Thesis Title

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Abstract

Abrégé

Acknowledgements

Preface

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Chapter 1

Introduction

Since 1960s, software development has been evolving rapidly to address the increasing demands of complex software. The complexity of modern software brings about difficulties in developing and maintaining quality software. Software engineering as a discipline ensures that developers follow a systematic production of software, by applying best practices to maximize quality of deliverables and minimize time-to-market. Various methodologies exist through the efforts of active research by theorists and practitioners, but the core of software development process typically consists of the following six phases—requirements gathering, design, implementation, testing, deployment, and maintenance.

Conceptual models help illustrates complex systems with a simple framework by creating abstractions to alleviate the amount of complexity. Hence, the use of models is progressively recommended in representing a software system. This simplifies the process of design, maximizes compatibility between different platforms, and promotes communication among stakeholders. Model-Driven Engineering (MDE) technologies offer the means to represent domain-specific knowledge within models, allowing modelers to express domain concepts effectively [1]. MDE advocates using the best modeling formalism that expresses relevant design intent declaratively at each level of abstraction. During development, we can use models to describe different aspects of the system vertically, in which the models are refined

from higher to lower levels of abstraction through model transformation. At the lowest level, models use implementation technology concepts, and appropriate tools can be used to generate code from these platform-specific models [2].

Modularity is key in designing computer programs that are extensible and easily maintainable, but concerns that are crosscutting and more scattered in the implementation are more likely to cause defects [3]. This poses obstacles for MDE because modeling such crosscutting concerns in a modular way is difficult from an object-oriented standpoint. Furthermore, reusability is also a main factor in allowing developers to leverage reusable solutions such as libraries and frameworks provided for a given programming language, thereby improving the development speed without having to implement existing software components from first principles. Model reuse is still in its early stage, but modeling libraries are emerging as well [4].

Concern-Oriented Reuse (CORE) introduces a modeling technique that focuses on concerns as units of reuse [5]. CORE enables large-scale model reuse by utilizing the ideas of MDE, Separation of Concerns (SoC), and Software Product Lines (SPL). This is possible because CORE uses aspect-oriented modeling techniques to allow complex models to be built by incrementally composing smaller, simpler models. Current state of CORE supports models at the design phase [6], but models of other development phases can also be supported by integrating with the CORE metamodel to benefit from advanced modularization and reuse support.

This thesis focuses on models at the requirements phase, typically built earlier than design models, and the User Requirements Notation (URN) sets the standard as a visual notation for modeling and analyzing requirements [7]. URN formalizes and integrates two complementary languages: (i) Goal-oriented Requirements Language (GRL) to describe non-

functional requirements as intentional elements, and (ii) Use Case Map (UCM) to describe functional requirements as causal scenarios. GRL and UCM are used to capture goal and scenario models, respectively. Since CORE already supports the use of goal models to analyze the impact of choosing features [5], we are interested in examining the possibility of having scenario models as part of the CORE toolkit. The goal of this thesis is to determine how UCMs can be integrated with the concepts of CORE. This leads to the question that begs to be investigated—whether actual MDE, i.e., software development with models at multiple levels of abstraction and model transformations that connect them, is compatible with CORE.

The remainder of this thesis is structured as follows. Chapter 2 offers background information on CORE and UCM. Chapter 3 presents the integration of CORE with UCM. Chapter 4 validates the resulting integration process. Finally, Chapter 5 concludes the thesis and discusses future work.

Chapter 2

Background

CORE builds on three key components—MDE, SoC, and SPL—to support large-scale model reuse. We are also interested in studying the early phases of software development, where the requirements of the software to be built are elaborated. In this chapter, we provide an overview of CORE as a reuse technique with the current state of development in Section 2.1. Then we describe UCM as part of the requirements engineering tool and its use in specifying scenarios in Section 2.2.

2.1 Concern-Oriented Reuse (CORE)

CORE is a reuse technique that extends MDE with best practices from advanced modularization and SoC techniques [8], as well as features and goal modeling to support SPL [9]. Variations exist for any given solution

You can reuse some of our text from previous papers here. Focus on what is really interesting for us in this thesis, i.e., interfaces, features + realization models, customization mappings, weaving algorithm. You should also show the CORE metamodel here (or at least a simplified version of it that is used as a basis for the integration in chapter 3. You can use some of the text from our SoSyM paper.

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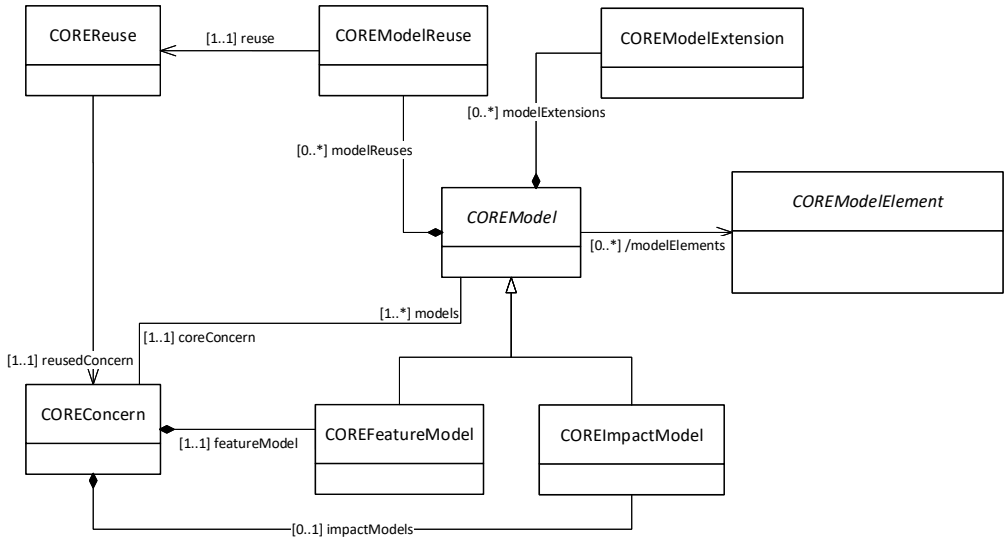

Figure 2.1: CORE metamodel: basic structure of a concern

2.1.1 Concern Interfaces

A concern groups related models serving the same purpose, and provides three interfaces to facilitate reuse [5]. The variation interface presents the design alternatives and their impact on non-functional requirements. The customization interface of the selected alternative details how to adapt the generic solution to a specific context. Finally, the usage interface specifies the provided behavior.

