UML Semantics 2

The UML Semantics section is primarily intended as a comprehensive and precise specification of the UML's semantic constructs.

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Part 1 - Background

2.1 Introduction

2.1.1 Purpose and Scope

The primary audience for this detailed description consists of the OMG, other standards organizations, tool builders, metamodelers, methodologists, and expert modelers. The authors assume familiarity with metamodeling and advanced object modeling. Readers looking for an introduction to the UML or object modeling should consider another source.

Although the document is meant for advanced readers, it is also meant to be easily understood by its intended audience. Consequently, it is structured and written to increase readability. The structure of the document, like the language, builds on previous concepts to refine and extend the semantics. In addition, the document is written in a ‘semi-formal’ style that combines natural and formal languages in a complementary manner.

This section specifies semantics for structural and behavioral object models. Structural models (also known as static models) emphasize the structure of objects in a system, including their classes, interfaces, attributes and relations. Behavioral models (also known as dynamic models) emphasize the behavior of objects in a system, including their methods, interactions, collaborations, and state histories.

This section provides complete semantics for all modeling notations described in the UML Notation Guide (Chapter 3). This includes support for a wide range of diagram techniques: class diagram, object diagram, use case diagram, sequence diagram, collaboration diagram, state diagram, activity diagram, and deployment diagram. The UML Notation Guide includes a summary of the semantics sections that are relevant to each diagram technique.

2.1.2 Approach

This section emphasizes language architecture and formal rigor. The architecture of the UML is based on a four-layer metamodel structure, which consists of the following layers: user objects, model, metamodel, and meta-metamodel. This document is

primarily concerned with the metamodel layer, which is an instance of the meta-metamodel layer. For example, Class in the metamodel is an instance of MetaClass in the meta-metamodel. The metamodel architecture of UML is discussed further in “Language Architecture” on page 2-4.

The UML metamodel is a logical model and not a physical (or implementation) model. The advantage of a logical metamodel is that it emphasizes declarative semantics, and suppresses implementation details. Implementations that use the logical metamodel must conform to its semantics, and must be able to import and export full as well as partial models. However, tool vendors may construct the logical metamodel in various ways, so they can tune their implementations for reliability and performance. The disadvantage of a logical model is that it lacks the imperative semantics required for accurate and efficient implementation. Consequently, the metamodel is accompanied with implementation notes for tool builders.

UML is also structured within the metamodel layer. The language is decomposed into several logical packages: Foundation, Behavioral Elements, and General Mechanisms. These packages in turn are decomposed into subpackages. For example, the Foundation package consists of the Core, Auxiliary Elements, Extension Mechanisms, and Data Types subpackages. The structure of the language is fully described in “Language Architecture” on page 2-4.

The metamodel is described in a semi-formal manner using these views:

- Abstract syntax
- Well-formedness rules
- Semantics

The abstract syntax is provided as a model described in a subset of UML, consisting of a UML class diagram and a supporting natural language description. (In this way the UML bootstraps itself in a manner similar to how a compiler is used to compile itself.) The well-formedness rules are provided using a formal language (Object Constraint Language) and natural language (English). Finally, the semantics are described primarily in natural language, but may include some additional notation, depending on the part of the model being described. The adaptation of formal techniques to specify the language is fully described in “Language Formalism” on page 2-7.

In summary, the UML metamodel is described in a combination of graphic notation, natural language and formal language. We recognize that there are theoretical limits to what one can express about a metamodel using the metamodel itself. However, our experience suggests that this combination strikes a reasonable balance between expressiveness and readability.

2.2 Language Architecture

2.2.1 Four-Layer Metamodel Architecture

The UML metamodel is defined as one of the layers of a four-layer metamodeling architecture. This architecture is a proven infrastructure for defining the precise semantics required by complex models. There are several other advantages associated with this approach:

- It validates core constructs by recursively applying them to successive metalayers.
- It provides an architectural basis for defining future UML metamodel extensions.
- It furnishes an architectural basis for aligning the UML metamodel with other standards based on a four-layer metamodeling architecture (e.g., the OMG Meta-Object Facility, CDIF).

The generally accepted conceptual framework for metamodeling is based on an architecture with four layers:

- meta-metamodel
- metamodel
- model
- user objects

These functions of these layers are summarized in the following table.

Table 2-1 Four Layer Metamodeling Architecture

Layer	Description	Example
meta-metamodel	The infrastructure for a metamodeling architecture. Defines the language for specifying metamodels.	*MetaClass, MetaAttribute, MetaOperation*
metamodel	An instance of a meta-metamodel. Defines the language for specifying a model.	*Class, Attribute, Operation, Component*
model	An instance of a metamodel. Defines a language to describe an information domain.	*StockShare, askPrice, sellLimitOrder, StockQuoteServer*
user objects (user data)	An instance of a model. Defines a specific information domain.	*<Acme_Software_Share_98789>, 654.56, sell_limit_order, <Stock_Quote_Svr_32123>*

The meta-metamodeling layer forms the foundation for the metamodeling architecture. The primary responsibility of this layer is to define the language for specifying a metamodel. A meta-metamodel defines a model at a higher level of abstraction than a

metamodel, and is typically more compact than the metamodel that it describes. A meta-metamodel can define multiple metamodels, and there can be multiple meta-metamodels associated with each metamodel[1].

While it is generally desirable that related metamodels and meta-metamodels share common design philosophies and constructs, this is not a strict rule. Each layer needs to maintain its own design integrity. Examples of meta-metaobjects in the meta-metamodeling layer are: MetaClass, MetaAttribute, and MetaOperation.

A metamodel is an instance of a meta-metamodel. The primary responsibility of the metamodel layer is to define a language for specifying models. Metamodels are typically more elaborate than the meta-metamodels that describe them, especially when they define dynamic semantics. Examples of metaobjects in the metamodeling layer are: Class, Attribute, Operation, and Component.

A model is an instance of a metamodel. The primary responsibility of the model layer is to define a language that describes an information domain. Examples of objects in the modeling layer are: StockShare, askPrice, sellLimitOrder, and StockQuoteServer.

User objects (a.k.a. user data) are an instance of a model. The primary responsibility of the user objects layer is to describe a specific information domain. Examples of objects in the user objects layer are: <Acme_Software_Share_98789>, 654.56, sell_limit_order, and <Stock_Quote_Svr_32123>.

The UML metamodel has been architected so that it can be instantiated from the OMG Meta Object Facility (MOF) meta-metamodel. The relationship of the UML metamodel to the MOF meta-metamodel is described in “Architectural Alignment with Other Technologies” in the Preface.

2.2.2 Package Structure

The UML metamodel is moderately complex. It is composed of approximately 90 metaclasses and over 100 metaassociations, and includes almost 50 stereotypes. The complexity of the metamodel is managed by organizing it into logical packages. These packages group metaclasses that show strong cohesion with each other and loose coupling with metaclasses in other packages. The UML metamodel is decomposed into the top-level packages shown in Figure 2-1 on page 2-6.

1. If there is not an explicit meta-metamodel, there is an implicit meta-metamodel associated with every metamodel.

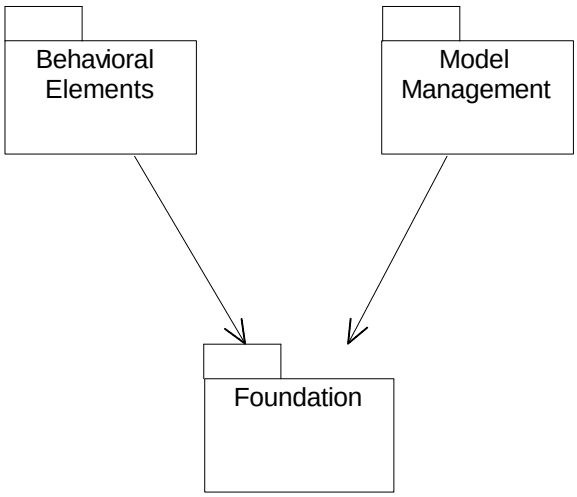

Figure 2-1 Top-Level Packages

The Foundation and Behavioral Elements packages are further decomposed as shown in Figure 2-2 and Figure 2-3 on page 2-7.

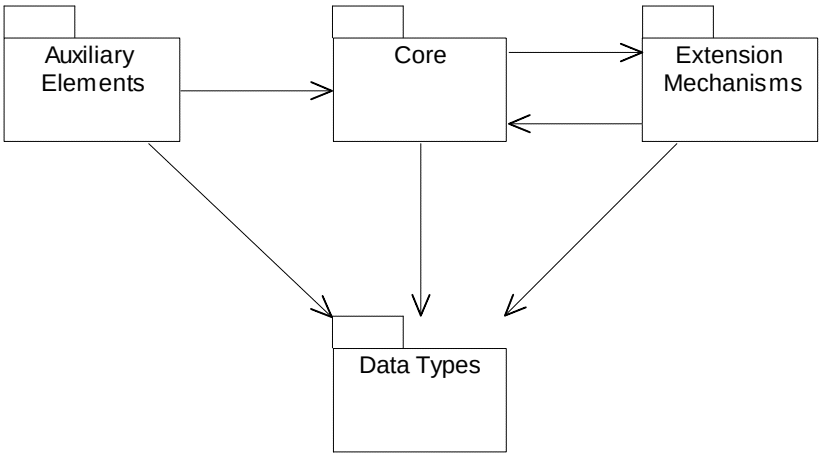

Figure 2-2 Foundation Packages

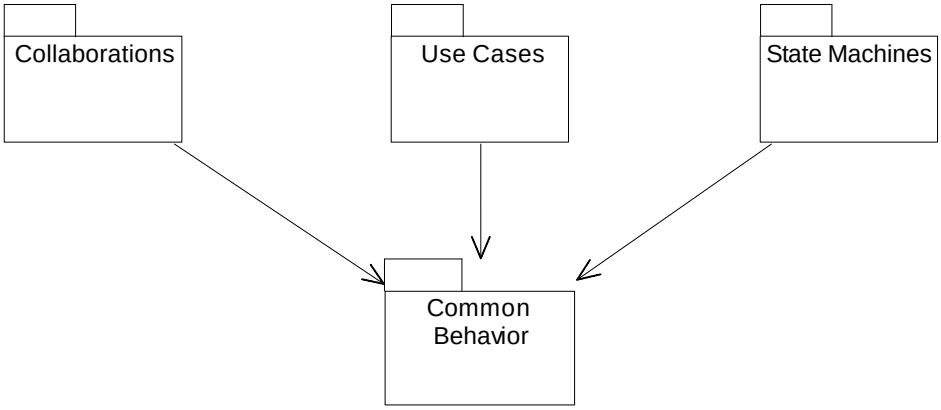

Figure 2-3 Behavioral Elements Packages

The functions and contents of these packages are described in this chapter's Part 3, Behavioral Elements.

2.3 Language Formalism

This section contains a description of the techniques used to describe UML. The specification adapts formal techniques to improve precision while maintaining readability. The technique describes the UML metamodel in three views using both text and graphic presentations. The benefits of adapting formal techniques include:

- the correctness of the description is improved,
- ambiguities and inconsistencies are reduced,
- the architecture of the metamodel is validated by a complementary technique, and
- the readability of the description is increased.

It is important to note that the current description is not a completely formal specification of the language because to do so would have added significant complexity without clear benefit. In addition, the state of the practice in formal specifications does not yet address some of the more difficult language issues that UML introduces.

The structure of the language is nevertheless given a precise specification, which is required for tool interoperability. The dynamic semantics are described using natural language, although in a precise way so they can easily be understood. Currently, the dynamic semantics are not considered essential for the development of tools; however, this will probably change in the future.

