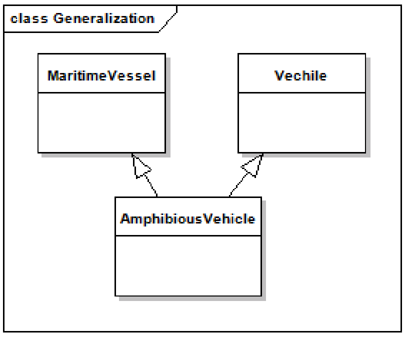


Figure 4.10: Multiple inheritance in UML.

Listing 4.9 shows a VDM class `AmphibiousVehicle` that inherits two other classes, `Vehicle` and `MaritimeVessel`. The three classes are mapped as UML classes with generalization arrows indicating the inheritance relationship between `AmphibiousVehicle` and the two other base classes.

> **Transformation Rule 14**
> A VDM class with the keyword **`is subclass of`** followed by class-names is mapped as the UML meta-class `Generalization`, with the attributes `general` and `specific` referencing the superclass and subclass, respectively. More than one subclass results in more than one instance of `Generalization`.

4.11 Abstract

A VDM class may delegate function or operation definitions to subclasses, in which case the class is abstract. An UML abstract class is distinguished from a conventional class by an italicized name.

```
class AbstractSensor
operations

public GetValue : () ==> ()
GetValue() ==
  is subclass responsibility;

end AbstractSensor
```

Listing 4.10: VDM class with an operation that is subclass responsibility.

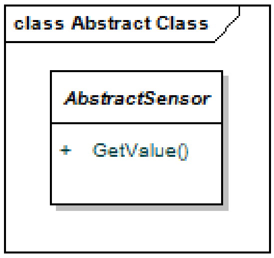


Figure 4.11: A UML Abstract class has an italicized name.

Listing 4.10 shows a VDM class `AbstractSensor` with an operation that delegates its responsibility to a subclass. `AbstractSensor` is mapped as an UML abstract class, as shown in Figure 4.11 by the italicized name of the class.

> **Transformation Rule 15**
> A VDM class with the keyword **`is subclass responsibility`** as a function or operation body is mapped as the UML meta-class `Class` with the meta-attribute `isAbstract` set to `true`.

4.12 Generic classes

VDM generic classes has one or more unbound parameters. Currently this is only defined in the OML AST used in the Overture parser. There is not a complete integration of VDM generic parameters and thereby no type check or interpreter functionality available to support this feature at the moment.

```
class List <[T1, T2]>
operations

Add : T1 ==> ()
Add(t) == skip;

Compare : T1 * T2 ==> bool
Compare(t1,t2) == return true;

Remove : T1 ==> ()
Remove(t1) == skip;

end List
```

Listing 4.11: A VDM class with template parameters. Only supported in Overture.

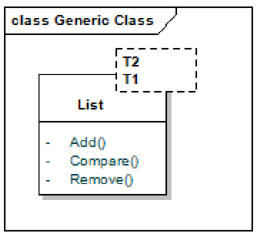


Figure 4.12: A List with template parameters.

Listing 4.11 shows a VDM class `List` with two template parameters `T1` and `T2` (`<[T1, T2]>`). The class `List` is mapped as a UML class with the two template parameters enclosed in the dotted rectangle in the upper right corner in figure 4.12.

> **Transformation Rule 16**
> A VDM generic class maps to the UML meta-class `Class` with the attribute `templateSignature` referencing a set of `TemplateParameter` having the name property set to the name of the parameter.

4.13 Operations and Functions

A VDM function or operation can be transformed into the UML meta-class `Operation`. A function does not change the internal state of the owning class, as opposed to an operation which may change the internal state of the owning class. Both functions and operations can take parameters as input and return one value as their output.

```
class Sensor
operations
public getValue : () ==> int
getValue() == return 1;

public setId : int ==> ()
setId(id) == skip;

end Sensor
```

Listing 4.12: A VDM class with two operations.

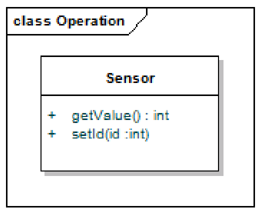


Figure 4.13: Sensor with two operations. The `isQuery` property is hidden.

Listing 4.12 shows a VDM class `Sensor` with two operations `getValue` with a return parameter **`int`** and `setId` with a parameter `id` of the type **`int`**. The operations are mapped to a UML class shown in figure 4.13 the property `isQuery` is not visible which is the property differencing a operation from a function.

Transformation Rule 17
A VDM operation and function are mapped to the UML meta-class `Operation` where the property `isQuery` determine whether the `Operation` represents a VDM function or operation:

- **`true`** for a function.
- **`false`** for a operation.

The return type of a function and operation is mapped collectively as the property `type` and the multiplicity[3]of the `Operation` meta-class. The parameters of the operation or function is mapped to the UML meta-class `Parameter` represented as the property `ownedParameters` of the `Operation` meta-class.
The name and type of a VDM parameter are mapped to the property `name`, `type` and the multiplicity[3] of the `Parameter` meta-class.

[3]The multiplicity consists of the properties `isOrdered`,`isUnique`,`lower` and `upper`.

Chapter 5

Static Model Specification

This chapter describes how the transformation rules from chapter 4 are turned into a VDM model. The chapter begins with an overview of the structure of the static model transformation. The Abstract Syntax Tree (AST) of UML and related tools are presented along with a description of how the specification enables a transformation from a VDM model to a UML model and vice versa. This is followed by a description of how to merge an abstract VDM and UML model without information loss.

5.1 Abstract Syntax Tree

An AST is an abstract structure which contains only core information, i.e. the VDM AST do not contain keywords or tokens used in the concrete syntax. The reason is that the concept of an instance variable is defined as a node in the tree, hence the member declaration group **`instance variables`** do not provide extra information.

The UML AST is inspired from the OML AST (the AST for VDM by Overture), and as such it consist of VDML-SL type definitions for each UML meta-class. Both the OML and UML AST can be populated with data originating from source files containing concrete information. For example, the OML AST can be populated using the Oml Parser, as shown in Figure 5.4, which parses VDM class files and returns the OML AST with a specification of the total model. The UML AST can be populated in an similar way by parsing a UML Model file (XMI).

5.1.1 AST definition to VDM class structure (ASTGen)

Using the types of an AST in a VDM model requires information about the structure of the AST in order to convert collections of type definitions into classes. The classes can subsequently be instantiated and populated with concrete information. The Overture tool ASTGen enables the transformation of a collection of type definitions into a class structure. It also generates a visitor pattern and creates Java interfaces that correspond to the abstract VDM classes used in the visitor pattern. The implementation of the visitor pattern makes it possible to add functionality to visit the AST by adding a virtual function to the classes in the AST. The tree can then be visited without changing the AST, just by the use of a reference to the AST [VisitorPattern]. The Java interfaces provides the ability to implement the instantiated AST directly into Java code. The tool works by taking a type specification as input in addition to information like a prefix and a output location also are provided.

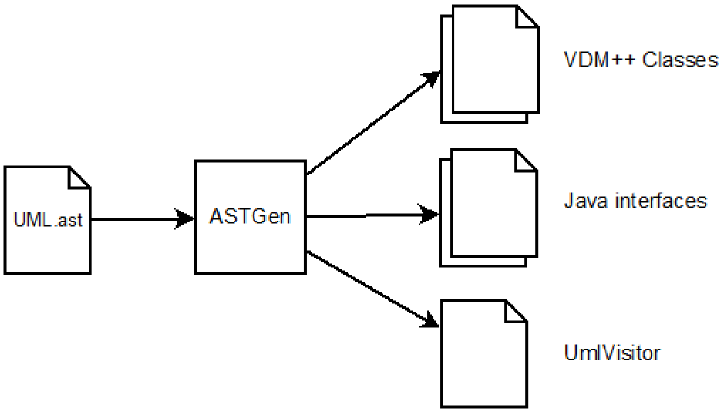


Figure 5.1: ASTGen with UML.ast as input.

ASTGen takes an AST file as input containing the AST for a language. For each type specified in the AST, e.g. `B` from listing 5.1, ASTGen produces the following:

Two VDM classes: One abstract class and one implementation of the abstract class per type definition: `IUmlA`, `IUmlB`, `IUmlC` with get and set operations for instance variables, `UmlA`, `IUmlB` and `UmlC` which inherits the corresponding `IUML` class and holds instance variables.

One Java interface: Corresponding to the abstract class mentioned above.

A visitor: An implementation of the Visitor pattern for visiting the each kind of node in the AST.

Listing 5.1 shows the AST type definitions. This definition defines `A`, `B` and `C` where `B` contains a name. All definitions are listed as VDM-SL type definitions. In the top of the file additional information for ASTGen such as prefixing and output location is located in addition to a package name and root node. Inheritance is generated from the union operator |. In this case `A = B | C` will be equivalent to `B` and `C` inheriting `A`.

```
%prefix Uml;
%package org.overturetool.uml.ast;
%directory "C:\tmp";
%top A;
A = B | C;
B ::
  name : seq of char;
C ::
```

Listing 5.1: AST definition used as input for ASTGen.

In Listing 5.2 the VDM interface class prefixed with `IUML` is shown which is similar to the Java interface also generated.

```
class IUmlB
 is subclass of IUmlA

operations
  public getName: () ==> seq of char
  getName() == is subclass responsibility;

end IUmlB
```

Listing 5.2: The VDM `TemplateParameter` interface class derived from the type defined in listing 5.1.

```
class UmlB is subclass of IUmlB
operations
  public identity: () ==> seq of char
  identity () == return "B";

  public accept: IUmlVisitor ==> ()
  accept (pVisitor) == pVisitor.visitB(self);
...
instance variables
  private ivName : seq of char := []

operations
  public getName: () ==> seq of char
  getName() == return ivName;

  public setName: seq of char ==> ()
  setName(parg) == ivName := parg;

end UmlB
```

Listing 5.3: The implementation of `B` defined in listing 5.1.

In Listing 5.3 the implementation class of the `B` type definition from listing 5.1 is shown. This class can be used in a specification. Additional to the interface and implementation classes a visitor is generated at the VDM level.

ASTGen is limited by the Java language since it has to create Java interfaces for each type definition. As a result of the close bounding to Java ASTGen is limited to single inheritance. It is possible to specify multiple inheritance as shown in 5.4. Figure 5.2 shows how the types definitions from Listing 5.4 results in multiple inheritance which ASTGen cannot resolve, since it violates the Java language specification.

```
A = B | C;
D = B | E;
B ::
  name : seq of char;
C ::;
E ::
```

Listing 5.4: AST definition with multiple definition. Not supported by ASTGen.

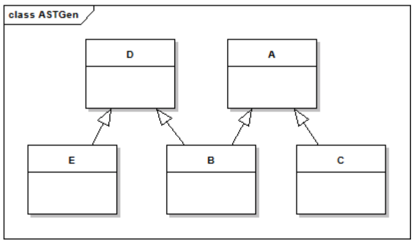


Figure 5.2: Shows multiple inheritance. `B` inherits `D` and `A`.

5.1.2 OML AST

The AST for VDM is already made and is available as a part of the Overture project [Overture07]. The abstract syntax is named Overture Modeling Language (OML) and it is specified as type definitions in VDM-SL, as shown in Listing 5.5. The entire AST can be found in Appendix G. The type definitions in the OML AST can be converted to VDM++ classes, VDM++ interface classes and Java interfaces using ASTGen as explained in section 5.1.1 above. The resulting VDM++ classes can be used when modeling in VDM++. The `Specifications` is the root node and it contains a sequence of classes which is specified as the next node. The node `Class` consists of new nodes specified further down in the OML AST.

```
Specifications ::
  class_list : seq of Class;

Class ::
  identifier : Identifier
  generic_types: seq of Type
  inheritance_clause : [InheritanceClause]
  class_body : seq of DefinitionBlock
  system_spec : bool;

InheritanceClause ::
  identifier_list : seq of Identifier;

DefinitionBlock =
  TypeDefinitions |
  ValueDefinitions |
  FunctionDefinitions |
  OperationDefinitions |
  InstanceVariableDefinitions |
```

Listing 5.5: Abstract syntax of VDM. Overture Modeling Language (OML).

5.1.3 UML AST

The UML AST is inspired by the OML AST and constructed from the UML specification [UMLInfrastructure2.1.2, UMLSuperstructure2.1.2], hence it is a flat tree structure with a root node, comparable to the `Specifications` node of the OML AST from Listing 5.5. The UML AST is modeled as VDM-SL type definitions to enable automatic model-generation using the tool ASTGen as explained in section 5.1.1. The type definitions are consistent with definitions from the UML Superstructure Specification (USS) [UMLSuperstructure2.1.2] and UML Infrastructure Specification [UMLInfrastructure2.1.2] (UIS), which makes intensive use of multiple inheritance that is not supported by ASTGen as explained in section 5.1.1. To change the structure into single inheritance some of the abstrace meta classes e.g. `Classifier` of the USS and UIS has been replaced by a specific class representing the classifier (`Classifier` is an abstract base class of `Class`).

Figure 5.3 shows a condensed class diagram from the UIS. The excerpt show the connections between the UML meta-classes which is used in the UML AST e.g. `Class`, `Operation`, `Property` etc. as explained on page 150.

The UML AST is constructed from the meta-classes needed in a class diagram. This means that nodes like: classes, operations, properties, associations, constraints etc. are considered as nodes in the UML AST. They all have a corresponding meta-class in the USS and UIS. In Listing 5.6 an example is given of the top level of the AST. The root

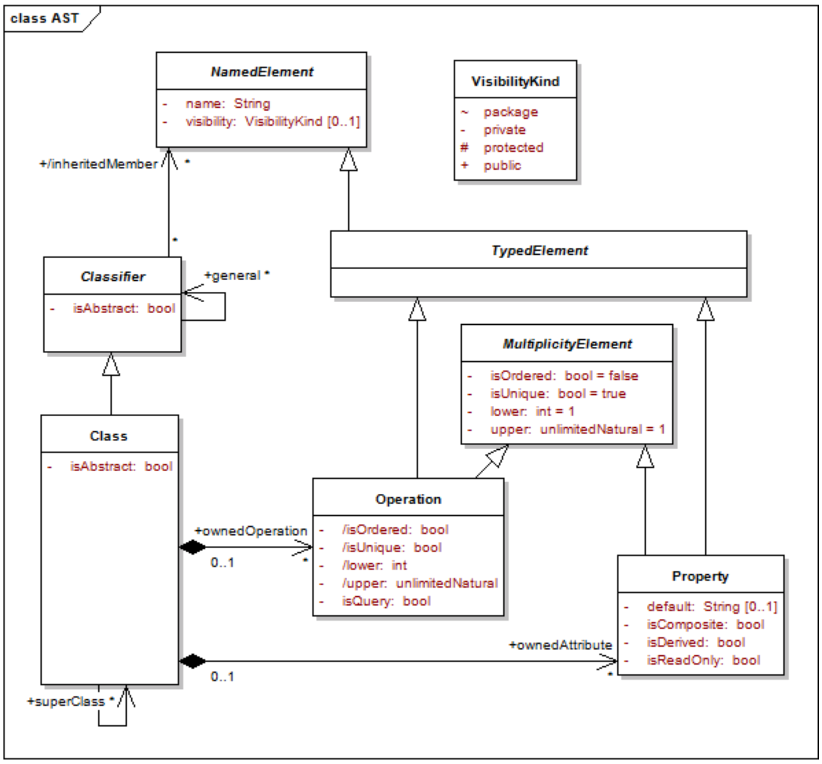


Figure 5.3: UML infrastructure class diagram.

node named `Model` is specified and it consists of a name and a set of definitions which is represented by model elements such as `Class`, `Association` etc.

```
Model ::
 name : String
 definitions : set of ModelElement;

ModelElement = Class | Association |
               Constraint | Collaboration;
```

Listing 5.6: UML toplevel AST

The complete UML AST is specified in appendix E along with a description that states where each node in the UML AST complies with the USS and UIS.

5.2 Transformation Specification Overview

From a users point-of-view, the model transformation between VDM and UML occurs on the concrete syntaxes. A common approach when working with constructs in a computer-based language, is to use an AST which definne the abstract syntax (i.e.

without tokens etc.). ASTs are often used when writing compilers, because it provides an easy way of accessing different constructs in a language [ASTFromWikipedia]. In the case of UML, an AST reduced the amount of information because the concrete syntax is presented in XML, which produces a lot of overhead. The UML AST defined as part of this thesis work can be found in Appendix E. The OML AST is located in Appendix G. The transformation rules specifying how to apply a transformation between the two ASTs are defined in chapter 4.

5.3 The Transformation Process

This section presents the transformation process that can be applied to a VDM and UML model. Figure 5.4 gives an overview of the steps involved when applying a transformation. The figure is supplemented with a walk-through for each transformation direction: (1) Transforming VDM to UML and (2) Transforming UML to VDM.

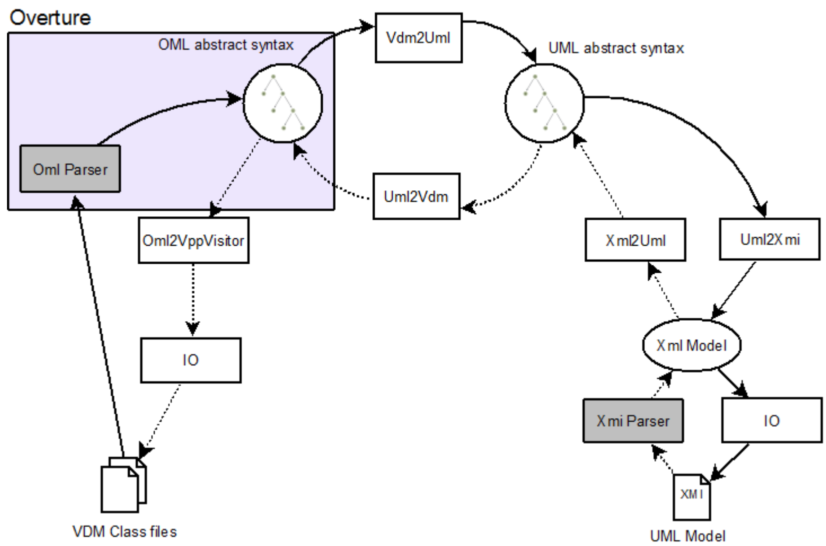


Figure 5.4: Overview of components involved in the transformation process.

In Figure 5.4 The solid lines show how a transformation from VDM to UML is carried out. The dotted line shows how an UML model (stored in an XMI file) is transformed into VDM class files. The rectangular shapes indicate processing and the round shapes indicates a processing result. The grey rectangular shapes indicate components written in Java. All other rectangular shapes indicate components written in VDM.

The transformation from VDM to UML consists of the following steps. Each step is supplemented with a note describing the status immediately after the step:

Step 1 (Oml Parser): The VDM classes are parsed using the OML Parser to a VDM abstract syntax, i.e. the parser populates the OML AST.

- *Status:* An OML AST existed before this thesis work started. It is comparable to the UML AST, thus making it possible to compare or transform between the two.

Step 2 (Vdm2Uml): The OML AST is transformed into an UML abstract syntax using the **Vdm2Uml** specification (which is consistent with the transformation rules from chapter 4).

- *Status:* The UML abstract syntax is ready to be transformed to a XML structure.

Step 3 (Uml2Xmi): The UML abstract syntax is transformed into a XML structure using the **Uml2Xmi** specification[1].

- *Status:* The XML data required to produce valid XMI is completed.

Step 4 (IO): The XML data is processed and output is a XML document formatted to comply with the rules for valid XMI structure.

- *Status:* The XML document which can be imported to a UML 2 and XMI 2.1 compliant tool.

The transformation of an UML model to VDM class files is shown in Figure 5.4 as dotted arrows. The following steps explains what happens.

Step 1 (Xmi Parser): The XMI file representing the UML model is transformed into a corresponding XML document (**Xml Model**).

- *Status:* The XML data representing the UML model is ready to be transformed to UML abstract syntax.

Step 2 (Xml2Uml): The XML data is transformed into UML abstract syntax, i.e. the UML AST is populated.

- *Status:* A UML abstract syntax exist, which is comparable to the VDM abstract syntax.

Step 3 (Uml2Vdm): The UML abstract syntax is transformed into a VDM abstract syntax using **Uml2Vdm**[2].

- *Status:* The VDM abstract syntax is ready to be visited by Oml2VppVisitor.

Step 4 (Oml2VppVisitor): Every construct of the VDM abstract syntax is visited by Oml2VppVisitor, which outputs a VDM class file equivalent to the UML model[3].

- *Status:* A VDM class file equivalent to the UML model has been produced.

[1]If modeling tools require the XML file to be tool specific this component needs to change and if one wants to be able to produce different XMI for different UML tools it would be done here.

[2]Only basic constructs are transformed.

[3]Only the VDM constructs supported by the transformation in this thesis work.

5.4 Transforming VDM to UML

The transformation of an abstract VDM model into a corresponding abstract UML model is modeled in the class **Vdm2Uml** and based on the transformation rules from chapter 4. **Vdm2Uml** is called with an `OmlSpecification` which is the root in the AST for VDM. It then walks down the tree and gathers information used to create a `UmlModel` which is the root of the UML AST.

The interesting part in the transformation of a OML class is the *class_body* which can consist of multiple definition blocks, e.g. **`types`**, **`values`**, **`instance variables`**, **`functions`**, **`operations`** and **`thread`** as shown on page 71. All these definition blocks have to be treated individually since they require a specific transformation, based on their type. The `ValueDefinitions` and `InstanceVariableDefinitions` have the most significant impact on the visual part of the static structure, since they present properties and associations that is directly visible in a class diagram. Both blocks are transformed into UML properties of the corresponding classes or associations according to rule 6 and rule 5.

The main path through the `OmlSpecification` is first to find all classes that can be mapped to UML Classes. When a class is found, it is transformed into a UML class using the transformation rules from chapter 4. The values and instance variables of the class are transformed into a corresponding structures in UML. When an `InstanceVariable-Definitions` of a data type is found in the body of an OML class, the definition is transformed into a UML property. The created property will be associated with the owning class as an attribute according to rule 6 on page 56. When an instance variable is a class reference type it is transformed into an association, according to rule 5 on page 55. See Figure 5.5 for an overview of the operations involved in the transformation of a class.

If the instance variable or value represents a product type, union type or map type, the created property needs additional transformation according to rule 10 on page 58, rule 9 on page 57 and rule 12 on page 62. Instead of being transformed into a property of the class, they are transformed into associations. An example is the union type explained in rule 9 on page 57. The union type is a composite type, which can be one of two types specified in the union, which means that apart from creating the association additional information needs to be added to the UML model to ensure that only one of the specified parts in a union type can exist at the time.

```
1  public init : IOmlSpecifications ==> IUmlModel
2  init(specs) ==
3  ( let model = build_uml(specs)
4    in
5    ( model.setDefinitions(model.getDefinitions()
6             union associations
7             union constraints);
8      return model;
9    );
10 );
```

Listing 5.7: Vdm2Uml init operation.

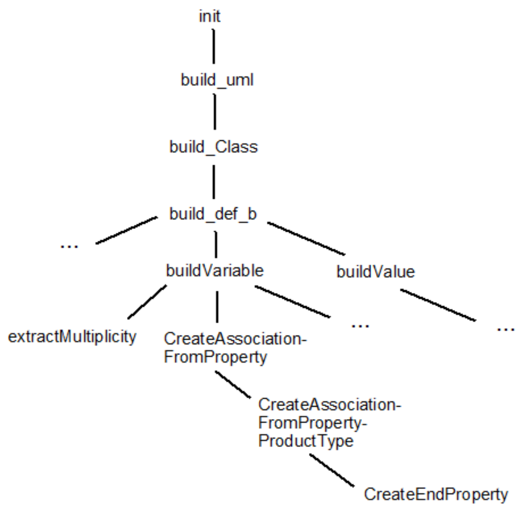


Figure 5.5: Overview operations/ functions involved the transformation.

The top level of the transformation specified in the `Vdm2Uml` class is shown in Listing 5.7 and its hierarchy position is shown in Figure 5.5. The steps involved in the transformation are described below:

- First, the `build_uml` operation jumps one level down in the tree to construct the classes.

- Each class is constructed by `build_Class`, which again jumps one level down to construct the body of each class. When constructing the body of the classes all associations are deduced from instance variables and values definitions.

- The instance variables, `association` and `constraints` shown in line 6 and 7, are populated from `buildVariable` (**`instance variables`**) and `buildValue` (**`values`**) seen in Figure 5.5. The caller of this operation is the `build_Class` operation.

After the creation of all classes from the OML specification, a UML model is created from the UML classes and the associations created from values and instance variables from the OML specification along with the constraints found from union types.

```
Class ::
  identifier         : Identifier
  generic_types      : seq of Type
  inheritance_clause : [InheritanceClause]
  class_body         : seq of DefinitionBlock
  system_spec        : bool;
```

Listing 5.8: Abstract syntax of an OML class.

```
Class ::
  name        : String
  classBody   : set of DefinitionBlock
  isAbstract  : bool
  superClass  : seq of ClassNameType
  visibility  : VisibilityKind
  isStatic    : bool
  isActive    : bool
  templatesignature : [TemplateSignature];
```

Listing 5.9: Abstract syntax of an UML class.

In Listing 5.8 and 5.9, the OML and UML representation of a class is shown. This is the first node that needs to be transformed. By the use of rule 1 on page 53 the class can be transformed into an UML class. Since all classes in VDM exists as public classes the corresponding UML class will have its visibility set to public.

- **Class name**: The name of the UML class can be extracted from the OML class identifier and the super classes for a UML class can be deduced from the inheritance clause.
- **Abstract or Active**: To deduce if a class should be mapped as abstract or active it is necessary to look inside the body definition of the OML class, if an operation is delegated to a subclass, it is an abstract class or if a thread definition exists the class is mapped as an active class.

```
1  public build_Class : IOmlClass ==> IUmlClass
2  build_Class(c) ==
3    let name       = c.getIdentifier(),
4        inh : [IOmlInheritanceClause]  = if c.hasInheritanceClause()
5                                         then c.getInheritanceClause()
6                                         else nil,
7        body       = c.getClassBody(),
8        isStatic   = false,
9        isActive   = card {body(i)
10                          | i in set inds body
11                          & isofclass(IOmlThreadDefinition,body(i))}
12                          > 0,
13       dBlock     = [ let dbs : IOmlDefinitionBlock =
14                        body(i) in build_def_b(dbs,name)
15                      | i in set inds body],
16       dBlockSet  = { d | d in set elems dBlock & d <> nil},
17       isAbstract = hasSubclassResponsibilityDefinition(body),
18       supers     = getSuperClasses(inh),
19       visibility =
20         new UmlVisibilityKind(UmlVisibilityKindQuotes`IQPUBLIC),
21       templateParameters = getGenericTypes(c.getGenericTypes())
22   in
23     return new UmlClass(name,
24                         dBlockSet,
25                         isAbstract,
26                         supers,
27                         visibility,
28                         isStatic,
29                         isActive,
30                         templateParameters);
```

Listing 5.10: Vdm2Uml operation for constructing an UML class.

The `build_Class` operation shown in listing 5.10 is called from the `init` operation with all the classes found in the OML specification. The `init` operation is the entry point at the transformation. The operation builds a `UmlClass` from a `OmlClass`. The interesting part is how the body of the OML class contributes to the UML class. The UML class is declared *active* if a thread definition is found in the body of the OML class at line 9, and *abstract* if an operation is found that is subclass responsibility at line 15. To construct the attributes of the class the values and instance variables definitions are handled in line 11. The `buildVariable` operation is shown in Listing 5.11. This operation is responsible for the transformation of instance variables and is called indirectly[4] from `build_Class` shown in figure 5.5.

[4] The creation of instance variables are indirectly called through `build_def_b` which is a utility function required by the code generator. The `build_def_b` redirects the call to `buildVariable`.

```
public buildVariable : IOmlInstanceVariable * String ==> [IUmlProperty]
buildVariable(var,owner) ==
  let
    access       = var.getAccess(),
    scope        = access.getScope(),
    assign       = var.getAssignmentDefinition(),
    isStatic     = access.getStaticAccess(),
    name         = assign.getIdentifier(),
    visibility   = convertScopeToVisibility(scope),
    omlType      = assign.getType(),
    multiplicity = Vdm2UmlType`extractMultiplicity(omlType),
    type         = Vdm2UmlType`convertPropertyType(omlType,owner),
    isReadOnly   = false,
    default : [String]= if assign.hasExpression()
                        then getDefaultValue(assign.getExpression())
                        else nil,
    isComposite  = false,
    isDerived    = false,
    qualifier : [IUmlType] = Vdm2UmlType`getQualifier(omlType)
  in
  ( ...
    if not isSimpleType(omlType)
    then
    (
       CreateAssociationFromProperty(property,omlType);
       return nil
     )
    else return property; );
```

Listing 5.11: Creates a property from an instance variable or an association depending on the type of the instance variable.

When a property is constructed, the OML type of the property decides whether it should be inserted into the UML model as an attribute of the owning class, or as an association-end of an association. The decision is based on rule 5 on page 55. This means that types like `class`, `maps`, `union types` and `product types` are all mapped as associations. If a property is of one of the abovementioned types, is must map as an association. Depending on the type of the property, the operation `CreateAssociationFromProperty` is called with the property and the original OML type:

- **Product Type**: `CreateAssociationFromPropertyProductType`
- **Union Type**: `CreateAssociationFromPropertyUnionType`
- **All other types**: `CreateAssociationFromPropertyGeneral`

When an instance variable of a product type is discovered it must be converted into an association. This causes the `CreateAssociationFromProperty` to delegate the construction to `CreateAssociationFromPropertyProductType` (see listing 5.12). Here, an association is created and stored in the `Vdm2Uml` class.

```
public CreateAssociationFromPropertyProductType:
  IUmlProperty * IOmlType ==> ()
CreateAssociationFromPropertyProductType(property,omlType) ==
let name : String = property.getName() ,
    prop : UmlProperty = property
    props : set of IUmlProperty =
                  dunion {CreateEndProperty(p,name)
                         | p in set {omlType}
                         & isofclass(IOmlProductType,p)}
  in
  ( prop.setName("");
    if card props > 1 then
      associations := associations union
        {new UmlAssociation(props, {prop},nil,GetNextId())};  );
```

Listing 5.12: Create an association from a Product type.

The association is constructed according to rule 10 on page 58 where each part of the product type is represented as an end in the association. To achieve this, the product type and the property (instance variable) name are passed to `CreateEndProperty` (see listing 5.13).

	Left type	Right type	
		ProductType2	
		Left type	right type
ProductType1	A *	B *	C

Table 5.1: Product type constructed of three types.

```
1  public CreateEndProperty : IOmlType * String ==> set of IUmlProperty
2  CreateEndProperty(t,name) ==
3  (
4    if (isofclass(IOmlProductType,t)) then
5    (
6      let typedType : IOmlProductType = t
7      in
8      return CreateEndProperty(typedType.getLhsType(),name)
9        union CreateEndProperty(typedType.getRhsType(),name);
10   )
11   else if (isofclass(IOmlUnionType,t)) then
12   (
13     let typedType : IOmlUnionType = t
14     in
15     return CreateEndProperty(typedType.getLhsType(),name)
16       union CreateEndProperty(typedType.getRhsType(),name);
17   )
18   else
19     return {new UmlProperty(name,
20                 new UmlVisibilityKind(
21                       UmlVisibilityKindQuotes`IQPRIVATE),
22                 Vdm2UmlType`extractMultiplicity(t),
23                 Vdm2UmlType`convertType(t),
24                 ...
25                 Vdm2UmlType`getQualifier(t))};  );
```

Listing 5.13: Create association ends property from a OML type.

The construction of association-end properties for both product and union types are shown in Listing 5.13. The operation `CreateEndProperty` is recursive in the sense that it keeps calling itself until it reaches the base case, which is defined such that the `t` at line 6, product type passed to the function is broken down in its left and right side and when it is no longer a product type the operation terminates and returns a new property for each recursion.

An example of such a product type can be seen in Table 5.1. The product type in Table 5.1 is constructed as two product types where the last `ProductType2 = (B * C)` is contained in the first `ProductType1 as (A * ProductType2)`. When this `ProductType1 = A * B * C` is put into `CreateEndProperty` (see listing 5.13) it will recognize the `ProductType1` in the first recursion. `CreateEndProperty` will then first resolve the right type, which again is a product type leading to the first recursion. After this type is resolved to two types `(B * C)` it will create properties from the `B` and `C` type. When returned the properties will be combined with the property created from `ProductType1` left side of the `A` type. The properties are then tied together into an association as non-navigable ends.

The transformation of collections are done by manipulating the multiplicity of the constructed properties. Listing 5.14 shows a snippet of the model setting the multiplicity for **`set`**, **`seq`**, **`seq1`**, **`map`** and **`imap`**. The multiplicity element is set according to rule 11 on page 60.

```
cases true:
  (isofclass(IOmlSetType,t))->
    (lower := 0 ; upper := nil ; isOrdered := false),
  (isofclass(IOmlSeq0Type,t))->
    (lower :=0 ; upper := nil ; isOrdered := true; isUnique := false),
  (isofclass(IOmlSeq1Type,t))->
    (lower := 1 ; upper := nil ; isOrdered := true; isUnique := false),
  (isofclass(IOmlGeneralMapType,t)),
  (isofclass(IOmlInjectiveMapType,t))->
    (lower := 0; upper := nil ; isOrdered := true ; isUnique := false),
  (isofclass(IOmlOptionalType,t))->
    (upper := 1 ; lower := 0)
end;
```

Listing 5.14: Setting multiplicity of properties.

Listing 5.14 shows an example of extracting the multiplicity. A **`set`** results in a multiplicity with no upper limit and a lower limit of zero. There are no ordering and all elements are unique, which corresponds to `isUnique=false`.

5.5 UML Model to XMI

To transform the UML AST into the XML Metadata Interchange (XMI)[5] an abstract model of a XML file has been made named XML API. This is a simple model structure that represents an XML document, where elements can have other elements, attributes and data. This abstract model is then implemented with a visitor pattern that enables easy implementation of a visitor to print the model to a file stream. In addition to this, a parser has been modeled to ease the process of parsing an existing file into this abstract model. The structure of the XML API can be seen in figure 5.6.

[5] OMG standard for exchanging metadata information via Extensible Markup Language (XML) used to serialize UML models to different UML modeling tools.

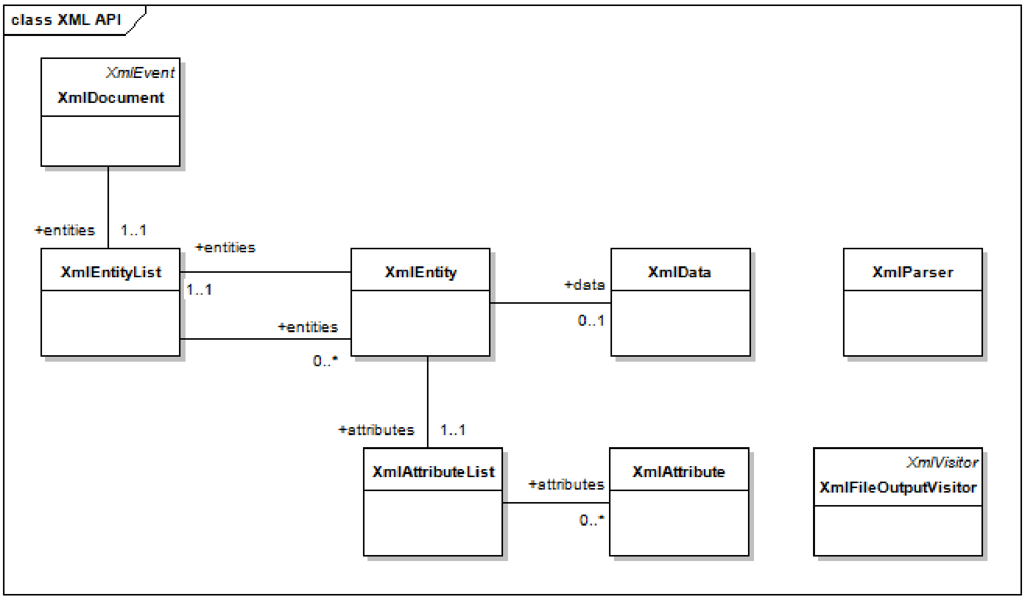


Figure 5.6: Overview of the XML API class structure.

Transforming the UML AST into an XML abstract model is trivial in principle. The only added information is an identifier for each element and the type of the element. The identifiers are used to relate elements such as the type of a property, qualifiers of associations and constraints of an association.

```
1 <xsd:element name="c" type="c"/>
2 <xsd:complexType name="c">
3       <xsd:choice minOccurs="0" maxOccurs="unbounded">
4          <xsd:element ref="xmi:Extension"/>
5       </xsd:choice>
6       <xsd:attribute ref="xmi:id"/>
7       <xsd:attributeGroup ref="xmi:ObjectAttribs"/>
8 </xsd:complexType>
```

Listing 5.15: XML Schema of Class representation in a XMI document specified in MOF.

In Listing 5.15 an XML Schema is shown specifying the rules for inserting a class into a XMI document where `name="c"` is the name of the class and `type="c"` corresponds to the complex type defined at line 2. At line 3-5 the optional `xmi:Extension` is listed. The attribute reference at line 7 indicated that the attributes from `xmi:ObjectAttribs` should be included. The description originates from the MOF XMI specification [MofXmi, p17]. The schema has included both a name space for UML elements and a name space for XMI elements:

- **uml**: http://schema.omg.org/spec/UML/2.0
- **xmi**: http://schema.omg.org/spec/XMI/2.1

```
<xmi:XMI xmlns:UML="http://schema.omg.org/spec/UML/2.0"
                 xmlns:xmi="http://schema.omg.org/spec/XMI/2.1">
  <UML:Class name="C1">
    <feature xmi:type="UML:Attribute" name="a1" visibility="private"/>
  </UML:Class>
</xmi:XMI>
```

Listing 5.16: Class representation in XML specified in MOF.

In Listing 5.16 a single class is inserted into an XMI document by the aid of the schema specified in listing 5.15. The class is named `C1` and has an attribute named `a1` with a private visibility. The same schema for both classes, properties, associations etc. can be applied the nodes specified in the UML AST. Listing 5.17 shows a snippet of the process of converting a UML AST Class into a XMI document. The process of converting the nodes from the UML AST into a XMI document is straightforward.

```
1  protected AddClass : IUmlClass ==> ()
2  AddClass (cl) ==
3  (
4    doc.StartE(oe);
5    doc.StartA("isAbstract", Util`ToStringBool(cl.getIsAbstract()));
6    doc.StartA("isActive",Util`ToStringBool(cl.getIsActive()));
7    doc.StartA("name",cl.getName());
8    doc.StartA("visibility","public");
9    doc.StartA(ID_TAG,classes(cl.getName()));
10   doc.StartA("xmi:type","uml:Class");
11 ...
```

Listing 5.17: Converting an abstract UML class to a XML element.

As seen in Listing 5.17, the different information from the UML AST class is mapped into specific named attributes, e.g. the name of the class in line 7.

5.5.1 XML parser / deparser

To enable a round-trip between a the UML AST and the XMI document a parser need to be introduced along with a deparser to transform an XML document into the UML AST.

- XML parser to populate the abstract model of the XML document.
- XML deparser (`Xml2Uml`) enabling the transformation from the abstract XML document into the UML AST. This is the reverse process of transforming the UML AST to XMI done be `Uml2Xmi`.

5.6 Transforming UML to VDM

Transforming a UML document into a VDM model is the reverse process of VDM to UML. If a transformation from UML to VDM is desired, then all the associations and their constraints have to be converted into values and instance variables so they can be attached the owning class when it is transformed back from a UML class. In Listing 5.18 the initial operation for the UML to VDM transformation process is shown.

```
1  public init : IUmlModel ==> IOmlDocument
2  init(model) ==
3    let
4        associations = { a | a in set model.getDefinitions()
5                           & isofclass(IUmlAssociation,a)},
6        constraints  = { a | a in set model.getDefinitions()
7                           & isofclass(IUmlConstraint,a)}
8    in
9    (
10     extractInstanceVarsFromAssociations(associations,constraints);
11     return new OmlDocument(model.getName(),
12       new OmlSpecifications(build_classes(model)),[]);  );
```

Listing 5.18: Setting multiplicity of properties.

Listing 5.18 shows how the associations and constraints are first extracted from the model definitions. Then all instance variables and values represented as associations are extracted (see line 10) and saved in a local[6] map linking a class name to the instance and value definitions found in the associations. In Figure 5.7 an overview tree is shown of the `Uml2Vdm` class. It lists the placement of the operations and functions described in this section.