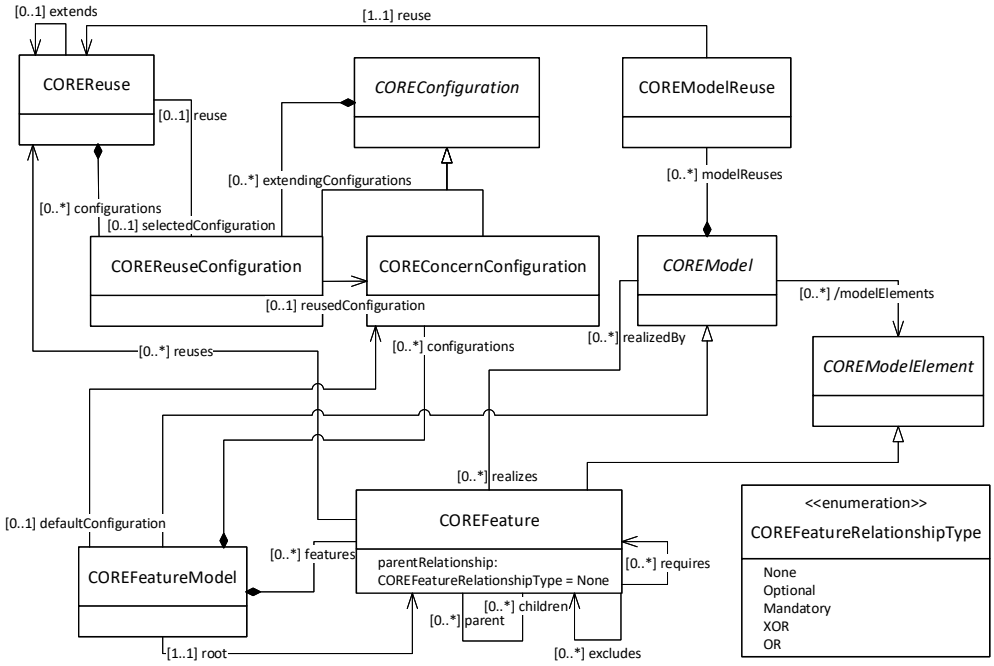

Figure 2.2: CORE metamodel: variation interface - features

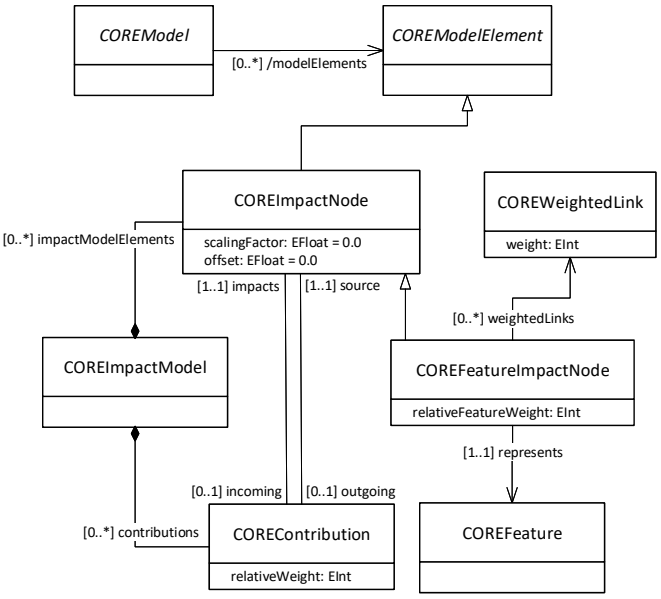

Figure 2.3: CORE metamodel: variation interface - impacts

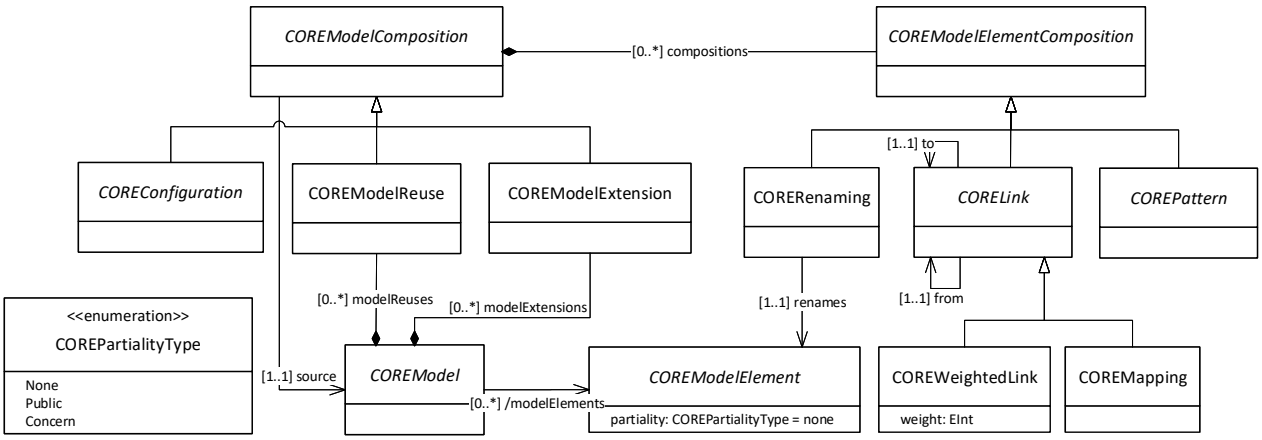

Figure 2.4: CORE metamodel: customization interface

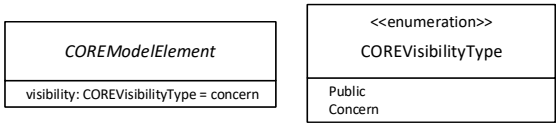

Figure 2.5: CORE metamodel: usage interface

Variation Interface

Customization Interface

Usage Interface

2.1.2 Reusable Aspect Models (RAM)

No need to explain too much here, since we don't use RAM really in the rest of the thesis, no? Explain mostly that RAM is the only language currently integrated with CORE, and that the models are about design. You could use class diagrams to give an example of weaving, if you think it is necessary

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2.1.3 Customization Mappings

2.1.4 CORE Weaver

2.2 Use Case Map (UCM)

Brief overview and what UCMs are used for. Maybe one example UCM (that is used later on)

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UCM metamodel (or a simplified version of it)

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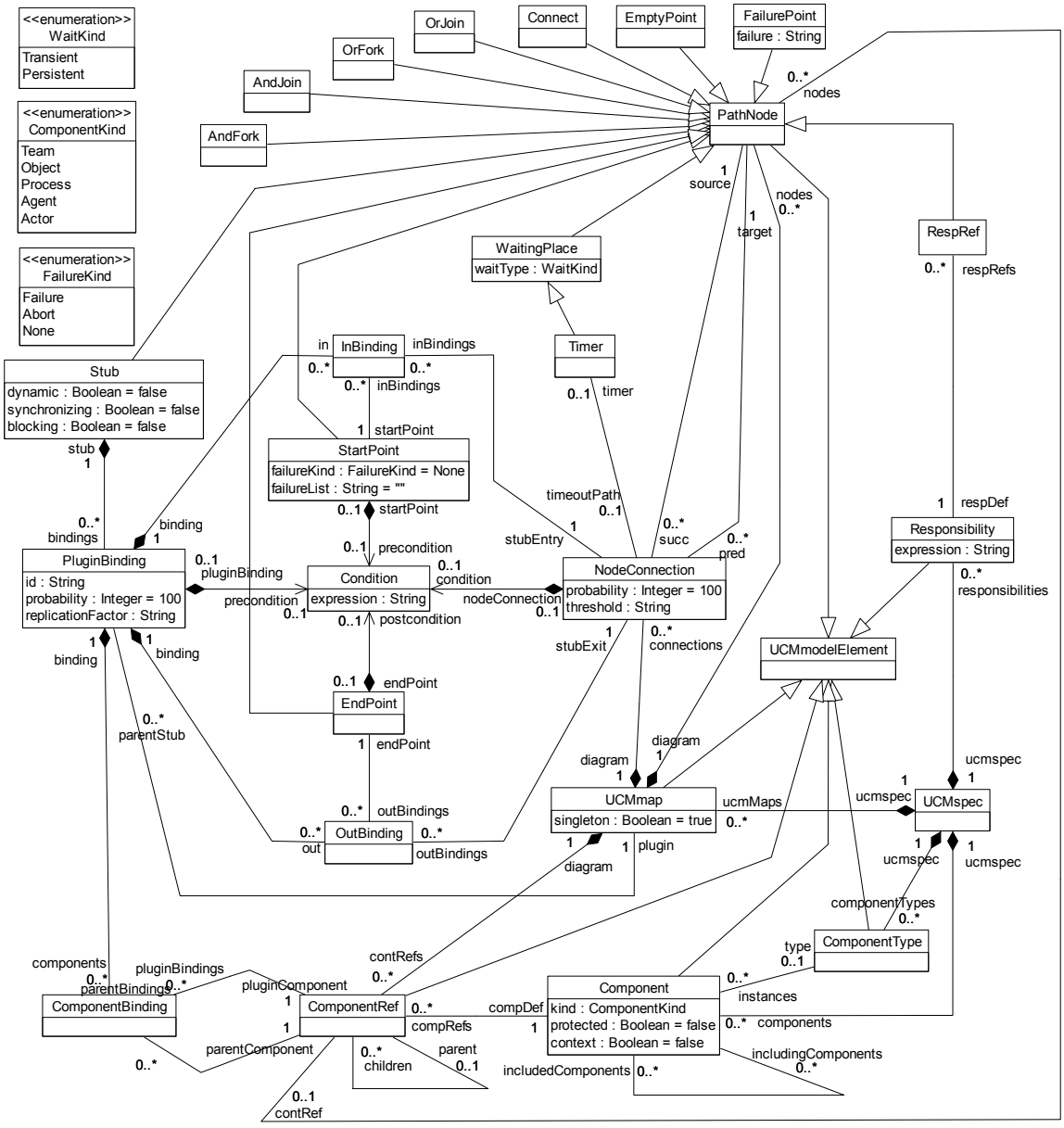