2.3.1 Levels of Formalism

A common technique for specification of languages is to first define the syntax of the language and then to describe its static and dynamic semantics. The syntax defines what constructs exist in the language and how the constructs are built up in terms of other constructs. Sometimes, especially if the language has a graphic syntax, it is important to define the syntax in a notation independent way (i.e., to define the abstract syntax of the language). The concrete syntax is then defined by mapping the notation onto the abstract syntax. The syntax is described in the Abstract Syntax sections.

The static semantics of a language define how an instance of a construct should be connected to other instances to be meaningful, and the dynamic semantics define the meaning of a well-formed construct. The meaning of a description written in the language is defined only if the description is well formed (i.e., if it fulfills the rules defined in the static semantics). The static semantics are found in sections headed Well-Formedness Rules. The dynamic semantics are described under the heading Semantics. In some cases, parts of the static semantics are also explained in the Semantics section for completeness.

The specification uses a combination of languages - a subset of UML, an object constraint language, and precise natural language to describe the abstract syntax and semantics of the full UML. The description is self-contained; no other sources of information are needed to read the document[2]. Although this is a metacircular description[3], understanding this document is practical since only a small subset of UML constructs are needed to describe its semantics.

In constructing the UML metamodel different techniques have been used to specify language constructs, using some of the capabilities of UML. The main language constructs are reified into metaclasses in the metamodel. Other constructs, in essence being variants of other ones, are defined as stereotypes of metaclasses in the metamodel. This mechanism allows the semantics of the variant construct to be significantly different from the base metaclass. Another more "lightweight" way of defining variants is to use metaattributes. As an example, the aggregation construct is specified by an attribute of the metaclass AssociationEnd, which is used to indicate if an association is an ordinary aggregate, a composite aggregate, or a common association.

2.3.2 Package Specification Structure

This section provides information for each package in the UML metamodel. Each package has one or more of the following subsections.

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2. Although a comprehension of the UML's four-layer metamodel architecture and its underlying meta-metamodel is helpful, it is not essential to understand the UML semantics.

3. In order to understand the description of the UML semantics, you must understand some UML semantics.

Abstract Syntax

The abstract syntax is presented in a diagram showing the metaclasses defining the constructs and their relationships. The diagram also presents some of the well-formedness rules, mainly the multiplicity requirements of the relationships, and whether or not the instances of a particular sub-construct must be ordered. Finally, a short informal description in natural language describing each construct is supplied. The first paragraph of each of these descriptions is a general presentation of the construct which sets the context, while the following paragraphs give the informal definition of the metaclass specifying the construct in UML. For each metaclass, its attributes are enumerated together with a short explanation. Furthermore, the opposite role names of associations connected to the metaclass are also listed in the same way.

Well-Formedness Rules

The static semantics of each construct in UML, except for multiplicity and ordering constraints, are defined as a set of invariants of an instance of the metaclass. These invariants have to be satisfied for the construct to be meaningful. The rules thus specify constraints over attributes and associations defined in the metamodel. Each invariant is defined by an OCL expression together with an informal explanation of the expression. In many cases, additional operations on the metaclasses are needed for the OCL expressions. These are then defined in a separate subsection after the well-formedness rules for the construct, using the same approach as the abstract syntax: an informal explanation followed by the OCL expression defining the operation.

The statement ‘No extra well-formedness rules’ means that all current static semantics are expressed in the superclasses together with the multiplicity and type information expressed in the diagrams.

Semantics

The meanings of the constructs are defined using natural language. The constructs are grouped into logical chunks that are defined together. Since only concrete metaclasses have a true meaning in the language, only these are described in this section.

Standard Elements

Stereotypes of the metaclasses defined previously in the section are listed, with an informal definition in natural language. Well-formedness rules, if any, for the stereotypes are also defined in the same manner as in the Well-Formedness Rules subsection.

Other kinds of standard elements (constraints and tagged-values) are listed, and are defined in the Standard Elements appendix.

Notes

This subsection may contain rationales for metamodeling decisions, pragmatics for the use of the constructs, and examples, all written in natural language.

2.3.3 Use of a Constraint Language

The specification uses the Object Constraint Language (OCL), as defined in Object Constraint Language Specification (Chapter 4), for expressing well-formedness rules. The following conventions are used to promote readability:

- Self - which can be omitted as a reference to the metaclass defining the context of the invariant, has been kept for clarity.
- In expressions where a collection is iterated, an iterator is used for clarity, even when formally unnecessary. The type of the iterator is usually omitted, but included when it adds to understanding.
- The ‘collect’ operation is left implicit where this is practical.

2.3.4 Use of Natural Language

We have striven to be precise in our use of natural language, in this case English. For example, the description of UML semantics includes phrases such as "X provides the ability to…" and "X is a Y." In each of these cases, the usual English meaning is assumed, although a deeply formal description would demand a specification of the semantics of even these simple phrases.

The following general rules apply:

- When referring to an instance of some metaclass, we often omit the word "instance". For example, instead of saying "a Class instance" or "an Association instance", we just say "a Class" or "an Association". By prefixing it with an "a" or "an", assume that we mean "an instance of". In the same way, by saying something like "Elements" we mean "a set (or the set) of instances of the metaclass Element".
- Every time a word coinciding with the name of some construct in UML is used, that construct is referred.
- Terms including one of the prefixes sub, super, or meta are written as one word (e.g., metamodel, subclass).

2.3.5 Naming Conventions and Typography

In the description of UML, the following conventions have been used:

- When referring to constructs in UML, not their representation in the metamodel, normal text is used.
- Metaclass names that consist of appended nouns/adjectives, initial embedded capitals are used (e.g., ‘ModelElement,’ ‘StructuralFeature’).
- Names of metaassociations/association classes are written in the same manner as metaclasses (e.g., ‘ElementReference’).
- Initial embedded capital is used for names that consist of appended nouns/adjectives (e.g., ‘ownedElement,’ ‘allContents’).
- Boolean metaattribute names always start with ‘is’ (e.g., ‘isAbstract’).

- While referring to metaclasses, metaassociations, metaattributes, etc. in the text, the exact names as they appear in the model are always used.
- Names of stereotypes are delimited by guillemets and begin with lowercase (e.g., «type»).

Part 2 - Foundation Packages

The Foundation package is the infrastructure for UML. The Foundation package is decomposed into several subpackages: Core, Auxiliary Elements, Extension Mechanisms, and Data Types.

2.4 Overview

Figure 2-4 illustrates the Foundation Packages. The Core package specifies the basic concepts required for an elementary metamodel and defines an architectural backbone for attaching additional language constructs, such as metaclasses, metaassociations, and metaattributes. The Auxiliary Elements package defines additional constructs that extend the Core to support advanced concepts such as dependencies, templates, physical structures and view elements. The Extension Mechanisms package specifies how model elements are customized and extended with new semantics. The Data Types package defines basic data structures for the language.

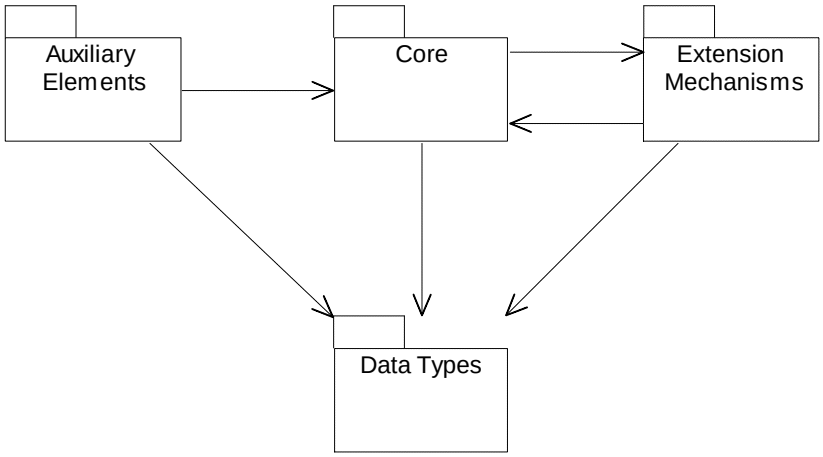


Figure 2-4 Foundation Packages

2.5 Core

2.5.1 Overview

The Core package is the most fundamental of the subpackages that compose the UML Foundation package. It defines the basic abstract and concrete constructs needed for the development of object models. Abstract metamodel constructs are not instantiable and are commonly used to reify key constructs, share structure, and organize the model. Concrete metamodel constructs are instantiable and reflect the modeling constructs used by object modelers (cf. metamodelers). Abstract constructs defined in the Core include ModelElement, GeneralizableElement, and Classifier. Concrete constructs specified in the Core include Class, Attribute, Operation, and Association.

The Core package specifies the core constructs required for a basic metamodel and defines an architectural backbone ("skeleton") for attaching additional language constructs such as metaclasses, metaassociations, and metaattributes. Although the Core package contains sufficient semantics to define the remainder of UML, it is not the UML meta-metamodel. It is the underlying base for the Foundation package, which in turn serves as the infrastructure for the rest of language. In other packages, the Core is extended by adding metaclasses to the backbone using generalizations and associations.

The following sections describe the abstract syntax, well-formedness rules, and semantics of the Core package.

2.5.2 Abstract Syntax

The abstract syntax for the Core package is expressed in graphic notation in the following figures. Figure 2-5 on page 2-13 shows the model elements that form the structural backbone of the metamodel. Figure 2-6 on page 2-14 shows the model elements that define relationships.