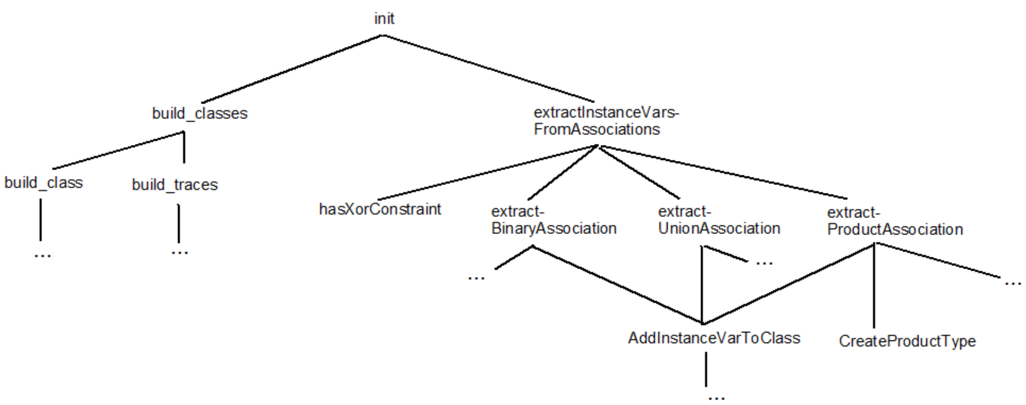


Figure 5.7: Overview of the operations and functions described in this section.

```
public extractInstanceVarsFromAssociations :
  set of IUmlAssociation *
  set of IUmlConstraint ==> ()
extractInstanceVarsFromAssociations(associations,constraints) ==
  let product = -- N-ary association to single product type
```

[6]The local map is not described in this chapter. It is named `classInstanceVars` and further details can be found in Appendix F.

```
6         {a | a in set associations
7            & not hasXorConstraint(constraints,a.getId()) and
8            (card a.getOwnedEnds() +
9             card a.getOwnedNavigableEnds()) > 2},
10  ...
11    in
12    ( ...
13      for all a in set product do
14        extractProductAssociation(a.getOwnedEnds()
15                                     union
16                                     a.getOwnedNavigableEnds());  );
```

Listing 5.19: Extract all associations that represents a product type.

Listing 5.19 shows how an association representing a product type is distinguished from other associations by the fact that it does not have an xor constraint and more than two ends. Such associations must have at least three ends: One for the class owning the product type and at least two others to construct the product type. When a N-ary association is found, the product type is extracted (line 14-16).

```
1  public exstractProductAssociation : set of IUmlProperty ==> ()
2  exstractProductAssociation(props) ==
3  (
4    let ownerEndSet   = {p | p in set props & len p.getName() =0},
5        propSeq       = Util`SetToSeq[IUmlProperty](props),
6        pOwnerEnd     = hd Util`SetToSeq[IUmlProperty](ownerEndSet),
7        pTypeEnd      =  [propSeq(i) | i in set inds propSeq
8                                & len propSeq(i).getName() > 0],
9        clName        = let t : IUmlClassNameType = pOwnerEnd.getType()
10                        in t.getName(),
11       endTypes : seq of IUmlType = Util`SetToSeq[IUmlType]({p.getType()
12                                               | p in set elems pTypeEnd}),
13       type : IOmlType = CreateProductType(endTypes)
14   in
15     AddInstanceVarToClass(clName,CreateInstanceVar(hd pTypeEnd,type));
16 )
17 pre card props > 0;
```

Listing 5.20: Extract the association end that owns the product type, convert the other ends into a product type and store it in a map linked to the owning class.

In listing 5.20 two important things occur: (1) the owner of the product type, the class where the product type should be placed are found and (2) the product type is created from the remaining ends of the association. Only the types of these ends are needed line 11. The product type is created at line 13 and then added to the owning class through a class name to definition map at line 15 through the `CreateProductType` operation. This makes the operation create the final class definition to include the definitions extracted as associations from e.g. product types.

```
1 private CreateProductType : seq of IUmlType ==> IOmlType
2 CreateProductType(tps) ==
3   let first = hd tps,
4       rest  = tl tps,
5       front = ConvertType(first)
6   in
7     if len tps = 1 then
8       return front
9     else
10      return new OmlProductType(front, CreateProductType(rest))
11 pre len tps > 0;
```

Listing 5.21: Create one product type from the types associated with the association ends.

The operation in Listing 5.21 is a recursive function that makes a recursion for each type in `tps`. Each time the head of the list is chopped of (line 3) and the current type is converted to the correct VDM type. If a rest exists (`rest` line 4), it is parsed to the function itself creating a product type of the `rest` (line 10). When done one product type has been created from all the types passed to the operation.

5.7 Merging Changes in VDM and UML Models

Merging a VDM and UML model which both differ, leads to problems such as determining which is the one that overrules the other. In this section the problem of merging will be discussed and a solution will be proposed based on the transformation described earlier in this chapter.

Before a merging process can be completed it is required that the structures that should be merged are comparable. In this case where an abstract model of VDM and UML should be compared, it is required first to bring them on the same form. This leads to the question if the OML AST or UML AST should be used as common base. The UML side would be preferred since the transformation VDM to UML contains most features at the time of writing.

In Figure 5.8 a merging process is shown. The VDM model is transformed into an abstract UML model and then compared with the existing UML model. The result of this comparison is a change log. This change log is a description of what has changed and the last modified date-time. The information leads to an estimate of which direction the classes should be mapped.

A problem occurs, if an operation depends on an instance variable and both change, but in different models, i.e. the instance variable changes in the UML model and the operation changes in the VDM model. This leads to multiple merging problems because the operation is depended on the instance variable. There are two solutions to this issue (1) Search the OML AST and find the operation, decide whether the instance variable is used: if not then merge, if it is possible without any problems. (2) A single class is

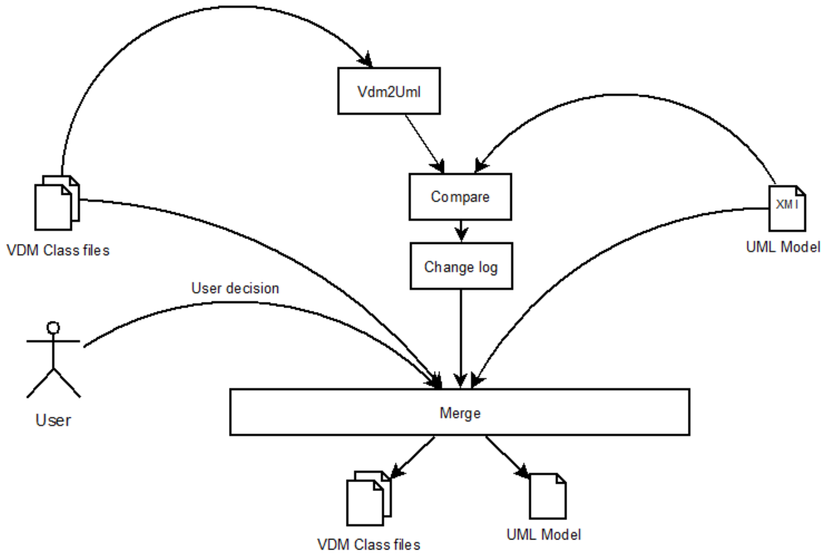


Figure 5.8: Merging a VDM and UML model.

declared changed if any part of it is changed and only complete classes can be merged from one model to another. When the change log is created and the user has decided which classes should be merged in a certain direction, a merge can take place. However, it is important to use the original OML AST when updating the VDM source, because this thesis work only has incorporated a subset of the available VDM constructs. Using the original OML AST avoids information loss. If only the OML AST is updated or parts removed, no information will be lost and the changes from the UML model will be applied to the OML AST. The final part would then be to backup the original files and write the new merged files.

Chapter 6

Interaction Model Transformation

In this section, VDM traces are related to UML 2 Sequence Diagrams (SDs) through model transformation. A significant extension to UML 2 Sequence Diagrams (SD) is the `CombinedFragment` which permit the expression of procedural logic in Sequence Diagrams. It is also possible to nest fragments to an unlimited degree. The expression of procedural logic in UML 1 SDs was possible using labels on messages, stating a condition and/or iteration expression. However, An SD could quickly lose its clarity with too many messages labeled with various conditions and iterations. The `Combined-Fragment`s of UML 2 mitigates the problem by surrounding entire sets of messages and supplying a common continuation predicate. In this chapter a description of how UML Sequence Diagrams (SD) and VDM traces can be combined used in such a way that they presents the same content is given in section 6.1 which illustrates the possible connection. Then rules are formed in chapter 6.2 clarifying how specific constructs can be transformed.

The following uses of SDs in conjunction with VDM traces may be utilized: The Unified Modeling Language 2 (UML) contains a dynamic view SD for presenting a dynamic interaction between objects of a system. A SD consists of `LifeLine`s which presents an instance of a class in the system, `Message`s which presents the interaction between objects, `CombinedFragment` together with `InteractionOperand` and its associated `Constraint` presents a constraint execution of messages. A `Combined-Fragment` is in itself a container as the SD which means that nesting are possible it self two kinds of `CombinedFragment`s are used **`alt`** and **`loop`** see section 2.6.2 for more information. The guard of an `InteractionOperand` the `Constraint` constrains the execution of messages associated with it. Practically, to avoid bloating nesting of SD should be limited to one level only. There by denying nesting of SD inside a `Combined-Fragment`.

The following uses of Sequence Diagrams in conjunction with VDM may be utilized:

Traces generation: VDM test cases may be generated automatically from traces, i.e. compressed representations of test cases. Sequence Diagrams may be utilized to visualize the resulting test cases from a trace.

Model generation: A specific interaction among objects may be specified by a Sequence Diagram and generated the traces part of a VDM model. The interaction among objects may represent a fragment of a model or test cases.

Diagram generation: The interaction of objects of the traces part of a VDM model may be visualized as a Sequence Diagram.

To meet the new traces feature of VDM introduced to enable easy regression testing SDs is regarded as having the greatest value for VDM modelers. By the use of SD both VDM specialists and ordinary software developers with UML experience will be able to specify test cases of a model. By transforming SD into a trace statement a trace can be seen both as a VDM statement or as a visual UML diagram. In this chapter the focus will be to construct rules to enable a transformation between both of them. From the rules round trip would be possible. Thus, this thesis pursues the application of Sequence Diagrams as means for an overview of test cases and the creation of VDM traces from the visual diagram.

6.1 VDM traces and UML sequence diagrams

VDM traces is an advanced way of specifying a sequence of execution (see section 3.6) and from this point of view a UML sequence diagram must be able to show the same execution. In figure 6.1 a SD is shown where the corresponding traces statement is specified in listing 6.1. It can be seen that `Message`s relates to the `MethodApply` Expression in the traces statement and the `LifeLine`s refer to the objects involved in the execution.

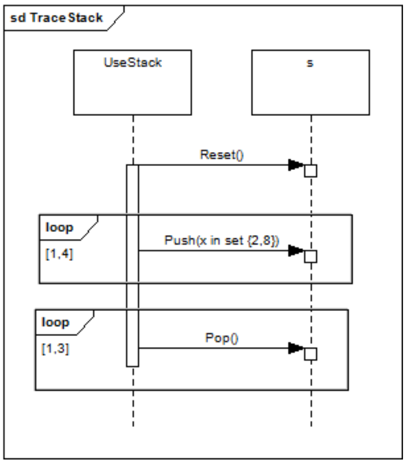


Figure 6.1: SD showing a simplified trace statement.

```
class Stack
...
end Stack

class UseStack
instance variables
  s : Stack := new Stack();
traces
  TracesStack :
    s.Reset() ;
    let x in set {2,8}
    in s.Push(x){1,4};
    s.Pop(){1,3}

end UseStack
```

Listing 6.1: VDM class showing the trace from figure 6.1.

6.2 Transformation Rules

The transformation rules for an interaction transformation describes, how instances of certain UML meta-classes are related to constructs of the VDM concrete syntax regarding Trace Definitions [LangManPPTraces]. The syntax definition can be found in section 3.6 on page 49.

6.2.1 Trace placement

The placement of a trace statement is derived from `LifeLines` of a SD. To deduce which `LifeLine` should be the owner of a trace statement a closer look at the `Messages` of the SD is needed. `Messages` consists of a `sendEvent` and `sendReceive` representing a `MessageEnd` which is of type `MessageOccorenceSpecification` `Mos` for short. Each `Mos` covers one `LifeLine`. The owner of the trace statement is the `LifeLine` where `Messages` only origin from.

Figure 6.2 shows the meta-classes involved when deducing the connection between `Message` `sendEvent` and `sendReceive` by a Lifeline.

```
class TracePlacement
functions
private getTraceOwnerName :
  seq of Message -> String
getTraceOwnerName(messages) ==
  let names : String =
    {  let mos : Mos = m.getSendEvent()
       in
         let lf: LifeLine = mos.getCovered()
         in lf.getName()
```

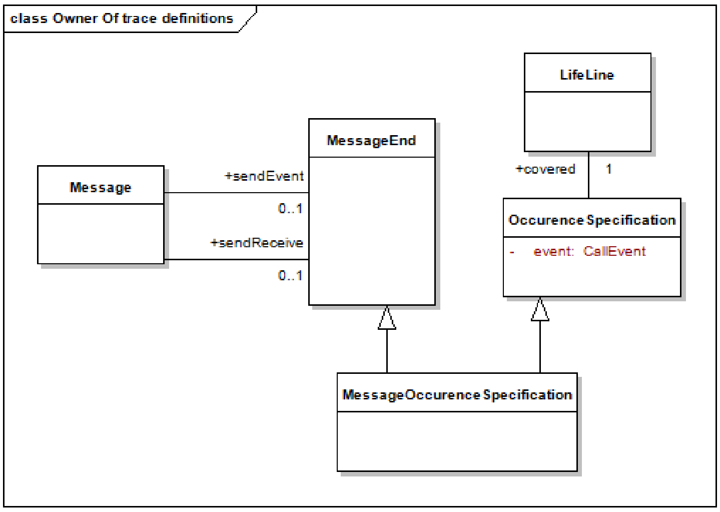


Figure 6.2: VDM Meta-classes showing the link between `Message` and `LifeLine`.

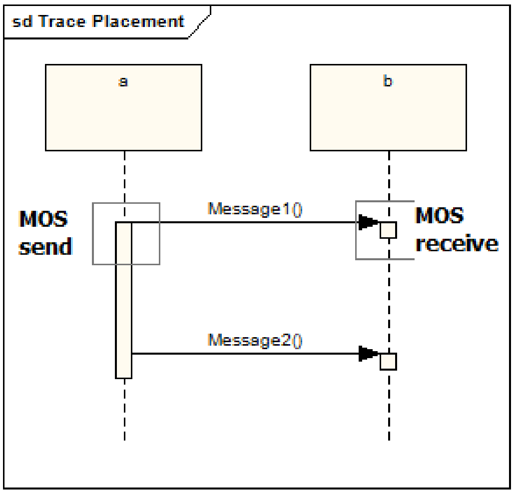


Figure 6.3: Sequence diagram.

```
        | m in set elems messages}
  in
    if card names > 1
    then undefined
    else let name in set names in name;

end TracePlacement
```

Listing 6.2: Operation to get owner of a trace form the messages involved.

Transformation Rule 18
The class where the trace is placed is the one from which all `Messages` in a SD originates.
An interaction transformation is only possible if all `Messages` origin from a single `Lifeline`.

6.2.2 Trace name

A named trace definition gets it name from its counterpart in UML `Interaction` which is the Meta-class holding all Meta-classes conforming a sequence diagram. It is the property `Name` of the `Interaction` Meta-class that holds the name that can be transformed to the name of a named trace.

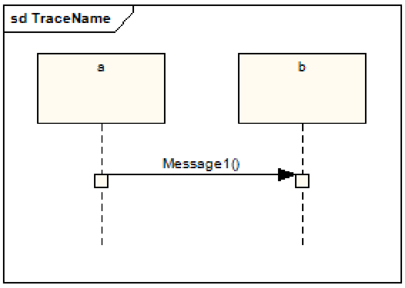


Figure 6.4: Sequence diagram with a name.

```
class TraceNameEx
traces
  TraceName : ...

end TraceNameEx
```

Listing 6.3: Class with a named trace acceding to Figure 6.2.2.

Transformation Rule 19
The attribute `Name` of the UML meta-class `Interaction` is mapped as the name of the trace.

6.2.3 Trace Apply Expression

The trace apply expression contains information about which object a certain method should be executed on and value for the parameters of the method. This information is transformed from the SD mainly by the Meta-class `Message` by the aide of `Mos`, `LifeLine` and `CallEvent`. Where the `LifeLine` represents the objects that the method should be executed upon and the `CallEvent` references the method that should be executed through the `Mos` to the `Message`.

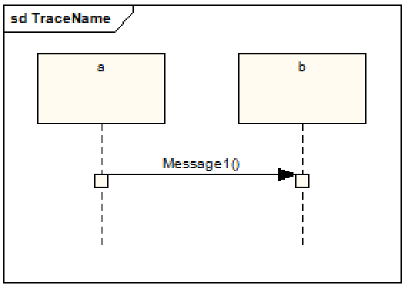


Figure 6.5: Sequence diagram with a single message.

```
class TraceNameEx
traces
  TraceName : b.Message1()

end TraceNameEx
```

Listing 6.4: Class with a named trace and a single method apply.

Transformation Rule 20
The method name in a trace apply expression is transformed from the `Operation` property of the Meta-class `CallEvent` and the variable on which the method should be executed is transformed from the `LifeLine` at the receive end of the message where a `Mos` is linking it to a `LifeLine` representing the object. The arguments are directly transformed from the `Message` Meta-class.

6.2.4 Sequencing of trace apply expressions

The apply expressions in a trace is transformed from the SD in the order they are specified in the SD. This is a one to one transformation between the ordering of `Messages` in a SD and the order of method apply expressions in a trace.

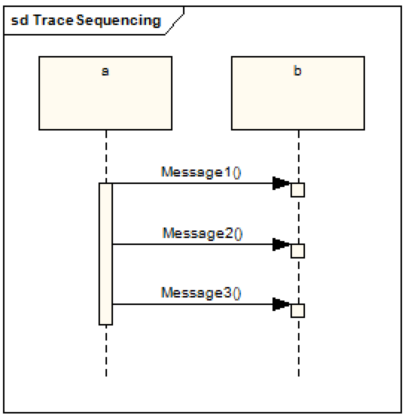


Figure 6.6: Sequence diagram.

```
class TraceSequencingEx
traces
  traceSequencing :
    b.Message1() ;
    b.Message2() ;
    b.Message3()

end TraceSequencingEx
```

Listing 6.5: Class with a named trace having a sequence of method apply expressions.

Transformation Rule 21
Method apply expressions in a trace are sequenced in the same order as messages in a SD.

6.2.5 Trace choice operator

`Messages` from a SD is transformed into method apply expressions separated by the choice operator if they are contained in the same `CombinedFragment` and placed in an operand each where the `CombinedFragment InteractionOperator` equals `alt`.

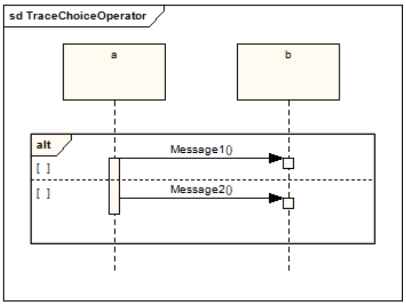


Figure 6.7: Sequence diagram with **`loop`** fragments.

```
class TraceChoiceEx
traces
  TraceChoiceOperator :
    b.Message1() |
    b.Message2()

end TraceChoiceEx
```

Listing 6.6: Class with a named trace showing the choice between two apply expressions.

Transformation Rule 22
`Messages` are transformed into method apply expressions separated be the choice if they are contained in the same `CombinedFragment` in each their operand where the `CombinedFragment InteractionOperator` equals **`alt`**.

6.2.6 Repeat Pattern for apply expressions

The repeat pattern is transformed from the UML Meta-class `Operand` holding the message, where the property `InteractionConstraint` decides the repeat pattern according to table 23 and the `CombinedFragment` where the `Operand` is contained in having its `InteractionOperator` set to **`loop`**.

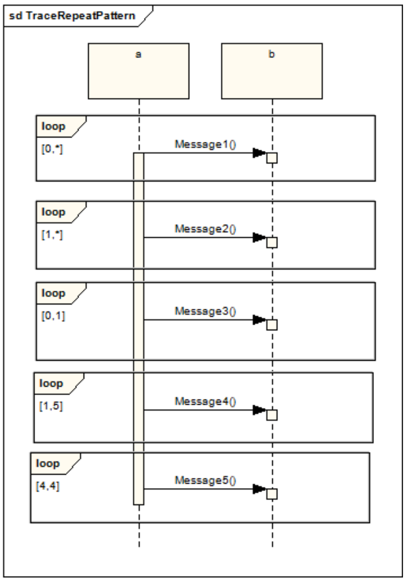


Figure 6.8: Sequence diagram with **alt** fragment.

```
class TraceRepeatPatternEx
traces
  traceRepeatPattern :
    b.Message1()* ;
    b.Message2()+ ;
    b.Message3()? ;
    b.Message4(){1,5};
    b.Message5(){4}

end TraceRepeatPatternEx
```

Listing 6.7: Class with a named trace showing repeat patterns.

Transformation Rule 23

The repeat pattern of a apply expression is transformed from the `InteractionConstraint` of an `Operand` contained in a `CombinedFragment` where the `InteractionOperator` equals **loop**. The constraint of the `Operand` holding the message specifies how the repeat pattern should be set:

Constraint (Guard)	RepeatPattern				
	a*	a+	a?	a{x}	a{x,y}
`minint`	0	1	0	x	x
`maxint`	*	*	1	x	y

Table 6.1: Transformation rules for VDM constructs modeling collections

6.2.7 Nested sequencing messages

`Message`s are transformed into method apply expression according to their order and they are grouped together in brackets with messages that exists in the same `CombinedFragment` where the `InteractionOperator` equals **loop**. It is allowed to have `CombinedFragment`'s inside other `CombinedFragment`'s which enables a `Message` to be both optional and have a repeat pattern. The `Mos` associated with a message must only be associated with one operand in one `CombinedFragment`.

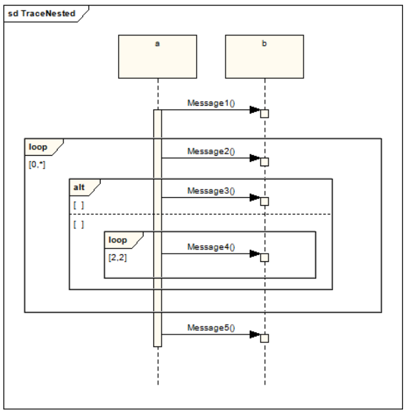


Figure 6.9: Class with nested messages in Combined fragments.

```
class TraceNestedEx
traces
  traceNested :
    b.Message1() ;
    (
      b.Message2() ;
        b.Message3() |
        b.Message4(){2}
     )*;
     b.Message5()

end TraceNestedEx
```

Listing 6.8: Class with nested method apply expressions.

Transformation Rule 24

`Messages` nested in a fragment of an `InteractionOperand` is added the same properties as `Messages` in the parent(s) `InteractionOperands`. The ordering does not change when they are nested.

This rule only apply to messages contained in a `Combined-Fragment` through a `InteractionOperand`.

Chapter 7

Interaction Model Specification

This chapter gives a description of how the transformation rules from chapter 6 are added to the existing model transformation described in chapter 5. The chapter begins with a short description of new constructs in the UML AST and then an introduction of how UML 2 Sequence Diagram (SD) is related to the nodes in the OML AST. Secondly the key features of the actual transformation from UML SD to VDM traces is given, primarily concerning the changes needed to handle SD in the already existing model. Finally a summary is made discussing what has been specified in the model and which difficulties had been discovered.

7.1 Subset of UML AST in relation to sequence diagrams

This section shortly describes the constructs of the UML AST used to specify constructs of a UML SD. References to a detailed description in Appendix E is supplied for each construct.

The main constructs of the UML AST are shown below:

Interaction An interaction represents a single sequence diagram. It holds the following: `lifelines : set of Lifeline` which represents an instance of a class (see section E.2.2). `fragments : set of InteractionFragment` an interaction fragment is a piece of an interaction (see section E.2.3). `messages : seq of Message` a Message defines a particular communication between `Lifelines` of an `Interaction` (see section E.2.4).

```
Interaction ::
  name : String
  lifeLines : set of LifeLine
  fragments : set of InteractionFragment
```

```
    messages  : seq of Message;
```

Listing 7.1: AST of a `Interaction`.

LifeLine Listing 7.2 shows the type `LifeLine`, which represents an instance of a class via the optional `represents : [Type]` (see section E.1.3). If `Lifeline` do not reference a class it will be ignored during a transformation.

```
  LifeLine ::
    name : String
    represents : [Type];
```

Listing 7.2: AST of a `LifeLine`.

Message Listing 7.3 shows the type `Message` of the `Interaction`, which includes, but is not limited: `sendEvent : Mos` references the specification of the sending of the `Message` and `receiveEvent : Mos` references the specification of the reception of the `Message`.

```
  Message ::
    name        : String
    sendEvent   : Mos
    sendReceive : Mos
    ...
```

Listing 7.3: AST of a `Message`.

7.2 Transformation Specification Overview

Transforming a UML SD into a VDM trace definition is carried out according to the rules defined in section 6.2. To illustrate how the rules apply to a SD, a VDM trace statement is shown in Listing 7.4 and an informal presentation of the populated UML AST is shown in Listing 7.5. The two Listings are supplemented with Figure 7.1, which supplies the reader with the link between Listing 7.5 and the SD resulting from the trace statement in Listing 7.4

```
class UseStack
instance variables
  s : Stack := new Stack();

traces
  testTraceStack = s.Reset() ;
                   s.Push()?;
end UseStack
```

Listing 7.4: VDM trace statement.

```
NamedTrace
  name = "testTraceStack"
  defs =
  [ SequenceDefinition
     defs =
      [ DefinitionItem
          test =
            MethodApply
              variable_name = "s"
              method_name = "Reset"
        ,
        DefinitionItem
          test =
            MethodApply
              variable_name = "s"
              method_name = "Push"
          regexpr = ZeroOrOne
      ]
   ]
```

Listing 7.5: Populated AST showing the trace from Listing 7.4.

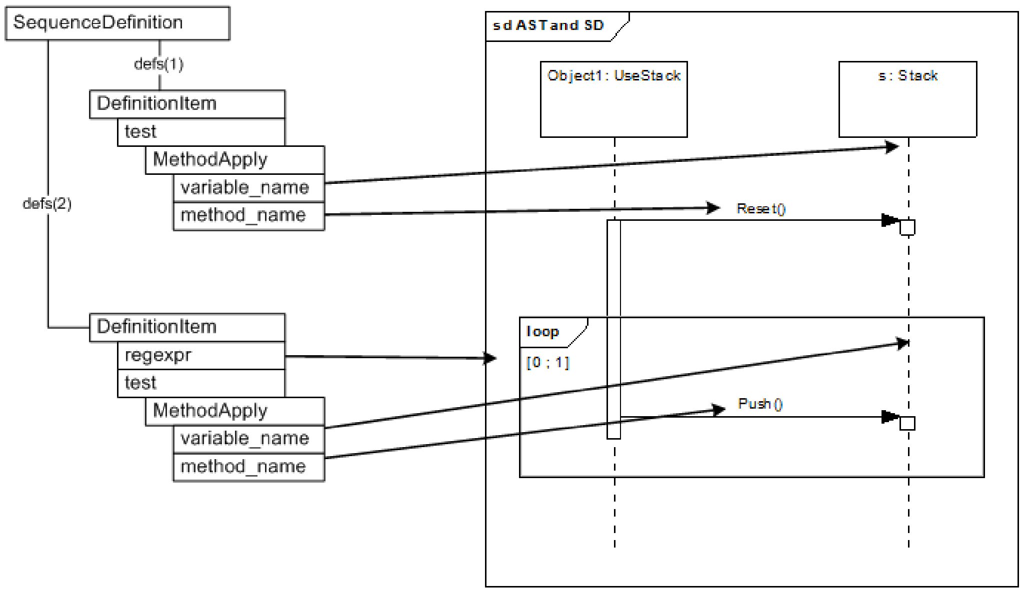


Figure 7.1: Transformation between OML AST and UML SD.

Figure 7.1 shows an example of the link between the OML AST and a UML SD. On the right side of Figure 7.1 the SD is shown. It consists of the lifelines `UseStack` and `s : Stack`. The message `Push` is placed inside an `InteractionOperand`, which has the interaction operator `loop` guarded by the expression `[0 ; 1]`.

To the left, the OML AST definitions from Listing 7.5 is shown. Each name from the definition is linked to the element in the SD that they represent in a trace statement. To illustrate this, the link to a `MethodApply` expression represents a `Message` by having the `variable_name` set to the name of the life line at the receive end of the message where the `method_name` is set to the operation that the message represents. (Complies with rule 20 on page 94). A `DefinitionItem` represents a `MethodApply` expression. If the method apply expression is inside a `CombinedFragment` of kind **loop**, the `regexpr` of the `DefinitionItem` is set according to the guard of the operand associated with the message. (Complies with rule 23 on page 96).

7.3 Transforming UML SD to VDM Trace

The transformation of a UML Sequence Diagram (SD) into a VDM trace definition is carried out between the UML AST and OML AST. The class `Uml2Vdm` shown in Figure 5.4 in section 5.3, is extended with new functions implementing the rules from chapter 6.2. Apart from the `Uml2Vdm`, an extension has been added to the `Xml2Uml` class, which handles the population of the UML AST. The extension added to `Xml2Uml` is carried out in the same manner as in section 5.5.1.

The transformation process from SD to trace statement can be split up into steps describing the different stages in the transformation, where messages are used as the starting point since they specify the ordering:

1. Extract trace name
2. Find owning class of trace
3. Create definitions from messages. Transformation of the `CombinedFragment`.
   - `SequenceDefinition`: If message is inside a `CombinedFragment` of type **loop**
   - `ChoiceDefinition`: If a message is inside a `CombinedFragment` of type **alt**
4. Extract `DefinitionItem` from message.

   `MethodApply`: Defines on which object and which method the message represents.

   `RepeatPattern`: Defines the `Constraint` of the `InteractionOperand` which the message is included in.

The name of a trace statement is extracted from the name of an interaction as shown in Listing 7.6 by the function `build_trace` (Conforms with rule 19 on page 93). Additional to this the trace definition is built by the function `getTraceDefinition` which recursively handles all messages. Finally a name representing the owning class of the

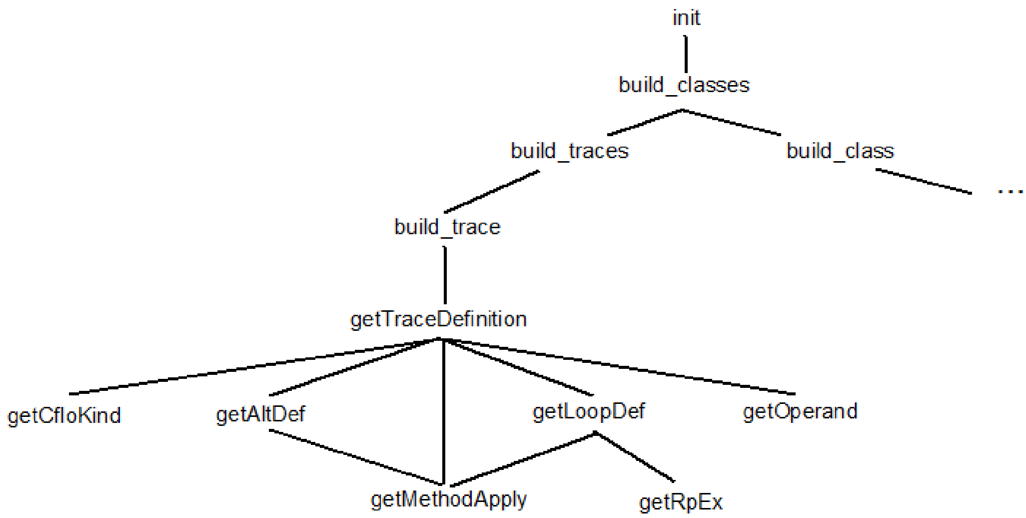


Figure 7.2: Overview of operations and functions involved in the transformation of a UML SD.

trace is exstracted. The name is taken from the `LifeLine` specified by the `sendEvent` of the `Message` (Conforms to rule 18 on page 93).

```
private build_trace : IUmlInteraction ->
  map String to IOmlTraceDefinitions
build_trace(interaction)==
  let name = interaction.getName(),
      messages : seq of IUmlMessage = interaction.getMessages()
  in
    let defs : IOmlTraceDefinition =
      getTraceDefinition(messages, interaction.getFragments(),nil)
    in
      let ownerClass in set
           {m.getSendEvent().getCovered().getRepresents()
           | m in set elems messages}
      in
         {let owr : IUmlClassNameType =ownerClass in owr.getName()
         |-> new OmlTraceDefinitions([new OmlNamedTrace(name,defs)])};
```

Listing 7.6: Build a named trace from a interaction diagram.

When the trace definitions are constructed and mapped to a class name they are attached to the body of its owning class. That is done in the construction of classes along with definitions of **`instance variables`**, **`values`** etc.

According to the goals of rule 21 (sequencing on page 94), rule 22 (choice on page 95) and rule 23 (repeat pattern on page 96) the function `getTraceDefinition` is introduced. The function iterates over messages from the SD. For each found `Message`, it is determined if the `Message` has one of the following states:

- Stand alone `Message`
- `Message`s contained in a `CombinedFragment` of kind **`loop`** with an `Interaction-Operand` specifying the repeat pattern.
- Message contained in a `CombinedFragment` of kind **`alt`** where each message related to an `InteractionOperand` of the same **`alt`** should be joined in a choice statement.

Common to all messages is the order which is preserved during a transformation. This also applies to messages sub grouped by a `CombinedFragment` where the same rule for ordering applies. The only exception is the `CombinedFragment` of kind **`alt`** where the ordering can be ignored, since **`alt`** implies a choice behavior. Figure 7.3 shows a state diagram of the three states a `Message` can end up in, according to its relation to `CombinedFragment` and their `InteractionOperand`s.

A state diagram is shown in figure 7.3 presenting the different states a `Message` can have according to its placement in a SD. The state diagram is a graphical representation of the function shown in listing 7.7. If the current message is a standalone message, e.g. it is not enclosed by an `InteractionOperand`, the message can be converted directly into a `DefinitionItem` with a `MessageApply` expression inside. If the current message is enclosed by an `InteractionOperand`, there are two choices depending on whether the message is enclosed by a `CombinedFragment` of **`loop`** or **`alt`** kind. If a `Message` is processed and no other `Message`s exist in the same `InteractionOperand`, the messages found are grouped in a sequence in the same order they occur in the SD, according to rule 21 on page 94. Listing 7.7 shows a snippet of the `getTraceDefinition` handling the case where a message is contained in a `CombinedFragment` with the kind **`loop`**. This conforms to a repeat pattern of a `MessageApply` inside a `DefinitionItem`, according to rule 23 on page 23.

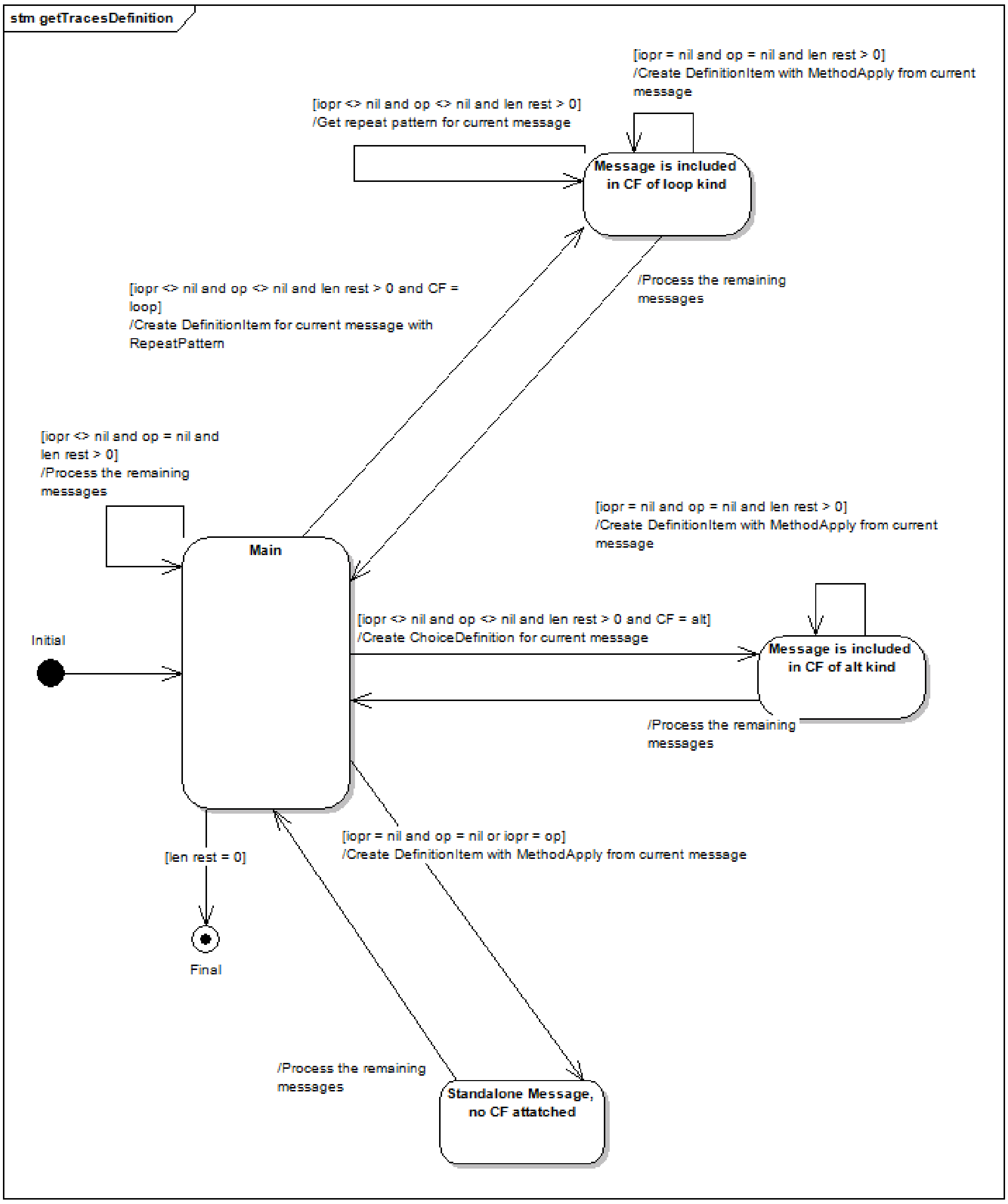


Figure 7.3: State diagram over the function `getTracesDefinition`.

```
1  getTraceDefinition : seq of IUmlMessage *
2                       set of IUmlInteractionFragment *
3                       [IUmlInteractionOperand] -> [IOmlTraceDefinition]
4  getTraceDefinition(msgs,fg,io) ==
5    if len msgs > 0 then
6    ( let m    = hd msgs,
7          rest = if len msgs > 1 then tl msgs else [],
8          cfg  = { f | f in set fg & isofclass(IUmlCombinedFragment,f) },
9          op   = getOperand(m,cfg)
10     in
11     ( --No current CF is select by a IO
12       if (io = nil and op = nil) or (io = op )
13       then -- no operand => no CF
14         ...
15       else
16         if op <> nil and getCfIoKind(fg,op).getValue() =
17             UmlInteractionOperatorKindQuotes`IQLOOP
18         then -- CF = Loop
19           let loopDef : IOmlTraceDefinition    =
20                 getLoopDef(m,op),
21               restDef : [IOmlTraceDefinition]  =
22                 getTraceDefinition(rest,cfg,op),
23               defs : seq of IOmlTraceDefinition =
24                 if restDef <> nil
25                 then [loopDef,restDef]
26                 else [loopDef],
27               ret : IOmlTraceDefinition =
28                 new OmlTraceSequenceDefinition(defs) in ret
29         else
30           ...
31      ) )else nil;
```

Listing 7.7: Function `getTraceDefinition` creates a `TraceDefinition` representing all messages in the SD.