Figure 2.6: Abstract grammar: UCM metamodel. Image courtesy of ITU [10]

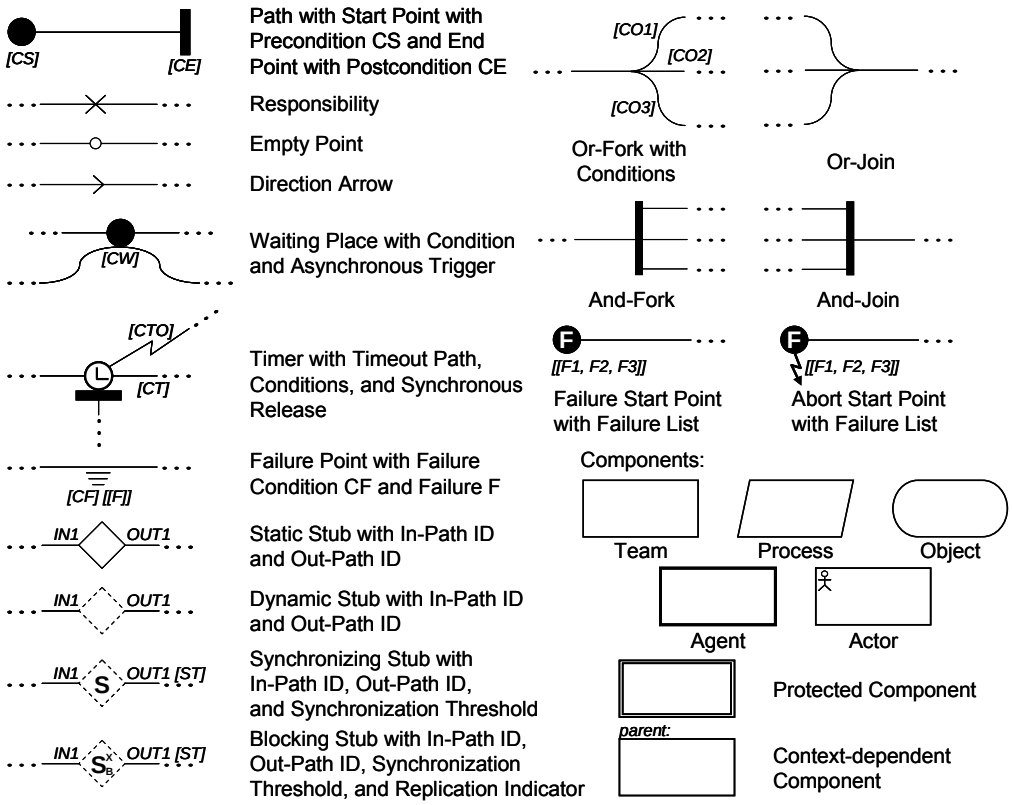

Figure 2.7: UCM notation. Image courtesy of ITU [10]

2.2.1 Aspect-oriented Use Case Map (AoUCM)

Most of your related work will be Gunter's AoUCM stuff, which you probably mention above already. jUCMNav as well, but this you could also mention above when you talk about UCMs.

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Chapter 3

Adding Support for UCM to CORE

This chapter presents the corification of a modeling language for the requirements phase using the CORE metamodel. We describe the steps taken to corify UCM in Section 3.1. We also present the weaving algorithm specific for UCM in the context of CORE in Section 3.2.

3.1 Corification of UCM

Abstract and concrete classes of the CORE metamodel are utilized differently when corifying a modeling language. The abstract classes *COREModel*, *COREModelElement*, and *COREPattern* serve as extension points and are intended to be subclassed by a modeling language. This enables the addition of arbitrary modeling languages to CORE and also uniform treatment of pattern-based composition. The remaining abstract classes *COREModelComposition*, *COREModelElementComposition*, and *CORELink* are used within the CORE metamodel and seldom subclassed by a modeling language. On the contrary, concrete classes are designed to be used exactly as it is in the corified modeling languages. They provide the necessary mechanisms for model extensions and reuses, feature and impact modeling, as well as a way to implements and visualizes these concepts in its modeling tool.

We follow the URN specification [10] closely in corifying the UCM metamodel. Figure 3.1 shows a partial view of the corified UCM metamodel, focusing on the elements that extend

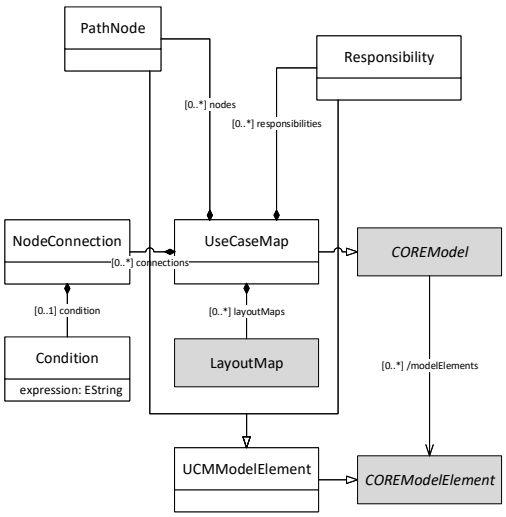


Figure 3.1: Extension of the CORE metamodel by UCM

the CORE metamodel through subclassing (from an existing metaclass in the modeling language to an abstract CORE metaclass [1]). By subclassing the necessary abstract classes of the CORE metamodel, UCM is able to provide all the properties of CORE:

- A UCM model may now belong to a concern by realizing at least one of its features.
- A realization model could potentially have impacts on high-level goals.
- A UCM model may extend another UCM model that belongs to a different feature.
- A UCM model may reuse another UCM model that belongs to a different concern.

Reusing a concern from a UCM model prompts the feature selection process, by asking the feature that the UCM model realizes to reuse the other concern with the selection of feature(s) it wants to reuse. The reusing UCM model then establishes the mappings to the reused UCM model that realizes the reused features. This is achieved as follows. The root element UseCaseMap subclasses *COREModel*, which makes it part of a COREConcern

[1] The gray elements in the figures are the classes that derived from the CORE metamodel.

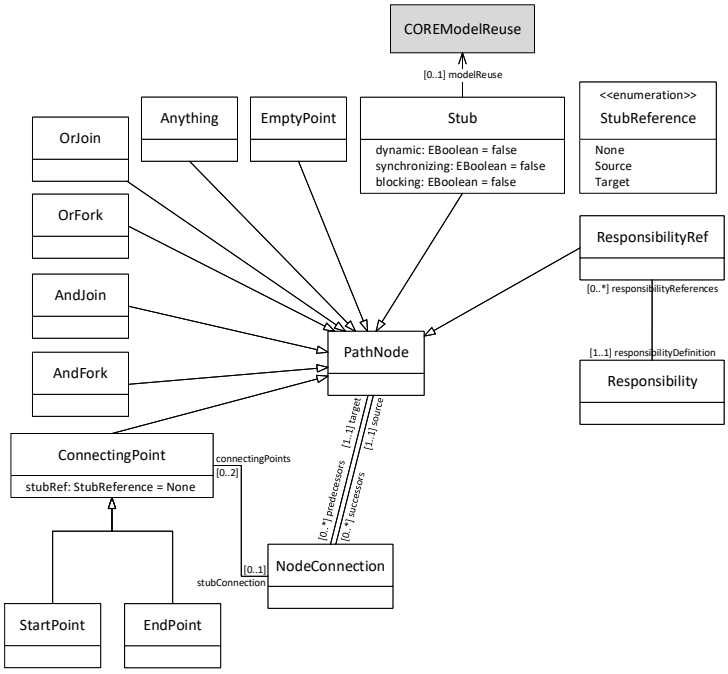


Figure 3.2: Path nodes for corified UCM

(see Figure 2.1, association between COREConcern and COREModel). This allows a UCM to realize a feature (see Figure 2.2, COREModel realizes COREFeature) within a concern. Therefore, the concern can create a COREReuse to reuse another concern. The reusing UCM then creates a COREModelReuse that has a direct association to the created COREReuse and a *COREConfiguration* that selects the desired features from the reused concern. The CORE modeling tool then composes the UCM models of the reused concern that realize the selected features to generate a single woven user-tailored UCM model of the reused concern. Mappings to the model elements of this generated model are established using the class COREMapping, consequently allowing the reusing UCM to customize the generated UCM model of the reused concern.