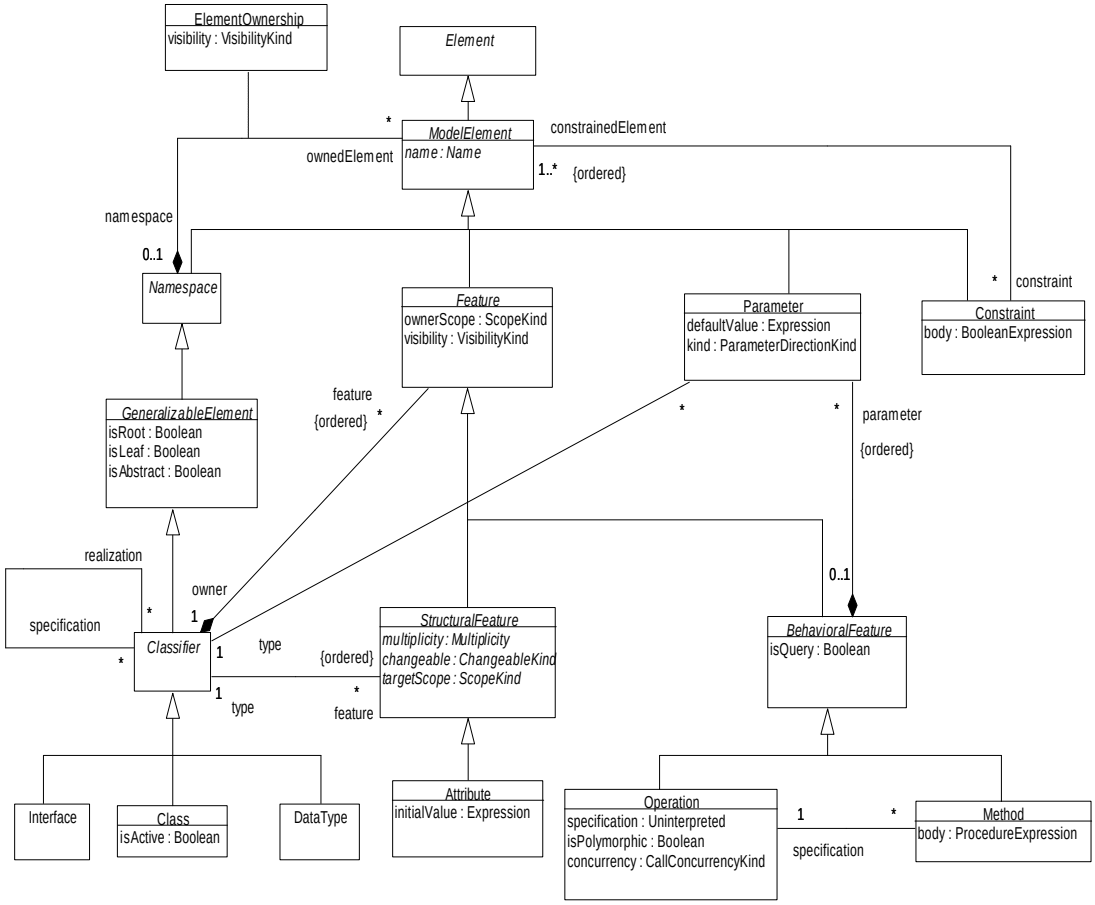


Figure 2-5 Core Package - Backbone

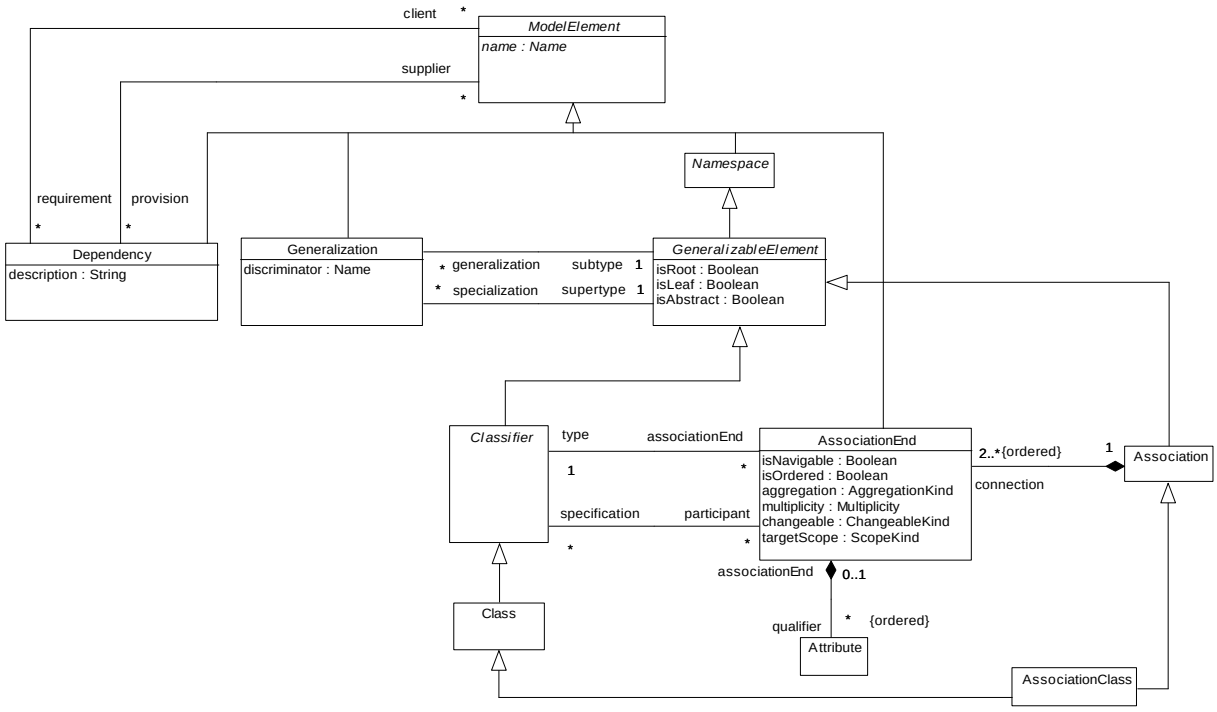


Figure 2-6 Core Package - Relationships

Association

An association defines a semantic relationship between classifiers. The instances of an association are a set of tuples relating instances of the classifiers. Each tuple value may appear at most once.

In the metamodel, an Association is a declaration of a semantic relationship between Classifiers, such as Classes. An Association has at least two AssociationEnds. Each end is connected to a Classifier - the same Classifier may be connected to more than one AssociationEnds in the same Association. The Association represents a set of connections among instances of the Classifiers. An instance of an Association is a Link, which is a tuple of Instances drawn from the corresponding Classifiers.

Attributes

name	The name of the Association which, in combination with its associated Classifiers, must be unique within the enclosing namespace (usually a Package).

Associations

connection	An Association consists of at least two AssociationEnds, each of which represents a connection of the association to a Classifier. Each AssociationEnd specifies a set of properties that must be fulfilled for the relationship to be valid. The bulk of the structure of an Association is defined by its AssociationEnds.

AssociationClass

An association class is an association that is also a class. It not only connects a set of classifiers but also defines a set of features that belong to the relationship itself and not any of the classifiers.

In the metamodel an AssociationClass is a declaration of a semantic relationship between Classifiers which has a set of features of its own. AssociationClass is a subclass of both Association and Class (i.e., each AssociationClass is both an Association and a Class); therefore, an AssociationClass has both AssociationEnds and Features.

AssociationEnd

An association end is an endpoint of an association, which connects the association to a classifier. Each association end is part of one association. The association-ends of each association are ordered.

In the metamodel an AssociationEnd is part of an Association and specifies the connection of an Association to a Classifier. It has a name and defines a set of properties of the connection (e.g., which Classifier the Instances must conform to, their multiplicity, and if they may be reached from another Instance via this connection).

In the following descriptions when referring to an association end for a binary association, the source end is the other end. The target end is the one whose properties are being discussed.

Attributes

aggregation — When placed on a target end, specifies whether the target end is an aggregation with respect to the source end. Only one end can be an aggregation. Possibilities are:

- none - The end is not an aggregate.
- aggregate - The end is an aggregate; therefore, the other end is a part and must have the aggregation value of none. The part may be contained in other aggregates.
- composite - The end is a composite; therefore, the other end is a part and must have the aggregation value of none. The part is strongly owned by the composite and may not be part of any other composite.

changeable — When placed on a target end, specifies whether an instance of the Association may be modified from the source end. Possibilities are:

- none - No restrictions on modification.
- frozen - No links may be added after the creation of the source object.
- addOnly - Links may be added at any time from the source object, but once created a link may not be removed before at least one participating object is destroyed.

isOrdered — When placed on a target end, specifies whether the set of links from the source instance to the target instance is ordered. The ordering must be determined and maintained by Operations that add links. It represents additional information not inherent in the objects or links themselves. A set of ordered links can be scanned in order. The alternative is that the links form a set with no inherent ordering.

isNavigable — 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.

multiplicity — When placed on a target end, specifies the number of target instances that may be associated with a single source instance across the given Association.

name	The role name of the end. When placed on a target end, provides a name for traversing from a source instance across the association to the target instance or set of target instances. It represents a pseudo-attribute of the source classifier (i.e., it may be used in the same way as an Attribute) and must be unique with respect to Attributes and other pseudo-attributes of the source Classifier.
targetScope	Specifies whether the targets are ordinary Instances or are Classifiers. Possibilities are: • instance - Each line of the Association contains a reference to an Instance of the target Classifier. This is the setting for a normal Association. • classifier - Each link of the Association contains a reference to the target Classifier itself. This represents a way to store meta-information.

Associations

qualifier	An optional list of qualifier Attributes for the end. If the list is empty, then the Association is not qualified.
specification	Designates zero or more Classifiers that specify the Operations that may be applied to an Instance accessed by the AssociationEnd across the Association. These determine the minimum interface that must be realized by the actual Classifier attached to the end to support the intent of the Association. May be an Interface or another Classifier.
type	Designates the Classifier connected to the end of the Association. It may not be an Interface because they have no physical structure.

Attribute

An attribute is a named slot within a classifier that describes a range of values that instances of the classifier may hold.

In the metamodel an Attribute is a named piece of the declared state of a Classifier, particularly the range of values that Instances of the Classifier may hold.

(The following list includes properties from StructuralFeature which has no other subclasses in the current metamodel.)

Attributes

changeable	Whether the value may be modified after the object is created. Possibilities are: • none - No restrictions on modification. • frozen - The value may not be altered after the object is instantiated and its values initialized. No additional values may be added to a set. • AddOnly - Meaningful only if the multiplicity is not fixed to a single value. Additional values may be added to the set of values, but once created a value may not be removed or altered.
initial value	An Expression specifying the value of the attribute upon initialization. It is meant to be evaluated at the time the object is initialized. (Note that an explicit constructor may supersede an initial value.)
multiplicity	The possible number of data values for the attribute that may be held by an instance. The cardinality of the set of values is an implicit part of the attribute. In the common case in which the multiplicity is 1..1, then the attribute is a scalar (i.e., it holds exactly one value).

Associations

type	Designates the classifier whose instances are values of the attribute. Must be a Class or DataType.

BehavioralFeature

A behavioral feature refers to a dynamic feature of a model element, such as an operation or method.

In the metamodel a BehavioralFeature specifies a behavioral aspect of a Classifier. All different kinds of behavioral aspects of a Classifier, such as Operation and Method, are subclasses of BehavioralFeature. BehavioralFeature is an abstract metaclass.

Attributes

isQuery	Specifies whether an execution of the Feature leaves the state of the system unchanged. True indicates that the state is unchanged; false indicates that side-effects may occur.
name	The name of the Feature. The entire signature of the Feature (name and parameter list) must be unique within its containing Classifier.

Associations

parameters	An ordered list of Parameters for the Operation. To call the Operation, the caller must supply a list of values compatible with the types of the Parameters.

Class

A class is a description of a set of objects that share the same attributes, operations, methods, relationships, and semantics. A class may use a set of interfaces to specify collections of operations it provides to its environment.

In the metamodel a Class describes a set of Objects sharing a collection of Features, including Operations, Attributes and Methods, that are common to the set of Objects. Furthermore, a Class may realize zero or more Interfaces; this means that its full descriptor (see “Inheritance” on page 2-37 for the definition) must contain every Operation from every realized Interface (it may contain additional operations as well).

A Class defines the data structure of Objects, although some Classes may be abstract (i.e., no Objects can be created directly from them). Each Object instantiated from a Class contains its own set of values corresponding to the StructuralFeatures declared in the full descriptor. Objects do not contain values corresponding to BehavioralFeatures or class-scope Attributes; all Objects of a Class share the definitions of the BehavioralFeatures from the Class, and they all have access to the single value stored for each class-scope attribute.

Attributes

isActive	Specifies whether an Object of the Class maintains its own thread of control. If true, then an Object has its own thread of control and runs concurrently with other active Objects. If false, then Operations run in the address space and under the control of the active Object that controls the caller.

Classifier

A classifier is an element that describes behavioral and structural features; it comes in several specific forms, including class, data type, interface, and others that are defined in other metamodel packages.

In the metamodel, a Classifier declares a collection of Features, such as Attributes, Methods, and Operations. It has a name, which is unique in the Namespace enclosing the Classifier. Classifier is an abstract metaclass.

Associations

feature	A list of Features, like Attribute, Operation, Method, owned by the Classifier.
participant	Inverse of specification on association to AssociationEnd. Denotes that the Classifier participates in an Association.
realization	Inverse of specification. A set of Classifiers that implement the Operations of the Classifier. These may not include Interfaces.
specification	A set of Classifiers that specify the Operations that the Classifier must implement. The Classifier may implement more Operations than contained in the set of Classifiers. The set may include Interfaces, but is not restricted to them.

Constraint

A constraint is a semantic condition or restriction.

In the metamodel a Constraint is a BooleanExpression on an associated ModelElement(s) which must be true for the model to be well formed. This restriction can be stated in natural language, or in different kinds of languages with a well-defined semantics. Certain Constraints are predefined in the UML, others may be user defined. Note that a Constraint is an assertion, not an executable mechanism. It indicates a restriction that must be enforced by correct design of a system.