In listing 7.7 the handling of a `Message` which is inside a `CombinedFragment` of kind **`loop`** is shown. It can be seen at line 6 that the current message `m` is extracted and the `rest` presenting the tail list of all messages. In line 9 an `InteractionOperand` for the current message is looked up. If an `InteractionOperand` exists and the operand is inside a `CombinedFragment` of kind **`loop`**, the current message `m` and the rest of the existing messages `rest` are dispatched to the `getLoopDef` function at line 20. The `getLoopDef` shown in listing 7.8 create a `DefinitionItem` with the required repeat pattern from the operand of the `Message`. Finally all messages processed by `getLoopDef` and `rest` (Is processed by the `getTraceDefinition` itself) are grouped and returned in a sequence (According to rule 21 on page 94) as shown in line 24-28, listing 7.7. If instead the `CombinedFragment` of kind **`alt`** had been present, the rest of messages would be passed back to the `getLoopDef` function to be processed accordingly.

```
getLoopDef : IUmlMessage * [IUmlInteractionOperand] ->
  IOmlTraceDefinition
getLoopDef(m,io) ==
    new OmlTraceDefinitionItem([],
                              getMethodApply(m),
                              getRpEx(io));
```

Listing 7.8: The function `getLoopDef` creates a `TraceDefinitionItem` from a `Message`.

In Listing 7.8 a `DefinitionItem` is created from a method apply expression through function `getMethodApply`. The regular expression specifying the repeat pattern is extracted from the constraint associated with the `InteractionOperand`.

```
1 private getMethodApply : IUmlMessage -> IOmlTraceMethodApply
2 getMethodApply(message) ==
3   let methodName   : String =
4         message.getSendReceive().getEvent().getOperation().getName(),
5       variableName : String =
6         message.getSendReceive().getCovered().getName(),
7     args : seq of IOmlExpression = []
8   in
9      new OmlTraceMethodApply(variableName,methodName,args);
```

Listing 7.9: Function `getMethodApply` creates a `OmlMethodApply` from a `Message`.

The creation of a `MethodApply` from a `Message` is shown in listing 7.9 (Complies to rule 20 on page 94). The name of a `Message` is extracted in line 4, listing 7.9. The name is extracted from the `Operation` which is linked to the `Message` as skown in line 4. The type of the objects presented in line 4 is as follows:

`Message.Mos.CallEvent.Operation.String`

The repeat pattern, which is applied to a `Message` if it belongs to a `CombinedFragment` of kind **`loop`** is constructed from the guard of the `InteractionOperand` associated with a message. The `guard` of an `InteractionOperand` is a constraint which has two properties:

- `minint`
- `maxint`

The repeat pattern of a `Message` can be created from the `minint` and `maxint` of a guard attached to an `InteractionOperand`, according to rule 23 on page 96. Listing 7.10 shows an example of a guard where `minint` and `maxint` is represented as `LiteralInteger`. The listing shown a sibset of the `getRpEx` function. If `min=0` and `max` is undefined the result would be a repeat pattern that equals `ZeroOrMore` as stated in line 11.

```
private getRpEx : [IUmlInteractionOperand] -> [IOmlTraceRepeatPattern]
getRpEx(iOperand) ==
  let guard = iOperand.getGuard(),
      min   = if guard.hasMinint()
              then let tmp : IUmlLiteralInteger =
                guard.getMinint() in tmp.getValue(),
         max = if guard.hasMaxint()
              then let tmp : IUmlLiteralInteger =
                guard.getMaxint() in tmp.getValue()
     in if  min = 0 and max = nil then
        new OmlTraceZeroOrMore()
     else
        ...
```

Listing 7.10: A subset of `getRpEx` showing how a repeat pattern is exstracted from a guard of an `InteractionOperand`.

7.3.1 Summary of traces specification

In the above section a description of one of the key features of the SD to trace transformation has been described namely the handling of `Message`s and their collaboration with `CombinedFragments` of king **`loop`**. The functions partly described in the above section are `build_trace`, `getTraceDefinition`, `getLoopDef`, `getRpEx` and `getMethodApply` as a part of figure 7.1. In addition to this the functions `getOperand`, `getAltDef` and `getCfloKind` exist and have been fulle specified as well. Before the transformation can be enables the UML AST needs to be populated, a complete specification has been made for this as well. During the process of specifying the XML Document to UML AST some difficulties has been discovered as described in section 2.7 on page 40.

Chapter 8

Transformation implementation

In this chapter first a discussion how test can be performed both the VDM model and the executable Java source code. It takes into account the fact that tests not only should be done at the implementation level but also at the specification level. Secondarily the process of code generation is presented along with a description of how the transformation tool fits into the Overture project.

8.1 Testing

VDM++ makes it possible to write invariant, pre- and postconditions which must be satisfied in order for the model to be valid. However, such statements are written by developers and are thus prone to errors. Even though it is possible to prove properties about a model, the risk of unforeseen unknowns is still present, e.g. the model is correct but it is not modeling the intended real world scenario or an invariant may be wrong. A way to further mitigate this risk is by executing test-cases against the model and observe the result. The test-cases may be code-generated and executed on the application level to increase confidence in the code-generator.

Two types of testing have been taken into consideration (1) Script testing and (2) Unit testing to be efficient both types should be performed as automated tests. Automated testing enables test to be performed automatically whenever the system changes. Undesired changes can then be identified right after a automatic test have been performed. Additional to the above a third type of test should be mentioned called regression testing which is the type of test VDM traces aims to cover. Regression testing is any type of software testing which seeks to uncover software regressions for instance a automated system could be setup to run a complete test suite each night to cover side effects from previous bug fixes. By using regression testing in an automated manner side effects of bug fixing will be known shortly after correction and the ability to create statistics of number of known errors can be made to indicate the system quality.

8.1.1 Script testing

A test script is a set of instructions that will be performed on the system under test. This can be done manually or automatically, by automating the process using a script or custom written program a series of tests can be performed on the system under test to unveil undesired behavior. A script could be made to read argument files, test the system with the arguments and compare the outcome of the execution with result files. The outcome of such a test can then later be analyzed to show if bugs were discovered.

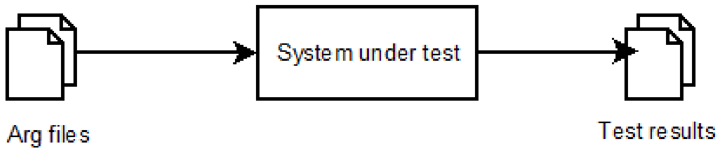


Figure 8.1: Testing a system with script testing.

8.1.2 Unit test

A unit in software testing can be defined as:

> A unit is the smallest possible testable software component.

Generally a unit can be considered as a test in a work breakdown structure, a piece the can be compiled separately or a piece that fits on a single page or screen. In relation to VDM a unit can be defined as a:

- function,
- operation or even a
- class.

No matter which type of component is selected as the smallest testable component, unit testing is a vital level of testing. Since unit test is performed on a small component it becomes easier to design, record, perform and analyze test results. If during a test a defect is discovered the relative small size of the component makes it easier to locate and repair the defect in the component [Burnstein&03]. When designing test cases they should be designed in a way which makes them independent upon each parts of the system under test. An important fact is that the test cannot discover all defects in a system, if a part is not tested or if the test case is incomplete. In the case of VDM the ideally way to use using Unit test would be to enable the same test cases to be performed both on the VDM specification level and the Java application level. This will ensure that the specification and the application reacts in the same way. At the Java level a JUnit framework exists which provides a freamwork for organicing tests includeing `TestCase`s and `TestSuite`s. A similar freamwork exist in VDM called

VDMUnit which is a freamwork compatible with JUnit. By code generating test cases from VDMUnit it becomes posible to execute them as JUnit test cases at the application level which enables the execution of the same test both at specification and application level. This however does not detect defects in the code generator or in the test it self. The construction of test cases could be automated by the use of an argument and result files. Tests could then be created from an argument and a corresponding desired result by inserting the following line in a test case:

```
assertTrue( operation identifier ( argument ) = desired result)
```

8.2 Java code-generator for VDM

The code generation process consists of two steps (1) Generate specification to Java and (2) Inspect, correct and write required stubs.

Generate specification to Java: The code generation are done by using the Java Java Code generator [CGManJavaPP] of VDM Tools [VDMTools]. The VDM specification is generated to Java which result in one class for each class in the specification.

Inspect, correct and write required stubs: By inspection it is clear that all classes not a part of the OML or UML AST e.g `Vdm2Uml` and `Uml2Vdm`, need to have an additional package import since the OML AST is used as an external JAR file already code generated and compressed into a JAR as a part of Overture. Due to minor errors in the code generator such as missing return from code generated **`cases`** with no **`others`** option a return must be inserted neither as **`return`** or **`throw`** of an exception. Both the `org.overturetool.parser.jar` file and the `VDM.jar` file from CSK should be added project buildpath. Then the code needed to invoke the UML transformation is simple, it consists of a main class enabling the program to operate as a self contained program alone and a class handling the invocation of the OML parser and XMI file read/write. Concerning JUnit all VDM test classes can be code generated as well since VDMUnit is compliant with JUnit 1.3.

8.3 Integrating UML in Overture Tool

The Overture tool has the Eclipse platform as its base which means that the UML transformation should be able to easily plug into the eclipse platform. To enable an easy plug-in of the UML transformation eclipse has a plug-in architecture that enables easy

Name	AST level		VDM model		Java source	
	Size (kB)	Lines	Size (kB)	Lines	Size (kB)	Lines
UML.ast	5.262	212	89.767	3556	287.769	9.921
Vdm2Uml.tex			21.684	533	55.728	1.550
Vdm2UmlType.tex			5.172	166	13.341	362
Uml2XmiEAxml.tex			19.391	622	53.992	1.498
Uml2Vdm.tex			26.416	609	76.173	2.128
Xml2UmlModel.tex			24.005	558	82.828	2.306
StdLib.vpp			4.260	143	13.106	359
Oml2Vpp.tex			412	24	1.631	61
Oml2VppVisitor.tex			19.636	681	59.055	1.678
external_IO.java					3.653	131
MainClass.java					2.787	118
Translator.java					2.863	96
XmlParser.java					2.947	99
ClassExstractor-FromTexFiles.java					1.621	65
Total			210.743	6.892	657.494	20.372

Table 8.1: Measure of model size on AST, VDM and Java level.

Name	VDM to Java	
	Size	Lines
UML.ast	320%	278%
Vdm2Uml.tex	257%	290%
Vdm2UmlType.tex	257%	218%
Uml2XmiEAxml.tex	278%	240%
Uml2Vdm.tex	288%	349%
Xml2UmlModel.tex	345%	413%
StdLib.vpp	307%	251%
Oml2Vpp.tex	395%	254%
Oml2VppVisitor.tex	300%	246%
Total	305%	288%

Table 8.2: Percentage increase from VDM to Java.

integration of different features. All Java based supporting tools in Eclipse are all plug-ins themselves. Plug-ins interact with each other by extension points in the Eclipse framework.

8.3.1 Development of the UML Plug-in

All information about a plug-in is stored in a `plugin.xml` file. Here the name, version, provider, runtime requirements, dependencies, extensions and extension points of the plug-in is placed. The UML transformation plug-in extents the `org.eclipse.ui.actionSets` where a menu is added to eclipse where it is possible to invoke the transformations (VDM to UML, UML to VDM). The plug-in depends on the JAR files from the Overture project [OvertureTool] containing the Overture parser and the Overture AST implementation found in appendix G.

Additional to the plug-in a feature need to be created such a feature groups plug-ins and exposes then as a feature that the update site can provide.

8.3.2 Deployment of the Plug-in

Eclipse has a well developed plug-in distribution system use on the Internet. Here plug-ins can be download / updated through the Eclipse Software Updates menu. To enable a plug-in for download through Eclipse an update site must be made and published. A update site is a web site where all the features containing the plug-ins are stored along with a description of each plug-in and its dependencies. When the feature is down loaded all the dependencies are resolved and installed before the feature. When installed Eclipse need to restart to load the feature properly before use. To enable the easy integration in Eclipse a Update Site has been created together with the plug-in and feature projects where all dependencies are specified in the plugin.xml files that makes up the plug-in projects. The update site is compiled to Eclipse version 3.4.1 Classic version. The plug-in is located at Eclipse Update Site for VDM-UML transformation [COMUUpdateSite].

Chapter 9

Concluding Remarks

9.1 Achieved Results

The two main goals of this thesis was to investigate the mapping potential between VDM++ and UML and to devise bidirectional transformation rules for each language construct. An important subgoal was to construct a prototype of a tool capable of performing a transformation between VDM++ and UML 2 Class Diagrams, and UML 2 Sequence Diagrams and the new VDM++ traces [Santos08]. The two main goals and associated subgoals were reached at the end of the project with comprehensible support of both VDM++ and UML 2, in addition to a finalized working tool integrated as an Eclipse plug-in in the Overture context.

9.1.1 Learning outcome

To accomplish the goals presented in the introductory section 1.5, thorough analyses of the UML 1, UML 2 and VDM++ notations have been carried out. The analyses resulted in detailed knowledge of the inner workings of both languages, i.e. their respective concrete and abstract syntaxes and their semantics.

The reason for examining UML 1 is that no more than *one* tool, Rose-VDM++ Link [RoseMan, CSKCORP], exists, which can perform a model transformation similar to the one made in this thesis. The tool is based on UML version 1.1, hence knowledge hereof was required in order to evaluate the quality of the tool in regards to the subset of UML 1 its supports and how well it preserves semantics.

Correspondingly, the reason for examining UML 2 is that the prototype made as part of this thesis work should support the latest development within UML. Thus, it was necessary to know the differences between UML 1 and UML 2 in order to clarify whether any progress has been made on the UML side since Rose-VDM++ Link was created.

The essential part of the model transformation, i.e. the actual mapping from one language to another, takes place of the abstract syntax level of the languages. The abstract syntax representation of VDM was available at the time this thesis work began in the form of an Abstract Syntax Tree (AST). The corresponding AST for UML had to be made during this thesis work. To reduce the manual workload, it was chosen to use the Overture tool ASTGen, which is also used in conjunction with the OML AST, hence the necessity to construct the UML AST in a fashion similar to the OML AST. This required investigation of how the OML AST is structured and how ASTGen works.

UML diagrams are exchanged between tools using an XML-based standard maintained by the Object Management Group (OMG). It was necessary to investigate this standard to determine to which degree UML tools adhere to the standard and how they deviate from it. That is important in order to know which UML tools will be able to import a UML model produced by the prototype made as part of this thesis. It turned out that the standard is not used by the tools as intended, hence the knowledge of the standard was also be utilized to tweak the prototype to satisfy the needs of selected UML tools.

9.1.2 Concrete achievements

This section describes the concrete achievements of the thesis work. It is structured into subsections, each devoted to a particular topic.

Comparison of the Rose-VDM++ Link and our prototype

The aim of the *model transformation* was to construct a tool with capabilities similar to the tool Rose-VDM++ Link. This thesis work has two important extensions compared to Rose-VDM++ Link:

Introducing UML 2: Rose-VDM++ Link only supports UML version 1.1 released in the late 1990s. The tool made in this thesis supports UML version 2.1.2, which is the latest version at the time of this writing [OMGUMLHomepage]. The tool made in this thesis has the ability to transform the following types, none of which is present in Rose-VDM++ Link:

- template parameters of classes (explained in section 4.12).
- data type definitions in a class definition (explained in section 4.3).
- union types as constrained associations (explained in section 4.5).
- product types as n-ary associations (explained in section 4.6).
- active classes (explained in section 4.9).

The tool also support a smaller subset of constructs to be transformed back to the VDM++ level. An excellent overview table of the supported features is given in Appendix I.

Introducing traces: Recent research have resulted in the introduction of the concept of VDM++ traces [LangManPPTraces, Santos08], which is compact representations of test-cases for regression testing. This work has also constructed a model transformation between UML 2 Sequence Diagrams and VDM++ traces.

The use of ASTs in the development

The abstract syntax of VDM++ was available via Overture at the time this thesis work began. It was supplied as an AST in which language constructs are specified as VDM-SL types. The UML AST, which describes the UML abstract syntax, is inspired by the OML AST. The drawback of using ASTs is that it is not directly usable and requires external tools in order to interpret and populate them with actual data. The advantage is that constructs that appear in the original source are abstracted away, leaving only the conceptual, essential elements from the syntax. This makes it easier to focus on the content, rather than on the form.

FM implies abstracting away information which is not considered important for achieving core functionality. The model transformation has been specified in VDM++ to abstract away details not directly related to the model transformation and to enable future refinement of the model. Also, the reduced size of a VDM++ model compared to an full-scale implementation yield a more easily maintainable software project. Tables 9.1, reproduced and adjusted from section , show an excerpt of the key figures regarding the advantages of code-generation and the resulting sub-totals. Table 9.1 show that the use of ASTGen to generate VDM++ classes from the UML AST resulted in no less than 3556 lines of VDM++ model being generated, corresponding to a 1677% difference between the UML AST (212 lines) and the generated VDM++ classes (3556 lines). In addition, the entire model transformation consist of a total of 583 VDM++ classes. The OML AST are responsible for 448 of these, 135 as the result of the UML AST. The figures in Table 9.1 show the difference between the VDM++ model and corresponding code-generated Java-classes. Notice the average reduction of approximately two thirds on manual-work when using code-generation.

Name	AST level		VDM model		Java source	
	Size	Lines	Size	Lines	Size	Lines
UML.ast	5.262	212	89.767	3556	287.769	9.921
Vdm2Uml			21.684	533	55.728	1.550
Uml2Vdm			26.416	609	76.173	2.128
Oml2VppVisitor			19.636	681	59.055	1.678
Subtotal			157.503	5.379	478.725	15.277

Table 9.1: Measure of model size on AST, VDM and Java level. Sizes are given in bytes.

If a transformation had been attempted on the data-layer level of UML diagrams, i.e. the raw XML, a risk exists that only a single or few UML tools would be supported due to the discovery of several violations of the standard for diagram exchange, advocated by OMG. While this is the case for the current implementation (only Enterprise Architect is supported), the UML AST makes it possible to extend the transformation specification according to the UML specification and implement any special requirements from different UML tools in order to support them.

The combination of using ASTs to capture the abstract language syntax and the formal specification of the model transformation has yielded an extendible and flexible solution. The extensible nature of the AST has proven to be the correct solution to pursuit, due to the quick and easy extension with Sequence Diagram types in the second phase of the project. In addition, the reuse of the Overture tool ASTGen saved a lot of manual work writing VDM classes representing the different UML constructs.

Utilized Overture Tools

Two tools, both part of the Overture project, and several utility-tools, made as part this thesis work, have been utilized to enable going from the data-layer to the abstract syntax and back again.

The Overture tools used are:

ASTGen: The abstract syntax of VDM++ was made as part of the Overture project and supplied as VDM-SL types in an AST. The Overture tool ASTGen takes as input an AST and produces as output one VDM++ class and one corresponding Java interface for each type found in the AST. The tool has been utilized to generate VDM++ classes for the UML AST.

OML Parser: The tool parses VDM++ classes and populates the OML AST.

Utility-tools made in this thesis

The utility-tools made during this thesis work comprise:

XML Parser: UML models are represented in an XML structure. The tool parses the XML structure and produces both VDM++ and Java compliant output, making it possible to perform a model transformation on the specification level without code-generating the entire model to Java first.

XML Serializer: The intermediate data structure representing a UML model during the model transformation must be serialized to correctly formatted XML in order for UML tools to import it.

Abstract to concrete syntax deparser: The abstract syntax of a VDM++ model is iterated through by visiting each construct. The tool produces a VDM++ class as its output, i.e. a notation that complies by the concrete syntax of VDM++.

Extending VDMEditor: The VDM++ specification of the model transformation was written using Eclipse. A plugin for Eclipse, called VDMEditor, provides a limited outline of the model, which presented operations and functions of a file with a single VDM++ class in it. VDMEditor was extended with the capability of surveying a multitude of VDM++ classes within a single file by coloring all keywords of VDM++.

VDMTools plug-in for Maven: The work of this thesis is to be included in the Overture product family. A plugin for Maven have been made which enable Maven to execute the type-checker of VDMTools on the model and automatically code-generate Java files when the specification has changed.

Eclipse plug-in and update site: A plugin for Eclipse and a corresponding update site has been made, which enables everyone to download, install and run the model transformation seamlessly.

Testing

The model has also been subject to testing, which increases confidence in the correctness of the model. The tests are specified in VDM++ and can be run against the model itself or be code-generated and run against the code-generated model. This help increase confidence in the model and also in the VDM++ code-generator, i.e. the same tests are performed on both specification and application level.

Bug-reports

A noticeable by-product of the formal specification of the transformation is the numerous bugs detected in VDMTools and VDMJ[1], which were reported to CSK and Nick Battle at Fujitsu, respectively [Fujitsu] [CSKCORP]. Both CSK and Fujitsu have been kind enough to correct the bugs as they surfaced, leading to increased quality of both products.

9.2 Future Work

To reach a higher level of completeness, the transformation tool requires attention in the areas presented in this section.

The transformation from UML Class Diagrams to VDM++ is not complete. The overview table in Appendix I shows the extent of the transformation. The rules describing the transformation are complete, but they have not been formally specified.

Additionally, if a user maintains both a VDM++ and a UML representation of a software system, and alterations are made to both models, it makes sense to provide

[1]Type-checker and interpreter, developed as part of the Overture project. Used for continuous testing to further refine the model.

a facility enabling a merge of two such models. This feature is present in the Rose-VDM++ Link. However, the merge of UML and VDM++ models is described only in theory in this thesis work, because it was considered of less importance from an academic point of view.

The map between VDM++ data types and UML nested classes should be further investigated. The transformation tool only has the notion of primitive types, e.g. `int` and `char`, hence data types defined explicitly in a VDM++ class definition do not map as the corresponding UML meta-class `DataType`. Instead, the VDM++ data types are treated as UML inner classes. That approach should be subject of a discussion with a larger part of the VDM community.

The transformation from UML Sequence Diagrams to VDM++ traces has been completed. A limitation is the **`let`** and **`let be st`** statements, which require further attention to fully support a round-trip between VDM and UML Sequence Diagrams. The other direction, from traces to Sequence Diagrams, remains as future work. However, the transformation of traces to Sequence Diagrams should be a trivial task since all rules support this already.

Further investigation of additional UML diagram types could also be carried out to determine whether other diagram types may be of interest. For example, it would be interesting to visualize VDM++ class behavior using a UML State Diagram.

Concerning the VICE extension of VDM++, a range of unclarified possibilities exist, among which the ability to use UML Deployment Diagrams to show distribution of classes on different CPUs, and the use of UML Sequence Diagram features like timing constraints and `par`[2] to show time constraints and parallelism [UMLSuperstructure2.1.2, p538]. In this regard, the use of OMG Systems Modeling Language (SysML) could be of interest. SysML reuses a subset of UML 2 and provides additional extensions to satisfy the requirements of the language. SysML is designed to provide simple but powerful constructs for modeling a wide range of systems engineering problems, i.e. problems related to the abovementioned [SysML].

9.3 Overall Conclusion

The initial discussion regarding UML and VDM++ concerned how VDM++ could benefit from tapping into the world of visual modeling using UML. The rationale for choosing UML 2 Class Diagrams was mainly due to the fact that Rose-VDM++ Link already supported them, albeit only version 1.1, hence developers already used UML Class Diagrams to a certain extent. The recently introduced concept of traces [Santos08] opened up the possibility of also connecting UML Sequence Diagrams and VDM++. The rationale for choosing sequence diagrams and traces for the second phase was the news-value it could generate around an already new concept. In addition, the combination of Sequence Diagrams and VDM++ traces should be viewed as a proof-of-concept for

[2] Denoted that the behavior of multiple operands is being executed C.3.

observing if the combination increase the understanding of traces in model development and testing.

In order to determine the differences between UML 1 and UML 2, it was necessary to study both specifications closely, i.e. the Superstructure and Infrastructure specifications of UML 1.4.2 [UML1.4.2] and UML 2 [UMLInfrastructure2.1.2] [UMLSuperstructure2.1.2]. Moreover, the VDM++ language specification was thoroughly examined to make sure the semantics of VDM++ was fully understood. Rose-VDM++ Link is the only tool available on the market which is able to perform a round-trip between VDM++ and UML. The mapping specification for Rose-VDM++ Link was also meticulously examined in order to understand the capabilities of the tool.

To summarize, both main goals have been reached, as described in the following.

VDM++ and UML Class Diagrams

- *VDM++ to UML Class Diagram:* Transformation rules for all relevant VDM++ constructs have been specified and the constructs can be mapped to a UML 2 Class Diagram, including template parameters, which is only supported by Overture. The excluded construct comprise invariants, pre- and postconditions, which were considered irrelevant to the purpose of a visual modeling language such as UML. Also, data types are not mapped as the UML metaclass `DataType` although rules are specified to aid the mapping. The reason for this was prioritizing of tasks in a tight time-frame.
- *UML Class Diagram to VDM++:* Transformation rules are specified as in the VDM++ to UML Class Diagram mapping.

UML Sequence Diagrams and VDM traces:

- *UML Sequence Diagram to VDM++ traces:* Transformation rules for all relevant constructs, except **`let`** and **`let be st`**, have been specified. The fragments `loop` and `alt` of a Sequence Diagram, used to express procedural logic, map to corresponding VDM++ repeat-patterns of traces.
- *VDM++ traces to Sequence Diagram:* Due to time constraint no final mapping is completed from VDM++ traces to UML Sequence Diagrams. However, transformation rules stating how to transform VDM++ traces constructs to Sequence Diagram constructs have been as rules in a natural language.

In order to deliver an executable prototype a number of utility-tools have been made, e.g. VDMTools plug-in for Maven, Eclipse plug-in, Eclipse Update site, Outline extension of VDMEditor etc.

The transformation tool has been developed to such an extend, that it has been used to produce most of the diagrams in this thesis. Even though the transformation is not complete, it should be seen as a solid starting point both for the completion of the transformation itself and for further development of the connection between VDM++ and

UML modeling. In particular, bidirectional transformation rules have been formulated for all relevant language constructs and the most complicated rules have been specified using VDM++ and are part of the prototype. The remaining work of incorporating the outstanding rules is considered fairly trivial, hence the academic value is limited. However, it is definitely possible to extend the thesis work presented here, but to do so will open up entire new research areas.

This thesis work has minimized the distance between VDM and UML with regards to the model transformation and opened up the possibility for others to take it further. We sincerely hope, that the tool will enrich the Overture tool-set and that the project will succeed in making VDM++ accessible even to developers not previously familiar with formal methods.

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Appendices

Appendix A

Overture Workshop 5 in Braga Portugal

A.1 Participation in Workshop

The Overture core team arrange a workshop at the University of Minho in Braga, Portugal, 8th and 9th of November 2008. The overall topic of this workshop was focus On Tool Development. The Overture core team invited us to participate and give a presentation of our M.Sc. thesis project.

The goal of the workshop were to develop a wider knowledge base of tool support for VDM and exercise different aspects of developing software of the Overture open source platform on top of Eclipse. Aspects covered included:

- Kernel functionality developed on top of the abstract syntax using VDM++ and with code generation to java .
- User interface functionality focusing on how to develop Eclipse plug-ins.
- Testing using VDMUnit and JUnit of Overture components.

A.2 What did we gain from the Workshop

The workshop was planed in the final phase of our project which meant that we in advance had worked with the VDMTools and a subset of the Overture components: Overture Parser, the Overture OML AST, ASTGen and VDMJ. This meant that we before the workshop had a good insight in which tools existed. Participating in the workshop we got introduced to other tools like Byaccj, jflex, the new Version of VDMUnit and Maven project management. Both the VDMUnit and Maven did integrate nicely with the UML transformation project. After the workshop we decided to enrich the VDM

- Maven integration by implementing a VDMToolMaven plug-in to enable type check directly in Eclipse followed to the invocation of the code generator for Java if changes had been made at the specification level. The implementation of the automatic code generator resulted in multiple upgrade requests to CSK concerning the ability to code generate single classes and better specification of packages.

A.3 Workshop conclusion

The aim of the workshop were to spread knowledge of the Overture project, try out the eclipse plug-in platform and introduce the VDMUnit framework. As a result of the workshop we gained a lot of knowledge of the Overture project and which tool currently exist among JFlex and Byaccj, as a part of Overture. We got the UML transformation rearranged into the desired Maven structure and checked in at the repository at SourceForge located at: Overture source at SF[1]. Additional to the rearrange of Java code plus VDM specification we changed all the VDM tests from the old test framework into the new VDMUnit which supports JUnit 1.3. To raise the Maven structure from the Java level to the specification level we started development on a VDMTools plug-in for Maven with the ability to type check and auto code generate.

[1] Source Forge Overturetool project https://overture.svn.sourceforge.net/svnroot/overture

Appendix B

Omitted UML 1 Constructs

The UML 1 constructs presented in this appendix have been omitted in this thesis for either three reasons: first, some exist at a higher level of abstraction and thus leave certain design decisions open. A tool is not capable of making those design decisions when performing a model transformation. Second, the concepts represented by some constructs cannot be implemented in VDM, hence the construct has no semantical counterpart in VDM. Or third, the elements are not considered relevant from an academic point of view.

B.1 Association

VDM does not have the notion of a shared attribute by value. Every object is referred to via the Object Reference Type [Fitzgerald&05, p78].

Composite aggregate association: The composite aggregate represents a whole/part relationship, i.e. it is a strong form of aggregation which means that the composite object has sole responsibility for the creation and destruction of the instances it owns. An object may be part of at most one composition at a time, thus forming a directed acyclic graph (DAG) of composite objects. Destruction of a higher level object will cause a cascading delete on the DAG as an direct implication of the one-owner property [UML1.4.2, p86].

Shared aggregate association: A shared aggregate exists semantically between an ordinary association and a composite association. The shared object may be owned by several aggregations and it may shift owner over time [UML1.4.2, p86]. The shared aggregate is tricky because it is not tightly defined [UML1.4.2, p86]. It is physically impossible for two distinct instances of a class to own *the* same instance of another class by value. So what exactly does a modeler mean by a shared aggregation? As Jim Rumbaugh says, ”Think of it as a modeling placebo”

[UMLDistilled, p67] and so this thesis exclude the shared aggregate association due to its undefined nature.

B.2 Dependency

A dependency states that the implementation or functioning of one or more elements requires the presence of one or more other elements. Dependencies cannot be transformed to VDM, because it denotes a dependency across levels of abstraction. For example, if two packages are dependent on each other, not at model level, but at implementation level, at thus have a dependency between them, that cannot be represented in VDM. [UMLSuperstructure2.1.2, p78].

B.3 Derived Element

A derived element is an element, whose value can be directly computed from values of its enclosing classifier. For example, if a class has an enumeration `gender` and a boolean attribute `isMale`, then either the former or the latter is a derived element [UMLSuperstructure2.1.2, 32]. The derived element has been omitted, because a machine in incapable of deciding whether the value of an element is directly computable from other values. Such a capability require knowledge of the semantics of the elements in some form of meta-data associated with the elements.

B.4 Package and subsystem

A package is a generic ordering of classifiers [UMLSuperstructure2.1.2, 123]. The ordering is identified by a name, which is the namespace of the package. In UML, packages may also have visibility. The concept of a package and package visibility is not part of VDM.

B.5 Association Class

An association class denotes an association with class-like properties such as state and operations. The semantics of such an association is a combination of the semantics of an ordinary association and of a class [UML1.4.2, p87]. An association class adds an extra constraint, in that there can be only one instance of the association class between any two participating objects. An example is given in Figure B.1. The primary use of an association class is to emphasize the existence of one instance of a class due to an association between instances of two other classes. Figure B.2 shows an example of a design where such an emphasis is practicable.

In figure B.1 an association class can be utilized to denote information specific to the association itself but not to either two classes, e.g. as it is done in the upper diagram.

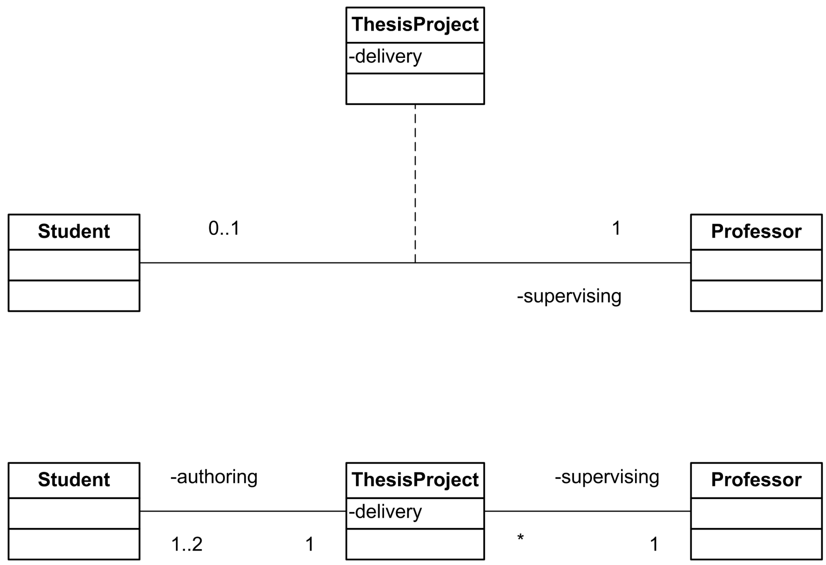

Figure B.1: Association class.

When an instance of a Professor class is associated with an instance of a Student class, there will also be an instance of a ThesisProject class. The relationship could also be modeled as in the lower diagram. There is a subtle difference between the two diagrams. In the upper diagram, the case of a thesis written by more than one Student will cause duplicate instances of ThesisProject to exist. That is not the case in the lower diagram where a single ThesisProject may be associated to two Students, thus the correct design decision here is to not use an association class.

In figure B.2 a the classes Person and Skill with association class Competence as the association between them. When an association between an instance of Person and Skill exist an instance of Competence also exist. Where could Competence go if it were an ordinary class? Placing it between Person and Skill is meaningless since a Person is expected to first have a skill and then a level of competence in exercising that skill (middle diagram). The main difference between the topmost and bottom diagram is that the bottom suggests that only Skill knows about Competence. That decision is left open in the topmost diagram. Common to both examples is the fact, that association classes leaves the design-decision of the exact implementation of the association class open. Thus it is not directly usable in the context of this thesis.

B.6 Interface

An abstract class with no implementation is semantically the same as an interface. An interface specifies the externally visible operations by a classifier that implements it. An interface contains no attributes or outgoing connections (i.e. an interface may be the target of a one-way connection). VDM do not have the concept of interfaces, only of

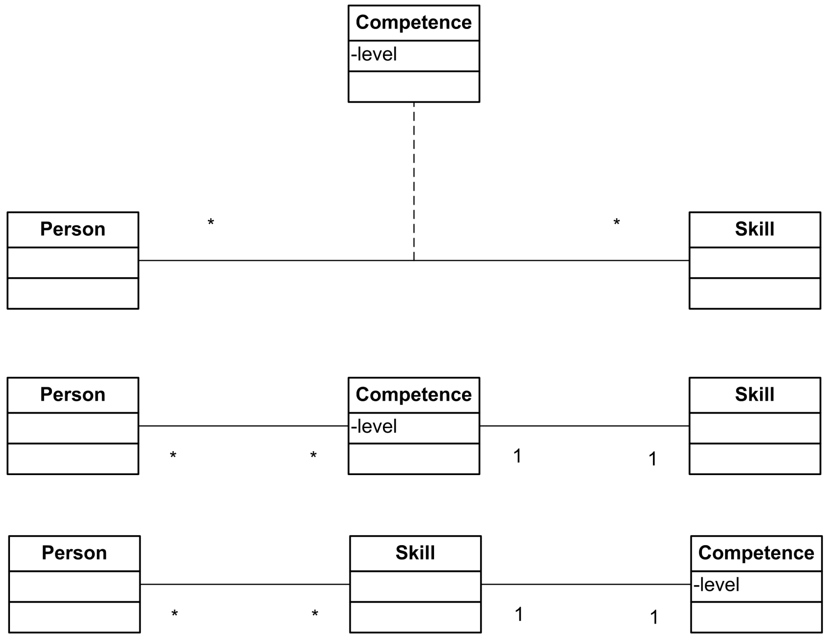

Figure B.2: Denotes an association class and how it can be realized.

abstract classes, which suffice due to the opening sentence of this section.

B.7 Realization

Realization is best described by relating it to generalization: Generalization connects a subclass to a superclass, hence it is another name for inheritance. Realization connects a class to an interface, hence it is another name for implementation. Since interfaces do not exist in VDM, realization is of no interest in this thesis.

B.8 Attributes of metaclass Class

A classifier has a number of attributes that dictates the role of the classifer. Common to both regarding VDM is that VDM do not pose any restrictions on what modelers are allowed to do with a VDM class.

isRoot: Specifies whether the classifier may inherit from other classifiers or not. A value of `true` states a lowest level superclass in a class hierarchy.

isLeaf: Specifies whether the classifier may be inherited or not. A value of `true` state that derivation from the class is illegal.

visibility: Denotes the visibility of a class. However, VDM classes are always public.

B.9 Concurrency

The enumeration `CallConcurrencyKind` defines three types of concurrent behavior a class may utilize [UML1.4.2, p102]. The different types of behavior can be modeled in VDM using history counters [Fitzgerald&05, p280] but have been omitted due to lack of visual benefit.

sequential: Callers must coordinate so that only one call to an Instance (on any sequential Operation) may be outstanding at once.

guarded: Multiple calls from concurrent threads may occur simultaneously to one Instance (on any guarded Operation), but only one is allowed to commence.

concurrent: Multiple calls from concurrent threads may occur simultaneously to one instance (on any concurrent Operation). All of them may proceed concurrently with correct semantics.

B.10 DataType

The meta-class `DataType` represents the general notion of being a data type (i.e., a type whose instances are identified only by their value). A primitive type is a data type implemented by the underlying infrastructure and made available for modeling. Typical use of data types would be to represent programming language primitive types, e.g. int, char, etc. Data type definitions in a VDM class definition are not mapped as the meta-class `DataType`. They are instead mapped as UML inner classes, because they resemble an inner class more than a simple data type.

Appendix C

Omitted UML 2 Constructs

The UML 2 constructs presented in this appendix have been omitted in this thesis for either three reasons: first, some exist at a higher level of abstraction and thus leave certain design decisions open. A tool is not capable of making those design decisions when performing a model transformation. Second, the concepts represented by some constructs cannot be implemented in VDM, hence the construct has no semantical counterpart in VDM. Or third, the elements are not considered relevant from an academic point of view.

C.1 Internal Structure of a Class

Specifies that certain classes are parts of another class, i.e. the parts do not have the same semantic meaning if found outside the scope of the owning class. This is an abstraction not applicable to VDM because it involves unmade design decisions that cannot be resolved by a machine [UMLSuperstructure2.1.2, p201].

C.2 Message kind

The meta-class `MessageKind` is an enumeration of the following values:

complete: Origin and target of message is known.

lost: Origin of message is known, but target is unknown.

found: Origin of message is unknown, but target is known.

asynchronous signal: Designates creation of another lifeline object.

delete: Designating the termination of another lifeline.

reply: Designating a reply message to an operation call.

(a) Lost. (b) Found.

Figure C.1: Messages Lost and Found [UMLSuperstructure2.1.2, p524].

The enumeration has no practical use in relation to VDM and UML SD, because only VDM traces are considered, thus any potential use of the semantics no longer apply.

C.2.1 Part decomposition

A message that points back to its originating object can represent a recursive message or a message calling another method on the same object. A more decorative way to show more than one lifeline stemming from an object, is to use part decomposition [UMLSuperstructure2.1.2, p513]. Figure C.2 shows an object of a class with an important internal structure. Part Decomposition can be utilized to describe the behavior of that internal structure.