A standard UCM consists of PathNode, Responsibility, and NodeConnection. LayoutMap

is added as part of the composition to allow positioning of the elements for viewing. We omit the inclusion of certain elements such as Component, Timer, and FailurePoint to limit the scope of this thesis. On the contrary, PluginBinding is excluded on purpose since we utilize COREMapping as our approach to bind separate UCMs to Stub. We incorporate several changes to the path nodes to support aspect-oriented modeling and reuse. Figure 3.2 illustrates the addition of Anything and ConnectingPoint, as well as a directed association from Stub to COREModelReuse, to the UCM metamodel.

Anything: We included the Anything pointcut element from the extended AoUCM metamodel [11]. Anything acts as a wild card and can represent a subset of nodes in a path. This is useful for facilitating complex model weaving, as it allows any sequence of UCM model elements, including an empty sequence, to be matched.

ConnectingPoint: We established a new path element to the metamodel. ConnectingPoint is used to replace PluginBinding and serves as an intermediate node that represents either a StartPoint or an EndPoint. By default, an actual start or end point within a UCM does not have a reference to a stub, hence the default value for StubReference is None. Instead, when we have a NodeConnection that connects an element with a stub, then a hidden connecting point is automatically attached to the node connection (and deleted upon removal of the connection). Each node connection can have at most two connecting points if both the source and target nodes of the connection are stubs. Incoming connection to a stub generates a hidden end point with the value of stubRef set to Target, whereas outgoing connection from a stub generates a hidden start point with the value of stubRef set to Source. These hidden points allow us to define composition specifications through customization mappings.

Since we are using COREMapping to specify customizations, it is necessary for UCMModelElement to subclass *COREModelElement*. That way, all subclasses of UCMModelElement

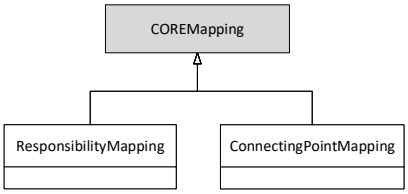


Figure 3.3: Customization mappings for corified UCM

(i.e., PathNode and Responsibility) can be used as source and destination classes for CO-REMapping. As shown in Figure 3.3, we defined the composition specifications for specific UCM model elements: Responsibility and ConnectingPoint. They were selected so that we can compose UCM models based on the mappings of these elements. This leads us to the next section where we describe in detail how model composition is achieved through weaving.

3.2 UCM Weaving

As explained in Section 2.1, the role of the weaver is to facilitate model extensions and reuses. We offer two options when mapping elements between UCMs: (i) direct mapping of responsibilities; and (ii) cross mapping of connecting points. Cross mapping is necessary because of the nature of start and end points, where a start point of a UCM maps to an end point of a stub, and vice versa. A stub can be perceived as being superimposed with an end point followed by a start point, and those points collapsed into a point that is the stub [12]. Here, the hidden end point of a stub represents the incoming connection and it signifies the end of the sequence before the stub, and the hidden start point of a stub represents the outgoing connection and it signifies the start of the sequence after the stub. Both options have different procedures when weaving.

3.2.1 Weaving Algorithm

The algorithms presented here are specific for single weaving, meaning that a composition is performed from one model (UCM_1) to another model (UCM_2). This action can be chained together with other compositions, even with the hierarchical structure of the concern features. Here, we specify the subscript $_1$ for the model elements of a UCM the weaver composes from, and the subscript $_2$ for the model elements of a UCM the weaver composes to. UCM_1 and UCM_2 are merged prior to weaving, retaining all the path nodes and node connections from both models. Then the weaver iterates through the available composition specifications and executes the algorithms based on the specific type of mapping. The output of the woven model results in the amalgamation of UCMs based on the composition specification defined by the designer of the models, as well as the selected features of the concern by the user.

Responsibility Mapping

Mapping with responsibilities allows for model extensions between parent and child UCMs. Composition specification can be defined by mapping from a parent UCM's responsibility to a child UCM's responsibility. Algorithm 1 illustrates the procedure of weaving for responsibility mappings. The function *WeaveResponsibilityMapping* initiates the process by identifying the mapped responsibilities (*from* UCM_1 *to* UCM_2), and traversal begins from the point of $responsibility_2$ in both directions: (i) toward predecessors until start point encountered; and (ii) toward successors until end point encountered. A UCM is represented as a directed graph, with possible cycles via OrForks and OrJoins. As such, we implemented a depth-first search approach for traversing the graph through recursion (lines 36 and 65), and a mechanism to determine whether a node has been explored (lines 19-23 and 43-47).

Furthermore, we allow multiple consecutive mappings between two UCM models. The

Algorithm 1 Weaving Algorithm: Responsibility Mapping

```
1: function WeaveResponsibilityMapping(ucm, composition)
2:     node_1 ← get first node of composition mapping (from)
3:     node_2 ← get second node of composition mapping (to)
4:     mark node_2 as visited
5:     indicate start point has not been encountered
6:     indicate end point has not been encountered
7:     call TraverseToSource(ucm, node_2, node_1)
8:     call TraverseToTarget(ucm, node_2, node_1)
9:     remove node_1 from ucm
10: end function
11: function TraverseToSource(ucm, node_2, node_1)
12:     for each predecessor of node_2 do
13:         sourceNode ← get source node of predecessor
14:         if linkage exists from previous mapping then
15:             set the source of node_2's connection to node_1's predecessor
16:             disable linkage
17:             skip this loop
18:         end if
19:         if sourceNode is visited then
20:             skip this loop
21:         else if sourceNode is not Anything then
22:             mark sourceNode as visited
23:         end if
24:         if sourceNode is StartPoint and start point is not encountered then
25:             if visibility of sourceNode is Concern then
26:                 set the source of node_2's connection to node_1's predecessor
27:                 remove sourceNode from ucm
28:                 indicate start point has been encountered
29:             end if
30:         else if sourceNode is Anything then
31:             set the source of node_2's connection to node_1's predecessor
32:             if sourceNode does not have any predecessor then
33:                 remove sourceNode from ucm
34:             end if
35:         else
36:             recursively call TraverseToSource(ucm, sourceNode, node_1)
37:         end if
38:     end for
39: end function
```

```
40: function TraverseToTarget(ucm, node_2, node_1)
41:     for each successor of node_2 do
42:         targetNode ← get target node of successor
43:         if targetNode is visited then
44:             skip this loop
45:         else if targetNode is not Anything then
46:             mark targetNode as visited
47:         end if
48:         if targetNode is Endpoint and end point is not encountered then
49:             if visibility of targetNode is Concern then
50:                 set the target of node_2's connection to node_1's successor
51:                 remove targetNode from ucm
52:                 indicate end point has been encountered
53:             end if
54:         else if targetNode is Anything then
55:             set the target of node_2's connection to node_1's successor
56:             if targetNode does not have any successor then
57:                 remove targetNode from ucm
58:             end if
59:         else if targetNode exists in compositions mapping (to) then
60:             copy node connection of successor
61:             set the target of copied connection to node_1's successor
62:             add the copied connection to ucm
63:             enable linkage to next mapping
64:         else
65:             recursively call TraverseToTarget(ucm, targetNode, node_1)
66:         end if
67:     end for
68: end function
```

path of a UCM may consist of mapped responsibilities interspersed with other path nodes. While traversing forward, lines 59-63 handle the next mapped responsibility. If exist, forward traversal stops for this specific composition and appropriate nodes are connected between UCM_1 and UCM_2. For subsequent mappings, lines 14-18 handle the linkage from previous mappings, and backward traversal stops at the point of mapped responsibilities and appropriate nodes are connected between UCM_1 and UCM_2. This pattern continues until the weaver reaches end point, whereby the predecessor of UCM_2's end point connects to the successor of mapped responsibility ($from$) UCM_1 and this end point gets deleted (lines 48-53). Same goes for backward traversal until the weaver reaches start point (lines 24-29). Lastly, mapped responsibility (to) UCM_2 retains while mapped responsibility ($from$) UCM_1 gets deleted for the final woven UCM model.