Attributes

body	A BooleanExpression that must be true when evaluated for an instance of a system to be well-formed.

Associations

constrainedElement	A ModelElement or list of ModelElements affected by the Constraint.

DataType

A data type is a type whose values have no identity (i.e., they are pure values). Data types include primitive built-in types (such as integer and string) as well as definable enumeration types (such as the predefined enumeration type boolean whose literals are false and true).

In the metamodel a DataType defines a special kind of type in which Operations are all pure functions (i.e., they can return DataValues but they cannot change DataValues - because they have no identity).

Dependency

A dependency states that the implementation or functioning of one or more elements requires the presence of one or more other elements. All of the elements must exist at the same level of meaning (i.e., they do not involve a shift in the level of abstraction or realization).

In the metamodel, a Dependency is a directed relationship from a client (or clients) to a supplier (or suppliers) stating that the client is dependent on the supplier (i.e., the client element requires the presence and knowledge of the supplier element).

Dependencies may be stereotyped to differentiate various kinds of dependency.

Attributes

description	A text description of the dependency.

Associations

client	The ModelElement or set of ModelElements that require the presence of the supplier.
supplier	The ModelElement or set of ModelElements whose presence is required by the client.

Element

An element is an atomic constituent of a model.

In the metamodel, an Element is the top metaclass in the metaclass hierarchy. It has two subclasses: ModelElement and ViewElement. Element is an abstract metaclass.

ElementOwnership

Element ownership has visibility in a namespace.

In the metamodel, ElementOwnership reifies the relationship between ModelElement and Namespace denoting the ownership of a ModelElement by a Namespace and its visibility outside the Namespace. See “ModelElement” on page 2-25.

Feature

A feature is a property, like operation or attribute, which is encapsulated within another entity, such as an interface, a class, or a data type.

In the metamodel a Feature declares a behavioral or structural characteristic of an Instance of a Classifier or of the Classifier itself. Feature is an abstract metaclass.

Attributes

name	The name used to identify the Feature within the Classifier or Instance. It must be unique across inheritance of names from ancestors including names of outgoing AssociationEnds.
ownerScope	Specifies whether Feature appears in each Instance of the Classifier or whether there is just a single instance of the Feature for the entire Classifier. Possibilities are: • instance - Each Instance of the Classifier holds its own value for the Feature. • classifier - There is just one value of the Feature for the entire Classifier.
visibility	Specifies whether the Feature can be used by other Classifier. Visibilities of nested Namespaces combine so that the most restrictive visibility is the result. Possibilities: • public - Any outside Classifier with visibility to the Classifier can use the Feature. • protected - Any descendent of the Classifier can use the Feature. • private - Only the Classifier itself can use the Feature.

Associations

owner	The Classifier containing the Feature.

GeneralizableElement

A generalizable element is a model element that may participate in a generalization relationship.

In the metamodel, a GeneralizableElement can be a generalization of other GeneralizableElements (i.e., all Features defined in and all ModelElements contained in the ancestors are also present in the GeneralizableElement). GeneralizableElement is an abstract metaclass.

Attributes

isAbstract	Specifies whether the GeneralizableElement is an incomplete declaration or not. True indicates that the GeneralizableElement is an incomplete declaration (abstract), false indicates that it is complete (concrete). An abstract GeneralizableElement is not instantiable since it does not contain all necessary information.
isLeaf	Specifies whether the GeneralizableElement is a GeneralizableElement with no descendents. True indicates that it is and may not add descendents, false indicates that it may add descendents (whether or not it actually has any descendents at the moment).
isRoot	Specifies whether the GeneralizableElement is a root GeneralizableElement with no ancestors. True indicates that it is and may not add ancestors, false indicates that it may add ancestors (whether or not it actually has any ancestors at the moment).

Associations

generalization	Designates a Generalization whose supertype GeneralizableElement is the immediate ancestor of the current GeneralizableElement.
specialization	Designates a Generalization whose subtype GeneralizableElement is the immediate descendent of the current GeneralizableElement.

Generalization

A generalization is a taxonomic relationship between a more general element and a more specific element. The more specific element is fully consistent with the more general element (it has all of its properties, members, and relationships) and may contain additional information.

In the metamodel a Generalization is a directed inheritance relationship, uniting a GeneralizableElement with a more general GeneralizableElement in a hierarchy. Generalization is a subtyping relationship (i.e., an Instance of the more general GeneralizableElement may be substituted by an Instance of the more specific GeneralizableElement). See Inheritance for the consequences of Generalization relationships.

Attributes

discriminator	Designates the partition to which the Generalization link belongs. All of the Generalization links that share a given supertype GeneralizableElement are divided into groups by their discriminator names. Each group of links sharing a discriminator name represents an orthogonal dimension of specialization of the supertype GeneralizableElement. The discriminator need not be unique. The empty string is considered just another name. If all of the Generalization below a given GeneralizableElement have the same name (including the empty name), then it is a plain set of subelements. Otherwise the subelements form two or more groups, each of which must be represented by one of its members as an ancestor in a concrete descendent element.

Associations

supertype	Designates a GeneralizableElement that is the generalized version of the subtype GeneralizableElement.
subtype	Designates a GeneralizableElement that is the specialized version of the supertype GeneralizableElement.

Interface

An interface is a declaration of a collection of operations that may be used for defining a service offered by an instance.

In the metamodel, an Interface contains a set of Operations that together define a service offered by a Classifier realizing the Interface. A Classifier may offer several services, which means that it may realize several Interfaces, and several Classifiers may realize the same Interface.

Interfaces are GeneralizableElements. All Operations declared by an heir must either be new Operations or specializations (restrictions) of Operations declared in its ancestor(s).

Interfaces may not have Attributes, Associations, or Methods.

Method

A method is the implementation of an operation. It specifies the algorithm or procedure that effects the results of an operation.

In the metamodel, a Method is a declaration of a named piece of behavior in a Classifier and realizes one or a set of Operations of the Classifier.

Attributes

body	The implementation of the Method as a ProcedureExpression.

Associations

specification	Designates an Operation that the Method implements. The Operation must be owned by the Classifier that owns the Method or be inherited by it. The signatures of the Operation and Method must match.

ModelElement

A model element is an element that is an abstraction drawn from the system being modeled. Contrast with view element, which is an element whose purpose is to provide a presentation of information for human comprehension.

In the metamodel, a ModelElement is a named entity in a Model. It is the base for all modeling metaclasses in the UML. All other modeling metaclasses are either direct or indirect subclasses of ModelElement. ModelElement is an abstract metaclass.

Attributes

name	An identifier for the ModelElement within its containing Namespace.

Associations

constraint	A set of Constraints affecting the element.
provision	Inverse of supplier. Designates a Dependency in which the ModelElement is a supplier.
requirement	Inverse of client. Designates a Dependency in which the ModelElement is a client.
namespace	Designates the Namespace that contains the ModelElement. Every ModelElement except a root element must belong to exactly one Namespace. The pathname of Namespace names starting from the system provides a unique designation for every ModelElement. The association attribute visibility specifies the visibility of the element outside its namespace (see Visibility).

Namespace

A namespace is a part of a model in which each name has a unique meaning.

In the metamodel, a Namespace is a ModelElement that can own other ModelElements, like Associations and Classifiers. The name of each owned ModelElement must be unique within the Namespace. Moreover, each contained ModelElement is owned by at most one Namespace. The concrete subclasses of Namespace have additional constraints on which kind of elements may be contained. Namespace is an abstract metaclass.

Associations

owned	A set of ModelElements owned by the Namespace.

Operation

An operation is a service that can be requested from an object to effect behavior. An operation has a signature, which describes the actual parameters that are possible (including possible return values).

In the metamodel, an Operation is a BehavioralFeature that can be applied to the Instances of the Classifier that contains the Operation.

Attributes

concurrency	Specifies the semantics of concurrent calls to the same passive instance (i.e., an Instance originating from a Classifier with isActive=false). Active instances control access to their own Operations so this property is usually (although not required in UML) set to sequential. Possibilities include: • sequential - Callers must coordinate so that only one call to an Instance (on any sequential Operation) may be outstanding at once. If simultaneous calls occur, then the semantics and integrity of the system cannot be guaranteed. • guarded - Multiple calls from concurrent threads may occur simultaneously to one Instance (on any guarded Operation), but only one is allowed to commence. The others are blocked until the performance of the first Operation is complete. It is the responsibility of the system designer to ensure that deadlocks do not occur due to simultaneous blocks. Guarded Operations must perform correctly (or block themselves) in the case of a simultaneous sequential Operation or guarded semantics cannot be claimed.

- concurrent - Multiple calls from concurrent threads may occur simultaneously to one Instance (on any concurrent Operations). All of them may proceed concurrently with correct semantics. Concurrent Operations must perform correctly in the case of a simultaneous sequential or guarded Operation or concurrent semantics cannot be claimed.

isPolymorphic	Whether the implementation of the Operation may be overridden by subclasses. If true, then Methods may be defined on subclasses. If false, then the Method realizing the Operation in the current Classifier is inherited unchanged by all descendents.
specification	Description of the effects of performing an Operation, stated as Uninterpreted.

Parameter

A parameter is an unbound variable that can be changed, passed, or returned. A parameter may include a name, type, and direction of communication. Parameters are used in the specification of operations, messages and events, templates, etc.

In the metamodel, a Parameter is a declaration of an argument to be passed to, or returned from, an Operation, a Signal, etc.

Attributes

defaultValue	An Expression whose evaluation yields a value to be used when no argument is supplied for the Parameter.
kind	Specifies what kind of a Parameter is required. Possibilities are: • in - An input Parameter (may not be modified). • out - An output Parameter (may be modified to communicate information to the caller). • inout - An input Parameter that may be modified. • return -A return value of a call.
name	The name of the Parameter, which must be unique within its containing Parameter list.

Associations

type	Designates a Classifier to which an argument value must conform.

StructuralFeature

A structural feature refers to a static feature of a model element, such as an attribute.

In the metamodel, a StructuralFeature declares a structural aspect of an Instance of a Classifier, such as an Attribute. For example, it specifies the multiplicity and changeability of the StructuralFeature. StructuralFeature is an abstract metaclass.

See Attribute for the descriptions of the attributes and associations, as it is the only subclass of StructuralFeature in the current metamodel.

2.5.3 Well-Formedness Rules

The following well-formedness rules apply to the Core package.

Association

[1] The AssociationEnds must have a unique name within the Association.

self.allConnections->forAll(r1, r2 | r1.name = r2.name **implies** r1 = r2)

[2] At most one AssociationEnd may be an aggregation or composition.

self.allConnections->select(aggregation <> #none)->size <= 1

[3] If an Association has three or more AssociationEnds, then no AssociationEnd may be an aggregation or composition.

[4] The connected Classifiers of the AssociationEnds should be included in the Namespace of the Association.

self.allConnections->forAll (r |

    self.namespace.allContents->includes (r.type))

Additional operations

[1] The operation allConnections results in the set of all AssociationEnds of the Association.

allConnections : Set(AssociationEnd);

allConnections = self.connection

AssociationClass

[1] The names of the AssociationEnds and the StructuralFeatures do not overlap.

self.allConnections->forAll(ar |

    self.allFeatures->forAll(f |

f.oclIsKindOf(StructuralFeature) **implies** ar.name <> f.name))

[2] An AssociationClass cannot be defined between itself and something else.

self.allConnections->forAll(ar | ar.type <> self)

Additional operations

[1] The operation allConnections results in the set of all AssociationEnds of the AssociationClass, including all connections defined by its supertype (transitive closure).

allConnections : Set(AssociationEnd);

allConnections = self.connection->union(self.supertype->select

(s | s.oclIsKindOf(Association))->collect (a : Association |

a.allConnections))->asSet

AssociationEnd

[1] The Classifier of an AssociationEnd cannot be an Interface or a DataType unless the DataType is part of a composite aggregation.

not self.type.oclIsKindOf (Interface)

and

(self.type.oclIsKindOf (DataType) **implies**

self.association.connection->select (ae | ae <> self)->forAll (ae |

ae.aggregation = #composite))

[2] An Instance may not belong by composition to more than one composite Instance.

self.aggregation = #composite **implies** self.multiplicity.max <= 1

Attribute

No extra well-formedness rules.