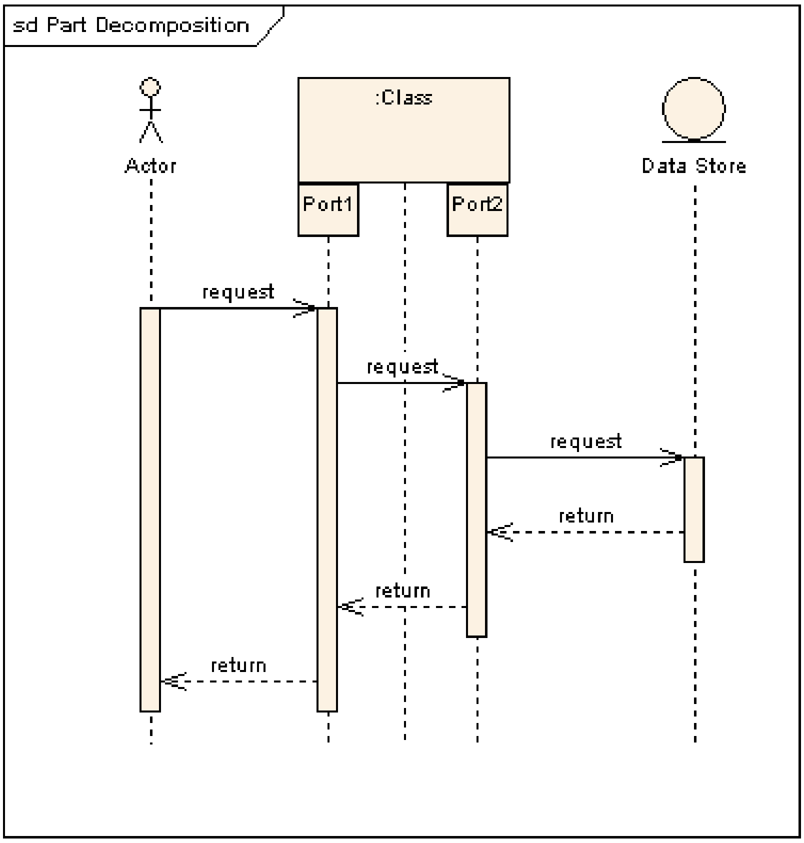

Figure C.2: Port1 and Port2 represents the UML 2 concept Port, which specifies a distinct interaction point on an object lifeline [UMLSuperstructure2.1.2, p196]

C.3 Fragment

The following fragments are not applicable in the context of this thesis. They are abstractions useful to humans but not to a model transformation.

Negative (neg): Denotes an invalid series of messages.

Ignore (ignore): Indicates that one or more message types are of no interest even if they occur. These message types can be considered insignificant and are implicitly ignored if they appear in a corresponding execution, i.e. the execution context modeled by the Sequence Diagram will ignore the message types because they are of no interest to the current execution, however, they may be significant in another context [UMLSuperstructure2.1.2, p489].

Consider (consider): A consider operator is in effect the opposite of the ignore operator, i.e. any message not present in the consider operator should be ignored.

Break (break): A break represents a behavior that is performed instead of the remainder of the enclosing fragment, thus it can be thought of as a way to model exception handling. If the guard of the break evaluates to true the break operand is executed and the rest of the enclosing sequence is ignored. If there is no guard the choice between a break and the remainder of the fragment is non-deterministic.

Parallel (par): Denotes that the behavior of multiple operands is being executed in parallel, i.e. each operand in the fragment represents a thread of execution done in parallel. The contents of each operand may be interleaved arbitrarily as long as the ordering imposed by each operand as such is respected. A notation shorthand for parallel combined fragments is Coregion, as showed in Figure C.3.

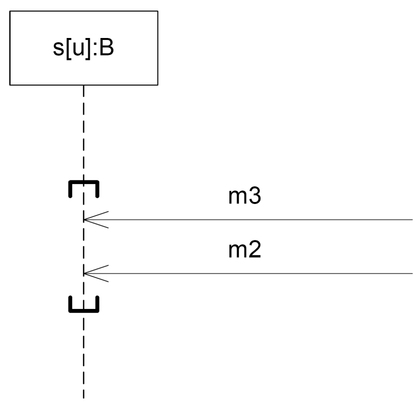

Figure C.3: The method calls `m2` and `m3` may appear in any order [UMLSuperstructure2.1.2, p522].

Weak Sequencing (seq): Denotes an sequence of messages that can occur on one or more lifelines. There is no decided order of messages within a seq that do not share the same lifeline. The only requirement is that all the events in a preceding operand must be completed before the following operand can start. Weak sequencing may be decorated with Continuations (see Alternative (alt)).

Option (opt): Denotes a binary choice of behavior where either nothing happens or the operand happens. It is equivalent to an if-then construct.

Strict Sequencing (strict): Encloses a series of messages which must be processed in the given order. It is a stronger notion of weak sequencing. Strict sequencing may be decorated with Continuations (see Alternative (alt)).

Critical Region (critical): A critical section declares an atomic subsequence which cannot be interleaved by any participant within the enclosure. Other operands (e.g. par) may imply the possibility to interleave a critical region, but this is prevented.

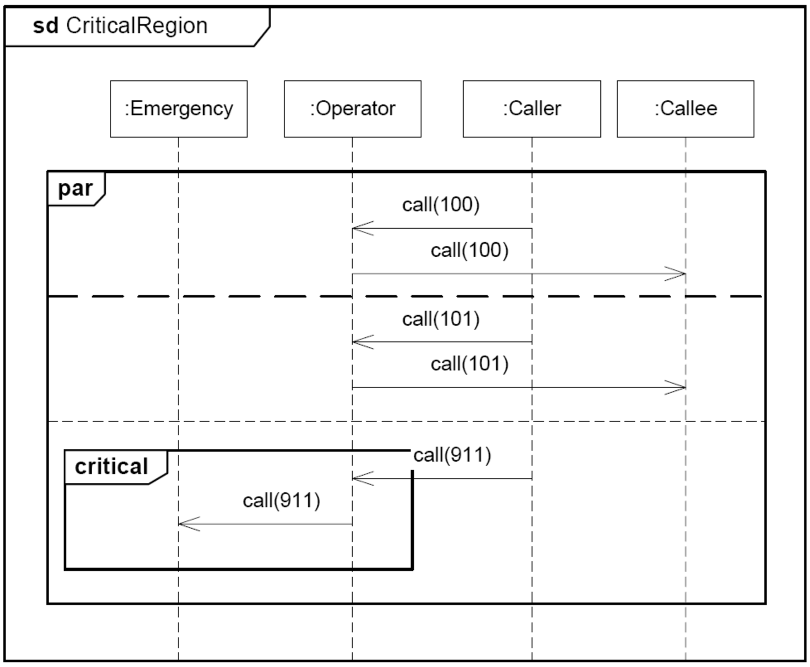

Figure C.4: Example of a parallel and critical region to denote concurrent emergency calls and focus on forwarding 911 calls [UMLSuperstructure2.1.2, p486]

Assertion (assert): Denotes an assertion of the messages within the enclosure. The sequences of the operand of the assertion are the only valid continuations. All other continuations result in an invalid trace.

C.3.1 ConsiderIgnore Fragment

A `ConsiderIgnoreFragment` is a kind of combined fragment with an interaction operator of kind `Ignore/Consider` [UMLSuperstructure2.1.2, p489]. The interaction operator `ignore` designates that there are some message types that are not shown within this combined fragment. These message types can be considered insignificant and are implicitly ignored if they appear in a corresponding execution. Alternatively, one can understand `ignore` to mean that the message types that are ignored can appear anywhere in the traces. Conversely, the interaction operator `consider` designates which messages should be considered within this combined fragment. The concept cannot be used in this thesis, because marking particular messages as more or less significant than other messages has no meaning in relation to VDM traces.

C.3.2 InteractionUse

If a CombinedFragment is used in multiple Sequence Diagrams, it may be represented more clearly as an InteractionUse. An InteractionUse is a form of z-layering or zooming capability which allows the modeler to refer to a CombinedFragment instead of drawing it repeatedly. The InteractionUse is shown as a CombinedFragment symbol where the operator is called *ref*.

Appendix D

Significant changes to the UML meta-model

This chapter contains a description of the changes of the UML meta-model from UML 1 to UML 2. The changes do not have a direct impact for the user of UML, because the changes are on the abstract syntax part of the UML meta-model. However, they are interesting in order to better understand some of the design decisions made by UML tool vendors (e.g. the use of `Collaboration` by EA in UML 2 SDs, see section 2.6.2 and appendix E.2.1 for further information).

D.1 Deprecated UML 1 meta-classes

ScopeKind: The meta-class has been replaced with the meta-attribute `isStatic`. `ScopeKind` was an enumeration of the values {`instance`} and {`classifier`} and was used by meta-classes `Feature` and `AssociationEnd`, which now use `isStatic` instead.

AssociationEnd: The meta-class has been demoted to the attribute `memberEnd` of `Association` [UMLSuperstructure2.1.2, p62].

Multiplicity: The meta-class has been replaced with the abstract meta-class `Multiplicity-Element`, which other meta-classes inherit in order to have a multiplicity. In UML 1, various meta-classes had attributes of type `Multiplicity` in order to specify multiplicity. In UML 2, that attribute is supplied by inheritance instead [UMLSuperstructure2.1.2, p110].

Collaboration: In UML 2, the meta-class `Collaboration` has been revoked and `Interaction` has been promoted to encompass in general any kind of interaction [UMLSuperstructure2.1.2, p501]. It is worth noticing that `Interaction` is a subclass of `Classifier`, which is also the superclass of `Class` from CD. Hence, any of the two meta-classes may be put instead of `Classifier`.

ClassifierRole: Participants of `Interaction` is modeled by `Lifeline`s instead of `ClassifierRole`s [UMLSuperstructure2.1.2, p499].

Sequencing of messages: The sequencing of messages by sequence numbers as used in UML 1 SD has been moved to Communication Diagrams, which correspond to simple UML 2 SDs. `CombinedFragment` is used to indicate sequencing in UML 2 SD.

D.2 New UML 2 meta-classes

ValueSpecification: The meta-class has been added in UML 2. A `ValueSpecification` is used to identify a value or values in a model. The range of a `ValueSpecification` may be restricted by `Constraint`, which specifies additional semantics for one or more elements [UMLSuperstructure2.1.2, p74]. The use of `ValueSpecification` is a further refinement of the UML meta-model.

isUnique: For a multi-valued multiplicity, this meta-attribute specifies whether the values in an instantiation of the element are unique, i.e. whether it is possible to have several links associating the same set of instances [UMLSuperstructure2.1.2, p110].

Appendix E

Specification of the UML Abstract Representation

This appendix describes how the UML AST corresponds to the UML Superstructure Specification [UMLSuperstructure2.1.2]. A future description on how the AST is comprised and a description on tool support for creating a AST to use in VDM is described in section 5.1 where a walk through is done with a small example showing the construction and how to apply the ASTGen[1] tool to the AST to create VDM specification classes that can be used in the modeling process.

The Superstructure defines the notational representation of the concrete meta-classes and how the various classes are interconnected. Some of the concrete classes do not have a graphical notation and serve only as "glue", e.g. the `Mos` used in SDs which link `Messages` to `Lifelines`. Both graphical and non-graphical constructs are equally important in order to allow further extensions to the UML AST while maintaining compliance with the UML specification. Some constructs, however, have been omitted from the AST of two reasons:

1. They did not add value to the UML AST in the context of this thesis, i.e. some constructs exist to bind together parts of the UML specification,

2. and meta-classes that makes use of multiple inheritance are collapsed into the inheriting class, because multiple inheritance is not possible in Java. Concerning the latter case it relates only to abstract classes in the meta model where the concrete class is used instead of its abstract super class.

All UML AST constructs have a UML counterpart by the same name, unless stated otherwise. The UML meta-classes corresponding to types defined in the UML AST can

[1]Tool to convert VDM-SL type definitions to VDM classes etc. see section 5.1.1.

be found in section E.3. This approach reduces the massive amount of citations that would otherwise have been present in the following text.

E.1 Class Diagram

E.1.1 Model and ModelElement

The top-level element of the AST is a `Model` which comprises a name and a set of `ModelElement`. UML does *not* have the notion of a diagram that contains a number of elements. Rather, a collection of elements constitute a diagram conceptually, hence the AST `Model` and `ModelElement` do not have a counterpart in UML.

The `ModelElement` shown in Listing E.1 consist of the following:

`Class`, `Association` and `Constraint`, which are described in sections E.1.2, E.1.4 and E.1.5 respectively.

`Collaboration`: The semantics of `Collaboration` has changed since UML 1. However, `Collaboration` is used here in a UML 1 context, because the primary UML tool used in this thesis uses it. See section E.2.1 for further explanation.

```
Model ::
 name : String
 definitions : set of ModelElement;

ModelElement = Class | Association |
               Constraint | Collaboration;
```

Listing E.1: `Model` and `ModelElement`.

E.1.2 Class

The type `Class` is shown in Listing E.2. It contains a number of types which are described in this subsection.

```
Class ::
  name        : String
  classBody   : set of DefinitionBlock
  isAbstract  : bool
  superClass  : seq of ClassNameType
  visibility  : VisibilityKind
  isStatic    : bool
  isActive    : bool
  templatesignature : [TemplateSignature];
```

Listing E.2: `Class`.

DefinitionBlock

The type `Class` defines `classBody` as a set of `DefinitionBlock`, shown in Listing E.3, which has no UML equivalent and act as a container for the following three types shown in Listings E.4, E.5 and E.6, respectively:

`OwnedOperations`: Defines a set of `Operation`.

- An `Operation` has a `MultiplicityElement` that defines the multiplicity of the *return parameter*, e.g. two or more to denote a collection as return parameter. Notice, that the multiplicity of the return parameter of `Operation` is actually defined as the attributes `lower` and `upper` in the UML specification. However, `MultiplicityElement` already define those two attributes, hence the reason they have been replaced by `MultiplicityElement` in this thesis work.
- The optional `Parameters` denote the parameters of the `Operation`. The direction of the `Parameters` are given by the enumeration `ParameterDirectionKind`.

`OwnedProperties`: Defines a set of `Property`. A `Property` represents a declared state of one or more instances in terms of a named relationship to a value or values, e.g. a named attribute of a class.

`NestedClassifiers`: Defines a set of `Type` which enables types e.g. `ClassNameType` to be nested inside other classes as a result of this classes can be nested.

```
DefinitionBlock =
  OwnedOperations | OwnedProperties | NestedClassifiers;
```

Listing E.3: `DefinitionBlock`.

```
OwnedOperations ::
  operationList :set of Operation;

Operation ::
  name         : String
  visibility   : VisibilityKind
  multiplicity : MultiplicityElement --aka return type
```

```
    isQuery      : bool
    type         : [Type]             --aka return type
    isStatic     : bool;

  MultiplicityElement::
    isOrdered : bool
    isUnique  : bool
    lower     : nat
    upper     : [nat];
```

Listing E.4: `OwnedOperations`, `Operation`, `Parameter`, `ParameterDirection-Kind` and `MultiplicityElement`.

```
  OwnedProperties ::
    propetityList : set of Property;

  Property ::
    name         : String
    visibility   : VisibilityKind
    multiplicity : [MultiplicityElement]
    type         : Type
    isReadOnly   : [bool]
    default      : [ValueSpecification]
    isComposite  : bool
    isDerived    : [bool]
    isStatic     : [bool]
    ownerClass   : String
    qualifier    : [Type];
```

Listing E.5: `OwnedProperties` and `Property`.

```
  NestedClassifiers ::
    typeList : set of Type;
```

Listing E.6: `NestedClassifiers`.

ClassNameType

See section E.1.3

VisibilityKind

The element `Package` of the enumeration `visibility : VisibilityKind` from `Class` has been omitted, because the notion of *packages* do not exist in VDM.

```
VisibilityKind = <PUBLIC> | <PRIVATE> | <PROTECTED> ;
```

Listing E.7: `VisibilityKind`.

TemplateSignature and TemplateParameter

The optional `templatesignature : TemplateSignature` of `Class` bundles the set of `TemplateParameter`, for the templated class.

```
TemplateSignature ::
  templateParameters : set of TemplateParameter;

TemplateParameter ::
  name        : String;
```

Listing E.8: `TemplateSignature` and `TemplateParameter`.

E.1.3 Type

`Type` has one constituent which is not self-explanatory:

`superClass : ClassNameType`: Defines `ClassNameType`, which is a construct introduced in this thesis to ease the way a class is referenced. In the UML superstructure a class is referenced as an object which means that a class that should be referenced should be fully constructed with all its members such as properties, operations etc. By introducing `ClassNameType` this can be avoided because class names in VDM are considered unique, this means that the use of `ClassNameType` does not compromise the UML structure it is just a weakening of the reference. `ClassNameType` do not have a UML counterpart.

```
Type =
  BoolType |
  IntegerType |
  StringType |
  UnlimitedNatural |
  VoidType |
```

```
    CharType |
    ClassNameType;
```

Listing E.9: `Type`.

```
ClassNameType ::
  name : String;
```

Listing E.10: `ClassNameType`.

E.1.4 Association

The `Association` of `ModelElement` is shown in Listing E.11. `Association` defines `id:Id` which is used to associate an `Association` with a `Constraint` (see section E.1.5). Notice, that the UML specification states the type of the UML attribute `constrainedElements` as `Element`, hence the UML AST construct `Id` should be replaced with a new UML AST construct `Element` in order to conform to the UML specification. However, multiple inheritance will then be introduced to the UML AST because `Element` is a top-level superclass, hence for now the `Id` must suffice. Alterations may be made in the future to accommodate for the missing UML AST `Element` construct. Listing E.12 shows how `Id` is defined.

```
Association ::
  ownedEnds : set of Property
  ownedNavigableEnds : set of Property
  name : [String]
  id : Id;
```

Listing E.11: `Association`.

```
String = seq of char;
Id = String
```

Listing E.12: `String` and `Id`.

E.1.5 Constraint and ValueSpecification

The type `Constraint`, shown in Listing E.13 defines a set of `Id`, which is the set of elements being constrained by the constraint. The specification of the constraint is defined by `specification : ValueSpecification` of `Constraint` and it contains the following:

`LiteralString`: Defines a String value. See Listing E.13.

`LiteralInteger`: Defines an Integer value. See Listing E.13.

```
Constraint ::
  constraintElements : set of Id
  specification : ValueSpecification;

ValueSpecification = LiteralString | LiteralInteger;
```

Listing E.13: `Constraint` and `ValueSpecification`.

```
LiteralString ::
 value : String;

LiteralInteger ::
  value : nat;
```

Listing E.14: `LiteralString` and `LiteralInteger`.

E.2 Sequence Diagram

The description so far has covered the abstract syntax of UML Static Structure diagram. The last entry in the `ModelElement` in the beginning if the UML AST is `Collaboration`, which represents a UML SD.

E.2.1 Collaboration

As mentioned in section E.1.1, `Collaboration` is used in this thesis with its UML 1 semantics, hence it represents a UML SD. The notion of a construct unifying a set of constructs into a coherent whole which could be perceived as a *diagram* existed in UML 1 [UML1.4.2, p128], but the idea has been abandoned in UML 2. The unifying construct for UML 1 SD was `Collaboration`, which is the reason it is used by various UML tools (EA, Eclipse UML, see 2.7) and in the UML AST as the entry point for SDs. `Collaboration` exist in UML 2 but is no longer used as suggested in the UML AST.

`Collaboration`, shown in Listing E.15, consist of `ownedBehavior : set of Interaction` which in turn has the following:

`lifelines : set of Lifeline`: Represents an instance of a class. See section E.2.2.

`fragments : set of InteractionFragment`: An interaction fragment is a piece of an interaction. See section E.2.3.

`messages : seq of Message`: A Message defines a particular communication between `Lifelines` of an `Interaction`. See section E.2.4.

```
Collaboration ::
  ownedBehavior : set of Interaction;

Interaction ::
  name : String
  lifeLines : set of LifeLine
  fragments : set of InteractionFragment
  messages  : seq of Message;
```

Listing E.15: `Collaboration`, `Interaction`.

E.2.2 LifeLine

Listing E.16 shows the type `LifeLine`, which represents an instance of a class via the optional `represents : [Type]` (see section E.1.3). If `Lifeline` do not reference a class it will be ignored during a transformation.

```
LifeLine ::
  name : String
  represents : [Type];
```

Listing E.16: `LifeLine`.

E.2.3 InteractionFragment

The type `InteractionFragment` shown in Listing E.2.3 defines the following:

`OccurrenceSpecification`: It is the basic semantic unit of `Interactions`. They give meaning to an `Interaction` by the sequence of occurrences (e.g. events) they specify.

`InteractionOperand`: It is contained in a `CombinedFragment` and represents one operand of the expression given by the enclosing `CombinedFragment`. See section E.2.3

`CombinedFragment`: It defines a boolean expression by an interaction operator and operand(s). See section E.2.3

`ExecutionSpecification`: It is a specification of the execution of a unit of behavior or action within a `Lifeline`.

Listing E.17 also shows the definition of `Mos` and `Bes`, which are explained in section E.2.3 and E.2.3, respectively.

```
InteractionFragment = OccurrenceSpecification |
                      InteractionOperand |
                      CombinedFragment |
                      ExecutionSpecification;

OccurrenceSpecification = Mos;
-- Mos = MessageOccurrenceSpecification

ExecutionSpecification = Bes;
-- Bes = BehaviorExecutionSpecification
```

Listing E.17: `InteractionFragment`, `Mos` and `Bes`.

InteractionOperand

The `InteractionOperand` of the `InteractionFragment` consist of the following:

`name : String`: The name of the fragment.

`fragments : seq of InteractionFragment`: The operand represents a part of an interaction.

`guard : [InteractionConstraint]`: It is an optional boolean expression that guards an operand in a `CombinedFragment`.

`operand : seq of InteractionOperand`: A sequence of interaction operands see listing E.21. The operand it the fragment linked to a message.

`covered : set of LifeLine`: A set of lifelines covered by the fragment.

```
InteractionOperand ::
  name     : String
  fragments: seq of InteractionFragment
  covered  : set of Mos
  guard    : [InteractionConstraint];
```

Listing E.18: `InteractionOperand`.

```
InteractionConstraint ::
  minint : [ValueSpecification]
  maxint : [ValueSpecification];
```

Listing E.19: `InteractionConstraint`.

CombinedFragment

The `CombinedFragment` of the `InteractionFragment` consist of the following:

`interactionOperator : InteractionOperatorKind`: It is an enumeration designating the different kinds of operators of `CombinedFragments`. Only `alt` and `loop` are used in the UML AST.

```
CombinedFragment ::
  name    : String
  interactionOperator : InteractionOperatorKind
  operand : seq of InteractionOperand
  covered : set of LifeLine;
```

Listing E.20: `CombinedFragment`.

```
InteractionOperatorKind = <ALT> | <LOOP>;
```

Listing E.21: `InteractionOperatorKind`.

Mos and CallEvent

The type `Mos` is an abbreviation of `MessageOccurrenceSpecification`. The reason it redefines `OccurrenceSpecification` in Listing E.17 is because it inherits `OccurrenceSpecification` in the UML specification.

`Mos` specifies the occurrence of event and in effect is the end of a `Message`, as shown in Listing E.22. The `Mos` has the optional `event : CallEvent` which is a specification of the reception of a request to invoke a specific operation. The `Mos` at the sending end of a `Message` has its `event` set to `nil`.

```
Mos ::
  name    : String
  message : [Message]
  covered : LifeLine
  event   : [CallEvent];

CallEvent ::
  operation : Operation;
```

Listing E.22: `Mos` and `CallEvent`.

Bes

The type `Bes` is an abbreviation of `BehaviorExecutionSpecification`. The reason it redefines `ExecutionSpecification` in Listing E.17 is because it inherits `ExecutionSpecification` in the UML specification.

`Bes`, shown in Listing E.23, represents the execution of a behavior on the same `Lifeline`. The notation is the thin rectangular shapes attached to the dotted, vertical line stemming from the `Lifeline`. The `Bes` has the following:

`startOs : OccurrenceSpecification`: It references the `Mos` which designates the start of the behavior.

`finishOs : OccurrenceSpecification`: It references the `Mos` which designates the finish of the behavior.

```
Bes ::
  name     : String
  startOs  : OccurrenceSpecification
  finishOs : OccurrenceSpecification
  covered  : set of LifeLine;
```

Listing E.23: `Bes`.

E.2.4 Message

Listing E.24 shows the type `Message` of the `Interaction`, which consist of the following:

`messageKind : MessageKind`: It is an enumerated type that identifies the type of message. Only `complete` and `unknown` have been included. Even though `unknown` does not occur, it is constructed as a union type to be up front with future development.

`messageSort : MessageSort`: It is an enumerated type that identifies the type of communication action that was used to generate the `Message`. Only `syncCall` and `asyncCall` have been included.

`sendEvent : Mos`: References the specification of the sending of the `Message`.

`receiveEvent : Mos`: References the specification of the reception of the `Message`.

```
Message ::
  name        : String
  messageKind : MessageKind
  messageSort : MessageSort
  sendEvent   : Mos
  sendReceive : Mos
  argument    : seq of ValueSpecification;

MessageKind = <COMPLETE> | <UNKNOWN>;
MessageSort = <SYNCHCALL> | <ASYNCHCALL>;
```

Listing E.24: `Message`, `MessageKind` and `MessageSort`.

E.3 UML Specification Citations

This section contains references to the UML meta-classes mentioned in section E, sorted alphabetically.

- Association [UMLSuperstructure2.1.2, p55]
- BehaviorExecutionSpecification (Bes) [UMLSuperstructure2.1.2, p483]
- CallEvent [UMLSuperstructure2.1.2, p450]
- Class [UMLSuperstructure2.1.2, p66]
- Collaboration [UML1.4.2, p128] and [UMLSuperstructure2.1.2, p184]
- CombinedFragment [UMLSuperstructure2.1.2, p483]
- Constraint [UMLSuperstructure2.1.2, p74]
- ExecutionSpecification [UMLSuperstructure2.1.2, p494]
- Interaction [UMLSuperstructure2.1.2, 497]

- InteractionConstraint [UMLSuperstructure2.1.2, p500]
- InteractionFragment [UMLSuperstructure2.1.2, p501]
- InteractionOperand [UMLSuperstructure2.1.2, p501]
- InteractionOperatorKind [UMLSuperstructure2.1.2, p502]
- Lifeline [UMLSuperstructure2.1.2, p506]
- LiteralInteger [UMLSuperstructure2.1.2, p107]
- LiteralString [UMLSuperstructure2.1.2, p108]
- Message [UMLSuperstructure2.1.2, p507]
- MessageKind [UMLSuperstructure2.1.2, p511]
- MessageSort [UMLSuperstructure2.1.2, p512]
- MultiplicityElement [UMLSuperstructure2.1.2, p110]
- OccurrenceSpecification [UMLSuperstructure2.1.2, p512]
- Operation [UMLSuperstructure2.1.2, p119]
- parameter [UMLSuperstructure2.1.2, p137]
- ParameterDirectionKind [UMLSuperstructure2.1.2, p138]
- Property [UMLSuperstructure2.1.2, p139]
- string [UMLSuperstructure2.1.2, p633]
- TemplateParameter [UMLSuperstructure2.1.2, p643]
- TemplateSignature [UMLSuperstructure2.1.2, p645]
- Type [UMLSuperstructure2.1.2, p151]
- ValueSpecification [UMLSuperstructure2.1.2, p154]
- VisibilityKind [UMLSuperstructure2.1.2, p155]
- MessageOccurrenceSpecification (Mos) [UMLSuperstructure2.1.2, p511]

Appendix F

Model coverage

In this chapter the model coverage is shown as a set of mathematical formatted VDM classes representing the core features of the transformation which includes `Vdm2UML`, `Uml2Vdm` and other core classes participating in the transformation. The coverage shown in this chapter is the result of a test suite which including a transformation test for each rule from chapter 4 and chapter 6. None executed paths are marked as **`gray`** and in the beginning of each section a comment list is shown. In the bottom of each section a table is provided showing the name, number of calls and coverage for each operation or function in the listed classes. The coverage of the model is only meant to illustrate that the transformation have been tested. From the coverage tables it can be seen that all involved class in a transformation has a coverage in the interval 90 to 99 percentage except the `Oml2VppVisitor` because it only implements a sub par of its base class. It is a fact that bugs exist in VDMTools which makes the coloring of the model e.g. `isofclass` colored wrong and there by calculates the coverage false. The complete model can be found on the attached CD-ROM.

F.1 Transforming from VDM to UML

In this section classes used to transform a VDM model into a UML model are shown.

F.1.1 Transformation from VDM to UML (Vdm2Uml)

The transformation from the OML AST to the UML AST.

init Convert a OmlSpecification to a UML Model.

build_uml Create the main UML model from a OML specification.

build_Class Convert a OML class to a UML class. This includes the creation of properties and associations.

getGenericTypes Get template signature from OML types. Finds the template parameters.

getSuperClasses Get super classes from a OML inheritance class. Returns nil if no super classes are found.

hasSubclassResponsibilityDefinition Test if a OML Class is abstract in UML. Checks for a is sub class responsibility operation. True if found.

build_def_b Proxy operation. Used to explicit set the type before redirecting operation call. This is introduced because of VDM Java gen limitation of type cast in Java.

build_def_block (IOmlInstanceVariableDefinitions) Create properties from OML instanca variables.

buildVariable Create a UML property from a OML instance variable definition. If the instance variable is not mapped to a UML property nil is returned. This is the case if the property should be represented as an Association.

getDefaultValue If a default value is defined for a instance variable it is returned as a string else nil.

convertScopeToVisibility Convert OML visibility to UML visibility.

build_def_block (IOmlValueDefinitions) Create UML properties from a value definition.

buildValue Create a UML property from a Value definition. If the value is not presented as a UML property nil is returned. Would be the case if mapped as an Association.

build_def_block (IOmlTypeDefinitions) Convert OML type definitions to a UML owned type.

build_def_block (IOmlOperationDefinitions) Convert OML operations to UML owwned operations.

buildOperation Convert a OML operation definition to a UML definition. All parameters are ignored - Project time limitation.

build_def_block (IOmlFunctionDefinitions) Convert OML functions to UML owhed operations.

buildFunction Convert a OML functions definition to a UML definition. All parameters are ignored - Project time limitation.

isSimpleType Check if a OML type is mapped to a UML simple type.

GetSimpleTypeName Get a simple type name.

CreateAssociationFromProperty Create an Association from a UML property and a OML type. The association is store in instance variable in the class.

CreateAssociationFromPropertyGeneral Create a UML association from a UML property where the OML type contains a OML type name.

CreateAssociationFromPropertyProductType Create a UML association from a UML property where the OML type is a product type.

CreateAssociationFromPropertyUnionType Create a UML association from a UML property where the OML type is a union type.

CreateEndProperty Create Association ends from a OML type. Ends constructed from Product and Union type and the anonymus end at the property owner end of a assocation.

GetNextId Get a new Id.

class $Vdm2Uml$
types
    public $String$ = char*
instance variables
    $associations$: $IUmlAssociation$-set := $\{\}$;
    $constraints$: $IUmlConstraint$-set := $\{\}$;
    $runningId$: $\mathbb{N}$:= 0;

operations
public
    $init : IOmlSpecifications \xrightarrow{o} IUmlModel$
    $init\,(specs)$ $\triangleq$
      (let $model = build\text{-}uml\,(specs)$ in
        ($model.setDefinitions$
            $(model.getDefinitions\,() \cup$
             $associations \cup$
             $constraints)$;
          return $model$
)
      );
public
    $build\text{-}uml : IOmlSpecifications \xrightarrow{o} UmlModel$
    $build\text{-}uml\,(specs)$ $\triangleq$
      let $classes = specs.getClassList\,()$,
        $uml\text{-}classes = [build\text{-}Class\,(classes\,(i)) \mid$
                        $i \in$ inds $classes]$ in
      return new $UmlModel$ ("$Root$", elems $uml\text{-}classes$);

public

$$
\begin{array}{l}
\mathit{build\text{-}Class} : \mathit{IOmlClass} \xrightarrow{o} \mathit{IUmlClass} \\
\mathit{build\text{-}Class}\,(c) \triangleq \\
\quad \textsf{let}\ \mathit{name} = c.\mathit{getIdentifier}\,(), \\
\qquad \mathit{inh} : [\mathit{IOmlInheritanceClause}] = \textsf{if}\ c.\mathit{hasInheritanceClause}\,() \\
\qquad\qquad \textsf{then}\ c.\mathit{getInheritanceClause}\,() \\
\qquad\qquad \textsf{else nil}\ , \\
\qquad \mathit{body} = c.\mathit{getClassBody}\,(), \\
\qquad \mathit{isStatic} = \textsf{false}, \\
\qquad \mathit{isActive} = \\
\qquad\quad \textsf{card}\ \{\mathit{body}\,(i) \mid \\
\qquad\qquad i \in \textsf{inds}\ \mathit{body} \cdot \\
\qquad\qquad\quad \textsf{isofclass}\,(\mathit{IOmlThreadDefinition}, \mathit{body}\,(i))\} > \\
\qquad\quad 0, \\
\qquad \mathit{dBlock} = [\textsf{let}\ \mathit{dbs} : \mathit{IOmlDefinitionBlock} = \\
\qquad\qquad\qquad \mathit{body}\,(i)\ \textsf{in} \\
\qquad\qquad \mathit{build\text{-}def\text{-}b}\,(\mathit{dbs}, \mathit{name}) \mid \\
\qquad\qquad\quad i \in \textsf{inds}\ \mathit{body}], \\
\qquad \mathit{dBlockSet} = \{d \mid d \in \textsf{elems}\ \mathit{dBlock} \cdot d \neq \textsf{nil}\ \}, \\
\qquad \mathit{isAbstract} = \mathit{hasSubclassResponsibilityDefinition}\,(\mathit{body}), \\
\qquad \mathit{supers} = \mathit{getSuperClasses}\,(\mathit{inh}), \\
\qquad \mathit{visibility} = \\
\qquad\quad \textsf{new}\ \mathit{UmlVisibilityKind}\,(\mathit{UmlVisibilityKindQuotes}`\mathit{IQPUBLIC}), \\
\qquad \mathit{templateParameters} = \mathit{getGenericTypes}\,(c.\mathit{getGenericTypes}\,())\ \textsf{in} \\
\quad \textsf{return new}\ \mathit{UmlClass}\,(\mathit{name}, \\
\qquad\qquad \mathit{dBlockSet}, \\
\qquad\qquad \mathit{isAbstract}, \\
\qquad\qquad \mathit{supers}, \\
\qquad\qquad \mathit{visibility}, \\
\qquad\qquad \mathit{isStatic}, \\
\qquad\qquad \mathit{isActive}, \\
\qquad\qquad \mathit{templateParameters});
\end{array}
$$

public

```
        getGenericTypes : IOmlType* -o-> [IUmlTemplateSignature]
        getGenericTypes (genericTypes) △
          if len genericTypes > 0
          then return new UmlTemplateSignature
                              (
                               {let tn : IOmlTypeName = t in
                                new UmlTemplateParameter (tn.getName ().getIdentifier ()) |

                                    t ∈ elems genericTypes})
          else return nil ;
public
        getSuperClasses : [IOmlInheritanceClause] -o-> IUmlClassNameType*
        getSuperClasses (inh) △
          if inh = nil
          then return []
          else let list = inh.getIdentifierList () in
                return [new UmlClassNameType (list (i)) | i ∈ inds list] ;
public
        hasSubclassResponsibilityDefinition : IOmlDefinitionBlock* -o-> 𝔹
        hasSubclassResponsibilityDefinition (dBlock) △
          let opList = conc [let op : IOmlOperationDefinitions = dBlock (i) in
                           op.getOperationList () |
                               i ∈ inds dBlock·isofclass (IOmlOperationDefinitions, dBlock (i))],
              hasIsSubClassResp =
                   {let explicitOp : IOmlExplicitOperation = opList (i).getShape () in
                     explicitOp.getBody ().getSubclassResponsibility () |
                        i ∈ inds opList·isofclass (IOmlExplicitOperation, opList (i).getShape ())} in
          return ∃ e ∈ hasIsSubClassResp · e = true;
private
        build-def-b : IOmlDefinitionBlock × String -o-> [IUmlDefinitionBlock]
        build-def-b (block, owner) △
           cases (true):
             (isofclass (IOmlInstanceVariableDefinitions, block)) →
                 let tmp : IOmlInstanceVariableDefinitions = block in
                 build-def-block(tmp, owner) ,
             (isofclass (IOmlValueDefinitions, block)) →
                 let tmp : IOmlValueDefinitions = block in
                 build-def-block(tmp, owner) ,
             (isofclass (IOmlTypeDefinitions, block)) →
                 let tmp : IOmlTypeDefinitions = block in
                 build-def-block(tmp, owner) ,
```

```
      (isofclass (IOmlOperationDefinitions, block)) →
          let tmp : IOmlOperationDefinitions = block in
          build-def-block(tmp, owner) ,
      (isofclass (IOmlFunctionDefinitions, block)) →
          let tmp : IOmlFunctionDefinitions = block in
          build-def-block(tmp, owner) ,
      others → return nil
    end;
public
    build-def-block : IOmlInstanceVariableDefinitions × String -o->
                      IUmlOwnedProperties
    build-def-block (v, owner) △
      let q = v.getVariablesList (),
          props = [buildVariable (q (i), owner) |
                       i ∈ inds q ·
                             isofclass (IOmlInstanceVariable, q (i))] in
      return new UmlOwnedProperties ({p | p ∈ elems props ·
                                                   p ≠ nil });
public
    buildVariable : IOmlInstanceVariable × String -o-> [IUmlProperty]
    buildVariable (var, owner) △
      let access = var.getAccess (),
          scope = access.getScope (),
          assign = var.getAssignmentDefinition (),
          isStatic = access.getStaticAccess (),
          name = assign.getIdentifier (),
          visibility = convertScopeToVisibility (scope),
          omlType = assign.getType (),
          multiplicity = Vdm2UmlType`extractMultiplicity (omlType),
          type = Vdm2UmlType`convertPropertyType (omlType, owner),
          isReadOnly = false,
          default : [String] = if assign.hasExpression ()
                               then getDefaultValue (assign.getExpression ())
                               else nil ,
          isComposite = false,
          isDerived = false,
```

```
        qualifier : [IUmlType] = Vdm2UmlType`getQualifier (omlType) in
      ( dcl property : IUmlProperty := new UmlProperty (name,
                                                  visibility,
                                                  multiplicity,
                                                  type,
                                                  isReadOnly,
                                                  default,
                                                  isComposite,
                                                  isDerived,
                                                  isStatic,
                                                  owner,
                                                  qualifier);
        if ¬ isSimpleType (omlType)
        then (   CreateAssociationFromProperty(property, omlType) ;
                 return nil
             )
        else return property
      );
public
    getDefaultValue : IOmlExpression o→ [String]
    getDefaultValue (expression) △
      cases true:
        (isofclass (IOmlSymbolicLiteralExpression, expression)) →
            (   let se : IOmlSymbolicLiteralExpression = expression in
                 cases true:
                   (isofclass (IOmlTextLiteral, se.getLiteral ())) →
                       (   let tx : IOmlTextLiteral = se.getLiteral () in
                           return tx.getVal ()
                       ),
                   (isofclass (IOmlNumericLiteral, se.getLiteral ())) →
                       (   let tx : IOmlNumericLiteral = se.getLiteral () in
                           return StdLib`ToString[ℕ] (tx.getVal ())
                       ),
                   others → return nil
                 end
            ),
        others → return nil
      end
functions
public
```

$convertScopeToVisibility : IOmlScope \rightarrow IUmlVisibilityKind$
$convertScopeToVisibility\,(sc) \triangleq$
let $val : \mathbb{N} = sc.getValue\,()$ in
cases val :
$(OmlScopeQuotes`IQPUBLIC) \rightarrow$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPUBLIC)$,
$(OmlScopeQuotes`IQPRIVATE)$,
$(OmlScopeQuotes`IQDEFAULT) \rightarrow$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPRIVATE)$,
$(OmlScopeQuotes`IQPROTECTED) \rightarrow$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPROTECTED)$
end
operations
public
$build\text{-}def\text{-}block : IOmlValueDefinitions \times String \xrightarrow{o} IUmlOwnedProperties$
$build\text{-}def\text{-}block\,(v, owner) \triangleq$
let $q = v.getValueList\,()$,
$props = [buildValue\,(q\,(i), owner) \mid$
$i \in$ inds $q]$,
$propsNoNil = \{p \mid p \in$ elems $props \cdot$
$p \neq$ nil $\}$ in
return new $UmlOwnedProperties\,((propsNoNil))$;
public
$buildValue : IOmlValueDefinition \times String \xrightarrow{o} [IUmlProperty]$
$buildValue\,(var, owner) \triangleq$
let $access = var.getAccess\,()$,
$scope = access.getScope\,()$,
$shape = var.getShape\,()$,
$isStatic = access.getStaticAccess\,()$,
$patternIdent : IOmlPatternIdentifier = shape.getPattern\,()$,
$name = patternIdent.getIdentifier\,()$,
$visibility = convertScopeToVisibility\,(scope)$,
$multiplicity = Vdm2UmlType`extractMultiplicity\,(shape.getType\,())$,
$type = Vdm2UmlType`convertType\,(shape.getType\,())$,
$isReadOnly =$ true,
$default = getDefaultValue\,(shape.getExpression\,())$,
$isComposite =$ false,
$isDerived =$ false,
$qualifier : [IUmlType] = Vdm2UmlType`getQualifier\,(shape.getType\,())$,

```
        omlType = shape.getType () in
    (    dcl property : IUmlProperty := new UmlProperty (name,
                                                        visibility,
                                                        multiplicity,
                                                        type,
                                                        isReadOnly,
                                                        default,
                                                        isComposite,
                                                        isDerived,
                                                        isStatic,
                                                        owner,
                                                        qualifier);
         if ¬ isSimpleType (omlType)
         then (    CreateAssociationFromProperty(property, omlType) ;
                   return nil
              )
         else return property
    );
public
    build-def-block : IOmlTypeDefinitions × String -o-> IUmlNestedClassifiers
    build-def-block (td, -) ≜
      let q = td.getTypeList (),
          tps = [buildType (q (i).getShape ()) |
                    i ∈ inds q ·
                        isofclass (IOmlSimpleType, q (i).getShape ())] in
      return new UmlNestedClassifiers (elems tps);
public
    buildType : IOmlSimpleType -o-> IUmlType
    buildType (var) ≜
      return Vdm2UmlType`convertType (var.getType ());
public
    build-def-block : IOmlOperationDefinitions × String -o-> IUmlOwnedOperations
    build-def-block (opDef, owner) ≜
      let ops : IOmlOperationDefinition* = opDef.getOperationList () in
      return new UmlOwnedOperations ({buildOperation (ops (i), owner)  |

                                                     i ∈ inds ops});
public
    buildOperation : IOmlOperationDefinition × String -o-> IUmlOperation
    buildOperation (op, -) ≜
      let access = op.getAccess (),
```