UCM may have multiple start points merging to a path, or a path may branch to multiple end points. In this case, we allow a start or end point to set its visibility level. By default, connecting point is given the visibility of Concern that signifies the start or end point is only visible when viewing a UCM model for a specific feature of a concern, but disappears after the composition process. The other option is Public for global visibility and is used to retain the start or end point even after the composition process—the weaver would just ignore Public connecting points and proceed to other branches. This feature is useful in defining multiple entry points, or alternative exit strategies, for a scenario.

Complex scenario model composition is also possible with the help of Anything. An anything node can represent a subset of nodes in a path and is commonly used in UCM_2 to capture the actual nodes that are specified in UCM_1. If an anything node is encountered during traversal, lines 30-34 and 54-58 signals the end of exploration and treat it as an end point. The difference is that the algorithm checks whether the anything node is still

connected to other nodes before removal. This is necessary because an anything node has a predecessor node and a successor node, and typically surrounded by forks and joins (loop cycle). Both sides have to be traversed and dealt with before removing the anything node from the woven model.

Connecting Point Mapping

Mapping with connecting points allows for model extensions between parent and child UCMs and also model reuses from UCMs of other concerns. Algorithm 2 illustrates the procedure of weaving for connecting point mappings. The function *WeaveConnectingPointMapping* initiates the process by identifying the mapped connecting points (*from* UCM_1 *to* UCM_2), and determine the type of composition to be performed based on whether the connecting points mapped from UCM_1 are attached to a stub or not. If the mapped start and end points from UCM_1 are attached to a stub (lines 5-6 and 11-12), it means that the connecting points are hidden and belong to a stub in UCM_1 and are mapped to actual end and start points of UCM_2, respectively (cross mapping). This type of composition is model extension. Vice versa for model reuse (lines 7-8 and 13-14).

Model extension for stubs work differently compared with responsibilities. No traversal is required since there is no need to explore the whole graph, but the composition specification requires exactly two connecting point mappings for each stub to be complete—one for the start point and the second for end point. The weaver first obtain the pair of mappings for the stub. The initial mapping usually maps the end point of a stub [2] to the start point of a UCM, and the weaver executes lines 18-24. The second mapping usually maps the start point of a stub [3] to the end point of a UCM, and the weaver executes lines 32-38.

[2]The end point of a stub symbolizes incoming node connection to the stub.
[3]The start point of a stub symbolizes outgoing node connection from the stub.

Algorithm 2 Weaving Algorithm: Connecting Point Mapping

```
1: function WeaveConnectingPointMapping(ucm, composition)
2:     node_1 ← get first node of composition mapping (from)
3:     node_2 ← get second node of composition mapping (to)
4:     if node_1 is StartPoint then
5:         if node_1 is connected to a stub then
6:             call ExtendingStub_End(ucm, node_2, node_1)
7:         else if node_2 is connected to a stub then
8:             call ReusingStub_Start(ucm, node_2, node_1)
9:         end if
10:    else if node_1 is EndPoint then
11:        if node_1 is connected to a stub then
12:            call ExtendingStub_Start(ucm, node_2, node_1)
13:        else if node_2 is connected to a stub then
14:            call ReusingStub_End(ucm, node_2, node_1)
15:        end if
16:    end if
17: end function
18: function ExtendingStub_End(ucm, node_2, node_1)
19:    source_2 ← get source node of node_2
20:    source_1 ← get source node of node_1 via stub connection
21:    target_1 ← get target node of node_1 via stub connection
22:    call MergePaths(source_2, source_1, target_1, node_1, node_1)
23:    remove node_2 from ucm
24: end function
25: function ReusingStub_Start(ucm, node_2, node_1)
26:    target_1 ← get target node of node_1
27:    target_2 ← get target node of node_2 via stub connection
28:    source_2 ← get source node of node_2 via stub connection
29:    call SplitPaths(target_1, target_2, source_2, node_2, node_1)
30:    remove node_1 from ucm
31: end function
32: function ExtendingStub_Start(ucm, node_2, node_1)
33:    target_2 ← get target node of node_2
34:    target_1 ← get target node of node_1 via stub connection
35:    source_1 ← get source node of node_1 via stub connection
36:    call SplitPaths(target_2, target_1, source_1, node_1, node_1)
37:    remove node_2 from ucm
38: end function
```

```
39: function ReusingStub_End(ucm, node_2, node_1)
40:     source_1 ← get source node of node_1
41:     source_2 ← get source node of node_2 via stub connection
42:     target_2 ← get target node of node_2 via stub connection
43:     call MergePaths(source_1, source_2, target_2, node_2, node_1)
44:     remove node_1 from ucm
45: end function
46: function SplitPaths(target, target', source', node, node')
47:     if target' is Stub then
48:         mark target' as removable stub
49:         set target node of node's stub connection to target
50:     else if target' is AndFork or OrFork then
51:         create node connection between target' and target
52:     else
53:         referenceStub ← get target node of node' via stub connection
54:         forkNode ← if referenceStub is dynamic then create AndFork else OrFork
55:         place forkNode in between source' and target'
56:         create node connection between forkNode and target'
57:         create node connection between forkNode and target
58:         set target node of node's stub connection to forkNode
59:     end if
60: end function
61: function MergePaths(source, source', target', node, node')
62:     if source' is Stub then
63:         mark source' as removable stub
64:         set source node of node's stub connection to source
65:     else if source' is AndJoin or OrJoin then
66:         create node connection between source and source'
67:     else
68:         referenceStub ← get source node of node' via stub connection
69:         joinNode ← if referenceStub is synchronizing then create AndJoin else OrJoin
70:         place joinNode in between source' and target'
71:         create node connection between source' and joinNode
72:         create node connection between source and joinNode
73:         set source node of node's stub connection to joinNode
74:     end if
75: end function
```

Model reuse, on the other hand, operates in reversed orientation—obtaining the pairs of mappings that mapped the start and end points of UCM_1 to the connecting points of a stub that is automatically generated in UCM_2 when reusing UCM_1. To be precise, the automatically generated stub is always a static stub so that it can only hold a single UCM that originates from the reused concern. The weaver then executes lines 25-31 and 39-45, respectively.

The execution procedure for both extension and reuse involves replacing a stub with plug-ins (sub-UCMs). Depending on the type of stub, it can bind either a single plug-in or multiple plug-ins. When facing a single plug-in binded to a stub, the weaver simply connects the nodes adjacent to the stub and nodes adjacent to the connecting points of a UCM, followed by the removal of the connecting points and the stub from the woven model (lines 47-49 and 62-64). If there are two plug-ins binded to a stub, the weaver creates branches to link the two UCMs as parallel paths via fork and join nodes (lines 52-59 and 67-74). The type of forks and joins being created is dependent on the type of stub. Synchronizing/blocking stubs produce branches that consist of AndFork and AndJoin, dynamic stubs produce branches that consist of AndFork and OrJoin, and static stubs produce branches that consist of OrFork and OrJoin. This process is also known as semantic flattening [10]. Additional plug-ins binded to a stub are linked via the created forks and joins (lines 50-51 and 65-66).

Chapter 4

Validation

The definition of UCM metamodel and the specification of weaving algorithm described in the previous chapter provide the foundation for the implementation of UCM in TouchCORE, a multitouch-enabled concern-oriented software design modeling tool. In this chapter, we illustrate the realization of scenario models in TouchCORE through the use of UCM notation in section 4.1. Then we attempt to validate our proposed approach of concern-oriented UCMs by means of case studies in section 4.2. Finally, we demonstrate that concern-oriented UCMs are able to cover the workflow patterns in section 4.3.