BehavioralFeature

[1] All Parameters should have a unique name.

self.parameter->forAll(p1, p2 | p1.name = p2.name **implies** p1 = p2)

[2] The type of the Parameters should be included in the Namespace of the Classifier.

self.parameter->forAll(p |

self.owner.namespace.allContents->includes (p.type))

Additional operations

[1] The operation hasSameSignature checks if the argument has the same signature as the instance itself.

```
hasSameSignature ( b : BehavioralFeature ) : Boolean;

hasSameSignature (b) =
    (self.name = b.name) and
    (self.parameter->size = b.parameter->size) and
    Sequence{ 1..(self.parameter->size) }->forAll( index : Integer |
        b.parameter->at(index).type =
            self.parameter->at(index).type and
        b.parameter->at(index).kind =
            self.parameter->at(index).kind
    )
```

Class

[1] If a Class is concrete, all the Operations of the Class should have a realizing Method in the full descriptor.

```
not self.isAbstract implies self.allOperations->forAll (op |
self.allMethods->exists (m | m.specification->includes(op)))
```

[2] A Class can only contain Classes, Associations, Generalizations, UseCases, Constraints, Dependencies, Collaborations, and Interfaces as a Namespace.

```
self.allContents->forAll->(c |
    c.oclIsKindOf(Class        ) or
    c.oclIsKindOf(Association  ) or
    c.oclIsKindOf(Generalization) or
    c.oclIsKindOf(UseCase      ) or
    c.oclIsKindOf(Constraint   ) or
    c.oclIsKindOf(Dependency   ) or
    c.oclIsKindOf(Collaboration ) or
    c.oclIsKindOf(Interface    )
)
```

[3] For each Operation in an Interface provided by the Class, the Class must have a matching Operation.

```
self.specification.allOperations->forAll (interOp |
    self.allOperations->exists( op | op.hasSameSignature (interOp) ) )
```

Classifier

[1] No BehavioralFeature of the same kind may have the same signature in a Classifier.

```
self.feature->forAll(f, g |
(
    (
        (f.oclIsKindOf(Operation) and g.oclIsKindOf(Operation)) or
        (f.oclIsKindOf(Method    ) and g.oclIsKindOf(Method    )) or
        (f.oclIsKindOf(Reception) and g.oclIsKindOf(Reception))
    ) and
    f.oclAsType(BehavioralFeature).hasSameSignature(g)
)
implies f = g)
```

[2] No Attributes may have the same name within a Classifier.

```
self.feature->select ( a | a.oclIsKindOf (Attribute) )->forAll ( p, q |
    p.name = q.name implies p = q )
```

[3] No opposite AssociationEnds may have the same name within a Classifier.

```
self.oppositeEnds->forAll ( p, q | p.name = q.name implies p = q )
```

[4] The name of an Attribute may not be the same as the name of an opposite AssociationEnd or a ModelElement contained in the Classifier.

```
self.feature->select ( a | a.oclIsKindOf (Attribute) )->forAll ( a |
    not self.allOppositeAssociationEnds->union (self.allContents)->collect ( q |
        q.name )->includes (a.name) )
```

[5] The name of an opposite AssociationEnd may not be the same as the name of an Attribute or a ModelElement contained in the Classifier.

```
self.oppositeAssociationEnds->forAll ( o |
    not self.allAttributes->union (self.allContents)->collect ( q |
        q.name )->includes (o.name) )
```

Additional operations

[1] The operation allFeatures results in a Set containing all Features of the Classifier itself and all its inherited Features.

```
allFeatures : Set(Feature);
allFeatures = self.feature->union(
                                    self.supertype.oclAsType(Classifier).allFeatures)
```

[2] The operation allOperations results in a Set containing all Operations of the Classifier itself and all its inherited Operations.

```
allOperations : Set(Operation);

allOperations = self.allFeatures->select(f | f.oclIsKindOf(Operation))
```

[3] The operation allMethods results in a Set containing all Methods of the Classifie itself and all its inherited Methods.

```
allMethods : set(Method);

allMethods = self.allFeatures->select(f | f.oclIsKindOf(Method))
```

[4] The operation allAttributes results in a Set containing all Attributes of the Classifier itself and all its inherited Attributes.

```
allAttributes : set(Attribute);

allAttributes = self.allFeatures->select(f | f.oclIsKindOf(Attribute))
```

[5] The operation associations results in a Set containing all Associations of the Classifier itself.

```
associations : set(Association);

associations = self.associationEnd.association->asSet
```

[6] The operation allAssociations results in a Set containing all Associations of the Classifier itself and all its inherited Associations.

```
allAssociations : set(Association);

allAssociations = self.associations->union (
                                    self.supertype.oclAsType(Classifier).allAssociations)
```

[7] The operation oppositeAssociationEnds results in a set of all AssociationEnds that are opposite to the Classifier.

```
oppositeAssociationEnds : Set (AssociationEnd);

oppositeAssociationEnds =
    self.association->select ( a | a.associationEnd->select ( ae |
        ae.type = self ).size = 1 )->collect ( a |
            a.associationEnd->select ( ae | ae.type <> self ) )->union (
    self.association->select ( a | a.associationEnd->select ( ae |
        ae.type = self ).size > 1 )->collect ( a |
            a.associationEnd) )
```

[8] The operation allOppositeAssociationEnds results in a set of all AssociationEnds, including the inherited ones, that are opposite to the Classifier.

```
allOppositeAssociationEnds : Set (AssociationEnd);

allOppositeAssociationEnds = self.oppositeAssociationEnds->union (
        self.supertype.allOppositeAssociationEnds )
```

Constraint

[1] A Constraint cannot be applied to itself.

not self.constrainedElement->includes (self)

DataType

[1] A DataType can only contain Operations, which all must be queries.

self.allFeatures->forAll(f |

f.oclIsKindOf(Operation) **and** f.oclAsType(Operation).isQuery)

[2] A DataType cannot contain any other ModelElements.

self.allContents->isEmpty

Dependency

No extra well-formedness rules.

Element

No extra well-formedness rules.

ElementOwnership

No additional well-formedness rules.

Feature

No extra well-formedness rules.

GeneralizableElement

[1] A root cannot have any Generalizations.

self.isRoot **implies** self.generalization->isEmpty

[2] No GeneralizableElement can have a supertype Generalization to an element which is a leaf.

self.supertype->forAll(s | **not** s.isLeaf)

[3] Circular inheritance is not allowed.

not self.allSupertypes->includes(self)

[4] The supertype must be included in the Namespace of the GeneralizableElement.

self.generalization->forAll(g |

self.namespace.allContents->includes(g.supertype))

Additional Operations

[1] The operation allContents returns a Set containing all ModelElements contained in the GeneralizableElement together with the contents inherited from its supertypes.

```
allContents : Set(ModelElement);

allContents = self.contents->union(

    self.supertype.allContents->select(e |

        e.elementOwnership.visibility = #public or

        e.elementOwnership.visibility = #protected))
```

[2] The operation supertype returns a Set containing all direct supertypes.

```
supertype : Set(GeneralizableElement);

supertype = self.generalization.supertype
```

[3]The operation allSupertypes returns a Set containing all the GeneralizableElements inherited by this GeneralizableElement (the transitive closure), excluding the GeneralizableElement itself.

```
allSupertypes : Set(GeneralizableElement);

allSupertypes = self.supertype->union(self.supertype.allSupertypes)
```

Generalization

[1] A GeneralizableElement may only be a subclass of GeneralizableElement of the same kind.

```
self.subtype.oclType = self.supertype.oclType
```

Interface

[1] An Interface can only contain Operations.

```
self.allFeatures->forAll(f | f.oclIsKindOf(Operation))
```

[2] An Interface cannot contain any Classifiers.

```
self.allContents->isEmpty
```

[3] All Features defined in an Interface are public.

```
self.allFeatures->forAll ( f | f.visibility = #public )
```

Method

[1] If one of the realized Operations is a query, then so is the Method.

```
self.specification->exists ( op | op.isQuery ) implies self.isQuery
```

[2] The signature of the Method should be the same as the signature of the realized Operations.

```
self. specification->forAll ( op | self.hasSameSignature (op) )
```

[3] The visibility of the Method should be the same as for the realized Operations.

```
self. specification->forAll ( op | self.visibility = op.visibility )
```

ModelElement

Additional Operations

[1] The operation supplier results in a Set containing all direct suppliers of the ModelElement.

```
supplier : Set(ModelElement);

supplier = self.provision.supplier
```

[2] The operation allSuppliers results in a Set containing all the ModelElements that are suppliers of this ModelElement, including the suppliers of these ModelElements. This is the transitive closure.

```
allSuppliers : Set(ModelElement);

allSuppliers = self.supplier->union(self.supplier.allSuppliers)
```

[3] The operation model results in the Model to which a ModelElement belongs.

```
model : Set(Model);

model = self.namespace->union(self.namespace.allSurroundingNamespaces)
                ->select( ns|
                        ns.oclIsKindOf (Model))
```

Namespace

[1] If a contained element, which is not an Association or Generalization has a name, then the name must be unique in the Namespace.

```
self.allContents->forAll(me1, me2 : ModelElement |
    (   not me1.oclIsKindOf (Association) and not me2.oclIsKindOf (Association) and
        me1.name <> '' and me2.name <> '' and me1.name = me2.name
    ) implies
        me1 = me2 )
```

[2] All Associations must have a unique combination of name and associated Classifiers in the Namespace.

```
self.allContents->select(oclIsKindOf(Association))->
    forAll(a1, a2 : Association |
        (   a1.name = a2.name and
            a1.connection->size = a2.connection->size and
            Sequence{1..a1.connection->size}->forAll(i |
                a1.connection->at(i).type = a2.connection->at(i).type)
```

) **implies**

a1 = a2)

Additional operations

[1] The operation contents results in a Set containing all ModelElements contained by the Namespace.

contents : Set(ModelElement)

contents = self.ownedElement

[2] The operation allContents results in a Set containing all ModelElements contained by the Namespace.

allContents : Set(ModelElement);

allContents = self.contents

[3] The operation allVisibleElements results in a Set containing all ModelElements visible outside of the Namespace.

allVisibleElements : Set(ModelElement)

allVisibleElements = self.allContents->select(e |

e.elementOwnership.visibility = #public)

[4] The operation allSurroundingNamespaces results in a Set containing all surrounding Namespaces.

allSurroundingNamespaces : Set(Namespace)

allSurroundingNamespaces =

self.namespace->union(self.namespace.allSurroundingNamespaces)

Operation

No additional well-formedness rules.

Parameter

[1] An Interface cannot be used as the type of a parameter.

not self.type.oclIsKindOf(Interface)

StructuralFeature

[1] The connected type should be included in the current Namespace.

self.owner.namespace.allContents->includes(self.type)

2.5.4 Semantics

This section provides a description of the dynamic semantics of the elements in the Core. It is structured based on the major constructs in the core, such as interface, class, and association.

Inheritance

To understand inheritance it is first necessary to understand the concept of a full descriptor and a segment descriptor. A full descriptor is the full description needed to describe an object or other instance (see “Instantiation” on page 2-38). It contains a description of all of the attributes, associations, and operations that the object contains. In a pre-object-oriented language, the full descriptor of a data structure was declared directly in its entirety. In an object-oriented language, the description of an object is built out of incremental segments that are combined using inheritance to produce a full descriptor for an object. The segments are the modeling elements that are actually declared in a model. They include elements such as class and other generalizable elements. Each generalizable element contains a list of features and other relationships that it adds to what it inherits from its ancestors. The mechanism of inheritance defines how full descriptors are produced from a set of segments connected by generalization. The full descriptors are implicit, but they define the structure of actual instances.