$scope = access.getScope\,(),$
$shape : IOmlExplicitOperation = op.getShape\,(),$
$isStatic = access.getStaticAccess\,(),$
$name = shape.getIdentifier\,(),$
$visibility = convertScopeToVisibility\,(scope),$
$multiplicity =$ new $UmlMultiplicityElement$ (false, false, $1, 1$),
$type = Vdm2UmlType`convertType\,(shape.getType\,())$ in
return new $UmlOperation\,(name,$
$visibility,$
$multiplicity,$
false,
$type,$
$isStatic,$
nil);

public
$build\text{-}def\text{-}block : IOmlFunctionDefinitions \times String \xrightarrow{o} IUmlOwnedOperations$
$build\text{-}def\text{-}block\,(opDef, owner) \triangleq$
let $ops : IOmlFunctionDefinition^{*} = opDef.getFunctionList\,()$ in
return new $UmlOwnedOperations\,(\{buildFunction\,(ops\,(i), owner) \mid$
$i \in$ inds $ops\});$

public
$buildFunction : IOmlFunctionDefinition \times String \xrightarrow{o} IUmlOperation$
$buildFunction\,(op, \text{-}) \triangleq$
let $access = op.getAccess\,(),$
$scope = access.getScope\,(),$
$shape : IOmlExplicitFunction = op.getShape\,(),$
$isStatic = access.getStaticAccess\,(),$
$name = shape.getIdentifier\,(),$
$visibility = convertScopeToVisibility\,(scope),$
$multiplicity =$ new $UmlMultiplicityElement$ (false, false, $1, 1$),
$type = Vdm2UmlType`convertType\,(shape.getType\,())$ in
return new $UmlOperation\,(name,$
$visibility,$
$multiplicity,$
true,
$type,$
$isStatic,$
nil)

functions
public

$isSimpleType : IOmlType \rightarrow \mathbb{B}$
$isSimpleType\ (t) \triangleq$
cases true :
(isofclass $(IOmlInjectiveMapType, t)$),
(isofclass $(IOmlGeneralMapType, t)$),
(isofclass $(IOmlTypeName, t)$),
(isofclass $(IOmlProductType, t)$),
(isofclass $(IOmlUnionType, t)$) $\rightarrow$ false,
(isofclass $(IOmlSetType, t)$) $\rightarrow$
let $t1 : IOmlSetType = t$ in
$isSimpleType\ (t1.getType\ ())$,
(isofclass $(IOmlSeq0Type, t)$) $\rightarrow$
let $t1 : IOmlSeq0Type = t$ in
$isSimpleType\ (t1.getType\ ())$,
(isofclass $(IOmlSeq1Type, t)$) $\rightarrow$
let $t1 : IOmlSeq1Type = t$ in
$isSimpleType\ (t1.getType\ ())$,
(isofclass $(IOmlOptionalType, t)$) $\rightarrow$
let $t1 : IOmlOptionalType = t$ in
$isSimpleType\ (t1.getType\ ())$,
others $\rightarrow$ true
end;
private
$GetSimpleTypeName : IUmlType \rightarrow String$
$GetSimpleTypeName\ (t) \triangleq$
cases true :
(isofclass $(IUmlBoolType, t)$) $\rightarrow$ ("$bool$"),
(isofclass $(IUmlIntegerType, t)$) $\rightarrow$ ("int"),
(isofclass $(IUmlCharType, t)$) $\rightarrow$ ("$char$"),
others $\rightarrow$ ("$String$")
end
operations
public
$CreateAssociationFromProperty : IUmlProperty \times IOmlType \xrightarrow{o} ()$
$CreateAssociationFromProperty\ (property, omlType) \triangleq$
cases true:
(isofclass $(IOmlProductType, omlType)$) $\rightarrow$
$CreateAssociationFromPropertyProductType(property, omlType)$,
(isofclass $(IOmlUnionType, omlType)$) $\rightarrow$
$CreateAssociationFromPropertyUnionType(property, omlType)$,

others $\rightarrow CreateAssociationFromPropertyGeneral(property, omlType)$
end;

public
$CreateAssociationFromPropertyGeneral : IUmlProperty \times IOmlType \xrightarrow{o}$
()

$CreateAssociationFromPropertyGeneral\ (property, \text{-}) \triangleq$
let $ownerClassName =$ if isofclass $(IUmlClassNameType, property.getType\ ())$
then let $pcn : IUmlClassNameType = property.getType\ ()$ in
$pcn.getName\ ()$
else $GetSimpleTypeName\ (property.getType\ ()),$
$propOtherEnd = \{$new $UmlProperty\ ($"",
new $UmlVisibilityKind\ (UmlVisibilityKindQuotes`IQP$
nil ,
new $UmlClassNameType\ (property.getOwnerClass\ ()),$
nil ,
nil ,
false,
nil ,
nil ,
$ownerClassName,$
nil)} in
$associations := associations \cup$
$\{$new $UmlAssociation\ (propOtherEnd, \{property\},$ nil , $GetNextId\ ())\};$

public
$CreateAssociationFromPropertyProductType : IUmlProperty \times IOmlType \xrightarrow{o}$
()

$CreateAssociationFromPropertyProductType\ (property, omlType) \triangleq$
let $name : String = property.getName\ (),$
$prop : UmlProperty = property,$
$props : IUmlProperty$-set $= \bigcup \{CreateEndProperty\ (p, name) \mid$
$p \in \{omlType\} \cdot$
isofclass $(IOmlProductType, p)\}$ in
($prop.setName($"") ;
if card $props > 1$
then $associations := associations \cup$
$\{$new $UmlAssociation\ (props, \{prop\},$ nil , $GetNextId\ ())\}$
);

public

$CreateAssociationFromPropertyUnionType : IUmlProperty \times IOmlType \xrightarrow{o}$ ()

$CreateAssociationFromPropertyUnionType\ (property, omlType) \triangleq$
let $name : String = property.getName\ ()$,
$prop : UmlProperty = property$,
$props : IUmlProperty$-set $= \bigcup \{CreateEndProperty\ (p, name) \mid$
$p \in \{omlType\} \cdot$
isofclass $(IOmlUnionType, p)\}$ in
($prop.setName("")$;
if card $props > 1$
then (dcl $assoc : IUmlAssociation$-set $:= \{$new $UmlAssociation\ (\{p\}, \{prop\},$ nil $, GetNex$

$p \in props\}$;
$associations := associations \cup assoc$;
$constraints := constraints \cup$
$\{$new $UmlConstraint\ (\{a.getId\ () \mid a \in$
$assoc\}$, new $UmlLiteralString\ ("xor"))\}$
)
);
public
$CreateEndProperty : IOmlType \times String \xrightarrow{o} IUmlProperty$-set
$CreateEndProperty\ (t, name) \triangleq$
(if (isofclass $(IOmlProductType, t)$)
then (let $typedType : IOmlProductType = t$ in
return $CreateEndProperty\ (typedType.getLhsType\ (), name) \cup$

$CreateEndProperty\ (typedType.getRhsType\ (), name)$
)
else if (isofclass $(IOmlUnionType, t)$)
then (let $typedType : IOmlUnionType = t$ in
return $CreateEndProperty\ (typedType.getLhsType\ (), name) \cup$

$CreateEndProperty\ (typedType.getRhsType\ (), name)$
)

else return {new $UmlProperty\,(name,$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQP$
$Vdm2UmlType`extractMultiplicity\,(t),$
$Vdm2UmlType`convertType\,(t),$
nil ,
nil ,
false,
nil ,
nil ,
"$Implementation\ \ prosponed$",
$Vdm2UmlType`getQualifier\,(t))\}$
);
private
$GetNextId : () \xrightarrow{o} String$
$GetNextId\,() \triangleq$
($runningId := runningId + 1;$
return $Util`ToString[\mathbb{N}]\,(runningId)$
)
end Vdm2Uml

Test Suite : vdm.tc
Class : Vdm2Uml

Name	#Calls	**C**overage
Vdm2Uml‘init	31	√
Vdm2Uml‘GetNextId	26	√
Vdm2Uml‘buildType	36	√
Vdm2Uml‘build-uml	31	√
Vdm2Uml‘buildValue	3	90%
Vdm2Uml‘build-Class	62	√
Vdm2Uml‘build-def-b	35	√
Vdm2Uml‘isSimpleType	71	86%
Vdm2Uml‘buildFunction	2	√
Vdm2Uml‘buildVariable	53	√
Vdm2Uml‘buildOperation	4	√
Vdm2Uml‘getDefaultValue	18	95%
Vdm2Uml‘getGenericTypes	62	√
Vdm2Uml‘getSuperClasses	62	√
Vdm2Uml‘CreateEndProperty	30	√
Vdm2Uml‘GetSimpleTypeName	2	62%
Vdm2Uml‘convertScopeToVisibility	62	√
Vdm2Uml‘CreateAssociationFromProperty	20	√

Name	#Calls	Coverage
Vdm2Uml‘hasSubclassResponsibilityDefinition	62	√
Vdm2Uml‘CreateAssociationFromPropertyGeneral	14	√
Vdm2Uml‘CreateAssociationFromPropertyUnionType	3	√
Vdm2Uml‘CreateAssociationFromPropertyProductType	3	√
Vdm2Uml‘build-def-block	9	√
Vdm2Uml‘build-def-block	3	√
Vdm2Uml‘build-def-block	2	√
Vdm2Uml‘build-def-block	4	√
Vdm2Uml‘build-def-block	15	√
Total Coverage		97%

F.1.2 VDM to UML type converter (Vdm2UmlType)

Class providing type conversion.

extractMultiplicity Extract multiplicity from type.

getQualifier Get qualifier from type.

convertType Convert a OML type to UML.

convertPropertyType Convert property.

class $Vdm2UmlType$
types
    public $String$ = char*
operations
public static
    $extractMultiplicity : IOmlType \xrightarrow{o} IUmlMultiplicityElement$
    $extractMultiplicity\ (t)\ \triangleq$
    (dcl $isOrdered : \mathbb{B}$:= false,
        $isUnique : \mathbb{B}$:= true,
        $lower : \mathbb{N} := 1$,
        $upper : [\mathbb{N}] := 1$;
      cases true:
        (isofclass ($IOmlSetType$, t)) $\rightarrow$
          ($upper$:= nil ;
            $lower := 0$;
            $isOrdered$:= false
          ),
        (isofclass ($IOmlSeq0Type$, t)) $\rightarrow$
          ($lower := 0$;
            $upper$:= nil ;
            $isOrdered$:= true;
            $isUnique$:= false
          ),
        (isofclass ($IOmlSeq1Type$, t)) $\rightarrow$
          ($lower := 1$;
            $upper$:= nil ;
            $isOrdered$:= true;
            $isUnique$:= false
          ),

```
            (isofclass (IOmlGeneralMapType, t)),
            (isofclass (IOmlInjectiveMapType, t)) →
                (   isOrdered := true;
                    upper := nil ;
                    lower := 0;
                    isUnique := false
                ),
            (isofclass (IOmlOptionalType, t)) →
                (   upper := 1;
                    lower := 0
                )
        end ;
        return new UmlMultiplicityElement (isOrdered, isUnique, lower, upper)
    )
functions
public static
    getQualifier : IOmlType → [IUmlType]
    getQualifier (t) ≜
      cases true :
        (isofclass (IOmlInjectiveMapType, t)) → let t1 : IOmlInjectiveMapType = t in
                                                  convertType (t1.getDomType ()),
        (isofclass (IOmlGeneralMapType, t)) → let t1 : IOmlGeneralMapType = t in
                                                 convertType (t1.getDomType ()),
        others → nil
      end;
public static
```

$convertType : IOmlType \rightarrow [IUmlType]$
$convertType\,(t) \triangleq$
cases true :
(isofclass $(IOmlBoolType, t)) \rightarrow$ new $UmlBoolType\,()$,
(isofclass $(IOmlNat1Type, t)) \rightarrow$ new $UmlIntegerType\,()$,
(isofclass $(IOmlNatType, t)) \rightarrow$ new $UmlIntegerType\,()$,
(isofclass $(IOmlIntType, t)) \rightarrow$ new $UmlIntegerType\,()$,
(isofclass $(IOmlRealType, t)) \rightarrow$ new $UmlUnlimitedNatural\,()$,
(isofclass $(IOmlCharType, t)) \rightarrow$ new $UmlCharType\,()$,
(isofclass $(IOmlTokenType, t)) \rightarrow$ new $UmlIntegerType\,()$,
(isofclass $(IOmlSetType, t)) \rightarrow$ let $t1 : IOmlSetType = t$ in
$convertType\,(t1.getType\,())$,
(isofclass $(IOmlSeq0Type, t)) \rightarrow$ let $t1 : IOmlSeq0Type = t$ in
$convertType\,(t1.getType\,())$,
(isofclass $(IOmlSeq1Type, t)) \rightarrow$ let $t1 : IOmlSeq1Type = t$ in
$convertType\,(t1.getType\,())$,
(isofclass $(IOmlInjectiveMapType, t)) \rightarrow$ let $t1 : IOmlInjectiveMapType = t$ in
$convertType\,(t1.getRngType\,())$,
(isofclass $(IOmlGeneralMapType, t)) \rightarrow$ let $t1 : IOmlGeneralMapType = t$ in
$convertType\,(t1.getRngType\,())$,
(isofclass $(IOmlEmptyType, t)) \rightarrow$ nil ,
(isofclass $(IOmlOptionalType, t)) \rightarrow$ let $t1 : IOmlOptionalType = t$ in
$convertType\,(t1.getType\,())$,
(isofclass $(IOmlTypeName, t)) \rightarrow$ let $a : IOmlTypeName = t$ in
new $UmlClassNameType\,(a.getName\,().getIdentifier\,())$,
others $\rightarrow$ nil
end;
public static
$convertPropertyType : IOmlType \times String \rightarrow IUmlType$
$convertPropertyType\,(t, owner) \triangleq$
let $ty = convertType\,(t)$ in
if $ty =$ nil
then new $UmlClassNameType\,(owner)$
else ty
end Vdm2UmlType

Test Suite : vdm.tc
Class : Vdm2UmlType

Name	#Calls	**C**overage
Vdm2UmlType‘convertType	167	87%
Vdm2UmlType‘getQualifier	74	$\surd$

Name	#Calls	**C**overage
Vdm2UmlType‘convertPropertyType	53	√
Vdm2UmlType‘extractMultiplicity	74	91%
Total Coverage		**9**0%

F.1.3 Serilize the UML AST to XMI with EA support (Uml2XmiEAxml)

Serialize the UML AST into a *abstract* XMI model.

Save Save UML model to file.

CreateXmlFile Create and construct XML model.

AddDefinitions Add definitions to XML model.

AddConstraint Add constraint to XML doc.

AddExstention Add EA extentions to XML doc. Association navigation symbol. Contraints. Qualified Association. Template parameters.

GenerateClassIds Create map of class names to class id in model.

AddClass Add class to XML model.

AddPropeties Add properties to XML model.

AddOperstions Add operations to XML model.

AddAssociation Add association to XML model.

AddAssociationMp Add multiplicity element to XML model.

AddGeneralization Add generalization to XML model.

AddTemplates Add template signature to XML model.

GetUmlPrimitiveTypeId Get id of UML primitive type used in XML model.

AddStdTypes Add primitive types to XML model.

AddPrimitiveType Add primitive type to XML model returns the id of the type added.

GetTypeId Get id in XML model of a UML type.

GetNextId Get next id for use in XML model.

GetId Construct if from a int.

GetVisibilityKind Get visibility name form visibility type. The name to use in the XML model.

class $Uml2XmiEAxml$ is subclass of $Uml2Xmi$
types
public

$QualifierInfo :: AssociationId : String$
$\quad ClassId : String$
$\quad QualifierName : String;$

public
$QualifierEnd :: Property : IUmlProperty$
$\quad IsNavigable : \mathbb{B}$

values
$ID\text{-}TAG : String = "xmi : id";$
$ownedMemberElementName : String = "ownedMember"$

instance variables
protected $id : \mathbb{Z} := 1;$
protected $packageId : \mathbb{Z} := 0;$
protected $classes : String \xrightarrow{m} String := \{\mapsto\};$
protected $primitiveTypes : String \xleftrightarrow{m} String := \{\mapsto\};$
protected $associationIdMap : String \xrightarrow{m} String := \{\mapsto\};$
protected $oe : String := ""$;
protected $extensionTemplateClasses : String$-set $:= \{\};$
protected $extensionConstrainElem : String$-set $:= \{\};$
protected $extensionConectorNonNavigable : String$-set $:= \{\};$
protected $extensionConectorQualifier : QualifierInfo$-set $:= \{\};$

operations
public
$Save : \text{char}^{+} \times IUmlModel \xrightarrow{o} ()$
$Save\,(fileName, model) \triangleq$
(dcl $xmlVisitor : XmlFileOutputVisitor :=$ new $XmlFileOutputVisitor\,();$
$\quad CreateXmlFile(model)\,;$
$\quad Util`Clear()\,;$
$\quad xmlVisitor.setEncoding("UTF\text{-}8")\,;$
$\quad xmlVisitor.VisitXmlDocument(doc)\,;$
$\quad Util`SaveBuf\,(fileName)$
);

protected

$CreateXmlFile : IUmlModel \xrightarrow{o} ()$
$CreateXmlFile\,(m) \triangleq$
$($ $oe := ownedMemberElementName;$
$doc.StartE(\texttt{"}xmi : XMI\texttt{"})\,;$
$doc.StartA(\texttt{"}xmi : version\texttt{"}, \texttt{"2.1"})\,;$
$doc.StartA(\texttt{"}xmlns{:}uml\texttt{"}, \texttt{"}http{:}//schema.omg.org/spec/UML/2.0\texttt{"});$
$doc.StartA(\texttt{"}xmlns{:}xmi\texttt{"}, \texttt{"}http{:}//schema.omg.org/spec/XMI/2.1\texttt{"});$
$doc.StartE(\texttt{"}xmi : Documentation\texttt{"})\,;$
$doc.StartA(\texttt{"}xmi : Exporter\texttt{"}, \texttt{"}Enterprise\ \ Architect\texttt{"})\,;$
$doc.StartA(\texttt{"}xmi : ExporterVersion\texttt{"}, \texttt{"6.5"})\,;$
$doc.StopE(\texttt{"}xmi : Documentation\texttt{"})\,;$
$doc.StartE(\texttt{"}uml : Model\texttt{"})\,;$
$doc.StartA(\texttt{"}name\texttt{"}, m.getName\,())\,;$
$doc.StartA(ID\text{-}TAG, GetNextId\,())\,;$
$doc.StartE(oe)\,;$
$doc.StartA(\texttt{"}xmi : type\texttt{"}, \texttt{"}uml : Package\texttt{"})\,;$
$doc.StartA(ID\text{-}TAG, GetId\,(packageId))\,;$
$doc.StartA(\texttt{"}name\texttt{"}, \texttt{"}VDM\ \ Generated\ \ model\texttt{"})\,;$
$AddStdTypes()\,;$
$GenerateClassIds(m.getDefinitions\,())\,;$
$AddDefinitions(\{d \mid d \in m.getDefinitions\,()\cdot(\text{isofclass}\,(), IUmlClass)\,d\});$
$AddDefinitions(\{d \mid d \in m.getDefinitions\,()\cdot(\text{isofclass}\,(), IUmlAssociation)\,d\});$
$AddDefinitions(\{d \mid d \in m.getDefinitions\,()\cdot(\text{isofclass}\,(), IUmlConstraint)\,d\});$
$doc.StopE(oe)\,;$
$doc.StopE(\texttt{"}uml : Model\texttt{"})\,;$
$AddExstention()\,;$
$doc.StopE(\texttt{"}xmi : XMI\texttt{"})$
);

private

$AddDefinitions : IUmlModelElement\text{-set} \xrightarrow{o} ()$
$AddDefinitions\,(defs) \triangleq$
for all $c \in \{d \mid d \in defs\}$
do (cases true:
(isofclass $(IUmlConstraint, c)) \rightarrow AddConstraint(c)$,
(isofclass $(IUmlAssociation, c)) \rightarrow AddAssociation(c)$,
(isofclass $(IUmlClass, c)) \rightarrow AddClass(c)$
end
) ;

private

$AddConstraint : IUmlConstraint \xrightarrow{o} ()$
$AddConstraint\,(c) \triangleq$
($doc.StartE(oe)$;
$doc.StartA($"$xmi : type$", "$uml : Constraint$"$)$;
let $constrainId = GetNextId\,()$ in
($extensionConstrainElem := extensionConstrainElem \cup \{constrainId\}$;
$doc.StartA(ID\text{-}TAG, constrainId)$
) ;
for all $a \in c.getConstraintElements\,()$
do ($doc.StartE($"$constrainedElement$"$)$;
$doc.StartA($"$xmi : idref$", $associationIdMap\,(a))$;
$doc.StopE($"$constrainedElement$"$)$
) ;
$doc.StartE($"$specification$"$)$;
$doc.StartA($"$xmi : type$", "$uml : OpaqueExpression$"$)$;
$doc.StartA(ID\text{-}TAG, GetNextId\,())$;
$doc.StopE($"$specification$"$)$;
$doc.StartE($"$body$"$)$;
$doc.StartD($if isofclass $(IUmlLiteralString, c.getSpecification\,())$
then let $spec : IUmlLiteralString = c.getSpecification\,()$ in
$spec.getValue\,()$
else ""$)$;
$doc.StopE($"$body$"$)$;
$doc.StopE($"$specification$"$)$;
$doc.StopE(oe)$
);

private

$AddExstention : () \xrightarrow{o} ()$
$AddExstention\,() \triangleq$
($doc.StartE($"$xmi : Extension$"$)$;
$doc.StartA($"$extender$", "$Enterprise\;\; Architect$"$)$;
$doc.StartA($"$extenderID$", "6.5"$)$;
$doc.StartE($"$elements$"$)$;
for all $c \in extensionTemplateClasses$

```
do (    doc.StartE("element") ;
        doc.StartA("xmi : idref", classes (c)) ;
        doc.StartA("xmi : type", "uml : Class") ;
        doc.StartA("name", c) ;
        doc.StartA("scope", "public") ;
        doc.StartE("properties") ;
        doc.StartA("sType", "Class") ;
        doc.StartA("nType", "1") ;
        doc.StopE("properties") ;
        doc.StopE("element")
   ) ;
for all constrainId ∈ extensionConstrainElem
do (    doc.StartE("element") ;
        doc.StartA("xmi : idref", constrainId) ;
        doc.StartA("xmi : type", "uml : Constraint") ;
        doc.StartA("scope", "public") ;
        doc.StartE("properties") ;
        doc.StartA("documentation", "xor") ;
        doc.StartA("isSpecification", "false") ;
        doc.StartA("sType", "Constraint") ;
        doc.StartA("nType", "2") ;
        doc.StartA("scope", "public") ;
        doc.StopE("properties") ;
        doc.StopE("element")
   ) ;
doc.StopE("elements") ;
doc.StartE("diagrams") ;
for all constrainId ∈ extensionConstrainElem
```

```
do ( doc.StartE("diagram");
     doc.StartA(ID-TAG, GetNextId());
     doc.StartE("model");
     doc.StartA("package", GetId(packageId));
     doc.StartA("localID", "24");
     doc.StartA("owner", GetId(packageId));
     doc.StopE("model");
     doc.StartE("properties");
     doc.StartA("name", "Constrain diagram " ⁀ constrainId);
     doc.StartA("type", "Logical");
     doc.StopE("properties");
     doc.StartE("elements");
     doc.StartE("element");
     doc.StartA("geometry", "Left = 100; Top = 100; Right =
100; Bottom = 100; ");
     doc.StartA("subject", constrainId);
     doc.StartA("seqno", "1");
     doc.StartA("style", "DUID = AE8AC20D; ");
     doc.StopE("element");
     doc.StopE("elements");
     doc.StopE("diagram")
   );
doc.StopE("diagrams");
doc.StartE("connectors");
for all associationEndId ∈ extensionConectorNonNavigable
do ( doc.StartE("connector");
     doc.StartA("xmi : idref", associationEndId);
     doc.StartE("properties");
     doc.StartA("ea_type", "Association");
     doc.StartA("direction", "Unspecified");
     doc.StopE("properties");
     doc.StopE("connector")
   );
for all qualifier ∈ extensionConectorQualifier
```

```
                do (   doc.StartE("connector") ;
                         doc.StartA("xmi:idref", qualifier.AssociationId) ;
                         doc.StartE("target") ;
                         doc.StartA("xmi:idref", qualifier.ClassId) ;
                         doc.StartE("constraints") ;
                         doc.StartA("qualifier", qualifier.QualifierName) ;
                         doc.StopE("constraints") ;
                         doc.StopE("target") ;
                         doc.StopE("connector")
                   ) ;
                doc.StopE("connectors") ;
                doc.StopE("xmi:Extension")
        );
protected
        GenerateClassIds : IUmlModelElement-set →o ()
        GenerateClassIds (defs) △
        (   for all c ∈ {d | d ∈ defs}
            do (   cases true:
                      (isofclass (IUmlClass, c)) →
                         (   let cl : IUmlClass = c in
                             classes := classes†{cl.getName () ↦ GetNextId ()}
                         )
                   end
               )
        );
protected
```

$AddClass : IUmlClass \xrightarrow{o} ()$
$AddClass\,(cl) \triangleq$
($doc.StartE(oe)$;
$doc.StartA("isAbstract", Util`ToStringBool\,(cl.getIsAbstract\,()))$;
$doc.StartA("isActive", Util`ToStringBool\,(cl.getIsActive\,()))$;
$doc.StartA("isLeaf", "false")$;
$doc.StartA("name", cl.getName\,())$;
$doc.StartA("visibility", "public")$;
$doc.StartA(ID\text{-}TAG, classes\,(cl.getName\,()))$;
$doc.StartA("xmi : type", "uml : Class")$;
$AddPropeties(\bigcup\{$let $d : IUmlOwnedProperties = df$ in
$d.getPropetityList\,()\ |$
$df \in cl.getClassBody\,()$·isofclass $(IUmlOwnedProperties, df)\})$;
$AddOperstions(\bigcup\{$let $d : IUmlOwnedOperations = df$ in
$d.getOperationList\,()\ |$
$df \in cl.getClassBody\,()$·isofclass $(IUmlOwnedOperations, df)\})$;
if len $cl.getSuperClass\,() > 0$
then $AddGeneralization(cl.getSuperClass\,())$;
if $cl.hasTemplatesignature\,()$
then ($AddTemplates(cl.getTemplatesignature\,())$;
$extensionTemplateClasses := extensionTemplateClasses \cup$

$\{cl.getName\,()\}$
) ;
$doc.StopE(oe)$
);

protected
$AddPropeties : IUmlProperty$-set $\xrightarrow{o} ()$
$AddPropeties\,(propeties) \triangleq$
(for all $prop \in propeties$

```
              do (   doc.StartE("ownedAttribute") ;
                     doc.StartA("name", prop.getName ()) ;
                     doc.StartA("ownerScope", "instance") ;
                     if prop.hasIsReadOnly ()
                     then doc.StartA("isReadOnly", StdLib`ToStringBool (prop.getIsReadOnly ()));
                     if prop.hasIsStatic ()
                     then doc.StartA("isStatic", Util`ToStringBool (prop.getIsStatic ()));
                     doc.StartA("visibility", GetVisibilityKind (prop.getVisibility ()));
                     doc.StartA(ID-TAG, GetNextId ()) ;
                     doc.StartA("xmi : type", "uml : Property") ;
                     if prop.hasMultiplicity ()
                     then (   doc.StartA("isOrdered", Util`ToStringBool (prop.getMultiplicity ().getIs
                              AddAssociationMp(prop.getMultiplicity ())
                          ) ;
                     if prop.hasDefault ()
                     then (   doc.StartE("defaultValue") ;
                              doc.StartA("xmi:type", "uml:LiteralString");
                              doc.StartA(ID-TAG, GetNextId ()) ;
                              doc.StartA("value", prop.getDefault ()) ;
                              doc.StopE("defaultValue")
                          ) ;
                     doc.StartE("type") ;
                     doc.StartA("xmi:idref", GetUmlPrimitiveTypeId (prop.getType ()));
                     doc.StopE("type") ;
                     doc.StopE("ownedAttribute")
                 )
         );
protected
      AddOperstions : IUmlOperation-set ⟶o ()
      AddOperstions (ops) △
        (  for all op ∈ ops
```

do ($doc.StartE($"$ownedOperation$"$)$;
$doc.StartA($"$isAbstract$"$, $"$false$"$)$;
$doc.StartA($"$isLeaf$"$, $"$false$"$)$;
$doc.StartA($"$isQuery$"$, $"$false$"$)$;
$doc.StartA($"$name$"$, op.getName\,())$;
$doc.StartA($"$ownerScope$"$, $"$instance$"$)$;
$doc.StartA($"$visibility$"$, GetVisibilityKind\,(op.getVisibility\,()))$;
$doc.StartA(ID\text{-}TAG, GetNextId\,())$;
$doc.StartA($"$xmi : type$"$, $"$uml : Operation$"$)$;
$doc.StopE($"$ownedOperation$"$)$
)
);

protected
$AddAssociation : IUmlAssociation \xrightarrow{o} ()$
$AddAssociation\,(association) \triangleq$
($doc.StartE(oe)$;
$doc.StartA($"$isAbstract$"$, $"$false$"$)$;
$doc.StartA($"$isDerived$"$, $"$false$"$)$;
$doc.StartA($"$isLeaf$"$, $"$false$"$)$;
$doc.StartA($"$name$"$, $""$)$;
let $associationId = GetNextId\,()$ in
($doc.StartA(ID\text{-}TAG, associationId)$;
$associationIdMap := associationIdMap \dagger \{association.getId\,() \mapsto$
$associationId\}$;
$doc.StartA($"$xmi : type$"$, $"$uml : Association$"$)$;
let $unNamedProps : QualifierEnd^* =$
$Util`SetToSeq[QualifierEnd]$
(
$\{$mk-$QualifierEnd\,(p,$ false$) \mid p \in association.getOwnedEnds\,() \cdot$

len $p.getName\,() = 0\} \cup$
$\{$mk-$QualifierEnd\,(p,$ true$) \mid p \in$
$association.getOwnedNavigableEnds\,() \cdot$
len $p.getName\,() = 0\})$,

```
    namedProps =
        Util`SetToSeq[QualifierEnd]
            (
             {mk-QualifierEnd (p, false) | p ∈ association.getOwnedEnds () ·

                     len p.getName () > 0} ∪
             {mk-QualifierEnd (p, true) | p ∈ association.getOwnedNavigableEnds ()

                     len p.getName () > 0}),
    props = (unNamedProps ⌒ namedProps) in
for all i ∈ inds props
do let prop = props (i) in
    (   if prop.Property.hasQualifier ()
        then (   extensionConectorQualifier := extensionConectorQualifier∪

                                        {mk-QualifierInfo (associationId,
                                                      GetTypeId (new
                                                      (primitiveTypes⁻¹
            ) ;
        doc.StartE("ownedEnd") ;
        doc.StartA("aggregation", "none") ;
        doc.StartA("association", associationId) ;
        doc.StartA("isNavigable", Util`ToStringBool (prop.IsNavigable));
        if len (prop.Property.getName ()) > 0
        then doc.StartA("name", prop.Property.getName ())
```

```
                    else doc.StartA("name", "");
                    doc.StartA("visibility", GetVisibilityKind (prop.Property.getVisibility ()));
                    let associationEndId = GetNextId () in
                    (    doc.StartA(ID-TAG, associationEndId);
                         doc.StartA("xmi : type", "uml : Property");
                         if prop.Property.hasMultiplicity ()
                         then (    doc.StartA("isOrdered", Util‘ToStringBool (prop.Property.getM
                                   AddAssociationMp(prop.Property.getMultiplicity ())
                              );
                         if ¬ prop.IsNavigable
                         then extensionConectorNonNavigable := extensionConectorNonNavigab
{associationEndId};
                         if prop.Property.hasIsStatic ()
                         then doc.StartA("isStatic", Util‘ToStringBool (prop.Property.getIsStati
                         doc.StartE("type");
                         doc.StartA("xmi:idref", GetTypeId (prop.Property.getType ()));
                         doc.StopE("type");
                         doc.StopE("ownedEnd");
                         doc.StartE("memberEnd");
                         doc.StartA("xmi : idref", associationEndId);
                         doc.StopE("memberEnd")
                    )
               );
            doc.StopE(oe)
         )
      );
protected
    AddAssociationMp : IUmlMultiplicityElement →o ()
    AddAssociationMp (me) △
      (    doc.StartE("lowerValue");
           doc.StartA("value", Util‘ToString[ℕ] (me.getLower ()));
           doc.StartA(ID-TAG, GetNextId ());
           doc.StartA("xmi : type", "uml : LiteralInteger");
           doc.StopE("lowerValue");
           if me.hasUpper ()
           then (    doc.StartE("upperValue");
                     doc.StartA("value", Util‘ToString[ℕ] (me.getUpper ()));
                     doc.StartA(ID-TAG, GetNextId ());
                     doc.StartA("xmi : type", "uml : LiteralInteger");
                     doc.StopE("upperValue")
                )
```

else ($doc.StartE($"$upperValue$"$)$;
$doc.StartA($"$value$"$, $"$ * $"$)$;
$doc.StartA(ID\text{-}TAG, GetNextId\,())$;
$doc.StartA($"$xmi : type$"$, $"$uml : LiteralString$"$)$;
$doc.StopE($"$upperValue$"$)$
)
);

protected
$AddGeneralization : IUmlClassNameType^* \xrightarrow{o} ()$
$AddGeneralization\,(supers) \triangleq$
(for all $a \in$ elems $supers$
do ($doc.StartE($"$generalization$"$)$;
$doc.StartA($"$xmi : type$"$, $"$uml : Generalization$"$)$;
$doc.StartA(ID\text{-}TAG, GetNextId\,())$;
$doc.StartA($"$general$"$, classes\,(a.getName\,()))$;
$doc.StopE($"$generalization$"$)$
)
);

protected
$AddTemplates : IUmlTemplateSignature \xrightarrow{o} ()$
$AddTemplates\,(tps) \triangleq$
($doc.StartE($"$ownedTemplateSignature$"$)$;
$doc.StartA($"$xmi : type$"$, $"$uml : TemplateSignature$"$)$;
$doc.StartA(ID\text{-}TAG, GetNextId\,())$;
for all $a \in tps.getTemplateParameters\,()$
do (dcl $parameterId : String := GetNextId\,()$;

$doc.StartE($"$ownedParameter$"$) ;
$doc.StartA($"$xmi{:}type$"$, $"$uml{:}ClassifierTemplateParameter$"$);
$doc.StartA(ID\text{-}TAG, parameterId)$;
$doc.StartE($"$ownedElement$"$) ;
$doc.StartA($"$xmi : type$"$, $"$uml : Class$"$) ;
$doc.StartA(ID\text{-}TAG, GetNextId\ ())$;
$doc.StartA($"$name$"$, a.getName\ ())$;
$doc.StartA($"$templateParameter$"$, parameterId)$;
$doc.StopE($"$ownedElement$"$) ;
$doc.StopE($"$ownedParameter$"$) ;
$doc.StartE($"$parameter$"$) ;
$doc.StartA($"$xmi : idref$"$, parameterId)$;
$doc.StopE($"$parameter$"$)
) ;
$doc.StopE($"$ownedTemplateSignature$"$)
);
protected
$GetUmlPrimitiveTypeId : IUmlType \xrightarrow{o} String$
$GetUmlPrimitiveTypeId\ (t) \triangleq$
cases true:
(isofclass $(IUmlBoolType, t)) \rightarrow$
return $primitiveTypes$ ("$bool$"),
(isofclass $(IUmlIntegerType, t)) \rightarrow$
return $primitiveTypes$ ("int"),
(isofclass $(IUmlUnlimitedNatural, t)) \rightarrow$
return $primitiveTypes$ ("$unlimitedNatural$"),
(isofclass $(IUmlCharType, t)) \rightarrow$
return $primitiveTypes$ ("$char$"),
others $\rightarrow$ return $primitiveTypes$ ("$String$")
end;
protected

$AddStdTypes : () \xrightarrow{o} ()$
$AddStdTypes\ () \triangleq$
($primitiveTypes := primitiveTypes\ \dagger$
$\{"bool" \mapsto AddPrimitiveType\ ("bool")\};$
$primitiveTypes := primitiveTypes\ \dagger$
$\{"int" \mapsto AddPrimitiveType\ ("int")\};$
$primitiveTypes := primitiveTypes\ \dagger$
$\{"char" \mapsto AddPrimitiveType\ ("char")\};$
$primitiveTypes := primitiveTypes\ \dagger$
$\{"unlimitedNatural" \mapsto AddPrimitiveType\ ("unlimitedNatural")\};$
$primitiveTypes := primitiveTypes\ \dagger$
$\{"String" \mapsto AddPrimitiveType\ ("String")\};$
$primitiveTypes := primitiveTypes\ \dagger$
$\{"NotSupportedType" \mapsto AddPrimitiveType\ ("NotSupportedType")\}$
);

protected
$AddPrimitiveType : String \xrightarrow{o} String$
$AddPrimitiveType\ (typeName) \triangleq$
($doc.StartE(oe)$;
$doc.StartA("name", typeName)$;
$doc.StartA("visibility", "public")$;
let $tid = GetNextId\ ()$ in
($doc.StartA(ID\text{-}TAG, tid)$;
$doc.StartA("xmi : type", "uml : Class")$;
$doc.StopE(oe)$;
return tid
)
);

protected
$GetTypeId : IUmlType \xrightarrow{o} String$
$GetTypeId\ (t) \triangleq$
cases true:
(isofclass $(IUmlClassNameType, t)) \rightarrow$
let $qc : IUmlClassNameType = t$ in
(if $\exists\, x \in$ dom $classes \cdot x = qc.getName\ ()$
then (return $classes\ (qc.getName\ ())$
)
else (return $primitiveTypes\ ("NotSupportedType")$
)
),

(isofclass $(IUmlBoolType, t)$),
(isofclass $(IUmlIntegerType, t)$),
(isofclass $(IUmlCharType, t)$),
(isofclass $(IUmlUnlimitedNatural, t)$) $\rightarrow$ return $GetUmlPrimitiveTypeId\ (t)$,
others $\rightarrow$ return $primitiveTypes$ ("$NotSupportedType$")
end;

protected
$GetNextId : () \xrightarrow{o} String$
$GetNextId\ () \triangleq$
($id := id + 1$;
return $GetId\ (id)$
)

functions

protected
$GetId : \mathbb{Z} \rightarrow String$
$GetId\ (idNum) \triangleq$
"$VDM.$" $\curvearrowright$ $Util`ToString[\mathbb{Z}]\ (idNum)$;

protected
$GetVisibilityKind : IUmlVisibilityKind \rightarrow String$
$GetVisibilityKind\ (visibility) \triangleq$
cases $visibility.getValue\ ()$:
$(UmlVisibilityKindQuotes`IQPUBLIC) \rightarrow$ ("$public$"),
$(UmlVisibilityKindQuotes`IQPRIVATE) \rightarrow$ ("$private$"),
$(UmlVisibilityKindQuotes`IQPROTECTED) \rightarrow$ ("$protected$")
end

end Uml2XmiEAxml

Test Suite : vdm.tc
Class : Uml2XmiEAxml

Name	#Calls	**C**overage
Uml2XmiEAxml‘Save	19	√
Uml2XmiEAxml‘GetId	406	√
Uml2XmiEAxml‘AddClass	38	√
Uml2XmiEAxml‘GetNextId	383	√
Uml2XmiEAxml‘GetTypeId	43	86%
Uml2XmiEAxml‘AddStdTypes	19	√
Uml2XmiEAxml‘AddPropeties	38	√
Uml2XmiEAxml‘AddTemplates	1	√
Uml2XmiEAxml‘AddConstraint	2	98%
Uml2XmiEAxml‘AddExstention	19	√
Uml2XmiEAxml‘AddOperstions	38	√

Name	#Calls	Coverage
Uml2XmiEAxml‘CreateXmlFile	19	$\surd$
Uml2XmiEAxml‘AddAssociation	17	$\surd$
Uml2XmiEAxml‘AddDefinitions	57	$\surd$
Uml2XmiEAxml‘AddAssociationMp	53	$\surd$
Uml2XmiEAxml‘AddPrimitiveType	114	$\surd$
Uml2XmiEAxml‘GenerateClassIds	19	$\surd$
Uml2XmiEAxml‘AddGeneralization	1	$\surd$
Uml2XmiEAxml‘GetVisibilityKind	65	$\surd$
Uml2XmiEAxml‘GetUmlPrimitiveTypeId	32	73%
Total Coverage		98%

F.2 Transforming UML to VDM

In this section classes used to transform a UML model into VDM is shown.