4.1 UCM Implementation in TouchCORE

TouchCORE is under active development within the Software Engineering Lab at McGill University [13]. Previous project, TouchRAM, successfully implemented concern-oriented software design paradigm, but support is limited to RAM (class, sequence, and state diagrams) [14, 15]. TouchCORE extends TouchRAM with numerous enhancements, and most notably, the support for arbitrary modeling languages in addition to RAM. Since we have a well-defined corified UCM metamodel, we attempted to add support for UCMs in TouchCORE as proof of concept, enabling TouchCORE the capability to build scalable and reusable scenario models.

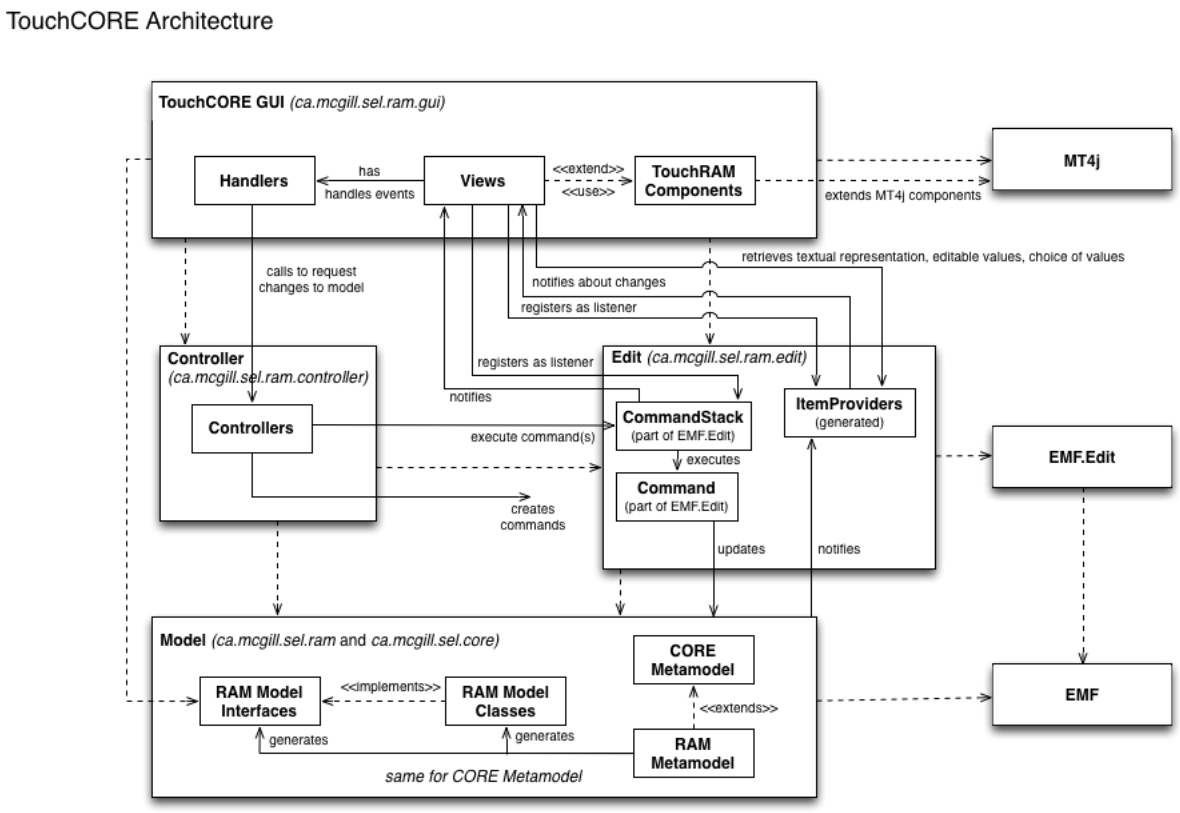


Figure 4.1: TouchCORE architecture. Image courtesy of Software Engineering Lab, McGill University

The project uses Java SE Development Kit 8 as the implementation language and Eclipse Modeling Framework (EMF) [16] as the modeling facility for developing TouchCORE. To support a new language, we need to define its metamodel based on Ecore. TouchCORE already has a complete CORE metamodel defined with an Ecore model (see Figure A.1). With RAM as a reference model, we constructed an Ecore model that expresses our complete UCM metamodel, subclassing the appropriate CORE metaclasses, through the use of EMF tooling (see Figure A.2). EMF is capable of generating structured Java code from valid Ecore models, allowing us to rapidly program the logic for UCM integration.

The software architecture of TouchCORE follows the model–view–controller (MVC) de-

sign pattern to separate the program into three main logical components. Figure 4.1 shows the three interconnected parts for the TouchCORE application: (i) the model layer for managing data, e.g., instances of RAM and UCM models; (ii) the TouchCORE graphical user interface (GUI) that constitutes the view layer for visualizing and manipulating models; and (iii) the controller layer for handling user interactions and act on the data model objects. The GUI for TouchCORE is built on top of MT4j for its multitouch capability [17]. Additional components include weaver, code generator, model validator, and classloader. The integration of UCM in TouchCORE involves modifying its core components with varying degrees, but the program is structured in such a way that we can add subcomponents when implementing a new modeling language, adhering to the open/closed principle.

4.1.1 Supported Concrete Syntax

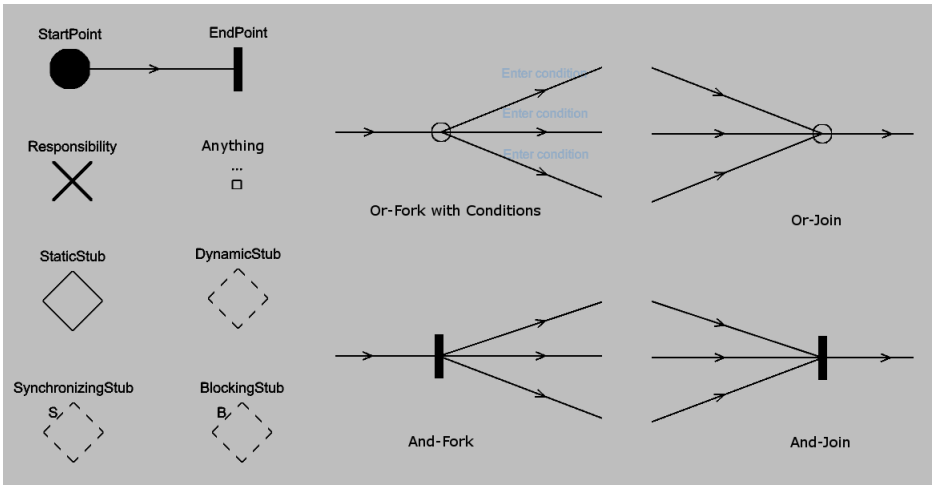


Figure 4.2: UCM notation in TouchCORE

The basic elements of the UCM notation that we implemented in TouchCORE are shown in Figure 4.2. Most of these elements are defined by the standards [10], with the exception of Anything that is taken from the extended AoUCM metamodel [11]. Users can create path

nodes by tap-and-hold on the canvas of TouchCORE during runtime and a list of path node selection will be displayed. To create a node connection between two path nodes, simply drag from the area adjacent of one element to the other element.

There are several anomalies with regards to the graphical representation of UCM symbols displayed in TouchCORE as compared with the standards (compare Figure 4.2 with Figure 2.7). For example, the symbol for or-fork and or-join is shown as a circle instead of no symbol (just direct branching and merging from the paths); anything is represented as a square with the label ... instead of just ...; and node connection is a straight line path instead of spline. These are some of the limitations that we faced at the moment when implementing the GUI. Our current method of creating nodes is to first create them on the canvas, then build the connections later. Or-fork and or-join need a space to receive events from the user, thus a circle serves as the area of interactivity as well as a statement of presence that an or-fork or or-join has been created. The idea of displaying the ... symbol of an anything node is that it should be part of the node connection and move along seamlessly with correct orientation whenever the predecessor or successor node of anything is moved, but since anything is considered a path node, we decided for now to just use a square with the label ... to represent the anything node. Lastly, spline drawing is not yet available in TouchCORE so we use straight lines for the time being.