Each kind of generalizable element has a set of inheritable features. For any model element, these include constraints. For classifiers, these include features (attributes, operations, signal takers, and methods) and participation in associations. The ancestors of a generalizable element are its supertypes (if any) together with all of their ancestors (with duplicates removed).

If a generalizable element has no supertype, then its full descriptor is the same as its segment descriptor. If a generalizable element has one or more supertypes, then its full descriptor contains the union of the features from its own segment descriptor and the segment descriptors of all of its ancestors. For a classifier, no attribute, operation, or signal with the same signature may be declared in more than one of the segments (in other words, they may not be redefined). A method may be declared in more than one segment. A method declared in any segment supersedes and replaces a method with the same signature declared in any ancestor. If two or more methods nevertheless remain, then they conflict and the model is ill-formed. The constraints on the full descriptor are the union of the constraints on the segment itself and all of its ancestors. If any of them are inconsistent, then the model is ill-formed.

In any full descriptor for a classifier, each method must have a corresponding operation. In a concrete classifier, each operation in its full descriptor must have a corresponding method in the full descriptor.

The purpose of the full descriptor is explained under “Instantiation” on page 2-38.

Instantiation

The purpose of a model is to describe the possible states of a system and their behavior. The state of a system comprises objects, values, and links. Each object is described by a full class descriptor. The class corresponding to this descriptor is the direct class of the object. Similarly each link has a direct association and each value has a direct data type. Each of these instances is said to be a direct instance of the classifier from which its full descriptor was derived. An instance is an indirect instance of the classifier or any of its ancestors.

The data content of an object comprises one value for each attribute in its full class descriptor (and nothing more). The value must be consistent with the type of the attribute. The data content of a link comprises a tuple containing a list of instances, one that is an indirect instance of each participant classifier in the full association descriptor. The instances and links must obey any constraints on the full descriptors of which they are instances (including both explicit constraints and built-in constraints such as multiplicity).

The state of a system is a valid system instance if every instance in it is a direct instance of some element in the system model and if all of the constraints imposed by the model are satisfied by the instances.

The behavioral parts of UML describe the valid sequences of valid system instances that may occur as a result of both external and internal behavioral effects.

Class

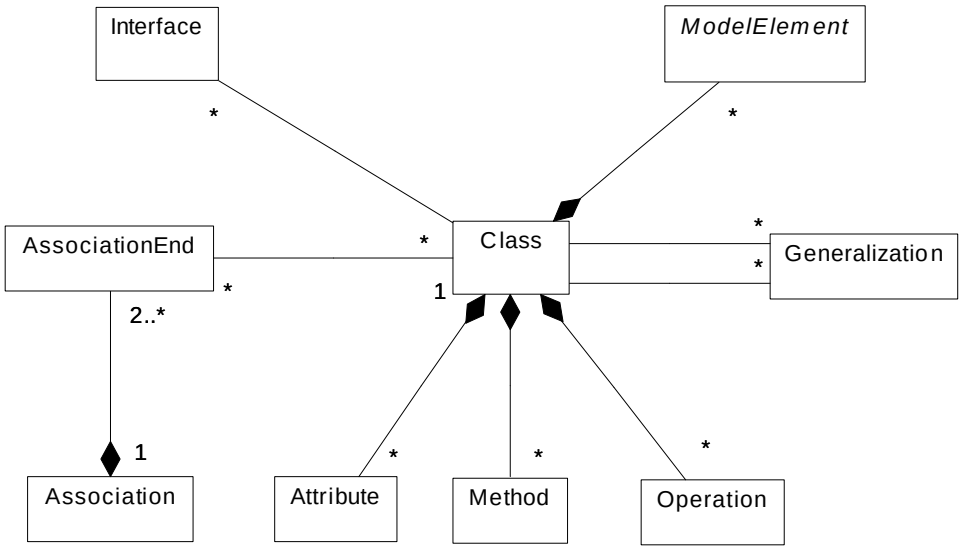


Figure 2-7 Class Illustration

The purpose of a class is to declare a collection of methods, operations, and attributes that fully describe the structure and behavior of objects. All objects instantiated from a class will have attribute values matching the attributes of the full class descriptor and

support the operations found in the full class descriptor. Some classes may not be directly instantiated. These classes are said to be abstract and exist only for other classes to inherit and reuse the features declared by them. No object may be a direct instance of an abstract class, although an object may be an indirect instance of one through a subclass that is non-abstract.

When a class is instantiated to create a new object, a new instance is created, which is initialized containing an attribute value for each attribute found in the full class descriptor. The object is also initialized with a connection to the list of methods in the full class descriptor.

Note – An actual implementation behaves as if there were a full class descriptor, but many clever optimizations are possible in practice.

Finally, the identity of the new object is returned to the creator. The identity of every instance in a well-formed system is unique and automatic.

A class can have generalizations to other classes. This means that the full class descriptor of a class is derived by inheritance from its own segment declaration and those of its ancestors. Generalization between classes implies substitutability (i.e., an instance of a class may be used whenever an instance of a superclass is expected). If the class is specified as a root, it cannot be a subclass of other classes. Similarly, if it is specified as a leaf, no other class can be a subclass of the class.

Each attribute declared in a class has a visibility and a type. The visibility defines if the attribute is publicly available to any class, if it is only available inside the class and its subclasses (protected), or if it can only be used inside the class (private). The targetScope of the attribute declares whether its value should be an instance (of a subtype) of that type or if it should be (a subtype of) the type itself. There are two alternatives for the ownerScope of an attribute:

- it may state that each object created by the class (or by its subclasses) has its own value of the attribute, or
- that the value is owned by the class itself.

An attribute also declares how many attribute values should be connected to each owner (multiplicity), what the initial values should be, and if these attribute values may be changed to:

- none - no constraints exists,
- frozen - the value cannot be replaced or added to once it has been initialized, or
- addOnly - new values may be added to a set but not removed or altered.

For each operation, the operation name, the types of the parameters, and the return type(s) are specified, as well as its visibility (see above). An operation may also include a specification of the effects of its invocation. The specification can be done in several different ways (e.g., with pre- and post-conditions, pseudo-code, or just plain text). Each operation declares if it is applicable to the instances, the class, or to the class itself (ownerScope). Furthermore, the operation states whether or not its application will modify the state of the object (isQuery). The operation also states

whether or not the operation may be realized by a different method in a subclass (isPolymorphic). An operation may have a set of extension points specifying where additional behavior may be inserted into the operation. A method realizing an operation has the same signature as the operation and a body implementing the specification of the operation. Methods in descendents override and replace methods inherited from ancestors (see Inheritance). Each method implements an operation declared in the class or inherited from an ancestor. The same operation may not be declared more than once in a full class descriptor. The specification of the method must match the specification of its matching operation, as defined above for operations. Furthermore, if the isQuery attribute of an operation is true, then it must also be true in any realizing method. However, if it is false in the operation, it may still be true if the method (isQuery=false) does not require that the operation modify the state. The concept of visibility is not relevant for methods.

Classes may have associations to each other. This implies that objects created by the associated classes are semantically connected (i.e., that links exist between the objects, according to the requirements of the associations). See *Association* on the next page. Associations are inherited by subclasses.

A class may realize a set of interfaces. This means that each operation found in the full descriptor for any realized interface must be present in the full class descriptor with the same specification. The relationship between interface and class is not necessarily one-to-one; a class may offer several interfaces and one interface may be offered by more than one class. The same operation may be defined in multiple interfaces that a class supports; if their specifications are identical then there is no conflict; otherwise, the model is ill-formed. Moreover, a class may contain additional operations besides those found in its interfaces.

A class acts as the namespace for attributes, outgoing role names on associations, and operations. Furthermore, since a class acts as a namespace for contained classes, interfaces, and associations (elements defined within its scope, they do not imply aggregation), the contained classifiers can be used as ordinary classifiers in the container class. However, the contents cannot be referenced by anyone outside the container class. If a class inherits another class, the visibility of the contents as it is defined in the superclass guides if the contained elements are visible in the subclass. If the visibility of an element is public or protected, then it is also visible in the subclass; however, if the visibility is private, then the element is not visible and therefore not available in the subclass.

Interface

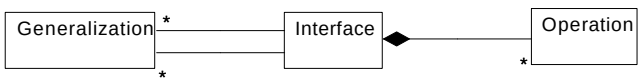


Figure 2-8 Interface Illustration

The purpose of an interface is to collect a set of operations that constitute a coherent service offered by classifiers. Interfaces provide a way to partition and characterize groups of operations. An interface is only a collection of operations with a name. It cannot be directly instantiated. Instantiable classifiers, such as class or use case, may use interfaces for specifying different services offered by their instances. Several classifiers may realize the same interface. All of them must contain at least the operations matching those contained in the interface. The specification of an operation contains the signature of the operation (i.e., its name, the types of the parameters and the return type). An interface does not imply any internal structure of the realizing classifier. For example, it does not define which algorithm to use for realizing an operation. An operation may, however, include a specification of the effects of its invocation. The specification can be done in several different ways (e.g., with pre and post-conditions, pseudo-code, or just plain text).

Each operation declares if it applies to the instances of the classifier declaring it or to the classifier itself (e.g., a constructor on a class (ownerScope)). Furthermore, the operation states whether or not its application will modify the state of the instance (isQuery). The operation also states whether or not all the classes must have the same realization of the operation (isPolymorphic).

An interface can be a subtype of other interfaces denoted by generalizations. This means that a classifier offering the interface must provide not only the operations declared in the interface but also those declared in the ancestors of the interface. If the interface is specified as a root, it cannot be a subtype of other interfaces. Similarly, if it is specified as a leaf, no other interface can be a subtype of the interface.

Association

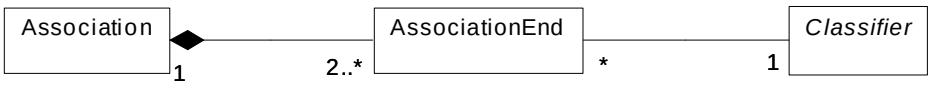


Figure 2-9 Association Illustration

An association declares a connection (link) between instances of the associated classifiers (e.g., classes). It consists of at least two association-ends, each specifying a connected classifier and a set of properties which must be fulfilled for the relationship to be valid. The multiplicity property of an association-end specifies how many instances of the classifier at a given end (the one bearing the multiplicity value) may be associated with a single instance of the classifier at the other end. A multiplicity is a range of nonnegative integers. The association-end also states whether or not the connection may be traversed towards the instance playing that role in the connection (isNavigable). For instance, if the instance is directly reachable via the association. An association-end also specifies whether or not an instance playing that role in a connection may be replaced by another instance. It may state

- that no constraints exists (none),
- that the link cannot be modified once it has been initialized (frozen), or

- that new links of the association may be added but not removed or altered (addOnly).

These constraints do not affect the modifiability of the objects themselves that are attached to the links. Moreover, the targetScope specifies if the association-end should be connected to an instance of (a subtype of) the classifier, or (a subtype of) the classifier itself. The isOrdered attribute of association-end states if the instances related to a single instance at the other end have an ordering that must be preserved. The order of insertion of new links must be specified by operations that add or modify links. Note that sorting is a performance optimization and is not an example of a logically ordered association, because the ordering information in a sort does not add any information.