F.2.1 Convert XMI to a UML model (Xml2UmlModel)

Convert the XMI document to the UML AST.

VisitXmlDocument Create UML model form document. If a valid document is passed the result variable will contain the result parsed document.

exstractClass Exstract UML class from XML element.

build_defBlock Create property definitions form XML property element. Attribute type is property.

build_Property Create property from property element.

getDefaultValue Get default value. Initial value.

getMultiplicity Get multiplicity.

build_Operation Create operation from xml element element.

build_Constraint Create constraint from constraint elements.

build_Association Create association from association element.

lookUpType Get UmlType from XML type name.

VisitXmlEntity Visit element and build classes or association depended on the element type attribute.

hasAttribute Test if a element has an attribute with a specific name.

hasAttributeValue Test if a element has a specific element with a specific name and type.

isAttributeType Test if a element has a specific type. By looking up the type attribute.

getElementType Get the UML type attribute value or the name of the element if no such attribute exists.

getAttribute Get XML attribute from name. If unknown return nil.

GetVisibility Convert visibility name to UmlVisibility type.

build_Collobration Create a Collaboration from a XML node.

build_Interaction Create a Collaboration from a XML node.

build_Message Create a Collaboration from a XML node.

build_Fragment Delegating the creation of a fragment to the responsible operation only needed because limitation in Java Code Gen.

build_Mos Create MOS from XmlElement.

build_Bes Create BES from XmlElement.

build_Combi Create CombinedFragment from XmlElement.

GetIntOperationKind Get interaction kind from a string.

build_Operand Create Operand from XmlElement.

GetCoveredExtension Get covered extension. Exstracts covered string.

GetCovered Get covered seq of ids.

GetGuard Get guard from entity.

getGuardConstraintValue Get value of constraint on a guard.

buildCallEventMap Build id to callEvent map.

class $Xml2UmlModel$ is subclass of $XmlVisitor$
types
public $String = \text{char}^*$
instance variables
public $result : [IUmlModel] := \text{nil}$;
$primiticeTypes : String\text{-set} := \{"char", "int", "bool", "String", "unlimitedNatural", "NotSu$
$classes : IUmlClass\text{-set} := \{\};$
$associations : IUmlAssociation\text{-set} := \{\};$
$constraints : IUmlConstraint\text{-set} := \{\};$
$classesTypeMap : String \xrightarrow{m} String := \{\mapsto\};$
$collaborations : IUmlCollaboration\text{-set} := \{\};$
$idToclassesMap : String \xrightarrow{m} IUmlClass := \{\mapsto\};$
$idToOperationMap : String \xrightarrow{m} IUmlOperation := \{\mapsto\};$
$idToClallEventMap : String \xrightarrow{m} IUmlCallEvent := \{\mapsto\};$
$lifeLineMap : String \xrightarrow{m} IUmlLifeLine := \{\mapsto\};$
$mosMap : String \xrightarrow{m} IUmlMos := \{\mapsto\};$
$besMap : String \xrightarrow{m} IUmlBes := \{\mapsto\};$
$combiMap : String \xrightarrow{m} IUmlCombinedFragment := \{\mapsto\};$

operations
public

$$VisitXmlDocument : XmlDocument \xrightarrow{o} ()$$

$$VisitXmlDocument\,(doc) \triangleq$$

$$(\ \ \mathsf{dcl}\ root : XmlEntity := \mathsf{hd}\ doc.entities.entities,$$

$$firstPackageAndRoot : XmlEntity^* := root.entities.entities \curvearrowright [root],$$

$$model : XmlEntity := \mathsf{hd}\ [firstPackageAndRoot\,(i) \mid i \in \mathsf{inds}\ firstPackageAndRoot \cdot firstPackageAndRoot\,(i).name = \texttt{"}uml{:}Model\texttt{"}],$$

$$package : XmlEntity := \mathsf{hd}\ [model.entities.entities\,(i) \mid i \in \mathsf{inds}\ model.entities.entities \cdot isAttributeType\,(model.entities.entities\,(i), \texttt{"}uml{:}Package\texttt{"})];$$

let $pes = package.entities.entities$ in
($classesTypeMap := classesTypeMap \dagger \{getAttribute\,(pes\,(i), "xmi{:}id").val \mapsto getAttribute\,(pes\,(i), "name").val \mid i \in$ inds $pes \cdot$
$isAttributeType\,(pes\,(i), "uml{:}Class")\}$;
$classes := classes \cup \{exstractClass\,(pes\,(i)) \mid i \in$ inds $pes \cdot$
$isAttributeType\,(pes\,(i), "uml{:}Class") \wedge$
$(getAttribute\,(pes\,(i), "name").val \notin primiticeTypes)\}$;
$associations := associations \cup \{build\text{-}Association\,(pes\,(i)) \mid i \in$ inds $pes \cdot$
$isAttributeType\,(pes\,(i), "uml{:}Association")\}$;
$constraints := constraints \cup \{build\text{-}Constraint\,(pes\,(i)) \mid i \in$ inds $pes \cdot$
$isAttributeType\,(pes\,(i), "uml{:}Constraint")\}$;
$idToClallEventMap := buildCallEventMap\,(\{(pes\,(i)) \mid i \in$ inds $pes \cdot$
$isAttributeType\,(pes\,(i), "uml{:}CallEvent")\})$;
$collaborations := collaborations \cup \{build\text{-}Collobration\,(pes\,(i)) \mid i \in$ inds $pes \cdot$
$isAttributeType\,(pes\,(i), "uml{:}Collaboration")\}$
);
$result :=$ new $UmlModel\,(getAttribute\,(package, "name").val,$
$classes \cup associations \cup constraints \cup collaborations)$
);

private

$exstractClass : XmlEntity \xrightarrow{o} IUmlClass$

$exstractClass\,(e) \triangleq$

let $name :$ char$^* = getAttribute\,(e, "name").val,$
$dBlocks : (IUmlDefinitionBlock$-set$) = build\text{-}defBlock\,(e, name),$
$abstract : \mathbb{B} =$ if $hasAttribute\,(e, "isAbstract")$
then $StdLib`StringToBool\,(getAttribute\,(e, "isAbstract").val)$
else false,
$supers : IUmlClassNameType^* = [],$
$visibility : (IUmlVisibilityKind) =$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPUBLIC),$

```
        isStatic : (𝔹) =
              false,
        active : (𝔹) = if hasAttribute (e, "isActive")
                      then let a = getAttribute (e, "isActive") in
                            if a ≠ nil
                            then StdLib‘StringToBool (a.val)
                            else false
                      else false,
        template : [IUmlTemplateSignature] = nil ,
        id : String = getAttribute (e, "xmi : id").val,
        cls : IUmlClass =
              new UmlClass (name,
                            dBlocks,
                            abstract,
                            supers,
                            visibility,
                            isStatic,
                            active,
                            template) in
    (   idToclassesMap := idToclassesMap † {id ↦ cls};
        return cls
    )
  pre  isAttributeType (e, "uml : Class") ;
private
  build-defBlock : XmlEntity × String →ᵒ (IUmlDefinitionBlock-set)
  build-defBlock (e, name) △
    let eList = e.entities.entities,
        props = {build-Property (eList (i), name) |
                    i ∈ inds eList · isAttributeType (eList (i), "uml :
Property")},
        ops = {build-Operation (p) |
                  p ∈ elems eList·isAttributeType (p, "uml:Operation")} in
    return {new UmlOwnedProperties (props)}∪{new UmlOwnedOperations (ops)};
private
  build-Property : XmlEntity × String →ᵒ IUmlProperty
  build-Property (e, ownerClass) △
    let name : char* = getAttribute (e, "name").val,
        visibility : (IUmlVisibilityKind) = if hasAttribute (e, "visibility")
                                           then GetVisibility (getAttribute (e, "visibility"))
                                           else new UmlVisibilityKind (UmlVisibilityKindQuotes
        multiplicity : [IUmlMultiplicityElement] = getMultiplicity (e),
```

$type : (IUmlType) = lookUpType\,(e)$,
$isReadOnly : [\mathbb{B}] =$
if $hasAttribute\,(e, "isReadOnly")$
then $StdLib`StringToBool\,(getAttribute\,(e, "isReadOnly").val)$
else false,
$default : [\text{char}^*] = getDefaultValue\,(e)$,
$isComposite : (\mathbb{B}) =$ false,
$isDerived : [\mathbb{B}] =$ false,
$isStatic : [\mathbb{B}] =$ false,
$qualifier : [IUmlType] =$
nil in
return new $UmlProperty\,(name,$
$visibility,$
$multiplicity,$
$type,$
$isReadOnly,$
$default,$
$isComposite,$
$isDerived,$
$isStatic,$
$ownerClass,$
$qualifier)$
pre $isAttributeType\,(e, "uml : Property")$;
private
$getDefaultValue : XmlEntity \xrightarrow{o} [String]$
$getDefaultValue\,(e) \triangleq$
let $eList = e.entities.entities$,
$tmp = \{getAttribute\,(el, "value").val \mid el \in$ elems $eList \cdot el.name =$
$"defaultValue"\}$ in
if card $tmp > 0$
then let $t \in tmp$ in
return t
else return nil ;
private
$getMultiplicity : XmlEntity \xrightarrow{o} [IUmlMultiplicityElement]$
$getMultiplicity\,(e) \triangleq$
let $eList = e.entities.entities$,
$lowerSet = \{getAttribute\,(el, "value").val \mid el \in$ elems $eList \cdot$
$el.name = "lowerValue" \wedge hasAttribute\,(e, "value")\}$,

$upperSet = \{getAttribute\,(el, "value").val \mid el \in$ elems $eList \cdot$
$el.name = "upperValue" \wedge hasAttribute\,(e, "value")\}$ in
if card $upperSet = 0 \wedge$ card $lowerSet = 0$
then return nil
else let $lower : \mathbb{N} =$ if card $lowerSet = 0$
then 0
else let $p \in lowerSet$ in
$StdLib`StringToInt\,(p)$,
$upper : [\mathbb{N}] =$ if card $upperSet = 0$
then nil
else let $p \in upperSet$ in
$StdLib`StringToInt\,(p)$ in
return new $UmlMultiplicityElement$ (false, false, $lower, upper$);

private
$build\text{-}Operation : XmlEntity \xrightarrow{o} IUmlOperation$
$build\text{-}Operation\,(e) \triangleq$
let $name$: char$^* = getAttribute\,(e, "name").val$,
$visibility : (IUmlVisibilityKind) = GetVisibility\,(getAttribute\,(e, "visibility"))$,
$multiplicity : IUmlMultiplicityElement =$ new $UmlMultiplicityElement$ (false, false, $0, 0$),
$isQuery : \mathbb{B} =$
if $hasAttribute\,(e, "isQuery")$
then $StdLib`StringToBool\,(getAttribute\,(e, "isQuery").val)$
else false,
$type : [IUmlType] =$ nil ,
$isStatic : \mathbb{B} =$ if $hasAttribute\,(e, "isStatic")$
then $StdLib`StringToBool\,(getAttribute\,(e, "isStatic").val)$
else false,
$id : String = getAttribute\,(e, "xmi : id").val$,
$operation : IUmlOperation =$ new $UmlOperation\,(name,$
$visibility,$
$multiplicity,$
$isQuery,$
$type,$
$isStatic,$
nil) in
($idToOperationMap := idToOperationMap \dagger \{id \mapsto operation\}$;
return $operation$
)
pre $isAttributeType\,(e, "uml : Operation")$

functions
private

$build\text{-}Constraint : XmlEntity \to IUmlConstraint$
$build\text{-}Constraint\,(e) \triangleq$
let $elist = e.entities.entities$,
$ids = \{getAttribute\,(p, "xmi : idref").val \mid p \in$ elems $elist \cdot hasAttribute\,(p, "xmi : idref")\}$,
$specification : String =$ hd $Util`SetToSeq$[char*] $(\{p.data.data \mid p \in$ elems $elist \cdot p.name = "body"\})$ in
new $UmlConstraint\,(ids,$ new $UmlLiteralString\,(specification))$
pre $isAttributeType\,(e, "uml : Constraint")$

operations

private

$build\text{-}Association : XmlEntity \xrightarrow{o} IUmlAssociation$
$build\text{-}Association\,(e) \triangleq$
let $elist = e.entities.entities$,
$props = \{elist\,(i) \mid i \in$ inds $elist \cdot isAttributeType\,(elist\,(i), "uml: Property")\}$,
$ownedNavivableEnds : (IUmlProperty$-set$) = \{build\text{-}Property\,(p, "") \mid p \in props \cdot hasAttributeValue\,(p, "name", "")\}$,
$one = Util`SetToSeq[IUmlProperty]\,(ownedNavivableEnds)$,
$ownerClassType =$ hd $[one\,(i).getType\,() \mid i \in$ inds $one]$,
$ownerClass =$ let $ct : IUmlClassNameType = ownerClassType$ in
$ct.getName\,()$,
$ownedEnds : (IUmlProperty$-set$) = \{build\text{-}Property\,(p, ownerClass) \mid p \in props \cdot$ len $getAttribute\,(p, "name").val > 0\}$,
$name :$ char* $= getAttribute\,(e, "name").val$,
$id : String = getAttribute\,(e, "xmi : id").val$ in
return new $UmlAssociation\,(ownedEnds, ownedNavivableEnds, name, id)$

pre $isAttributeType\,(e, "uml : Association")$;

private

$lookUpType : XmlEntity \xrightarrow{o} IUmlType$
$lookUpType\,(e) \triangleq$
let $elist = e.entities.entities$,
$typeOption1 =$ if $hasAttribute\,(e, "type")$
then $\{getAttribute\,(e, "type").val\}$
else $\{\}$,

$typeOption2 = \{getAttribute\,(elist\,(i), "xmi : idref").val \mid i \in$ inds $elist \cdot elist\,(i).name = "type"\} \cup$
$\{a.val \mid a \in \{getAttribute\,(e, "type")\} \cdot a \neq$ nil $\}$ in
let $id \in typeOption1 \cup typeOption2$ in
let $typeName =$ if $id \in$ dom $classesTypeMap$
then $classesTypeMap\,(id)$
else nil in
cases $typeName$:
nil $\rightarrow$ return new $UmlIntegerType\,()$,
$"String" \rightarrow$ return new $UmlStringType\,()$,
$"int" \rightarrow$ return new $UmlIntegerType\,()$,
$"bool" \rightarrow$ return new $UmlBoolType\,()$,
$"char" \rightarrow$ return new $UmlCharType\,()$,
$"unlimitedNatural" \rightarrow$ return new $UmlUnlimitedNatural\,()$,
others $\rightarrow$ return new $UmlClassNameType\,(typeName)$
end;
public
$VisitXmlEntity : XmlEntity \xrightarrow{o} ()$
$VisitXmlEntity\,(e) \triangleq$
($classes := classes \cup \{exstractClass\,(entity) \mid entity \in \{e\} \cdot$
$isAttributeType\,(entity, "uml : Class") \wedge$
$(getAttribute\,(entity, "name").val \notin primiticeTypes)\}$;
$associations := associations \cup \{build\text{-}Association\,(entity) \mid entity \in \{e\} \cdot$
$isAttributeType\,(entity, "uml:Association")\}$
)
functions
private
$hasAttribute : XmlEntity \times String \rightarrow \mathbb{B}$
$hasAttribute\,(e, name) \triangleq$
let $list = e.attributes.attributes$ in
$\exists\, i \in$ inds $list \cdot list\,(i).name = name$;
private
$hasAttributeValue : XmlEntity \times String \times String \rightarrow \mathbb{B}$
$hasAttributeValue\,(e, name, val) \triangleq$
let $list = e.attributes.attributes$ in
$\exists\, i \in$ inds $list \cdot list\,(i).name = name \wedge list\,(i).val = val$;
private

$isAttributeType : XmlEntity \times String \rightarrow \mathbb{B}$
$isAttributeType\,(e, val) \triangleq$
$hasAttributeValue\,(e, \texttt{"}xmi : type\texttt{"}, val);$

private
$getElementType : XmlEntity \rightarrow String$
$getElementType\,(e) \triangleq$
if $getAttribute\,(e, \texttt{"}xmi : type\texttt{"}) \neq$ nil
then $getAttribute\,(e, \texttt{"}xmi : type\texttt{"}).val$
else $e.name$;

private
$getAttribute : XmlEntity \times String \rightarrow [XmlAttribute]$
$getAttribute\,(e, name) \triangleq$
let $list = e.attributes.attributes,$
$attList = [list\,(i) \mid i \in$ inds $list \cdot list\,(i).name = name]$ in
if len $attList > 0$
then hd $attList$
else nil ;

private static
$GetVisibility : [XmlAttribute] \rightarrow IUmlVisibilityKind$
$GetVisibility\,(v) \triangleq$
if $v \neq$ nil
then cases $v.val$:
$\texttt{"}private\texttt{"} \rightarrow$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPRIVATE),$
$\texttt{"}public\texttt{"} \rightarrow$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPUBLIC),$
$\texttt{"}protected\texttt{"} \rightarrow$
new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPROTECTED)$
end
else new $UmlVisibilityKind\,(UmlVisibilityKindQuotes`IQPRIVATE)$

operations
private
$build\text{-}Collobration : XmlEntity \xrightarrow{o} IUmlCollaboration$
$build\text{-}Collobration\,(e) \triangleq$
let $elist = e.entities.entities,$
$interactions = \{build\text{-}Interaction\,(p) \mid p \in$ elems $elist \cdot isAttributeType\,(p, \texttt{"}uml: Interaction\texttt{"})\}$ in
return new $UmlCollaboration\,(interactions)$
pre $isAttributeType\,(e, \texttt{"}uml : Collaboration\texttt{"})$;

private

```
        build-Interaction : XmlEntity →(o) IUmlInteraction
        build-Interaction (e) △
          let elist = e.entities.entities,
              props : String →(m) IUmlProperty = {getAttribute (p, "xmi:id").val ↦
build-Property (p, "") | p ∈ elems elist·isAttributeType (p, "uml:Property")} in
          (    lifeLineMap := lifeLineMap†{getAttribute (p, "xmi:id").val ↦

                                   new UmlLifeLine (getAttribute (p, "name").val,
                                                    props (getAttribute (p, "represents").val).getType (

                                     p ∈ elems elist ·
                                         p.name = "lifeline"};
             let name : char* = getAttribute (e, "name").val,
                 lifeLines : IUmlLifeLine-set = rng lifeLineMap,
                 mosfragments : IUmlInteractionFragment-set =
                       {build-Fragment (f) | f ∈ elems elist ·
                              isAttributeType (f, "uml:MessageOccurrenceSpecification")},
                 besfragments : IUmlInteractionFragment-set =
                       {build-Fragment (f) | f ∈ elems elist ·
                              isAttributeType (f, "uml:BehaviorExecutionSpecification")},
                 combifragments : IUmlInteractionFragment-set =
                       {build-Fragment (f) | f ∈ elems elist ·
                              isAttributeType (f, "uml:CombinedFragment")},
                 messages : IUmlMessage* =
                       [build-Message (elist (i)) | i ∈ inds elist ·
                              elist (i).name = "message"] in
             return new UmlInteraction (name,
                                        lifeLines,
                                        mosfragments∪besfragments∪combifragments,
                                        messages)
          )
        pre  isAttributeType (e, "uml : Interaction") ;
private
        build-Message : XmlEntity →(o) IUmlMessage
        build-Message (e) △
          let messageKind : IUmlMessageKind =
                  new UmlMessageKind (UmlMessageKindQuotes‘IQCOMPLETE),
              messageSort : IUmlMessageSort = new UmlMessageSort (UmlMessageSortQuotes‘IQSY
              mosSend : IUmlMos = mosMap (getAttribute (e, "sendEvent").val),
              mosRecive : IUmlMos = mosMap (getAttribute (e, "receiveEvent").val),
              args : (IUmlValueSpecification*) = [],
```

$name : String = mosRecive.getEvent().getOperation().getName()$ in
return new $UmlMessage(name,$
$messageKind,$
$messageSort,$
$mosSend,$
$mosRecive,$
$args)$
pre $e.name =$ "$message$" ;

private
$build\text{-}Fragment : XmlEntity \xrightarrow{o} IUmlInteractionFragment$
$build\text{-}Fragment(e) \triangleq$
cases $getElementType(e)$:
"$uml : MessageOccurrenceSpecification$" $\rightarrow$
return $build\text{-}Mos(e)$,
"$uml : BehaviorExecutionSpecification$" $\rightarrow$
return $build\text{-}Bes(e)$,
"$uml : CombinedFragment$" $\rightarrow$
return $build\text{-}Combi(e)$
end
pre $isAttributeType(e,$ "$uml : MessageOccurrenceSpecification$"$) \vee$
$isAttributeType(e,$ "$uml : BehaviorExecutionSpecification$"$) \vee$
$isAttributeType(e,$ "$uml : CombinedFragment$"$)$;

private
$build\text{-}Mos : XmlEntity \xrightarrow{o} IUmlMos$
$build\text{-}Mos(e) \triangleq$
let $name = getAttribute(e,$ "$name$"$).val,$
$message : [IUmlMessage] =$ nil ,
$lifeLines : IUmlLifeLine =$ let $l \in \{lifeLineMap(c) \mid c \in$ elems $GetCovered(e)\}$ in
$l,$
$id = getAttribute(e,$ "$xmi : id$"$).val,$
$event : IUmlCallEvent = idToClallEventMap(getAttribute(e,$ "$event$"$).val),$
$mos =$ new $UmlMos(name,$
$message,$
$lifeLines,$
$event)$ in
($mosMap := mosMap \dagger \{id \mapsto mos\};$
return mos
)
pre $isAttributeType(e,$ "$uml : MessageOccurrenceSpecification$"$)$;

private

$build\text{-}Bes : XmlEntity \xrightarrow{o} IUmlBes$
$build\text{-}Bes\,(e) \triangleq$
let $name = getAttribute\,(e, \texttt{"}name\texttt{"}).val,$
$startOc : IUmlMos = mosMap\,(getAttribute\,(e, \texttt{"}start\texttt{"}).val),$
$finishOc : IUmlMos = mosMap\,(getAttribute\,(e, \texttt{"}finish\texttt{"}).val),$
$covered : IUmlLifeLine\text{-}\mathsf{set} = \{lifeLineMap\,(c) \mid c \in \mathsf{elems}\ GetCovered\,(e)\},$
$id = getAttribute\,(e, \texttt{"}xmi : id\texttt{"}).val,$
$bes =$ new $UmlBes\,(name,$
$startOc,$
$finishOc,$
$covered)$ in
($besMap := besMap \dagger \{id \mapsto bes\};$
return bes
)
pre $isAttributeType\,(e, \texttt{"}uml : BehaviorExecutionSpecification\texttt{"})$;

private

$build\text{-}Combi : XmlEntity \xrightarrow{o} IUmlCombinedFragment$
$build\text{-}Combi\,(e) \triangleq$
let $elist = e.entities.entities,$
$name = getAttribute\,(e, \texttt{"}name\texttt{"}).val,$
$interactionOperatorKind : IUmlInteractionOperatorKind = GetIntOperationKind\,(getAt$
$operands : IUmlInteractionOperand^{*} = [build\text{-}Operand\,(elist\,(i)) \mid$
$i \in \mathsf{inds}\ elist \cdot elist\,(i).name = \texttt{"}operand\texttt{"}],$
$covered : IUmlLifeLine\text{-}\mathsf{set} = \{lifeLineMap\,(c) \mid c \in \mathsf{elems}\ GetCovered\,(e)\},$
$id = getAttribute\,(e, \texttt{"}xmi : id\texttt{"}).val,$
$combi =$ new $UmlCombinedFragment\,(name,$
$interactionOperatorKind,$
$operands,$
$covered)$ in
($combiMap := combiMap \dagger \{id \mapsto combi\};$
return $combi$
)
pre $isAttributeType\,(e, \texttt{"}uml : CombinedFragment\texttt{"})$

functions

private

$GetIntOperationKind : String \rightarrow IUmlInteractionOperatorKind$
$GetIntOperationKind\,(text) \triangleq$
cases $text$:
$\texttt{"}alt\texttt{"} \rightarrow$ new $UmlInteractionOperatorKind\,(UmlInteractionOperatorKindQuotes`IQALT$
$\texttt{"}loop\texttt{"} \rightarrow$ new $UmlInteractionOperatorKind\,(UmlInteractionOperatorKindQuotes`IQLO$
end

pre $text = "alt" \vee text = "loop"$
operations
private
$build\text{-}Operand : XmlEntity \xrightarrow{o} IUmlInteractionOperand$
$build\text{-}Operand\,(e) \triangleq$
let $elist = e.entities.entities,$
$name$: char* $= ""$,
$fragments : IUmlInteractionFragment^* = [],$
$covered : IUmlMos$-set $= \{mosMap\,(c) \mid c \in$ elems $StdLib`Split$ (conc $[GetCoveredExtensi$
$i \in$ inds $elist \cdot$
$hasAttributeValue\,(elist\,(i), "extende$
$' ')\},$
$guard : [IUmlInteractionConstraint] =$ if $\exists\, gu \in$ elems $elist \cdot gu.name =$
$"guard"$
then $GetGuard$ (let $g \in \{p \mid$
$p \in$ elems $elist \cdot p.name = "guard"\}$ in
$g)$
else nil in
return new $UmlInteractionOperand\,(name,$
$fragments,$
$covered,$
$guard)$
pre $e.name = "operand"$
functions
private
$GetCoveredExtension : XmlEntity \to$ char*
$GetCoveredExtension\,(e) \triangleq$
let $elist = e.entities.entities$ in
let $p \in \{co.data.data \mid co \in$ elems $elist \cdot co.name = "covered"\}$ in
p
pre $hasAttributeValue\,(e, "extender", "umltrans") \wedge$
$\exists\, el \in$ elems $e.entities.entities \cdot el.data \neq$ nil $\wedge el.name = "covered"$
;
private
$GetCovered : XmlEntity \to String^*$
$GetCovered\,(e) \triangleq$
let $text : String = getAttribute\,(e, "covered").val$ in
$StdLib`Split\,(text, ' ')$
pre $hasAttribute\,(e, "covered")$;
private

$GetGuard : XmlEntity \rightarrow IUmlInteractionConstraint$
$GetGuard\,(e) \triangleq$
let $elist = e.entities.entities$,
$minint =$ let $tmp \in \{getGuardConstraintValue\,(p) \mid$
$p \in$ elems $elist \cdot$
$p.name = "minint"\}$ in
tmp,
$maxint =$ let $tmp \in \{getGuardConstraintValue\,(p) \mid$
$p \in$ elems $elist \cdot$
$p.name = "maxint"\}$ in
tmp in
new $UmlInteractionConstraint\,(minint, maxint)$
pre $e.name = "guard"$;
private
$getGuardConstraintValue : XmlEntity \rightarrow [IUmlValueSpecification]$
$getGuardConstraintValue\,(e) \triangleq$
if $hasAttribute\,(e, "value") \wedge isAttributeType\,(e, "uml{:}LiteralInteger")$
then new $UmlLiteralInteger\,(StdLib`StringToInt\,(getAttribute\,(e, "value").val))$
else nil
operations
private
$buildCallEventMap : XmlEntity$-set $\xrightarrow{o} String \xrightarrow{m} IUmlCallEvent$
$buildCallEventMap\,(elist) \triangleq$
let $m = \{getAttribute\,(e, "xmi{:}id").val \mapsto$ new $UmlCallEvent\,(idToOperationMap\,(getAttri$

$e \in elist\}$ in
return m
pre $\forall\, e \in elist \cdot isAttributeType\,(e, "uml : CallEvent")$;
public
$VisitXmlAttribute : XmlAttribute \xrightarrow{o} ()$
$VisitXmlAttribute$ (-) $\triangleq$
skip;
public
$VisitXmlData : XmlData \xrightarrow{o} ()$
$VisitXmlData$ (-) $\triangleq$
skip
end Xml2UmlModel

Test Suite : vdm.tc
Class : Xml2UmlModel

Name	#Calls	**C**overage
Xml2UmlModel`GetGuard	2	$\surd$

Name	#Calls	Coverage
Xml2UmlModel‘build-Bes	8	√
Xml2UmlModel‘build-Mos	12	√
Xml2UmlModel‘GetCovered	23	√
Xml2UmlModel‘lookUpType	32	88%
Xml2UmlModel‘build-Combi	3	√
Xml2UmlModel‘VisitXmlData	0	0%
Xml2UmlModel‘getAttribute	572	√
Xml2UmlModel‘hasAttribute	220	√
Xml2UmlModel‘GetVisibility	33	88%
Xml2UmlModel‘build-Message	6	√
Xml2UmlModel‘build-Operand	4	√
Xml2UmlModel‘exstractClass	15	98%
Xml2UmlModel‘VisitXmlEntity	0	0%
Xml2UmlModel‘build-Fragment	23	√
Xml2UmlModel‘build-Property	32	√
Xml2UmlModel‘build-defBlock	15	√
Xml2UmlModel‘getElementType	23	85%
Xml2UmlModel‘build-Operation	5	77%
Xml2UmlModel‘getDefaultValue	32	√
Xml2UmlModel‘getMultiplicity	32	52%
Xml2UmlModel‘isAttributeType	715	√
Xml2UmlModel‘VisitXmlDocument	7	√
Xml2UmlModel‘build-Constraint	1	√
Xml2UmlModel‘VisitXmlAttribute	0	0%
Xml2UmlModel‘buildCallEventMap	7	√
Xml2UmlModel‘build-Association	6	√
Xml2UmlModel‘build-Interaction	2	√
Xml2UmlModel‘hasAttributeValue	739	√
Xml2UmlModel‘build-Collobration	2	√
Xml2UmlModel‘GetCoveredExtension	4	√
Xml2UmlModel‘GetIntOperationKind	3	√
Xml2UmlModel‘getGuardConstraintValue	4	√
Total Coverage		92%

F.2.2 Transform UML to VDM (Uml2Vdm))

Transform a UML AST into a OML AST.

init Convert UML model to OmlDocument.

build_classes Build Oml Classes from the Uml model. This needs the constraints and associations to be pre parsed before this is called.

build_class Build Oml class from Uml class.

build_defs Build definitions from Uml definition block. Here both values and instance variables are extracted.

build_defValues Build value definitions from Uml properties.

build_value Build value definition from a Uml property.

build_defInstanceVariables Build instance variable definition form Uml property.

build_instanceVariable Create instance variable from Uml property.

build_defOperations Build operation definition form Uml property.

build_Operation Create operation from Uml property.

extractInstanceVarsFromAssociations extract instance variables form associations.

hasXorConstraint Test of an association has a constraint.

extractBinaryAssociation extract property from binary association.

extractUnionAssociation extract union type from association.

extractProductAssociation extract product type from association.

CreateProductType Create product type from Uml type.

CreateInstanceVar Create instance variable form Uml property and Oml type.

AddInstanceVarToClass Add instance variable to the owning class.

getAssociationInstanceVars Get instance variabled for a specific class extracted from associations.

getDefaultExpression Get default expression from Uml default value and type.

ConvertVisibility Convert visibility to scope .

ConvertType Convert type and multiplicity to Omltype .

ApplyMultiplicity add multiplicity extracted information to type. eg chat with upper* is a set of char.

build_traces Build traces from interaction.

build_trace build a trace definition from a SD by using the name of the SD as the name of the trace.

getTraceDefinition Get definitions loops through the messages of the SD. It keeps looping until non of the messages are back. It handles one message at the time and groups the according to the fragments they are contained in by the interaction operand.

getLoopDef Get loop definition converts a combined fragment into a Trace definition item where the repeat pattern is set according to the constraint of the interaction operand inside the loop where the messages that is used as test is located.

getRpEx Get repeat pattern from an interaction operand the operand is associated with a message the there by the link to the trace repeat pattern with a test of the message.

getAltDef Get alt definition converts a CF kind of alt into a Choice Definition. Adding the message that is loceted inside it by the interaction operands.

getMethodApply Get Method Apply from a Message.

getOperand Get Interaction Operand where a message is placed if the message is places in a IO else return nil.

getCfIoKind Get Combined fragment kind from a set of CF and a InteractionOperand.

class $Uml2Vdm$
types
public $String = \mathsf{char}^*$
instance variables
$classInstanceVars : String \xrightarrow{m} IOmlInstanceVariable^* := \{\mapsto\};$

operations
public
$init : IUmlModel \xrightarrow{o} IOmlDocument$
$init\,(model) \triangleq$
let $associations = \{a \mid a \in model.getDefinitions\,() \cdot$
isofclass $(IUmlAssociation, a)\},$

$constraints = \{a \mid a \in model.getDefinitions\,() \cdot$
isofclass $(IUmlConstraint, a)\}$ in
($extractInstanceVarsFromAssociations(associations, constraints);$
return new $OmlDocument\,(model.getName\,(),$
new $OmlSpecifications\,(build\text{-}classes\,(model)), [])$
);

public
$build\text{-}classes : IUmlModel \xrightarrow{o} IOmlClass^*$
$build\text{-}classes\,(model) \triangleq$
let $traceDefMap : String \xrightarrow{m} IOmlTraceDefinitions = build\text{-}traces\,(model),$
$classes : IUmlClass$-set $= \{c \mid c \in model.getDefinitions\,() \cdot$
isofclass $(IUmlClass, c)\}$ in
return $Util`SetToSeq[IOmlClass]\,(\{$let $cName = c.getName\,(),$
$traceDef =$
if $cName \in$ dom $traceDefMap$
then $traceDefMap\,(cName)$
else nil in
$build\text{-}class\,(c, traceDef) \mid$
$c \in classes\});$

public
$build\text{-}class : IUmlClass \times [IOmlTraceDefinitions] \xrightarrow{o} IOmlClass$
$build\text{-}class\,(c, traceDef) \triangleq$
let $name$: char* $= c.getName\,(),$
$supers = c.getSuperClass\,(),$
$inheritanceClause : [OmlInheritanceClause] =$
if len $supers > 0$
then new $OmlInheritanceClause\,([supers\,(i).getName\,() \mid i \in$
inds $supers])$
else nil ,
$body : IOmlDefinitionBlock$-set $= \bigcup \{build\text{-}defs\,(d) \mid d \in c.getClassBody\,()\},$
$bodyWithTrace : IOmlDefinitionBlock$-set $=$ if $traceDef \neq$ nil
then $body \cup \{traceDef\}$
else $body,$
$systemSpec : \mathbb{B} =$ false,
$instVars : IOmlInstanceVariableShape^* = getAssociationInstanceVars\,(name),$

$bodyLst =$ if len $instVars > 0$
then $bodyWithTrace \cup \{$new $OmlInstanceVariableDefinitions\,(instVars)\}$
else $bodyWithTrace$ in
return new $OmlClass\,(name,$
$[],$
$inheritanceClause,$
$Util`SetToSeq[IOmlDefinitionBlock]\,(bodyLst),$
$systemSpec);$

public
$build\text{-}defs : IUmlDefinitionBlock \xrightarrow{o} IOmlDefinitionBlock$-set
$build\text{-}defs\,(db) \triangleq$
cases true:
(isofclass $(IUmlOwnedProperties, db)) \rightarrow$
let $tmp : IUmlOwnedProperties = db$ in
return $\{build\text{-}defValues\,(tmp)\} \cup$
$\{build\text{-}defInstanceVariables\,(tmp)\},$
(isofclass $(IUmlOwnedOperations, db)) \rightarrow$
let $tmp : IUmlOwnedOperations = db$ in
return $\{build\text{-}defOperations\,(tmp)\},$
others $\rightarrow$ return $\{\}$
end;

public
$build\text{-}defValues : IUmlOwnedProperties \xrightarrow{o} IOmlDefinitionBlock$
$build\text{-}defValues\,(block) \triangleq$
let $props = block.getPropetityList\,(),$
$valueProps = \{p \mid p \in props \cdot$
$p.hasIsReadOnly\,() \wedge p.getIsReadOnly\,() =$
true$\},$
$val = \{build\text{-}value\,(v) \mid v \in valueProps\}$ in
return new $OmlValueDefinitions\,(Util`SetToSeq[IOmlValueDefinition]\,(val));$

public
$build\text{-}value : IUmlProperty \xrightarrow{o} IOmlValueDefinition$
$build\text{-}value\,(prop) \triangleq$
let $asyncAccess =$ false,
$statAccess = prop.getIsStatic\,(),$
$scope = ConvertVisibility\,(prop.getVisibility\,()),$
$access =$ new $OmlAccessDefinition\,(asyncAccess, statAccess, scope),$
$pattern =$ new $OmlPatternIdentifier\,(prop.getName\,()),$
$multiplicity =$ if $prop.hasMultiplicity\,()$
then $prop.getMultiplicity\,()$
else nil ,

```
            type = ConvertType (prop.getType (), multiplicity),
            expression : IOmlExpression =
                getDefaultExpression (prop.getDefault (), type),
            valueShape = new OmlValueShape (pattern, type, expression) in
        return new OmlValueDefinition (access, valueShape)
      pre prop.hasDefault () ;
public
      build-defInstanceVariables : IUmlOwnedProperties o→ IOmlDefinitionBlock
      build-defInstanceVariables (block) △
        let props = block.getPropetityList (),
            valueProps = {p | p ∈ props ·
                                    p.hasIsReadOnly () ∧
                                    p.getIsReadOnly () = false},
            val = {build-instanceVariable (v) | v ∈ valueProps},
            seqVal = Util‘SetToSeq[IOmlInstanceVariable] (val) in
        return new OmlInstanceVariableDefinitions (seqVal);
public
      build-instanceVariable : IUmlProperty o→ IOmlInstanceVariable
      build-instanceVariable (prop) △
        let asyncAccess = false,
            statAccess = prop.getIsStatic (),
            scope = ConvertVisibility (prop.getVisibility ()),
            access = new OmlAccessDefinition (asyncAccess, statAccess, scope),
            multiplicity = if prop.hasMultiplicity ()
                           then prop.getMultiplicity ()
                           else nil ,
            type = ConvertType (prop.getType (), multiplicity),
            expression : [IOmlExpression] =
                if prop.hasDefault ()
                then getDefaultExpression (prop.getDefault (), type)
                else nil ,
            assignmentDef =
                new OmlAssignmentDefinition (prop.getName (), type, expression) in
        return new OmlInstanceVariable (access, assignmentDef);
public
      build-defOperations : IUmlOwnedOperations o→ IOmlDefinitionBlock
      build-defOperations (block) △
        let props = block.getOperationList (),
            valOps = {p | p ∈ props},
            val = {build-Operation (v) | v ∈ valOps},
```