Elements with extra features can be accessed by tap-and-hold an element (Figure 4.3). We allow start and end points to set its visibility. By default, all path nodes are concern visible, but start and end points can switch to public visible (see Section 3.2.1 for visibility discussion). Likewise, we allow responsibilities to set its partiality. By default, all path nodes are not partial, meaning that they are well-defined and require no further action. Since we have customization mappings for responsibility, we can specify whether a responsibility

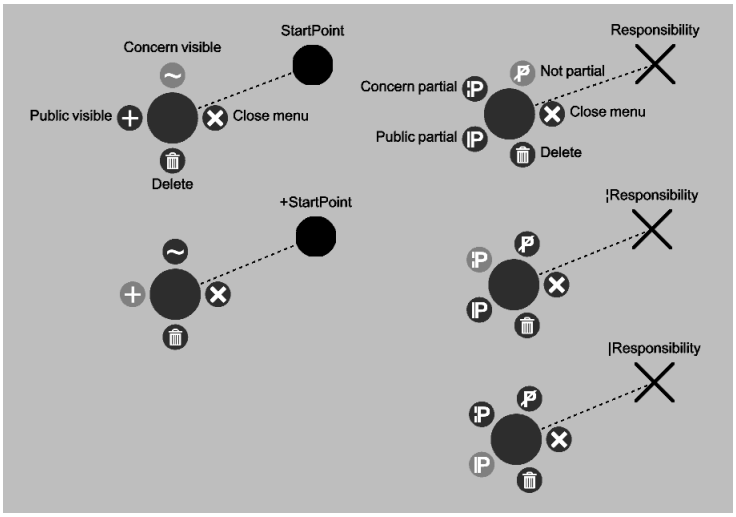


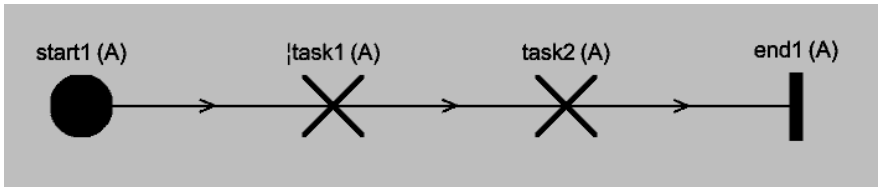
Figure 4.3: Visibility and partiality

is partially defined and require appropriate composition to be semantically complete. A responsibility that is concern partial should fulfill its significance through model extension, whereas a responsibility that is public partial should fulfill its significance through model reuse.

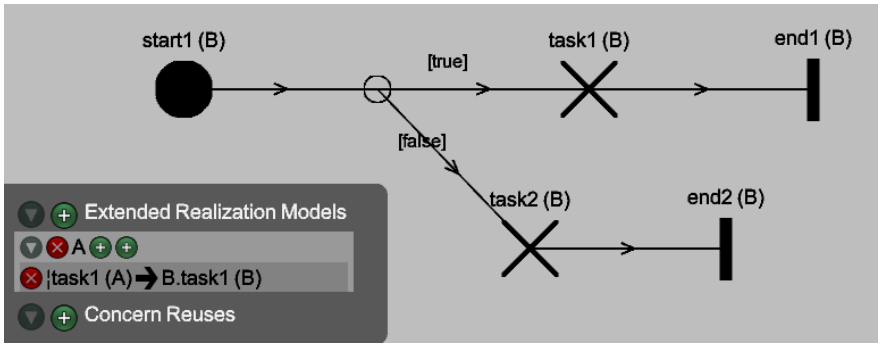
4.1.2 Scenario Model Composition

Model Extension

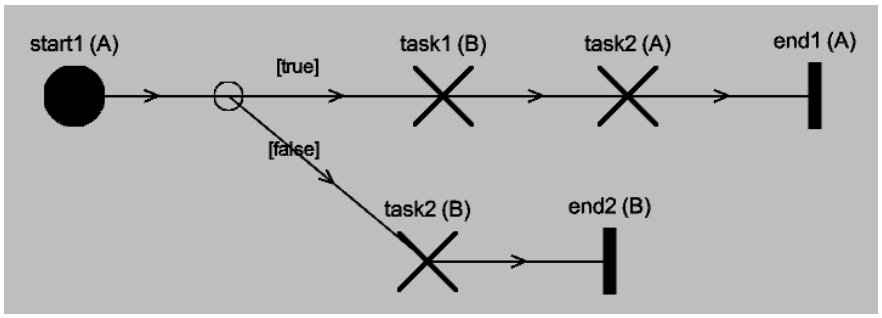
Figure 4.4 illustrates the usage of UCM model extension within a concern. Given a concern with 2 features in a hierarchy, the model of a child feature (Model B) extends the model of a parent feature (Model A). Composition specifications are specified in Model B, where an element of Model A is mapped to an element of Model B. Multiple mappings can be set per extension as needed and the available types of mapping are defined in the metamodel. The result of weaving Model B to Model A is depicted in Figure 4.4c. Based on the mappings set in Model B, the predecessors and successors of the mapped responsibility from Model B



(a) Model A - parent UCM



(b) Model B - child UCM



(c) Woven model B_A

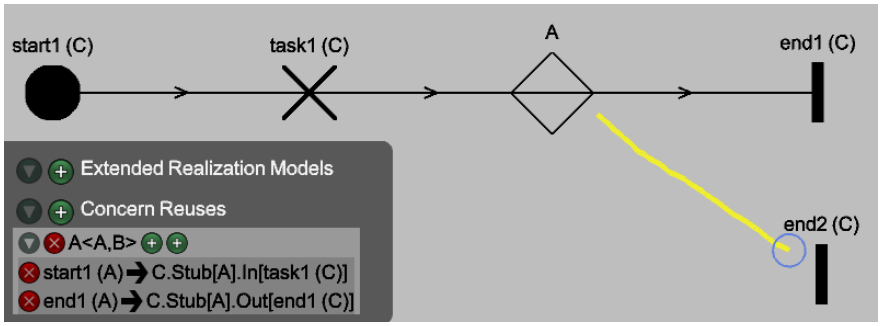
Figure 4.4: Example model extension

are introduced as adjoined path nodes of the mapped responsibility from Model A, and the mapped responsibility from Model A is being replaced with the mapped responsibility from Model B.

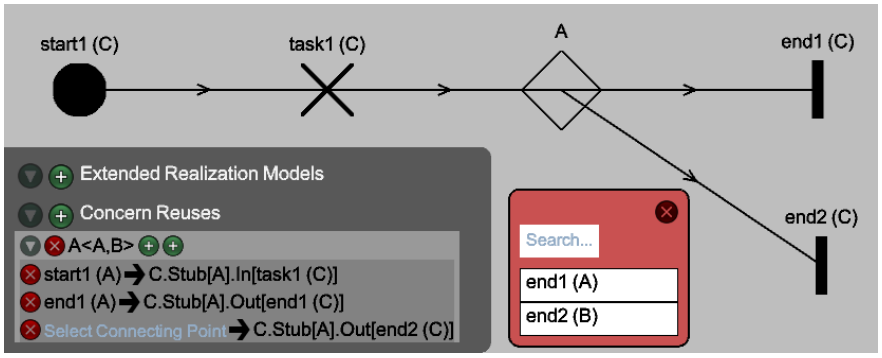
The idea of isolating features as individual models supports the use of advanced separation of concerns—each feature encapsulates its realization model. Features of a concern are nested in a hierarchical order, and the connection between features can be seen as parent-child relationship. Extension of a model depends on this relationship to ensure that models are woven in the correct order. Only the selected features of a concern are woven as a whole, providing only the absolute necessary details to fully describe the different use cases.