An association may represent an aggregation (i.e., a whole/part relationship). In this case, the association-end attached to the whole element is designated, and the other association-end of the association represents the parts of the aggregation. Only binary associations may be aggregations. Composite aggregation is a strong form of aggregation which requires that a part instance be included in at most one composite at a time, although the owner may be changed over time. Furthermore, a composite implies propagation semantics (i.e., some of the dynamic semantics of the whole is propagated to its parts). For example, if the whole is copied or deleted, then so are the parts as well. A shared aggregation denotes weak ownership (i.e., the part may be included in several aggregates) and its owner may also change over time. However, the semantics of a shared aggregation does not imply deletion of the parts when one of its containers is deleted. Both kinds of aggregations define a transitive, antisymmetric relationship (i.e., the instances form a directed, non-cyclic graph). Composition instances form a strict tree (or rather a forest).

A qualifier declares a partition of the set of associated instances with respect to an instance at the qualified end (the qualified instance is at the end to which the qualifier is attached). A qualifier instance comprises one value for each qualifier attribute. Given a qualified object and a qualifier instance, the number of objects at the other end of the association is constrained by the declared multiplicity. In the common case in which the multiplicity is 0..1, the qualifier value is unique with respect to the qualified object, and designates at most one associated object. In the general case of multiplicity 0..*, the set of associated instances is partitioned into subsets, each selected by a given qualifier instance. In the case of multiplicity 1 or 0..1, the qualifier has both semantic and implementation consequences. In the case of multiplicity 0..*, it has no real semantic consequences but suggests an implementation that facilities easy access of sets of associated instances linked by a given qualifier value.

Note that the multiplicity of a qualifier is given assuming that the qualifier value is supplied. The "raw" multiplicity without the qualifier is assumed to be 0..*. This is not fully general but it is almost always adequate, as a situation in which the raw multiplicity is 1 would best be modeled without a qualifier.

Note also that a qualified multiplicity whose lower bound is zero indicates that a given qualifier value may be absent, while a lower bound of 1 indicates that any possible qualifier value must be present. The latter is reasonable only for qualifiers with a finite number of values (such as enumerated values or integer ranges) that represent full tables indexed by some finite range of values.

AssociationClass

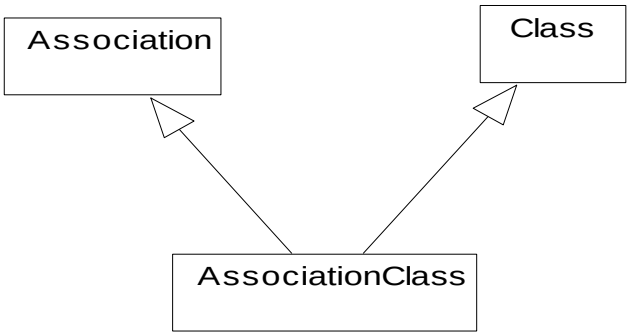


Figure 2-10 AssociationClass Illustration

An association may be refined to have its own set of features (i.e., features that do not belong to any of the connected classifiers) but rather to the association itself. Such an association is called an association class. It will be both an association, connecting a set of classifiers, and a class, and as such have features and be included in other associations. The semantics of such an association is a combination of the semantics of an ordinary association and of a class.

Miscellaneous

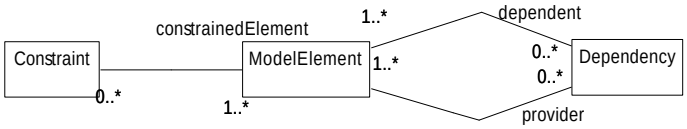


Figure 2-11 Miscellaneous Illustration

A constraint is a Boolean expression over one or several elements which must always be true. A constraint can be specified in several different ways (e.g., using natural language or a constraint language).

A dependency specifies that the semantics of a set of model elements requires the presence of another set of model elements. This implies that if the source is somehow modified, the dependents probably must be modified. The reason for the dependency can be specified in several different ways (e.g., using natural language or an algorithm) but is often implicit.

A special kind of classifier, similar to class, is data type; however, the instances of a data type are primitive values (i.e., non-objects). For example, the integers and strings are usually treated as primitive values. A primitive value does not have an identity, so two occurrences of the same value cannot be differentiated. Usually, it is used for specification of the type of an attribute. An enumeration type is a user-definable type comprising a finite number of values.

2.5.5 Standard Elements

The predefined stereotypes, constraints, and tagged values for the Core package are listed in Table 2-2 and defined in Appendix A - UML Standard Elements.

Table 2-2 Core - Standard Elements

Model Element	Stereotypes	Constraints	Tagged Values
Association		implicit or	
Attribute			persistence
BehavioralFeature	«create» «destroy»		
Class	«implementationClass» «type»		
Classifier	«metaclass» «powertype» «process» «stereotype» «thread» «utility»		location persistence responsibility semantics
Constraint	«invariant» «postcondition» «precondition»		
Element			documentation
Generalization	«extends» «inherits» «private» «subclass» «subtype» «uses»	complete disjoint incomplete overlapping	
Operation			semantics

2.5.6 Notes

In UML, Associations can be of three different kinds: 1) ordinary association, 2) composite aggregate, and 3) shared aggregate. Since the aggregate construct can have several different meanings depending on the application area, UML gives a more precise meaning to two of these constructs (i.e., association and composite aggregate) and leaves the shared aggregate more loosely defined in between.

Operation is a conceptual construct, while Method is the implementation construct. Their common features, such as having a signature, are expressed in the BehavioralFeature metaclass, and the specific semantics of the Operation. The Method constructs are defined in the corresponding subclasses of BehavioralFeature.

A Usage or Binding dependency can be established only between elements in the same model, since the semantics of a model cannot be dependent on the semantics of another model. If a connection is to be established between elements in different models, a Trace or Refinement should be used.

The AssociationClass construct can be expressed in a few different ways in the metamodel (e.g., as a subclass of Class, as a subclass of Association, or as a subclass of Classifier). Since an AssociationClass is a construct being both an association (having a set of association-ends) and a class (declaring a set of features), the most accurate way of expressing it is as a subclass of both Association and Class. In this way, AssociationClass will have all the properties of the other two constructs. Moreover, if new kinds of associations containing features (e.g., AssociationDataType) are to be included in UML, these are easily added as subclasses of Association and the other Classifier.

Note – The terms subtype and subclass are synonyms and mean that an instance of a classifier being a subtype of another classifier can always be used where an instance of the latter classifier is expected.

2.6 Auxiliary Elements

2.6.1 Overview

The Auxiliary Elements package is the subpackage that defines additional constructs that extend the Core. Auxiliary Elements provide infrastructure for dependencies, templates, physical structures, and view elements.

2.6.2 Abstract Syntax

The abstract syntax for the Auxiliary Elements package is expressed in graphic notation in the following figures.

Auxiliary Elements: Dependencies

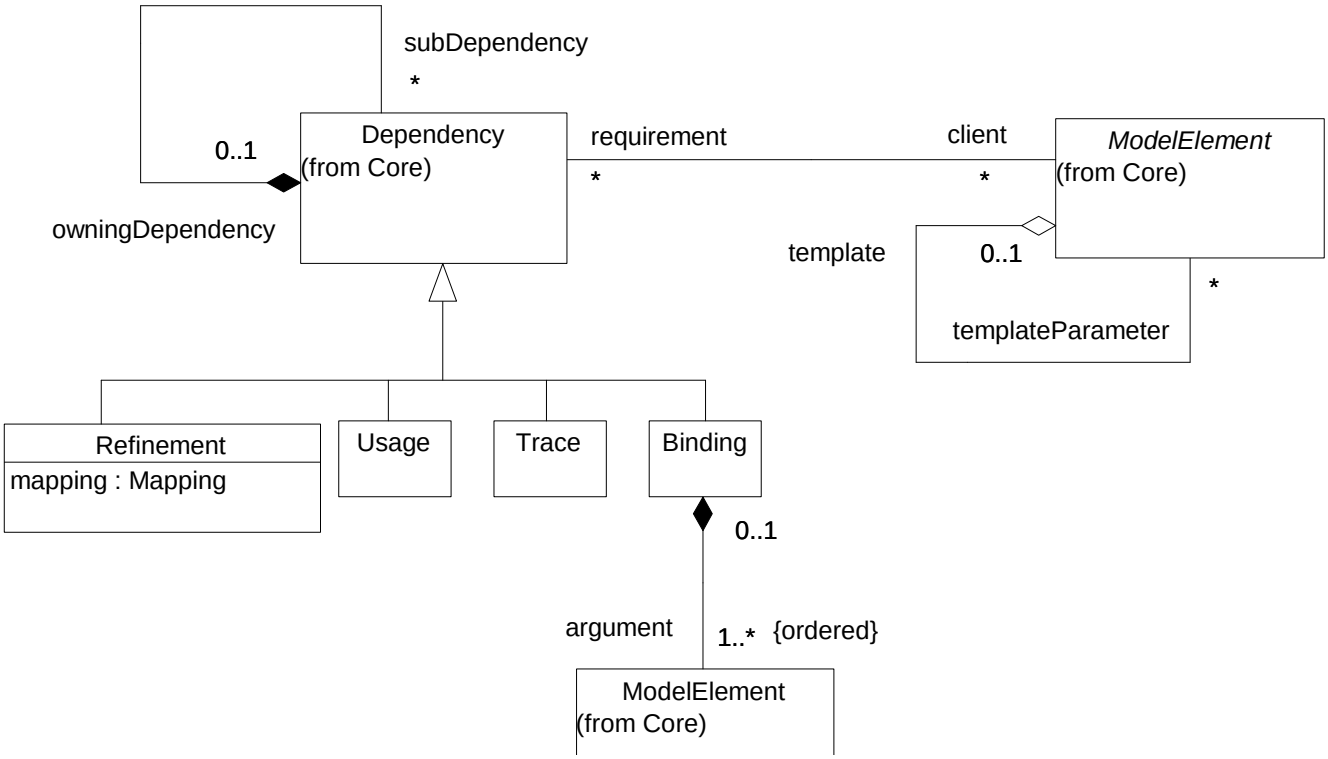


Figure 2-12 Auxiliary Elements - Dependencies and Templates

Auxiliary Elements:
Physical Structures and View Elements

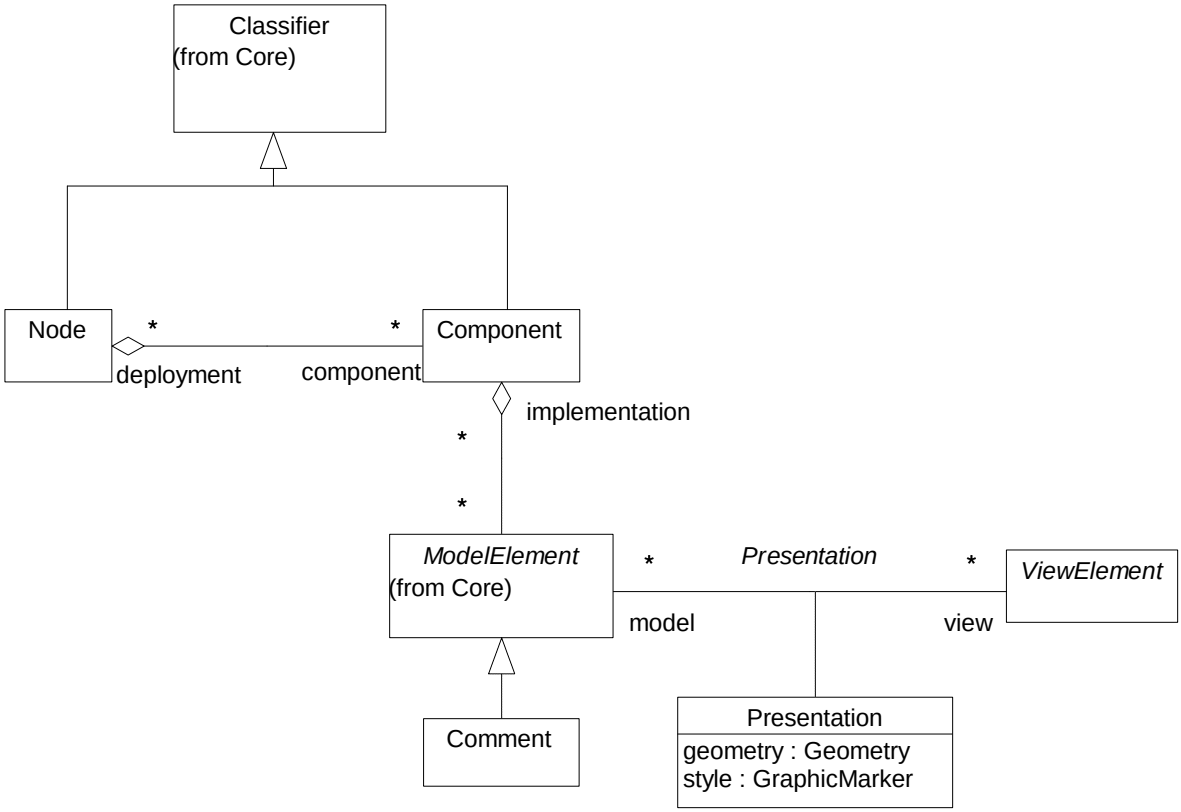


Figure 2-13 Auxiliary Elements - Physical Structures and View Elements

The following metaclasses are contained in the Auxiliary Elements package.