$seqVal = Util`SetToSeq[IOmlOperationDefinition]\,(val)$ in
return new $OmlOperationDefinitions\,(seqVal)$;

public
$build\text{-}Operation : IUmlOperation \xrightarrow{o} IOmlOperationDefinition$
$build\text{-}Operation\,(prop) \triangleq$
let $asyncAccess =$ false,
$statAccess = prop.getIsStatic\,()$,
$scope = ConvertVisibility\,(prop.getVisibility\,())$,
$access =$ new $OmlAccessDefinition\,(asyncAccess, statAccess, scope)$,
$type =$ new $OmlOperationType$ (new $OmlEmptyType\,()$, new $OmlEmptyType\,()$),
$name$: char$^* =$
$prop.getName\,()$,
$body =$ new $OmlOperationBody$ (new $OmlSkipStatement\,()$, false, false),
$trailer =$ new $OmlOperationTrailer$ (nil , nil , nil , nil),
$explicitOp =$ new $OmlExplicitOperation\,(name, type, [], body, trailer)$ in
return new $OmlOperationDefinition\,(access, explicitOp)$;

public
$extractInstanceVarsFromAssociations : IUmlAssociation$-set$\times IUmlConstraint$-set $\xrightarrow{o}$
$()$
$extractInstanceVarsFromAssociations\,(associations, constraints) \triangleq$
let $normalBiAss =$
$\{a \mid a \in associations \cdot$
$\neg\, hasXorConstraint\,(constraints, a.getId\,()) \wedge$
(card $a.getOwnedEnds\,()+$card $a.getOwnedNavigableEnds\,()) =$
$2\}$,
$product =$
$\{a \mid a \in associations \cdot$
$\neg\, hasXorConstraint\,(constraints, a.getId\,()) \wedge$
(card $a.getOwnedEnds\,()+$card $a.getOwnedNavigableEnds\,()) >$
$2\}$,
$xor =$
$\{a \mid a \in associations \cdot$
$hasXorConstraint\,(constraints, a.getId\,()) \wedge$
(card $a.getOwnedEnds\,()+$card $a.getOwnedNavigableEnds\,()) \geq$
$2\}$ in
(for all $a \in normalBiAss$

```
            do extractBinaryAssociation
                    (a.getOwnedEnds () ∪
                     a.getOwnedNavigableEnds ()) ;
            let xorEndss = {(⋃{a.getOwnedEnds () ∪
                              a.getOwnedNavigableEnds () |
                                 a ∈ xor ·
                                     ∃ id ∈ c.getConstraintElements ()·
                                          id = a.getId ()}) |
                              c ∈ constraints} in
            for all a ∈ xorEndss
            do extractUnionAssociation(a) ;
            for all a ∈ product
            do extractProductAssociation
                    (a.getOwnedEnds () ∪
                     a.getOwnedNavigableEnds ())
        );
public
        hasXorConstraint : IUmlConstraint-set × String -o-> 𝔹
        hasXorConstraint (constraints, associationId) △
          return ∃ c ∈ constraints ·
                    if isofclass (IUmlLiteralString, c.getSpecification ())
                    then let spec : IUmlLiteralString = c.getSpecification () in
                         spec.getValue () = "xor"
                    else false ∧
                         (∃ ce ∈ c.getConstraintElements () ·
                              ce = associationId);
public
        extractBinaryAssociation : IUmlProperty-set -o-> ()
        extractBinaryAssociation (props) △
          (    let propSeq = Util‘SetToSeq[IUmlProperty] (props),
                   pOwnerEnd = hd [propSeq (i) | i ∈ inds propSeq ·
                                        len propSeq (i).getName () = 0],
                   pTypeEnd = hd [propSeq (i) | i ∈ inds propSeq ·
                                        len propSeq (i).getName () > 0],
                   clName = let t : IUmlClassNameType = pOwnerEnd.getType () in
                                t.getName (),
                   multiplicity = if pTypeEnd.hasMultiplicity ()
                                  then pTypeEnd.getMultiplicity ()
                                  else nil ,
```

```
            type = ConvertType (pTypeEnd.getType (), multiplicity) in
         AddInstanceVarToClass(clName,
              CreateInstanceVar (pTypeEnd,
                                 type))
   )
   pre card props > 0 ;
public
   extractUnionAssociation : IUmlProperty-set →o ()
   extractUnionAssociation (props) △
   (   let ownerEndSet = {p | p ∈ props · len p.getName () = 0},
            propSeq = Util‘SetToSeq[IUmlProperty] (props),
            pOwnerEnd = hd Util‘SetToSeq[IUmlProperty] (ownerEndSet),
            pTypeEnd = [propSeq (i) | i ∈ inds propSeq ·
                                 len propSeq (i).getName () > 0],
            clName = let t : IUmlClassNameType = pOwnerEnd.getType () in
                         t.getName (),
            endTypes : IOmlType* =
                 Util‘SetToSeq[IOmlType] ({ConvertType (p.getType (), if p.hasMultiplicity ()
                                                                then p.getMultiplicity ()
                                                                else nil ) |
                                                         p ∈ elems pTypeEnd}),
            lhs : IOmlType = hd endTypes,
            rhs : IOmlType = hd Util‘SetToSeq[IOmlType] ((elems endTypes)\
{lhs}),
            type = new OmlUnionType (lhs, rhs) in
         AddInstanceVarToClass(clName, CreateInstanceVar (hd pTypeEnd, type))
   )
   pre card props > 0 ;
public
   extractProductAssociation : IUmlProperty-set →o ()
   extractProductAssociation (props) △
   (   let ownerEndSet = {p | p ∈ props · len p.getName () = 0},
            propSeq = Util‘SetToSeq[IUmlProperty] (props),
            pOwnerEnd = hd Util‘SetToSeq[IUmlProperty] (ownerEndSet),
            pTypeEnd = [propSeq (i) | i ∈ inds propSeq ·
                                 len propSeq (i).getName () > 0],
            clName = let t : IUmlClassNameType = pOwnerEnd.getType () in
                         t.getName (),
```

$endTypes : IUmlType^{*} = Util`SetToSeq[IUmlType](\{p.getType() \mid$

$p \in$
elems $pTypeEnd\}),$
$type : IOmlType = CreateProductType(endTypes)$ in
$AddInstanceVarToClass(clName, CreateInstanceVar($hd $pTypeEnd, type))$
)
pre card $props > 0$
functions
private
$CreateProductType : IUmlType^{*} \to IOmlType$
$CreateProductType(tps) \triangleq$
let $first =$ hd $tps,$
$rest =$ tl $tps,$
$front = ConvertType(first,$ nil $)$ in
if len $tps = 1$
then $front$
else new $OmlProductType(front, CreateProductType(rest))$
operations
public
$CreateInstanceVar : IUmlProperty \times IOmlType \xrightarrow{o} IOmlInstanceVariable$
$CreateInstanceVar(prop, type) \triangleq$
let $asyncAccess =$
false,
$statAccess = prop.getIsStatic(),$
$scope = ConvertVisibility(prop.getVisibility()),$
$access =$ new $OmlAccessDefinition(asyncAccess, statAccess, scope),$
$multiplicity =$ if $prop.hasMultiplicity()$
then $prop.getMultiplicity()$
else nil ,
$type1 = ConvertType(prop.getType(), multiplicity),$
$expression : [IOmlExpression] =$
if $prop.hasDefault()$
then $getDefaultExpression(prop.getDefault(), type1)$
else nil ,
$assignmentDef =$ new $OmlAssignmentDefinition(prop.getName(), type, expression)$ in
return new $OmlInstanceVariable(access, assignmentDef);$
private
$AddInstanceVarToClass : String \times IOmlInstanceVariable \xrightarrow{o} ()$
$AddInstanceVarToClass(clName, instanceVar) \triangleq$
let $existingSet = getAssociationInstanceVars(clName),$

$addedSet$ = if len $existingSet > 0$
then $existingSet \curvearrowright [instanceVar]$
else $[instanceVar]$ in
$classInstanceVars := classInstanceVars \dagger \{clName \mapsto addedSet\}$;

public
$getAssociationInstanceVars : String \xrightarrow{o} IOmlInstanceVariableShape^*$
$getAssociationInstanceVars\,(clName) \triangleq$
if $clName \in$ dom $classInstanceVars$
then return $classInstanceVars\,(clName)$
else return [] ;

public
$getDefaultExpression$: [char*] $\times\ IOmlType \xrightarrow{o} [IOmlExpression]$
$getDefaultExpression\,(defaultValue, t) \triangleq$
if $defaultValue =$ nil
then return nil
else cases true:
(isofclass ($IOmlTypeName, t$)) $\rightarrow$
return new $OmlNewExpression$ (new $OmlName$ (nil , $defaultValue$), [], []),
(isofclass ($IOmlIntType, t$)) $\rightarrow$
return new $OmlSymbolicLiteralExpression$ (new $OmlNumericLiteral$ (0)),
(isofclass ($IOmlCharType, t$)) $\rightarrow$
return new $OmlSymbolicLiteralExpression$ (new $OmlTextLiteral$ ($defaultValue$)),
(isofclass ($IOmlSeq0Type, t$)) $\rightarrow$
return $getDefaultExpression$ ($defaultValue$, let tmp:$IOmlSeq0Type$ in
$tmp.getType$ ()),
others $\rightarrow$ return nil
end;

public
$ConvertVisibility : IUmlVisibilityKind \xrightarrow{o} IOmlScope$
$ConvertVisibility\,(visibility) \triangleq$
let $val : \mathbb{N} = visibility.getValue$ () in
cases val:
($UmlVisibilityKindQuotes$‘$IQPUBLIC$) $\rightarrow$
return new $OmlScope$ ($OmlScopeQuotes$‘$IQPUBLIC$),
($UmlVisibilityKindQuotes$‘$IQPRIVATE$) $\rightarrow$
return new $OmlScope$ ($OmlScopeQuotes$‘$IQDEFAULT$),
($UmlVisibilityKindQuotes$‘$IQPROTECTED$) $\rightarrow$
return new $OmlScope$ ($OmlScopeQuotes$‘$IQPROTECTED$)
end;

public

```
        ConvertType : IUmlType × [IUmlMultiplicityElement] →ᵒ IOmlType
        ConvertType (t, mul) ≜
          cases true:
            (isofclass (IUmlClassNameType, t)) →
                return new OmlTypeName (let tmp : IUmlClassNameType = t in
                                        new OmlName (nil , tmp.getName ())),
            (isofclass (IUmlCharType, t)) → return ApplyMultiplicity (new OmlCharType (), mul),
            (isofclass (IUmlStringType, t)) → return new OmlSeq0Type (new OmlCharType ()),
            (isofclass (IUmlIntegerType, t)) → return ApplyMultiplicity (new OmlIntType (), mul),
            (isofclass (IUmlBoolType, t)) → return ApplyMultiplicity (new OmlBoolType (), mul),
            (isofclass (IUmlUnlimitedNatural, t)) → return ApplyMultiplicity (new OmlRealType (), mu
            others → return ApplyMultiplicity (new OmlNatType (), mul)
          end;
private
        ApplyMultiplicity : IOmlType×[IUmlMultiplicityElement] →ᵒ IOmlType
        ApplyMultiplicity (t, mul) ≜
          if mul = nil
          then return t
          else if mul.getLower () = 0 ∧ ¬ mul.hasUpper ()
               then return new OmlSeq0Type (t)
               else return t
functions
private
        build-traces : IUmlModel → String →ᵐ IOmlTraceDefinitions
        build-traces (model) ≜
          let collOwnedBehavior = ⋃ {let tmp : IUmlCollaboration =
                                          coll in
                                     tmp.getOwnedBehavior () |
                                        coll ∈ model.getDefinitions () ·
                                           isofclass (IUmlCollaboration, coll)} in
          merge {build-trace (interaction) | interaction ∈ collOwnedBehavior};
private
```

$$
\begin{array}{l}
\mathit{build\text{-}trace} : \mathit{IUmlInteraction} \rightarrow \mathit{String} \xrightarrow{m} \mathit{IOmlTraceDefinitions} \\
\mathit{build\text{-}trace}\,(\mathit{interaction}) \triangleq \\
\quad \textsf{let}\ \mathit{name} = \mathit{interaction.getName}\,(), \\
\qquad \mathit{messages} : \mathit{IUmlMessage}^{*} = \mathit{interaction.getMessages}\,()\ \textsf{in} \\
\quad \textsf{let}\ \mathit{defs} : \mathit{IOmlTraceDefinition} = \\
\qquad\quad \mathit{getTraceDefinition}\,(\mathit{messages}, \mathit{interaction.getFragments}\,(), \textsf{nil}\,)\ \textsf{in} \\
\quad \textsf{let}\ \mathit{ownerClass} \in \{\mathit{m.getSendEvent}\,().\mathit{getCovered}\,().\mathit{getRepresents}\,() \mid \\
\\
\qquad\quad m \in \textsf{elems}\ \mathit{messages}\}\ \textsf{in} \\
\quad \{\textsf{let}\ \mathit{owr} : \mathit{IUmlClassNameType} = \mathit{ownerClass}\ \textsf{in} \\
\quad\ \mathit{owr.getName}\,() \mapsto \\
\quad\ \textsf{new}\ \mathit{OmlTraceDefinitions}\,([\textsf{new}\ \mathit{OmlNamedTrace}\,(\mathit{name}, \mathit{defs})])\};
\end{array}
$$

$getTraceDefinition : IUmlMessage^* \times IUmlInteractionFragment$-set$\times$
$[IUmlInteractionOperand] \rightarrow$
$[IOmlTraceDefinition]$
$getTraceDefinition\,(msgs, fg, io) \triangleq$
if len $msgs > 0$
then (let $m =$ hd $msgs$,
$rest =$ if len $msgs > 1$
then tl $msgs$
else $[]$,
$cfg = \{f \mid f \in fg \cdot$isofclass$\,(IUmlCombinedFragment, f)\}$,
$op = getOperand\,(m, cfg)$ in
(if $(io =$ nil $\wedge\ op =$ nil $) \vee (io = op)$
then let $mappDef : IOmlTraceDefinition =$
new $OmlTraceDefinitionItem\,([], getMethodApply\,(m),$ nil $)$,
$restDef : IOmlTraceDefinition = getTraceDefinition\,(rest, cfg, op)$,
$defs : IOmlTraceDefinition^* = [mappDef, restDef]$ in
let $ret : IOmlTraceDefinition =$ new $OmlTraceSequenceDefinition\,(defs)$ in
ret
else if $op \neq$ nil $\wedge\ getCfIoKind\,(fg, op).getValue\,() =$
$UmlInteractionOperatorKindQuotes`IQLOOP$
then let $loopDef : IOmlTraceDefinition = getLoopDef\,(m, op)$,
$restDef : [IOmlTraceDefinition] = getTraceDefinition\,(rest, cfg, op)$,
$defs : IOmlTraceDefinition^* =$ if $restDef \neq$ nil
then $[loopDef, restDef]$
else $[loopDef]$,
$ret : IOmlTraceDefinition =$ new $OmlTraceSequenceDefinition\,(defs)$ in
ret
else if $op \neq$ nil $\wedge\ getCfIoKind\,(fg, op).getValue\,() =$
$UmlInteractionOperatorKindQuotes`IQALT$
then let $altDef : IOmlTraceDefinition = getAltDef\,(rest, m, cfg, op)$,
$restDef : [IOmlTraceDefinition] = getTraceDefinition\,(rest, cfg, op)$,
$defs : IOmlTraceDefinition^* =$ if $restDef \neq$
nil
then $[altDef, restDef]$
else $[altDef]$,
$ret : IOmlTraceDefinition =$ new $OmlTraceSequenceDefinition\,(defs)$
ret
else let $ret : IOmlTraceDefinition =$ new $OmlTraceSequenceDefinition\,()$ in
ret))
else nil ;
private

$getLoopDef : IUmlMessage \times [IUmlInteractionOperand] \rightarrow IOmlTraceDefinition$
$getLoopDef\ (m, io) \triangleq$
new $OmlTraceDefinitionItem\ ([],$
$getMethodApply\ (m),$
$getRpEx\ (io));$

private

$getRpEx : [IUmlInteractionOperand] \rightarrow [IOmlTraceRepeatPattern]$
$getRpEx\ (iOperand) \triangleq$
if $iOperand =$ nil
then nil
else if $iOperand.hasGuard\ ()$
then let $guard = iOperand.getGuard\ (),$
$min =$ if $guard.hasMinint\ ()$
then let $tmp : IUmlLiteralInteger =$
$guard.getMinint\ ()$ in
$tmp.getValue\ ()$
else nil ,
$max =$ if $guard.hasMaxint\ ()$
then let $tmp : IUmlLiteralInteger =$
$guard.getMaxint\ ()$ in
$tmp.getValue\ ()$
else nil in
if $min \neq$ nil $\wedge\ min = 0 \wedge max =$ nil
then new $OmlTraceZeroOrMore\ ()$
else if $min \neq$ nil $\wedge\ min = 1 \wedge max =$ nil
then new $OmlTraceOneOrMore\ ()$
else if $min \neq$ nil $\wedge\ max \neq$ nil $\wedge\ min = 0 \wedge max = 1$
then new $OmlTraceZeroOrOne\ ()$
else if $min \neq$ nil
then let $minL =$ new $OmlNumericLiteral\ (min),$
$maxL =$ if $max \neq$ nil
then new $OmlNumericLiteral\ (max)$
else nil in
new $OmlTraceRange\ (minL, maxL)$
else nil
else nil ;

private

```
        getAltDef : IUmlMessage* × IUmlMessage × IUmlCombinedFragment-set ×
[IUmlInteractionOperand] →
                IOmlTraceDefinition
        getAltDef (msgs, m, fg, io) ≜
          let mapp = getMethodApply (m),
              rest = getTraceDefinition (msgs, fg, io),
              defs = if rest ≠ nil
                     then [new OmlTraceDefinitionItem ([], mapp, nil ), rest]
                     else [new OmlTraceDefinitionItem ([], mapp, nil )] in
          new OmlTraceChoiceDefinition (defs);
private
        getMethodApply : IUmlMessage → IOmlTraceMethodApply
        getMethodApply (message) ≜
          let methodName : String =
                 message.getSendReceive ().getEvent ().getOperation ().getName (),
              variableName : String =
                 message.getSendReceive ().getCovered ().getName (),
              args : IOmlExpression* = [] in
          new OmlTraceMethodApply (variableName, methodName, args);
private
        getOperand : IUmlMessage × IUmlCombinedFragment-set → [IUmlInteractionOperand]
        getOperand (m, fragments) ≜
          let ops = {io | io ∈ elems conc Util`SetToSeq[IUmlInteractionOperand*]
                             (
                              {f.getOperand () | f ∈ fragments ·
                                     isofclass (IUmlCombinedFragment, f)})·

                             ∃ mos ∈ io.getCovered () ·
                                 mos = m.getSendEvent ()} in
          if card ops > 0
          then let p ∈ ops in
                 p
          else nil ;
private
```

$getCfIoKind : IUmlCombinedFragment\text{-set} \times IUmlInteractionOperand$
$\rightarrow IUmlInteractionOperatorKind$
$getCfIoKind\ (fms, io) \triangleq$
let $cf \in$
$\{f \mid f \in fms \cdot$
isofclass $(IUmlCombinedFragment, f) \land$
$\exists\, iop \in$ elems $f.getOperand\ () \cdot iop = io\}$ in
$cf.getInteractionOperator\ ()$

end Uml2Vdm

Test Suite : vdm.tc
Class : Uml2Vdm

Name	#Calls	**C**overage
Uml2Vdm‘init	7	√
Uml2Vdm‘getRpEx	2	85%
Uml2Vdm‘getAltDef	3	√
Uml2Vdm‘build-defs	30	92%
Uml2Vdm‘getLoopDef	2	√
Uml2Vdm‘getOperand	7	√
Uml2Vdm‘ConvertType	26	70%
Uml2Vdm‘build-class	15	96%
Uml2Vdm‘build-trace	2	√
Uml2Vdm‘build-value	1	92%
Uml2Vdm‘getCfIoKind	8	√
Uml2Vdm‘build-traces	7	√
Uml2Vdm‘build-classes	7	√
Uml2Vdm‘getMethodApply	7	√
Uml2Vdm‘build-Operation	5	√
Uml2Vdm‘build-defValues	15	√
Uml2Vdm‘hasXorConstraint	18	62%
Uml2Vdm‘ApplyMultiplicity	14	27%
Uml2Vdm‘ConvertVisibility	23	√
Uml2Vdm‘CreateInstanceVar	4	78%
Uml2Vdm‘CreateProductType	3	√
Uml2Vdm‘getTraceDefinition	12	96%
Uml2Vdm‘build-defOperations	15	√
Uml2Vdm‘getDefaultExpression	5	51%
Uml2Vdm‘AddInstanceVarToClass	4	80%
Uml2Vdm‘build-instanceVariable	13	92%
Uml2Vdm‘extractUnionAssociation	1	96%
Uml2Vdm‘extractBinaryAssociation	2	95%

Name	#Calls	Coverage
Uml2Vdm‘extractProductAssociation	1	$\surd$
Uml2Vdm‘build-defInstanceVariables	15	$\surd$
Uml2Vdm‘getAssociationInstanceVars	19	$\surd$
Uml2Vdm‘extractInstanceVarsFromAssociations	7	$\surd$
Total Coverage		**91%**

F.3 OML AST to VDM files printer

F.3.1 Proxy for printer (Oml2Vpp)

Provides a easy to use interface for printing a OML AST to source files. Connects the `Oml2Vpp` visitor to the IO facility.

class $Oml2Vpp$
types
  public $String = \text{char}^*$
operations
public
  $Save : String \times IOmlDocument \xrightarrow{o} ()$
  $Save\,(fileName, doc) \triangleq$
   (dcl $visitor : Oml2VppVisitor :=$ new $Oml2VppVisitor\,()$;
    $visitor.visitDocument(doc)$;
    $Util`SetFileName(fileName)$;
    $Util`PrintL(visitor.result)$
)
end Oml2Vpp

Test Suite : vdm.tc
Class : Oml2Vpp

Name	**#**Calls	**C**overage
Oml2Vpp‘Save	7	$\surd$
Total Coverage		**1**00%

F.3.2 Visitor for OML which implements a printer for source files (Oml2VppVisitor)

Implemtation of the OML source file printer.

class $Oml2VppVisitor$ is subclass of $OmlVisitor$

types

$String$ = char*

values

private

nl : char* = "$\backslash n$"

instance variables

public $result$: char* := [];

private lvl : $\mathbb{N}$:= 0;

operations

private

$printNodeField : IOmlNode \xrightarrow{o} ()$

$printNodeField\,(pNode) \triangleq pNode.$

$accept$(self) ;

private

$printBoolField : \mathbb{B} \xrightarrow{o} ()$

$printBoolField\,(pval) \triangleq$

$result$:= if $pval$

then "$true$"

else "$false$";

private

$printNatField : \mathbb{N} \xrightarrow{o} ()$

$printNatField\,(pval) \triangleq$

$result := StdLib`ToStringInt\,(pval);$

private

$printRealField : \mathbb{R} \xrightarrow{o} ()$

$printRealField$ (-) $\triangleq$

error;

private

$printCharField$: char $\xrightarrow{o} ()$

$printCharField\,(pval) \triangleq$

$result$:= "'" $\curvearrowright$ $[pval]$ $\curvearrowright$ "'";

private

$printField : IOmlNode`FieldValue \xrightarrow{o} ()$

$printField\,(fld) \triangleq$

if is-$\mathbb{B}\,(fld)$

then $printBoolField(fld)$

```
      elseif is-char (fld)
      then printCharField(fld)
      elseif is-ℕ (fld)
      then printNatField(fld)
      elseif is-ℝ (fld)
      then printRealField(fld)
      elseif isofclass (IOmlNode, fld)
      then printNodeField(fld)
      else printStringField(fld) ;
private
    printStringField : char* -o-> ()
    printStringField (str) ≜
      result := "\"" ⁀ str ⁀ "\"";
private
    printSeqofField : IOmlNode`FieldValue* -o-> ()
    printSeqofField (pval) ≜
      (   dcl str : char* := "",
              cnt : ℕ := len pval;
          while cnt > 0
          do (    printField(pval (len pval − cnt + 1)) ;
                  str := str ⁀ result;
                  cnt := cnt − 1
             );
          result := str
      );
public
    visitNode : IOmlNode -o-> ()
    visitNode (pNode) ≜ pNode.
      accept(self) ;
public
    visitDocument : IOmlDocument -o-> ()
    visitDocument (pcmp) ≜
      (   dcl str : char* := "−BEGIN  FileName: "⁀pcmp.getFilename ()⁀
nl;
          if pcmp.hasSpecifications ()
          then visitSpecifications(pcmp.getSpecifications ()) ;
          result := str⁀result⁀"−END  FileName: "⁀pcmp.getFilename ()
      );
public
```

$visitSpecifications : IOmlSpecifications \xrightarrow{o} ()$
$visitSpecifications\,(pcmp) \triangleq$
(dcl str : char* := nl;
for $node$ in $pcmp.getClassList\,()$
do ($printNodeField(node)$;
$str := str \curvearrowright nl \curvearrowright result \curvearrowright nl$
) ;
$result := str$
);

public
$visitClass : IOmlClass \xrightarrow{o} ()$
$visitClass\,(pcmp) \triangleq$
(dcl str : char* := "$class$ " $\curvearrowright pcmp.getIdentifier\,()$;
if $pcmp.hasInheritanceClause\,()$
then $printNodeField(pcmp.getInheritanceClause\,())$
else $result$:= "";
for db in $pcmp.getClassBody\,()$
do ($printNodeField(db)$;
$str := str \curvearrowright nl \curvearrowright result$
) ;
$result := str \curvearrowright nl \curvearrowright$ "end " $\curvearrowright pcmp.getIdentifier\,()$
);

public
$visitInheritanceClause : IOmlInheritanceClause \xrightarrow{o} ()$
$visitInheritanceClause\,(pcmp) \triangleq$
(dcl str : char* := " is $subclass$ of ",
$list : String^* := pcmp.getIdentifierList\,()$,
$length : \mathbb{N}$:= len $list$,
$i : \mathbb{N} := 1$;
while $i \leq length$
do ($str := str \curvearrowright list\,(i)$;
$i := i + 1$;
if $i \leq length$
then $str := str \curvearrowright$ " , "
) ;
$result := str \curvearrowright nl$
);

public
$visitValueDefinitions : IOmlValueDefinitions \xrightarrow{o} ()$
$visitValueDefinitions\,(pcmp) \triangleq$
(dcl str : char* := $nl \curvearrowright$ "$values$" $\curvearrowright nl$;

```
            for db in pcmp.getValueList ()
            do (    printNodeField(db) ;
                    str := str ⁀ result ⁀ nl
               ) ;
            if len pcmp.getValueList () = 0
            then result := ""
            else result := str
        );
public
        visitValueDefinition : IOmlValueDefinition ⟶ ()
        visitValueDefinition (pcmp) ≜
        (   dcl str : char*;
            printNodeField(pcmp.getAccess ()) ;
            str := result;
            printNodeField(pcmp.getShape ()) ;
            str := str ⁀ result ⁀ ";" ⁀ nl;
            result := str
        );
public
        visitAccessDefinition : IOmlAccessDefinition ⟶ ()
        visitAccessDefinition (pcmp) ≜
        (   dcl str : char* := "";
            if pcmp.getStaticAccess ()
            then str := " static ";
            printNodeField(pcmp.getScope ()) ;
            str := str ⁀ result ⁀ " ";
            result := str
        );
public
        visitScope : IOmlScope ⟶ ()
        visitScope (pNode) ≜
        (    cases pNode.getValue ():
               (OmlScopeQuotes‘IQPUBLIC) → result := "public",
               (OmlScopeQuotes‘IQPRIVATE),
               (OmlScopeQuotes‘IQDEFAULT) → result := "private",
               (OmlScopeQuotes‘IQPROTECTED) → result := "protected",
               others → error
            end
        );
public
```

$visitValueShape : IOmlValueShape \xrightarrow{o} ()$
$visitValueShape\,(pcmp) \triangleq$
(dcl str : char*;
  $printNodeField(pcmp.getPattern\,())$;
  $str := result \curvearrowright$ " ";
  if $pcmp.hasType\,()$
  then ($printNodeField(pcmp.getType\,())$;
    $str := str \curvearrowright$ " : " $\curvearrowright result \curvearrowright$ " "
)
  else $result :=$ "";
  $printNodeField(pcmp.getExpression\,())$;
  $str := str \curvearrowright$ " = " $\curvearrowright result \curvearrowright$ " ";
  $result := str$
);

public
$visitPattern : IOmlPattern \xrightarrow{o} ()$
$visitPattern\,(pNode) \triangleq pNode.$
  $accept$(self) ;

public
$visitExpression : IOmlExpression \xrightarrow{o} ()$
$visitExpression\,(pNode) \triangleq pNode.$
  $accept$(self) ;

public
$visitLiteral : IOmlLiteral \xrightarrow{o} ()$
$visitLiteral\,(pNode) \triangleq pNode.$
  $accept$(self) ;

public
$visitType : IOmlType \xrightarrow{o} ()$
$visitType\,(pNode) \triangleq pNode.$
  $accept$(self) ;

public
$visitPatternIdentifier : IOmlPatternIdentifier \xrightarrow{o} ()$
$visitPatternIdentifier\,(pcmp) \triangleq$
(dcl str : char* $:= pcmp.getIdentifier\,() \curvearrowright$ " ";
  $result := str$
);

public

```
        visitSymbolicLiteralExpression : IOmlSymbolicLiteralExpression -o->
()
        visitSymbolicLiteralExpression (pcmp) ≜
          (    printNodeField(pcmp.getLiteral ())
          );
public
        visitTextLiteral : IOmlTextLiteral -o-> ()
        visitTextLiteral (pcmp) ≜
          (    dcl str : char* := pcmp.getVal ();
               result := "\"" ⁀ str ⁀ "\""
          );
public
        visitSeq0Type : IOmlSeq0Type -o-> ()
        visitSeq0Type (pcmp) ≜
          (    dcl str : char* := "seq of ";
               printNodeField(pcmp.getType ()) ;
               str := str ⁀ result;
               result := str
          );
public
        visitCharType : IOmlCharType -o-> ()
        visitCharType (-) ≜
          (    dcl str : char* := "char";
               result := str
          );
public
        visitInstanceVariableDefinitions : IOmlInstanceVariableDefinitions -o->
()
        visitInstanceVariableDefinitions (pcmp) ≜
          (    dcl str : char* := nl ⁀ "instance variables" ⁀ nl ⁀ nl;
               for db in pcmp.getVariablesList ()
               do (    printNodeField(db) ;
                       str := str ⁀ result ⁀ nl
                  ) ;
               if len pcmp.getVariablesList () = 0
               then result := ""
               else result := str
          );
public
```

$visitInstanceVariable : IOmlInstanceVariable \xrightarrow{o} ()$
$visitInstanceVariable\,(pcmp) \triangleq$
(dcl str : char* := "";
  $printNodeField(pcmp.getAccess\,())$;
  $str := str \curvearrowright result$;
  $printNodeField(pcmp.getAssignmentDefinition\,())$;
  $str := str \curvearrowright result$;
  $result := str$
);
public
$visitAssignmentDefinition : IOmlAssignmentDefinition \xrightarrow{o} ()$
$visitAssignmentDefinition\,(pcmp) \triangleq$
(dcl str : char* := "";
  $str := str \curvearrowright pcmp.getIdentifier\,()$;
  $printNodeField(pcmp.getType\,())$;
  $str := str \curvearrowright$ " : " $\curvearrowright result$;
  if $pcmp.hasExpression\,()$
  then ($printNodeField(pcmp.getExpression\,())$;
    $str := str \curvearrowright$ " := "
)
  else $result$:= "";
  $str := str \curvearrowright result \curvearrowright$ ";";
  $result := str$
);
public
$visitTypeName : IOmlTypeName \xrightarrow{o} ()$
$visitTypeName\,(pcmp) \triangleq$
($printNodeField(pcmp.getName\,())$
);
public
$visitName : IOmlName \xrightarrow{o} ()$
$visitName\,(pcmp) \triangleq$
(dcl str : char* := "";
  if $pcmp.hasClassIdentifier\,()$
  then $str := str \curvearrowright pcmp.getClassIdentifier\,()$;
  $str := str \curvearrowright pcmp.getIdentifier\,()$;
  $result := str$
);
public

$visitIntType : IOmlIntType \xrightarrow{o} ()$
$visitIntType$ (-) $\triangleq$
(dcl str : char* := "int";
$result := str$
);

public
$visitNatType : IOmlNatType \xrightarrow{o} ()$
$visitNatType$ (-) $\triangleq$
(dcl str : char* := "nat";
$result := str$
);

public
$visitNat1Type : IOmlNat1Type \xrightarrow{o} ()$
$visitNat1Type$ (-) $\triangleq$
(dcl str : char* := "$nat1$";
$result := str$
);

public
$visitSeq1Type : IOmlSeq1Type \xrightarrow{o} ()$
$visitSeq1Type\ (pcmp)$ $\triangleq$
(dcl str : char* := "$seq1\ \ of$ ";
$printNodeField(pcmp.getType\ ())$;
$str := str \curvearrowright result;$
$result := str$
);

public
$visitRealType : IOmlRealType \xrightarrow{o} ()$
$visitRealType$ (-) $\triangleq$
(dcl str : char* := "$real$";
$result := str$
);

public
$visitSetType : IOmlSetType \xrightarrow{o} ()$
$visitSetType\ (pcmp)$ $\triangleq$
(dcl str : char* := "$set\ \ of$ ";
$printNodeField(pcmp.getType\ ())$;
$str := str \curvearrowright result;$
$result := str$
);

public

```
        visitTypeDefinitions : IOmlTypeDefinitions o-> ()
        visitTypeDefinitions (pcmp) ≜
          (   dcl str : char* := nl ⁀ "types" ⁀ nl ⁀ nl;
              for db in pcmp.getTypeList ()
              do (    printNodeField(db) ;
                      str := str ⁀ result ⁀ nl
                 ) ;
              result := str
          );
public
        visitTypeDefinition : IOmlTypeDefinition o-> ()
        visitTypeDefinition (pcmp) ≜
          (   dcl str : char* := "";
              printNodeField(pcmp.getAccess ()) ;
              str := str ⁀ result;
              printNodeField(pcmp.getShape ()) ;
              str := str ⁀ result ⁀ ";";
              result := str
          );
public
        visitSimpleType : IOmlSimpleType o-> ()
        visitSimpleType (pcmp) ≜
          (   dcl str : char* := pcmp.getIdentifier ();
              printNodeField(pcmp.getType ()) ;
              result := str ⁀ " = " ⁀ result
          );
public
        visitEmptyType : IOmlEmptyType o-> ()
        visitEmptyType (-) ≜
          (   dcl str : char* := "()";
              result := str
          );
public
        visitNewExpression : IOmlNewExpression o-> ()
        visitNewExpression (pcmp) ≜
          (   dcl str : char* := "new ";
              printNodeField(pcmp.getName ()) ;
              str := str ⁀ result ⁀ "()";
              result := str
          );
public
```

$visitNumericLiteral : IOmlNumericLiteral \xrightarrow{o} ()$
$visitNumericLiteral\,(pcmp) \triangleq$
(dcl str : char* := "";
$printNatField(pcmp.getVal\,())$;
$str := str \curvearrowright result$;
$result := str$
);

public
$visitOperationDefinitions : IOmlOperationDefinitions \xrightarrow{o} ()$
$visitOperationDefinitions\,(pcmp) \triangleq$
(dcl str : char* := $nl \curvearrowright$ "operations" $\curvearrowright nl \curvearrowright nl$;
for db in $pcmp.getOperationList\,()$
do ($printNodeField(db)$;
$str := str \curvearrowright result \curvearrowright nl$
) ;
if len $pcmp.getOperationList\,() > 0$
then $result := str$
else $result :=$ ""
);

public
$visitOperationDefinition : IOmlOperationDefinition \xrightarrow{o} ()$
$visitOperationDefinition\,(pcmp) \triangleq$
(dcl str : char* := "";
$printNodeField(pcmp.getAccess\,())$;
$str := str \curvearrowright result$;
$printNodeField(pcmp.getShape\,())$;
$str := str \curvearrowright result$;
$result := str$
);

public
$visitExplicitOperation : IOmlExplicitOperation \xrightarrow{o} ()$
$visitExplicitOperation\,(pcmp) \triangleq$
(dcl str : char* := $pcmp.getIdentifier\,() \curvearrowright$ " : ";
$printNodeField(pcmp.getType\,())$;
$str := str \curvearrowright result$;
$str := str \curvearrowright nl \curvearrowright pcmp.getIdentifier\,() \curvearrowright$ "(";
for db in $pcmp.getParameterList\,()$

```
            do (    printNodeField(db) ;
                    str := str ⁀ result
               );
            str := str ⁀ ")  ==  ";
            printNodeField(pcmp.getBody ()) ;
            str := str ⁀ result ⁀ ";" ⁀ nl;
            result := str
        );
public
    visitOperationType : IOmlOperationType -o-> ()
    visitOperationType (pcmp) △
        (   dcl str : char* := "";
            printNodeField(pcmp.getDomType ()) ;
            str := str ⁀ result ⁀ "  ==>  ";
            printNodeField(pcmp.getRngType ()) ;
            str := str ⁀ result;
            result := str
        );
public
    visitOperationBody : IOmlOperationBody -o-> ()
    visitOperationBody (pcmp) △
        (   dcl str : char* := "(";
            if pcmp.hasStatement ()
            then printNodeField(pcmp.getStatement ())
            else result := "";
            str := str ⁀ result;
            if pcmp.getNotYetSpecified ()
            then str := str ⁀ "is not yet specified";
            if pcmp.getSubclassResponsibility ()
            then str := str ⁀ "sub class responsibility";
            str := str ⁀ ")";
            result := str
        );
public
    visitSkipStatement : IOmlSkipStatement -o-> ()
    visitSkipStatement (-) △
        (   dcl str : char* := "skip";
            result := str
        );
public
```

```
        visitParameter : IOmlParameter -o-> ()
        visitParameter (pcmp) ≜
          (   dcl str : char* := "";
              for db in pcmp.getPatternList ()
              do (    printNodeField(db) ;
                      str := str ⌒ result ⌒ ", "
                 ) ;
              str := str (1, ..., len str − 2);
              result := str
          );
public
        visitFunctionDefinitions : IOmlFunctionDefinitions -o-> ()
        visitFunctionDefinitions (pcmp) ≜
          (   dcl str : char* := nl ⌒ "functions" ⌒ nl ⌒ nl;
              for db in pcmp.getFunctionList ()
              do (    printNodeField(db) ;
                      str := str ⌒ result ⌒ nl
                 ) ;
              result := str
          );
public
        visitFunctionDefinition : IOmlFunctionDefinition -o-> ()
        visitFunctionDefinition (pcmp) ≜
          (   dcl str : char* := "";
              printNodeField(pcmp.getAccess ()) ;
              str := str ⌒ result;
              printNodeField(pcmp.getShape ()) ;
              str := str ⌒ result;
              result := str
          );
public
        visitExplicitFunction : IOmlExplicitFunction -o-> ()
        visitExplicitFunction (pcmp) ≜
          (   dcl str : char* := pcmp.getIdentifier () ⌒ " : ";
              for db in pcmp.getTypeVariableList ()
```

```
        do (  printNodeField(db) ;
                str := str ⁀ result
           ) ;
        printNodeField(pcmp.getType ()) ;
        str := str ⁀ result;
        str := str ⁀ nl ⁀ pcmp.getIdentifier () ⁀ "(";
        for db in pcmp.getParameterList ()
        do (  printNodeField(db) ;
                str := str ⁀ result
           ) ;
        str := str ⁀ ")  ==  is not yet specified;";
        result := str
    );
public
    visitPartialFunctionType : IOmlPartialFunctionType o→ ()
    visitPartialFunctionType (pcmp) △
    (   dcl str : char* := "";
        printNodeField(pcmp.getDomType ()) ;
        str := str ⁀ result ⁀ " -> ";
        printNodeField(pcmp.getRngType ()) ;
        str := str ⁀ result;
        result := str
    );
public
    visitUnionType : IOmlUnionType o→ ()
    visitUnionType (pcmp) △
    (   dcl str : char* := "";
        pcmp.getLhsType ( ) .accept(self) ;
        str := str ⁀ result;
        pcmp.getRhsType ( ) .accept(self) ;
        str := str ⁀ " | " ⁀ result;
        result := str
    );
public
    visitProductType : IOmlProductType o→ ()
    visitProductType (pcmp) △
    (   dcl str : char* := "";
```