Model Reuse

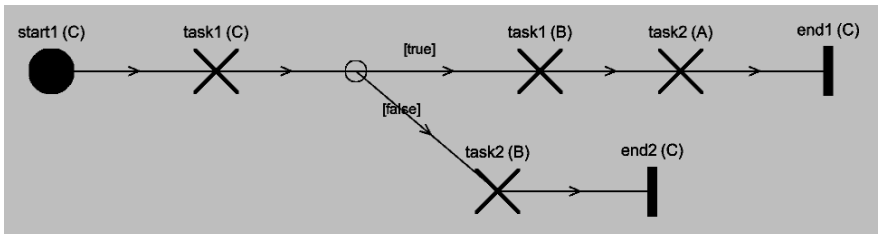
Figure 4.5 illustrates the usage of UCM model reuse across concerns. Given that Model C of a concern reuses Concern A, the configuration for the set of features of Concern A will be displayed. Here, we chose to use features A and B, thus woven Model B_A (see Figure 4.4c) is generated and represented as a static Stub A (appears in canvas automatically after successful reuse). Mappings for connecting points of Stub A can be established by linking a path node to/from Stub A. As shown in Figures 4.5a and 4.5b, a node connection was created from Stub A to an end point. A list of end points from woven Model B_A will be displayed for the user to set which end point of Model B_A corresponds to which outgoing connection of Stub A in Model C. We label the incoming connection of a stub as `<Model_2>.Stub[<Model_1>].In[Predecessor]`, and the outgoing connection as `<Model_2>.Stub[<Model_1>].Out[Successor]`. The result of weaving Model C to Model B_A is depicted in Figure 4.5c.



(a) Model C - reuse Concern A with selected features <A,B>



(b) Model C - establish connecting point mapping through node connection



(c) Woven model C_A<A,B>

Figure 4.5: Example model reuse

4.2 Case Studies

4.2.1 Authentication

4.2.2 Online Payment

4.3 Workflow Patterns

Chapter 5

Conclusion

5.1 Summary

Recap of thesis: what I did so far and what can the tool achieve.

5.2 Future Work

Remaining tasks such as components, path drawing, validation, semantics, etc.

Appendix A

Complete Metamodels

A.1 CORE Metamodel

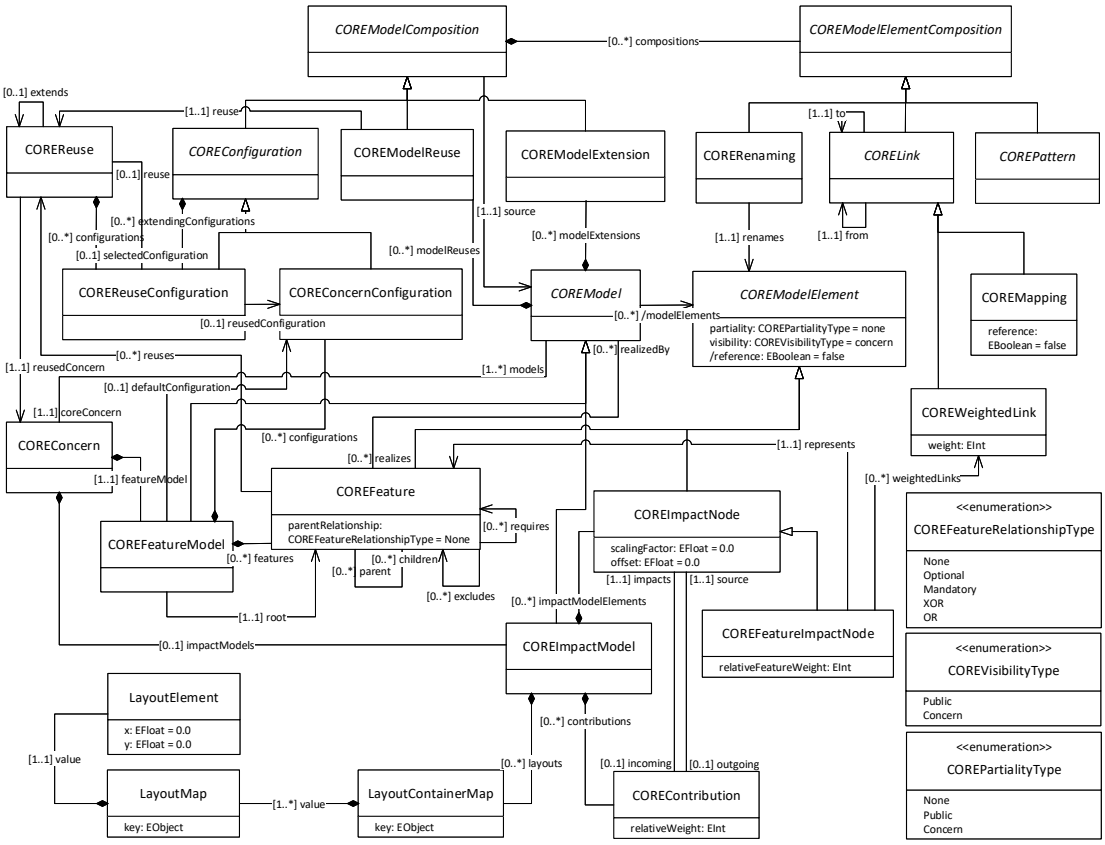


Figure A.1: Abstract grammar: CORE metamodel overview

A.2 UCM Metamodel

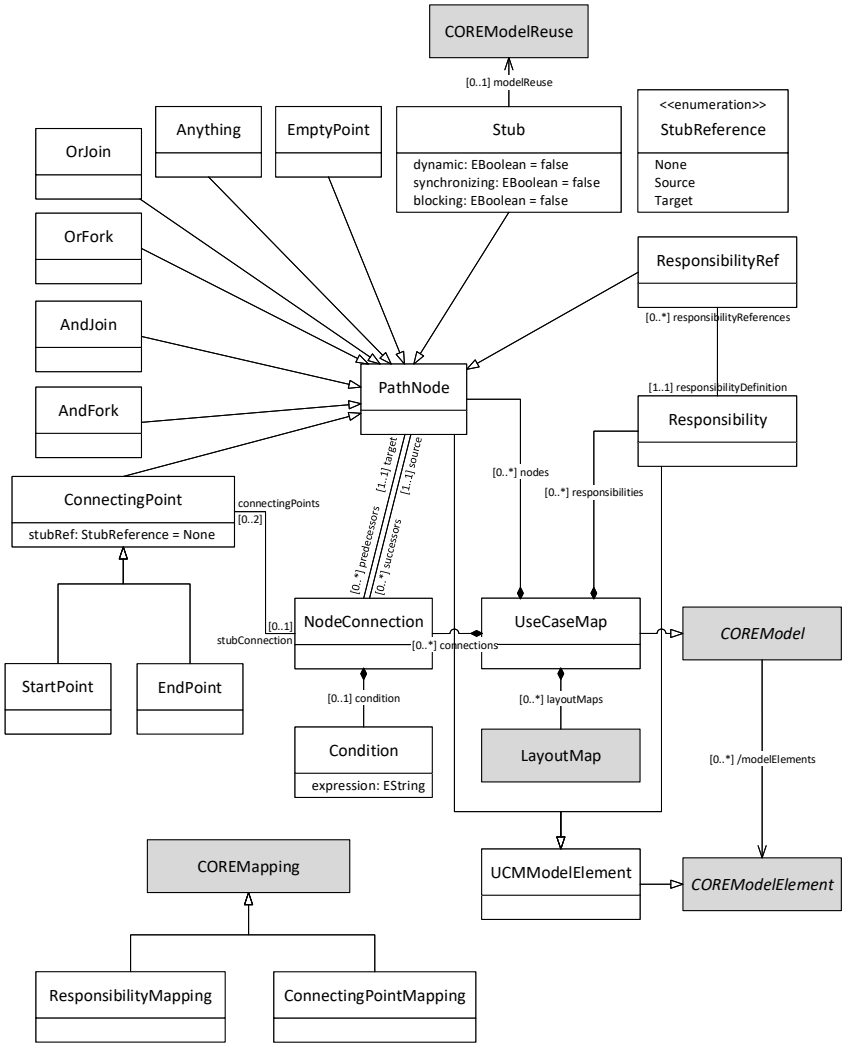


Figure A.2: Abstract grammar: corified UCM metamodel overview

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