$pcmp.getLhsType\ ()\ .accept($self$)$;
$str := str \curvearrowright result;$
$pcmp.getRhsType\ ()\ .accept($self$)$;
$str := str \curvearrowright$ " * " $\curvearrowright result;$
$result := str$
);

public
$visitTraceDefinitions : IOmlTraceDefinitions \xrightarrow{o} ()$
$visitTraceDefinitions\ (pcmp) \triangleq$
(dcl str : char* $:= nl \curvearrowright$ "$traces$" $\curvearrowright nl \curvearrowright nl;$
for db in $pcmp.getTraces\ ()$
do ($printNodeField(db)$;
$str := str \curvearrowright result \curvearrowright nl$
) ;
$result := str$
);

public
$visitNamedTrace : IOmlNamedTrace \xrightarrow{o} ()$
$visitNamedTrace\ (pcmp) \triangleq$
(dcl str : char* := " ";
$str := str \curvearrowright pcmp.getName\ () \curvearrowright$ " : ";
$printNodeField(pcmp.getDefs\ ())$;
$str := str \curvearrowright result;$
$result := str$
);

public
$visitTraceDefinition : IOmlTraceDefinition \xrightarrow{o} ()$
$visitTraceDefinition\ (pNode) \triangleq pNode.$
$accept($self$)$;

public
$visitTraceDefinitionItem : IOmlTraceDefinitionItem \xrightarrow{o} ()$
$visitTraceDefinitionItem\ (pcmp) \triangleq$
(dcl str : char* := "";
$printSeqofField(pcmp.getBind\ ())$;
$str := str \curvearrowright result;$
$printNodeField(pcmp.getTest\ ())$;
$str := str \curvearrowright result;$
if $pcmp.hasRegexpr\ ()$
then $printNodeField(pcmp.getRegexpr\ ())$

```
            else result := "";
            str := str ⁀ result;
            result := str
        );
public
    visitTraceBinding : IOmlTraceBinding →o ()
    visitTraceBinding (pNode) ≜ pNode.
      accept(self) ;
public
    visitTraceLetBinding : IOmlTraceLetBinding →o ()
    visitTraceLetBinding (pcmp) ≜
      (   dcl str : char* := "";
          printSeqofField(pcmp.getDefinitionList ()) ;
          str := str ⁀ result;
          result := str
      );
public
    visitTraceBracketedDefinition : IOmlTraceBracketedDefinition →o ()
    visitTraceBracketedDefinition (pcmp) ≜
      (   dcl str : char* := "(";
          printNodeField(pcmp.getDefinition ()) ;
          str := str ⁀ result ⁀ ")";
          result := str
      );
public
    visitTraceMethodApply : IOmlTraceMethodApply →o ()
    visitTraceMethodApply (pcmp) ≜
      (   dcl str : char* := "";
          str := str ⁀ pcmp.getVariableName () ⁀ ".";
          str := str ⁀ pcmp.getMethodName () ⁀ "(";
          printSeqofField(pcmp.getArgs ()) ;
          str := str ⁀ result ⁀ ")";
          result := str
      );
public
    visitTraceCoreDefinition : IOmlTraceCoreDefinition →o ()
    visitTraceCoreDefinition (pNode) ≜ pNode.
      accept(self) ;
public
```

$visitTraceRepeatPattern : IOmlTraceRepeatPattern \xrightarrow{o} ()$
$visitTraceRepeatPattern\,(pNode) \triangleq pNode.$
$accept$(self) ;

public
$visitTraceZeroOrMore : IOmlTraceZeroOrMore \xrightarrow{o} ()$
$visitTraceZeroOrMore$ (-) $\triangleq$
(dcl str : char* := " * ";
$result := str$
);

public
$visitTraceOneOrMore : IOmlTraceOneOrMore \xrightarrow{o} ()$
$visitTraceOneOrMore$ (-) $\triangleq$
(dcl str : char* := " + ";
$result := str$
);

public
$visitTraceZeroOrOne : IOmlTraceZeroOrOne \xrightarrow{o} ()$
$visitTraceZeroOrOne$ (-) $\triangleq$
(dcl str : char* := "?";
$result := str$
);

public
$visitTraceRange : IOmlTraceRange \xrightarrow{o} ()$
$visitTraceRange\,(pcmp) \triangleq$
(dcl str : char* := "{";
$printNodeField(pcmp.getLower\,())$;
$str := str \curvearrowright result$;
if $pcmp.hasUpper\,()$
then ($printNodeField(pcmp.getUpper\,())$;
$str := str \curvearrowright$ "," $\curvearrowright result$
) ;
$str := str \curvearrowright$ "}";
$result := str$
);

public
$visitTraceChoiceDefinition : IOmlTraceChoiceDefinition \xrightarrow{o} ()$
$visitTraceChoiceDefinition\,(pcmp) \triangleq$
(dcl str : char* := "",
$count : \mathbb{N} := 1$;
for db in $pcmp.getDefs\,()$

```
            do (  printNodeField(db) ;
                  if len pcmp.getDefs () = count
                  then str := str ⁀ result
                  else str := str ⁀ result ⁀ "  |  ";
                  count := count + 1
               );
            result := str
         );
public
      visitTraceSequenceDefinition : IOmlTraceSequenceDefinition →ᵒ ()
      visitTraceSequenceDefinition (pcmp) △
         (  dcl str : char* := "",
                count : ℕ := 1;
            for db in pcmp.getDefs ()
            do (  printNodeField(db) ;
                  if len pcmp.getDefs () = count
                  then str := str ⁀ result
                  else str := str ⁀ result ⁀ "  ;  ";
                  count := count + 1
               );
            result := str
         )
end Oml2VppVisitor
```

Test Suite : vdm.tc
Class : Oml2VppVisitor

Name	#Calls	**C**overage
Oml2VppVisitor‘visitName	9	70%
Oml2VppVisitor‘visitNode	0	0%
Oml2VppVisitor‘visitType	0	0%
Oml2VppVisitor‘printField	0	0%
Oml2VppVisitor‘visitClass	15	89%
Oml2VppVisitor‘visitScope	23	93%
Oml2VppVisitor‘visitIntType	7	√
Oml2VppVisitor‘visitLiteral	0	0%
Oml2VppVisitor‘visitNatType	0	0%
Oml2VppVisitor‘visitPattern	0	0%
Oml2VppVisitor‘visitSetType	0	0%
Oml2VppVisitor‘printNatField	5	√
Oml2VppVisitor‘visitCharType	4	√
Oml2VppVisitor‘visitDocument	7	√

Name	#Calls	Coverage
Oml2VppVisitor‘visitNat1Type	0	0%
Oml2VppVisitor‘visitRealType	1	√
Oml2VppVisitor‘visitSeq0Type	0	0%
Oml2VppVisitor‘visitSeq1Type	0	0%
Oml2VppVisitor‘visitTypeName	9	√
Oml2VppVisitor‘printBoolField	0	0%
Oml2VppVisitor‘printCharField	0	0%
Oml2VppVisitor‘printNodeField	251	√
Oml2VppVisitor‘printRealField	0	0%
Oml2VppVisitor‘visitEmptyType	10	√
Oml2VppVisitor‘visitParameter	0	0%
Oml2VppVisitor‘visitUnionType	1	√
Oml2VppVisitor‘printSeqofField	14	35%
Oml2VppVisitor‘visitExpression	0	0%
Oml2VppVisitor‘visitNamedTrace	2	√
Oml2VppVisitor‘visitSimpleType	0	0%
Oml2VppVisitor‘visitTraceRange	1	√
Oml2VppVisitor‘visitValueShape	1	95%
Oml2VppVisitor‘printStringField	0	0%
Oml2VppVisitor‘visitProductType	2	√
Oml2VppVisitor‘visitTextLiteral	2	√
Oml2VppVisitor‘visitTraceBinding	0	0%
Oml2VppVisitor‘visitNewExpression	0	0%
Oml2VppVisitor‘visitOperationBody	5	73%
Oml2VppVisitor‘visitOperationType	5	√
Oml2VppVisitor‘visitSkipStatement	5	√
Oml2VppVisitor‘visitNumericLiteral	5	√
Oml2VppVisitor‘visitSpecifications	7	√
Oml2VppVisitor‘visitTraceOneOrMore	1	√
Oml2VppVisitor‘visitTraceZeroOrOne	0	0%
Oml2VppVisitor‘visitTypeDefinition	0	0%
Oml2VppVisitor‘visitTraceDefinition	0	0%
Oml2VppVisitor‘visitTraceLetBinding	0	0%
Oml2VppVisitor‘visitTraceZeroOrMore	0	0%
Oml2VppVisitor‘visitTypeDefinitions	0	0%
Oml2VppVisitor‘visitValueDefinition	1	√
Oml2VppVisitor‘visitAccessDefinition	23	90%
Oml2VppVisitor‘visitExplicitFunction	0	0%
Oml2VppVisitor‘visitInstanceVariable	17	√

Name	#Calls	Coverage
Oml2VppVisitor‘visitTraceDefinitions	2	√
Oml2VppVisitor‘visitTraceMethodApply	7	√
Oml2VppVisitor‘visitValueDefinitions	15	√
Oml2VppVisitor‘visitExplicitOperation	5	86%
Oml2VppVisitor‘visitInheritanceClause	0	0%
Oml2VppVisitor‘visitPatternIdentifier	1	√
Oml2VppVisitor‘visitFunctionDefinition	0	0%
Oml2VppVisitor‘visitTraceRepeatPattern	0	0%
Oml2VppVisitor‘visitFunctionDefinitions	0	0%
Oml2VppVisitor‘visitOperationDefinition	5	√
Oml2VppVisitor‘visitPartialFunctionType	0	0%
Oml2VppVisitor‘visitTraceCoreDefinition	0	0%
Oml2VppVisitor‘visitTraceDefinitionItem	7	√
Oml2VppVisitor‘visitAssignmentDefinition	17	√
Oml2VppVisitor‘visitOperationDefinitions	15	√
Oml2VppVisitor‘visitTraceChoiceDefinition	3	√
Oml2VppVisitor‘visitTraceSequenceDefinition	7	√
Oml2VppVisitor‘visitTraceBracketedDefinition	0	0%
Oml2VppVisitor‘visitSymbolicLiteralExpression	5	√
Oml2VppVisitor‘visitInstanceVariableDefinitions	19	√
Total Coverage		63%

Appendix G

OML AST

In this appendix the OML AST is listed.

```
--
-- OVERTURE VDM++ ABSTRACT SYNTAX DEFINITION
--
-- $Id: overture.ast,v 1.4 2008/05/27 09:52:42 mave Exp $
--

%prefix Oml;
%package org.overturetool.ast;
%directory "c:\COMU\buildOml";
%top Specifications Expression;

Specifications ::
  class_list : seq of Class;

Class ::
  identifier : Identifier
  generic_types: seq of Type
  inheritance_clause : [InheritanceClause]
  class_body : seq of DefinitionBlock
  system_spec : bool;

InheritanceClause ::
  identifier_list : seq of Identifier;

DefinitionBlock =
  TypeDefinitions |
  ValueDefinitions |
  FunctionDefinitions |
```

```
  OperationDefinitions |
  InstanceVariableDefinitions |
  SynchronizationDefinitions |
  ThreadDefinition |
  TraceDefinitions;

----
---- TYPE DEFINITIONS
----

TypeDefinitions ::
  type_list : seq of TypeDefinition;

TypeDefinition ::
  access : AccessDefinition
  shape  : TypeShape;

AccessDefinition ::
  async_access  : bool
  static_access : bool
  scope  : Scope;

Scope =
  <PUBLIC> | <PRIVATE> | <PROTECTED> | <DEFAULT>;

TypeShape =
  SimpleType | ComplexType;

SimpleType ::
  identifier : Identifier
  type       : Type
  invariant  : [Invariant];

ComplexType ::
  identifier : Identifier
  field_list : seq of Field
  invariant  : [Invariant];

Type =
  BracketedType |
  BoolType |
  NatType |
  Nat1Type |
  IntType |
  RatType |
  RealType |
  CharType |
```

```
  TokenType |
  QuoteType |
  CompositeType |
  UnionType |
  ProductType |
  OptionalType |
  SetType |
  Seq0Type |
  Seq1Type |
  GeneralMapType |
  InjectiveMapType |
  PartialFunctionType |
  TotalFunctionType |
  OperationType |
  EmptyType |
  TypeName |
  TypeVariable |
  ClassTypeInstantiation;                        -- added for Thomas Christens

Invariant ::
  pattern : Pattern
  expression : Expression;

BracketedType ::
  type : Type;

BoolType :: ;

NatType  :: ;

Nat1Type :: ;

IntType :: ;

RatType :: ;

RealType :: ;

CharType :: ;

TokenType :: ;

QuoteType ::
  quote_literal : QuoteLiteral;

CompositeType ::
  identifier : Identifier
```

```
  field_list : seq of Field;

Field ::
  identifier : [seq of char]
  type : Type
  ignore : bool;

UnionType ::
  lhs_type : Type
  rhs_type : Type;

ProductType ::
  lhs_type : Type
  rhs_type : Type;

OptionalType ::
  type : Type;

SetType ::
  type : Type;

Seq0Type ::
  type : Type;

Seq1Type ::
  type : Type;

GeneralMapType ::
  dom_type : Type
  rng_type : Type;

InjectiveMapType ::
  dom_type : Type
  rng_type : Type;

PartialFunctionType ::
  dom_type : Type
  rng_type : Type;

TotalFunctionType ::
  dom_type : Type
  rng_type : Type;

OperationType ::
  dom_type : Type
  rng_type : Type;
```

```
EmptyType ::;

TypeName ::
  name : Name;

TypeVariable ::
  identifier : Identifier;

ClassTypeInstantiation ::                       -- added for Thomas Christens
  name : Name
  generic_types : seq of Type;

---
--- VALUE DEFINITIONS
---

ValueDefinitions ::
  value_list : seq of ValueDefinition;

ValueDefinition ::
  access     : AccessDefinition
  shape      : ValueShape;

ValueShape ::
  pattern    : Pattern
  type       : [Type]
  expression : Expression;

---
--- FUNCTION DEFINITIONS
---

FunctionDefinitions ::
  function_list : seq of FunctionDefinition;

FunctionDefinition ::
  access : AccessDefinition
  shape  : FunctionShape;

FunctionShape =
  ExplicitFunction |
  ImplicitFunction |
  ExtendedExplicitFunction |
  TypelessExplicitFunction;             -- added for Thomas Christensen

ExplicitFunction ::
  identifier : Identifier
```

```
  type_variable_list : seq of TypeVariable
  type : Type
  parameter_list : seq of Parameter
  body : FunctionBody
  trailer : FunctionTrailer;

Parameter ::
  pattern_list : seq of Pattern;

ImplicitFunction ::
  identifier : Identifier
  type_variable_list : seq of TypeVariable
  pattern_type_pair_list : seq of PatternTypePair
  identifier_type_pair_list : seq of IdentifierTypePair
  trailer : FunctionTrailer;

PatternTypePair ::
  pattern_list : seq of Pattern
  type : Type;

IdentifierTypePair ::
  identifier : Identifier
  type : Type;

ExtendedExplicitFunction ::
  identifier : Identifier
  type_variable_list : seq of TypeVariable
  pattern_type_pair_list : seq of PatternTypePair
  identifier_type_pair_list : seq of IdentifierTypePair
  body : FunctionBody
  trailer : FunctionTrailer;

TypelessExplicitFunction ::                                    -- ad
  identifier : Identifier
  parameter_list : seq of Parameter
  body : FunctionBody
  trailer : FunctionTrailer;

FunctionBody ::
  function_body : [Expression]
  not_yet_specified : bool
  subclass_responsibility : bool;

FunctionTrailer ::
  pre_expression : [Expression]
  post_expression : [Expression];
```

```
---
--- OPERATION DEFINITIONS
---

OperationDefinitions ::
  operation_list : seq of OperationDefinition;

OperationDefinition ::
  access : AccessDefinition
  shape : OperationShape;

OperationShape =
  ExplicitOperation |
  ImplicitOperation |
  ExtendedExplicitOperation;

ExplicitOperation ::
  identifier : Identifier
  type : Type
  parameter_list : seq of Pattern
  body : OperationBody
  trailer : OperationTrailer;

ImplicitOperation ::
  identifier : Identifier
  pattern_type_pair_list : seq of PatternTypePair
  identifier_type_pair_list : seq of IdentifierTypePair
  trailer : OperationTrailer;

ExtendedExplicitOperation ::
  identifier : Identifier
  pattern_type_pair_list : seq of PatternTypePair
  identifier_type_pair_list : seq of IdentifierTypePair
  body : OperationBody
  trailer : OperationTrailer;

OperationBody ::
  statement : [Statement]
  not_yet_specified : bool
  subclass_responsibility : bool;

OperationTrailer ::
  externals : [Externals]
  pre_expression : [Expression]
  post_expression : [Expression]
  exceptions : [Exceptions];
```

```
Externals ::
  ext_list : seq of VarInformation;

VarInformation ::
  mode : Mode
  name_list : seq of Name
  type : [Type];

Mode =
  <RD> | <WR>;

Exceptions ::
  error_list : seq of Error;

Error ::
  identifier : Identifier
  lhs : Expression
  rhs : Expression;

---
--- INSTANCE VARIABLES
---

InstanceVariableDefinitions ::
  variables_list : seq of InstanceVariableShape;

InstanceVariableShape =
  InstanceVariable |
  InstanceVariableInvariant;

InstanceVariable ::
  access : AccessDefinition
  assignment_definition : AssignmentDefinition;

InstanceVariableInvariant ::
  invariant : Expression;

---
--- SYNCHRONIZATION
---

SynchronizationDefinitions ::
  sync_list : seq of SyncPredicate;

SyncPredicate =
  PermissionPredicate |
  MutexPredicate |
```

```
  MutexAllPredicate ;

PermissionPredicate ::
  name : Name
  expression : Expression;

MutexPredicate ::
  name_list : seq of Name;

MutexAllPredicate ::;

---
--- THREAD DEFINITIONS
---

ThreadDefinition ::
  thread_specification : [ThreadSpecification];

ThreadSpecification =
  PeriodicThread |
  SporadicThread |
  ProcedureThread ;

PeriodicThread ::
  args : seq of Expression
  name : Name;

SporadicThread ::                              -- added for Marcel Verhoef
  args : seq of Expression
  name : Name;

ProcedureThread ::
  statement : Statement;

---
--- TRACE DEFINITIONS (added for Adriana Sucena)
---

TraceDefinitions ::
  traces : seq of NamedTrace;

NamedTrace ::
  name : seq of char
  defs : TraceDefinition;

TraceDefinition =
  TraceDefinitionItem |
```

```
  TraceSequenceDefinition |
  TraceChoiceDefinition;

TraceSequenceDefinition ::
  defs : seq of TraceDefinition;

TraceChoiceDefinition ::
  defs : seq of TraceDefinition;

TraceDefinitionItem ::
  bind    : seq of TraceBinding
  test    : TraceCoreDefinition
  regexpr : [TraceRepeatPattern];

TraceBinding =
        TraceLetBinding |
        TraceLetBeBinding;

TraceLetBinding ::
  definition_list : seq of ValueShape;

TraceLetBeBinding ::
  bind : Bind
  best : [Expression];

TraceCoreDefinition =
  TraceMethodApply |
  TraceBracketedDefinition;

TraceMethodApply ::
  variable_name : Identifier
  method_name : Identifier
  args : seq of Expression;

TraceBracketedDefinition ::
  definition : TraceDefinition;

TraceRepeatPattern =
  TraceZeroOrMore |
  TraceOneOrMore |
  TraceZeroOrOne |
  TraceRange;

TraceZeroOrMore :: ;

TraceOneOrMore :: ;
```

```
TraceZeroOrOne :: ;

TraceRange ::
  lower : NumericLiteral
  upper : [NumericLiteral];

---
--- EXPRESSIONS
---

Expression =
  BracketedExpression |
  LetExpression |
  LetBeExpression |
  DefExpression |
  IfExpression |
  CasesExpression |
  UnaryExpression |
  BinaryExpression |
  ForAllExpression |
  ExistsExpression |
  ExistsUniqueExpression |
  IotaExpression |
  TokenExpression |
  SetEnumeration |
  SetComprehension |
  SetRangeExpression |
  SequenceEnumeration |
  SequenceComprehension |
  SubsequenceExpression |
  MapEnumeration |
  MapComprehension |
  TupleConstructor |
  RecordConstructor |
  MuExpression |
  ApplyExpression |
  FieldSelect |
  FunctionTypeSelect |
  FunctionTypeInstantiation |
  LambdaExpression |
  NewExpression |
  SelfExpression |
  ThreadIdExpression |
  TimeExpression |
  IsExpression |
  UndefinedExpression |
  PreconditionExpression |
```

```
    IsofbaseclassExpression |
    IsofclassExpression |
    SamebaseclassExpression |
    SameclassExpression |
    ReqExpression |
    ActExpression |
    FinExpression |
    ActiveExpression |
    WaitingExpression |
    Name |
    OldName |
    SymbolicLiteralExpression;

  BracketedExpression ::
    expression : Expression;

  LetExpression ::
    definition_list : seq of ValueShape
    expression : Expression;

  LetBeExpression ::
    bind : Bind
    best : [Expression]
    expression : Expression;

  DefExpression ::
    pattern_bind_list : seq of PatternBindExpression
    expression : Expression;

  PatternBindExpression ::
    pattern_bind : PatternBind
    expression : Expression;

  IfExpression ::
    if_expression : Expression
    then_expression : Expression
    elseif_expression_list : seq of ElseIfExpression
    else_expression : Expression;

  ElseIfExpression ::
    elseif_expression : Expression
    then_expression : Expression;

  CasesExpression ::
    match_expression : Expression
    alternative_list : seq of CasesExpressionAlternative
    others_expression : [Expression];
```

```
CasesExpressionAlternative ::
  pattern_list : seq of Pattern
  expression : Expression;

UnaryExpression ::
  operator : UnaryOperator
  expression : Expression;

UnaryOperator =
  <PLUS> |
  <MINUS> |
  <ABS> |
  <FLOOR> |
  <NOT> |
  <CARD> |
  <POWER> |
  <DUNION> |
  <DINTER> |
  <HD> |
  <TL> |
  <LEN> |
  <ELEMS> |
  <INDS> |
  <DCONC> |
  <DOM> |
  <RNG> |
  <DMERGE> |
  <INVERSE>;

BinaryExpression ::
  lhs_expression : Expression
  operator : BinaryOperator
  rhs_expression : Expression;

BinaryOperator =
  <PLUS> |
  <MINUS> |
  <MULTIPLY> |
  <DIVIDE> |
  <DIV> |
  <REM> |
  <MOD> |
  <LT> |
  <LE> |
  <GT> |
  <GE> |
```

```
  <EQ> |
  <NE> |
  <OR> |
  <AND> |
  <IMPLY> |
  <EQUIV> |
  <INSET> |
  <NOTINSET> |
  <SUBSET> |
  <PSUBSET> |
  <UNION> |
  <DIFFERENCE> |
  <INTER> |
  <CONC> |
  <MODIFY> |
  <MUNION> |
  <MAPDOMRESTO> |
  <MAPDOMRESBY> |
  <MAPRNGRESTO> |
  <MAPRNGRESBY> |
  <COMP> |
  <ITERATE> |
  <TUPSEL> ;

ForAllExpression ::
  bind_list : seq of Bind
  expression : Expression;

ExistsExpression ::
  bind_list : seq of Bind
  expression : Expression;

ExistsUniqueExpression ::
  bind : Bind
  expression : Expression;

IotaExpression ::
  bind : Bind
  expression : Expression;

TokenExpression ::
  expression : Expression;

SetEnumeration ::
  expression_list : seq of Expression;

SetComprehension ::
```

```
  expression : Expression
  bind_list : seq of Bind
  guard : [Expression];

SetRangeExpression ::
  lower : Expression
  upper : Expression;

SequenceEnumeration ::
  expression_list : seq of Expression;

SequenceComprehension ::
  expression : Expression
  set_bind : SetBind
  guard : [Expression];

SubsequenceExpression ::
  expression : Expression
  lower : Expression
  upper : Expression;

MapEnumeration ::
  maplet_list : seq of Maplet;

Maplet ::
  dom_expression : Expression
  rng_expression : Expression;

MapComprehension ::
  expression : Maplet
  bind_list : seq of Bind
  guard : [Expression];

TupleConstructor ::
  expression_list : seq of Expression;

RecordConstructor ::
  name : Name
  expression_list : seq of Expression;

MuExpression ::
  expression : Expression
  modifier_list : seq of RecordModifier;

RecordModifier ::
  identifier : Identifier
  expression : Expression;
```

```
ApplyExpression ::
  expression : Expression
  expression_list : seq of Expression;

FieldSelect ::
  expression : Expression
  name : Name;

FunctionTypeSelect ::
  expression : Expression
  function_type_instantiation : FunctionTypeInstantiation;

FunctionTypeInstantiation ::
  name : Name
  type_list : seq of Type;

LambdaExpression ::
  type_bind_list : seq of TypeBind
  expression : Expression;

NewExpression ::
  name : Name
  generic_types : seq of Type                           -- added for Thomas C
  expression_list : seq of Expression;

SelfExpression :: ;

ThreadIdExpression :: ;

TimeExpression :: ;

IsExpression ::
  type : Type
  expression : Expression;

UndefinedExpression ::;

PreconditionExpression ::
  expression_list : seq of Expression;

IsofbaseclassExpression ::
  name : Name
  expression : Expression;

IsofclassExpression ::
  name : Name
```

```
  expression : Expression;

SamebaseclassExpression ::
  lhs_expression : Expression
  rhs_expression : Expression;

SameclassExpression ::
  lhs_expression : Expression
  rhs_expression : Expression;

ReqExpression ::
  name_list : seq of Name;

ActExpression  ::
  name_list : seq of Name;

FinExpression  ::
  name_list : seq of Name;

ActiveExpression  ::
  name_list : seq of Name;

WaitingExpression ::
  name_list : seq of Name;

Name ::
  class_identifier : [Identifier]
  identifier : Identifier;

OldName ::
  identifier : Identifier;

SymbolicLiteralExpression ::
  literal : Literal;

---
--- STATEMENTS
---

Statement =
  LetStatement |
  LetBeStatement |
  DefStatement |
  BlockStatement |
  DclStatement |
  AssignStatement |
  AtomicStatement |
```

```
  IfStatement |
  CasesStatement |
  SequenceForLoop |
  SetForLoop |
  IndexForLoop |
  WhileLoop |
  NondeterministicStatement |
  CallStatement |
  ReturnStatement |
  SpecificationStatement |
  StartStatement |
  DurationStatement |
  CyclesStatement |
  AlwaysStatement |
  TrapStatement |
  RecursiveTrapStatement |
  ExitStatement |
  ErrorStatement |
  SkipStatement ;

LetStatement ::
  definition_list : seq of ValueShape
  statement : Statement;

LetBeStatement ::
  bind : Bind
  best : [Expression]
  statement : Statement;

DefStatement ::
  definition_list : seq of EqualsDefinition
  statement : Statement;

EqualsDefinition ::
  pattern_bind : PatternBind
  expression : Expression;

BlockStatement ::
  dcl_statement_list : seq of DclStatement
  statement_list : seq of Statement;

DclStatement ::
  definition_list : seq of AssignmentDefinition;

AssignmentDefinition ::
  identifier : Identifier
  type : Type
```

```
  expression : [Expression];

AssignStatement ::
  state_designator : StateDesignator
  expression : Expression;

AtomicStatement ::
  assignment_list : seq of AssignStatement;

StateDesignator =
  StateDesignatorName |
  FieldReference |
  MapOrSequenceReference;

StateDesignatorName ::
  name : Name;

FieldReference ::
  state_designator : StateDesignator
  identifier : Identifier;

MapOrSequenceReference ::
  state_designator : StateDesignator
  expression : Expression;

IfStatement ::
  expression : Expression
  then_statement : Statement
  elseif_statement : seq of ElseIfStatement
  else_statement : [Statement];

ElseIfStatement ::
  expression : Expression
  statement : Statement;

CasesStatement ::
  match_expression : Expression
  alternative_list : seq of CasesStatementAlternative
  others_statement : [Statement];

CasesStatementAlternative ::
  pattern_list : seq of Pattern
  statement : Statement;

SequenceForLoop ::
  pattern_bind : PatternBind
  in_reverse : bool
```

```
  expression : Expression
  statement : Statement;

SetForLoop ::
  pattern : Pattern
  expression : Expression
  statement : Statement;

IndexForLoop ::
  identifier : Identifier
  init_expression : Expression
  limit_expression : Expression
  by_expression : [Expression]
  statement : Statement;

WhileLoop ::
  expression : Expression
  statement : Statement;

NondeterministicStatement ::
  statement_list : seq of Statement;

CallStatement ::
  object_designator : [ObjectDesignator]
  name : Name
  expression_list : seq of Expression;

ObjectDesignator =
  ObjectDesignatorExpression |
  ObjectFieldReference |
  ObjectApply;

ObjectDesignatorExpression ::
  expression : Expression;

ObjectFieldReference ::
  object_designator : ObjectDesignator
  name : Name;

ObjectApply ::
  object_designator : ObjectDesignator
  expression_list : seq of Expression;

ReturnStatement ::
  expression : [Expression];

SpecificationStatement ::
```

```
  externals : [Externals]
  pre_expression : [Expression]
  post_expression : Expression
  exceptions : [Exceptions];

StartStatement ::
  expression : Expression;

DurationStatement ::
  duration_expression : seq of Expression
  statement : Statement;

CyclesStatement ::
  cycles_expression : seq of Expression
  statement : Statement;

AlwaysStatement ::
  always_part : Statement
  in_part : Statement;

TrapStatement ::
  pattern_bind : PatternBind
  with_part : Statement
  in_part : Statement;

RecursiveTrapStatement ::
  trap_list : seq of TrapDefinition
  in_part : Statement;

TrapDefinition ::
  pattern_bind : PatternBind
  statement : Statement;

ExitStatement ::
  expression : [Expression];

ErrorStatement ::;

SkipStatement ::;

---
--- PATTERNS
---

Pattern =
  DontCarePattern |
  PatternIdentifier |
```

```
  MatchValue |
  SymbolicLiteralPattern |
  SetEnumPattern |
  SetUnionPattern |
  SeqEnumPattern |
  SeqConcPattern |
  TuplePattern |
  RecordPattern;

DontCarePattern ::;

PatternIdentifier ::
  identifier : Identifier;

MatchValue ::
  expression : Expression;

SymbolicLiteralPattern ::
  literal : Literal;

SetEnumPattern ::
  pattern_list : seq of Pattern;

SetUnionPattern ::
  lhs_pattern : Pattern
  rhs_pattern : Pattern;

SeqEnumPattern ::
  pattern_list : seq of Pattern;

SeqConcPattern ::
  lhs_pattern : Pattern
  rhs_pattern : Pattern;

TuplePattern ::
  pattern_list : seq of Pattern;

RecordPattern ::
  name : Name
  pattern_list : seq of Pattern;

---
--- BINDINGS
---

PatternBind =
  Pattern |
```

```
  Bind;

Bind =
  SetBind |
  TypeBind;

-- SetBind is used for both single and multiple binds

SetBind ::
  pattern : seq of Pattern
  expression : Expression;

-- TypeBind is used for both single and multiple binds

TypeBind ::
  pattern : seq of Pattern
  type : Type;

---
--- LEXICAL ELEMENTS
---

Literal =
  NumericLiteral |
  RealLiteral |
  BooleanLiteral |
  NilLiteral |
  CharacterLiteral |
  TextLiteral |
  QuoteLiteral;

NumericLiteral ::
  val : nat;

RealLiteral ::
  val : real;

BooleanLiteral ::
  val : bool;

NilLiteral ::;

CharacterLiteral ::
  val : char;

TextLiteral ::
  val : seq of char;
```

```
QuoteLiteral ::
  val : seq of char;

Identifier = seq of char
```

Listing G.1: OML AST

Appendix H

UML AST

In this appendix the UML AST is listed.

```
-----------------------------------------------
-- UML ABSTRACT SYNTAX DEFINITION
--
-- File: UML.ast
-- Created: 09 - 2008
-- Authour: Kenneth Lausdahl
--          and
--          Hans Kristian Lintrup
-- Description: Subpart of UML represented as
--  an AST. Contains the UML static structure
------------------------------------------------
%prefix Uml;
%package org.overturetool.uml.ast;
%directory "C:\COMU\build";
%top Model;

Model ::
 name : String
 definitions : set of ModelElement;

ModelElement = Class | Association |
               Constraint | Collaboration;

Class ::
  name       : String
  classBody  : set of DefinitionBlock
  isAbstract : bool
  superClass : seq of ClassNameType
```

```
  visibility : VisibilityKind
  isStatic   : bool
  isActive   : bool
  templatesignature : [TemplateSignature];

VisibilityKind = <PUBLIC> | <PRIVATE> | <PROTECTED> ;

TemplateSignature ::
  templateParameters : set of TemplateParameter;

TemplateParameter ::
  name       : String;

DefinitionBlock =
  OwnedOperations | OwnedProperties | NestedClassifiers;

-------------------------------
-- Operation
-------------------------------
OwnedOperations ::
  operationList :set of Operation;

Operation ::
  name            : String
  visibility      : VisibilityKind
  multiplicity    : MultiplicityElement --aka return type
  isQuery         : bool
  type            : [Type]              --aka return type
  isStatic        : bool
  ownedParameters : [Parameters];

Parameters ::
  parameterList : seq of Parameter;

Parameter ::
  name         : String
  type         : Type
  multiplicity : MultiplicityElement
  default      : String
  direction    : ParameterDirectionKind;

ParameterDirectionKind = <IN> | <INOUT> | <OUT> | <RETURN>;

MultiplicityElement::
  isOrdered : bool
  isUnique  : bool
  lower     : nat
```

```
  upper     : [nat];

-------------------------------
-- Property
-------------------------------
OwnedProperties ::
  propetityList : set of Property;

Property ::
  name         : String
  visibility   : VisibilityKind
  multiplicity : [MultiplicityElement]
  type         : Type
  isReadOnly   : [bool]
  default      : [ValueSpecification]
  isComposite  : bool
  isDerived    : [bool]
  isStatic     : [bool]
  ownerClass   : String
  qualifier    : [Type];

-------------------------------
-- Types
-------------------------------
NestedClassifiers ::
  typeList : set of Type;

Type =
  BoolType |
  IntegerType |
  StringType |
  UnlimitedNatural |
  VoidType |
  CharType |
  ClassNameType;

BoolType ::;
IntegerType ::;
StringType ::;
UnlimitedNatural ::;
VoidType :: ;
CharType :: ;

ClassNameType ::
  name : String;

-------------------------------
```

```
-- Association
-------------------------------
Association ::
  ownedEnds : set of Property
  ownedNavigableEnds : set of Property
  name : [String]
  id : Id;

-------------------------------
-- Constraint
-------------------------------
Constraint ::
  constraintElements : set of Id
  specification : ValueSpecification;

ValueSpecification = LiteralString | LiteralInteger;



-------------------------------
-- Diagrams
-------------------------------
Collaboration :: -- Unknown in superstructure
  ownedBehavior : set of Interaction;

Interaction ::
  name : String
  lifeLines : set of LifeLine
  fragments : set of InteractionFragment
  messages  : seq of Message;

LifeLine ::
  name : String
  represents : [Type]; -- ConnectableElement - TypedElement - Class
  --coveredBy : set of InteractionFragment;

InteractionFragment = OccurrenceSpecification |
                      InteractionOperand |
                      CombinedFragment |
                      ExecutionSpecification;

OccurrenceSpecification = Mos; -- Mos = MessageOccurrenceSpecification
ExecutionSpecification = Bes; -- Bes = BehaviorExecutionSpecification

Mos ::
  name    : String
  message : [Message]
```

```
  covered : LifeLine
  event   : [CallEvent];

CallEvent ::
  operation : Operation;

Bes ::
  name     : String
  startOs  : OccurrenceSpecification
  finishOs : OccurrenceSpecification
  covered  : set of LifeLine;

CombinedFragment ::
  name    : String
  interactionOperator : InteractionOperatorKind
  operand : seq of InteractionOperand --seq1
  covered : set of LifeLine;

InteractionOperatorKind = <ALT> | <LOOP>;

InteractionOperand ::
  name     : String
  fragments: seq of InteractionFragment
  covered  : set of Mos --LifeLine
  guard    : [InteractionConstraint];
--inv io == forall cf in set elems io.fragments & is_CombinedFragment(cf)
--                                        and forall mos in set io.covered
--                                          & forall childMos in set dunion
--                                            & mos <> childMos;

InteractionConstraint ::
  minint : [ValueSpecification]
  maxint : [ValueSpecification];

Message ::
  name        : String
  messageKind : MessageKind
  messageSort : MessageSort
  sendEvent   : Mos
  sendReceive : Mos
  argument    : seq of ValueSpecification;

MessageKind = <COMPLETE> | <UNKNOWN>;
MessageSort = <SYNCHCALL> | <ASYNCHCALL>;

LiteralString ::
 value : String;
```

```
LiteralInteger ::
  value : nat;

-------------------------------
-- Others
-------------------------------
String = seq of char;
Id = String
```

Listing H.1: UML AST

Appendix I

Features supported by Transformation

In this appendix a table I.1 shows a overview of the supported features by the VDM - UML transformation. An X denotes that the feature is fully specified. An (X) denotes that the feature is partly specified.

Name (VDM)	Rule #	AST	VDM►UML	UML►VDM
Core				
Classes	1	X	X	X
Inheritance	14	X	X	X
Functions	17	X	X	X
Operations	17	X	X	X
Generic classes	16	X	X	-
Values	6, 5	X	X	X
Instance variables	6, 5	X	X	X
Initial value	7	X	X	X
Visibility	2	X	X	X
Thread	13	X	X	-
Abstract Class	15	X	X	-
Static Access	3	X	X	X
Types				
Product Types	10	X	X	X
Union Types	9	X	X	X
Record Types	-	-	-	-
Optional Types	5	X	X	-
Object Reference Types	5	X	X	X
Collections and Relationships				
map	12	X	X	-
set	11	X	X	(X)
seq	11	X	X	(X)
seq1	11	X	X	(X)
Traces				
Core Definition	1819,20,24	X	-	X
Definition List	21	X	-	X
Choice Definition	22	X	-	X
Repeat Pattern	23	X	-	X
Bindings	-	-	-	-

Table I.1: Overview of supported features. X equals full support where (X) implies a partly support.

List of Symbols and Abbreviations

Abbreviation	Description	Definition
API	Application Programming Interface	page 82
AST	Abstract Syntax Tree, a tree representation of the syntax of some source code	page 67
ASTGen	Converts an AST to VDM classes and Java interfaces. Maintained by the Overture project.	page 67
BES	Behavior Execution Specification, denoted the rectangle defining the execution time of a message in a SD	page 157
CD	UML Class Diagram	page 24
CSK	CSK is a Japanese conglomerate, owned by CSK Holdings Corporation	page 44
DAG	Directed Acyclic Graph, a directed graph with no directed cycles	page 135
FM	Formal Method	page 9
GAO	Gesellschaft für Organisation	page 44
IBM	International Business Machines	page 43
IFAD	IFAD develops and markets simulation & training products, networked simulation solutions, web and information technology solutions for civilian, military and Homeland Defence applications	page 44
ISO	International Standards Organization	page 43
JAR	Java ARchive, Java archive for source code, a optional manifest can specify which class to execute within the JAR file	page 111
MDA	Model-driven architecture, a software design approach	page 15
MOF	Meta-Object Facility, a meta-model used to formally define Unified Modeling Language (UML)	page 21
MOS	Message Occurrence Specification, links a message to other elements in a SD such as life lines and fragments	page 157

Abbreviation	Description	Definition
OMG	Object Management Group, the consortium responsible for CORBA architecture, Unified Modeling Language, and Model-driven architecture	page 19
OML	Overture Modeling Language, a specification language inspired by the object-oriented formal specification language VDM++ (Vienna Development Method)	page 17
OO	Object-oriented, a computer programming paradigm	page 19
RVL	Rose-VDM++ Link, integrates UML and VDM++ by providing a tight coupling between the VDM Toolbox and Rational Rose	page 31
SD	UML Sequence Diagram	page 23
SIC	Sensor Integration Controller	page 44
UIS	UML Infrastructure Specification	page 71
UML	Unified Modeling Language	page 19
USS	UML Superstructure Specification	page 71
VDM	Vienna Development Method	page 43
VDMEditor	Eclipse based editor for VDM	page 119
VDMJ	VDM tool implemented in Java by Nick Battle from Fujitsu	page 46
VDMTools	A development tool supporting precise modeling in the notations VDM-SL or VDM++	page 44
VDMUnit	VDM unit test freamwork	page 111
VICE	VDM In Constrained Environment, a recent research extension of	page 43
XMI	XML Metadata Interchange (XMI), is an Object Management Group (OMG) standard for exchanging metadata information via Extensible Markup Language (XML)	page 82
XML	Extensible Markup Language (XML)	page 40