Binding

A binding is a relationship between a template and a model element generated from the template. It includes a list of arguments matching the template parameters. The template is a form that is cloned and modified by substitution to yield an implicit model fragment that behaves as if it were a direct part of the model.

In the metamodel, a Binding is a Dependency where the supplier is the template and the client is the instantiation of the template that performs the substitution of parameters of a template. A Binding has a list of arguments that replace the parameters of the supplier to yield the client. The client is fully specified by the binding of the supplier's parameters and does not add any information of its own.

Associations

argument	An ordered list of arguments. Each argument replaces the corresponding supplier parameter in the supplier definition, and the result represents the definition of the client as if it had been defined directly.

Comment

A comment is an annotation attached to a model element or a set of model elements.

In the metamodel, a Comment is a subclass of ViewElement. It is associated with a set of ModelElements.

Component

A component is a reusable part that provides the physical packaging of model elements.

In the metamodel, a Component is a subclass of Classifier. It provides the physical packaging of its associated specification elements.

Associations

deployment	The set of Nodes the Component is residing on.

Dependency (from Core)

A dependency indicates a semantic relationship among model elements themselves (rather than instances of them) in which a change to one element may affect or require changes to other elements.

In the metamodel, a Dependency is a directed relationship from a client (or clients) to a supplier (or suppliers) stating that the client is dependent on the supplier (i.e., a change to the supplier may affect the client). The relationship is directed, although the direction may be ignored for certain subtypes of Dependency (such as Trace).

To enable grouping of dependencies that belong together, a dependency can serve as a container for a group of Dependencies. This is useful, because often dependencies are between groups of elements (such as Packages, Models, Classifiers, etc.). For example, the dependency of one package on another can be expanded into a set of dependencies among elements within the two packages.

Associations

client	The element that is affected by the supplier element. In some cases (such as Trace) the direction is unimportant and serves only to distinguish the two elements.
owningDependency	The inverse of subDependency.
subDependency	A set of more specific dependencies that elaborate a more general dependency.
supplier	Inverse of client. Designates the element that is unaffected by a change. In a two-way relationship (such as some Refinements) this should be the more general element.

ModelElement (from Core)

A model element is an element that is an abstraction drawn from the system being modeled. Contrast with view element, which is an element whose purpose is to provide a presentation of information for human comprehension.

In the metamodel, a ModelElement is a named entity in a Model. It is the base for all modeling metaclasses in the UML. All other modeling metaclasses are either direct or indirect subclasses of ModelElement.

Each ModelElement can be regarded as a template. A template has a set of templateParameters that denotes which of the parts of a ModelElement are the template parameters. A ModelElement is a template when there is at least one template parameter. If it is not a template, a ModelElement cannot have template parameters. However, such embedded parameters are not usually complete and need not satisfy well-formedness rules. It is the arguments supplied when the template is instantiated that must be well-formed.

Partially instantiated templates are allowed. This is the case when there are arguments provided for some, but not all templateParameters. A partially instantiated template is still a template, since it still has parameters.

Associations

templateParameter	An ordered list of parameters. Each parameter designates a ModelElement within the scope of the overall ModelElement. The designated ModelElement may be a placeholder for a real ModelElement to be substituted. In particular, the template parameter element will lack structure. For example, a parameter that is a Class lacks Features; they are found in the actual argument.

Node

A node is a run-time physical object that represents a computational resource, generally having at least a memory and often processing capability as well, and upon which components may be deployed.

In the metamodel, a Node is a subclass of Classifier. It is associated with a set of Components residing on the Node.

Associations

component	The set of Components residing on the Node.

Presentation

A presentation is the relationship between a view element and a model element (or possibly a set of each). The details are dependent on the implementation of a graphic editor tool.

In the metamodel, Presentation reifies the relationship between ModelElement and ViewElement and provides the placement and the style of presentation to be used when presenting the ModelElements.

Attributes

geometry	A description of the geometry of the ViewElement image.
style	A description of the graphic markers pertaining to the ViewElement image, such as color, texture, font, line width, shading, etc.

Refinement

A refinement is a relationship between model elements at different semantics levels, such as analysis and design.

In the metamodel, a Refinement is a Dependency where the clients are derived from the suppliers. The derivation cannot necessarily be described by an algorithm; human decisions may be required to produce the clients. The details of specifying the derivation are beyond the scope of UML but can be indicated with constraints. Refinement can be used to model stepwise refinement, optimizations, transformations, templates, model synthesis, framework composition, etc.

Attributes

mapping	A description of the mapping between the two elements. The mapping is an expression whose syntax is beyond the scope of UML. For exchange purposes, it should be represented as a string.

Trace

A trace is a conceptual connection between two elements or sets of elements that represent a single concept at different semantic levels or from different points of view; however, there is no specific mapping between the elements. The construct is mainly a tool for tracing of requirements. It is also useful for the modeler to keep track of changes to different models.

In the metamodel, a Trace is a Dependency between ModelElements in different Models abstracting the same part of the system being modeled. Traces denote dependencies at specification level, rather than runtime dependencies; therefore, traces do not express information on the system as such, but rather on the Models of the system. The directionality of the dependency can usually be ignored.

Usage

A usage is a relationship in which one element requires another element (or set of elements) for its full implementation or operation. The relationship is not a mere historical artifact, but an ongoing need; therefore, two elements related by usage must be in the same model.

In the metamodel, a Usage is a Dependency in which the client requires the presence of the supplier. How the client uses the supplier, such as a class calling an operation of another class, a method having an argument of another class, and a method from a class instantiating another class, is defined in the description of the Usage.

ViewElement

A view element is a textual or graphical presentation of one or more model elements.

In the metamodel, a ViewElement is an Element which presents a set of ModelElements to a reader. It is the base for all metaclasses in the UML used for presentation. All other metaclasses with this purpose are either direct or indirect subclasses of ViewElement. ViewElement is an abstract metaclass. The subclasses of this class are proper to a graphic editor tool and are not specified here.

2.6.3 Well-Formedness Rules

The following well-formedness rules apply to the Auxiliary Elements package.

Binding

[1]The argument ModelElement must conform to the parameter ModelElement in a Binding. In an instantiation it must be of the same kind.

-- not described in OCL

Comment

No extra well-formedness rules.

Component

No extra well-formedness rules.

Dependency

No extra well-formedness rules.

Additional operations

[1]A Dependency is a composite dependency if it contains other dependencies.

isComposite : Boolean;

isComposite = (self.subDependency->size >= 1);

ModelElement

A model element owns everything connected to it by composition relationships.

A template is a model element with at least one template parameter.

That part of the model owned by a template is not subject to all well-formedness rules. A template is not directly usable in a well-formed model. The results of binding a template are subject to well-formedness rules.

Additional operations

[1] A ModelElement is a template when it has parameters.

isTemplate : Boolean;

isTemplate = (self.templateParameter->notEmpty)

[2] A ModelElement is an instantiated template when it is related to a template by a Binding relationship.

isInstantiated : Boolean;

isInstantiated = self.requirement->select(oclIsKindOf(Binding))->notEmpty

[3] The templateArguments are the arguments of an instantiated template, which substitute for template parameters.

templateArguments : Set(ModelElement);

templateArguments = self.requirement->

select(oclIsKindOf(Binding)).oclAsType(Binding).argument

Node

No extra well-formedness rules.

Presentation

No extra well-formedness rules.

Refinement

No extra well-formedness rules.

Trace

[1] A Trace connects two sets of ModelElements from two different Models in the same System.

self.client->forAll(e1, e2 | e1.model = e2.model) **and**

self.supplier->forAll(e1, e2 | e1.model = e2.model) **and**

self.client->asSequence->at (1).model <>

self.supplier->asSequence->at (1).model **and**

self.client->asSequence->at (1).model.namespace =

self.supplier->asSequence->at (1).model.namespace

Usage

No extra well-formedness rules.

ViewElement

No extra well-formedness rules.

2.6.4 Semantics

Whenever the supplier element of a dependency changes, the client element is potentially invalidated. After such invalidation, a check should be performed followed by possible changes to the derived client element. Such a check should be performed after which action can be taken to change the derived element to validate it again. The semantics of this validation and change is outside the scope of UML.

Template

An important dynamic consequence is that any model element that is a template cannot be instantiated. Only a fully instantiated model element can have instances. This applies specifically to classifier templates.

Also a template is a form, not a final model element. As such, it is not subject to normal well-formedness rules because it is intentionally incomplete. Only when a template is bound with arguments can the result be fully subject to well-formedness rules.

A further consequence is that a template must own a fragment of the model that is not part of the final effective model. When a template is bound, the model fragment that it owns is implicitly duplicated, the parameters are replaced by the arguments, and the result is implicitly added to the effective model, as if the effective model had been modeled directly.

ViewElement

The responsibility of view element is to provide a textual and graphical projection of a collection of model elements. In this context, projection means that the view element represents a human readable notation for the corresponding model elements. The notation for UML can be found in a separate document.

View elements and model elements must be kept in agreement, but the mechanisms for doing this are design issues for model editing tools.

2.6.5 Standard Elements

The predefined stereotypes, constraints and tagged values for the Auxiliary Elements package are listed in Table 2-3 and defined in Appendix A - UML Standard Elements.

Table 2-3 Auxiliary Elements - Standard Elements

Model Element	Stereotypes	Constraints	Tagged Values
Comment	«requirement»		
Component	«document» «executable» «file» «library» «table»		location
Dependency	«becomes» «call» «copy» «derived» «friend» «import» «instance» «metaclass» «powertype» «send»		
Refinement	«deletion»		

2.7 Extension Mechanisms

2.7.1 Overview

The Extension Mechanisms package is the subpackage that specifies how model elements are customized and extended with new semantics. It defines the semantics for stereotypes, constraints, and tagged values.

The UML provides a rich set of modeling concepts and notations that have been carefully designed to meet the needs of typical software modeling projects. However, users may sometimes require additional features and/or notations beyond those defined in the UML standard. In addition, users often need to attach non-semantic information to models. These needs are met in UML by three built-in extension mechanisms that enable new kinds of modeling elements to be added to the modeler's repertoire as well as to attach free-form information to modeling elements. These three extension mechanisms can be used separately or together to define new modeling elements that can have distinct semantics, characteristics, and notation relative to the built in UML modeling elements specified by the UML metamodel. Concrete constructs defined in Extension Mechanisms include Constraint, Stereotype, and TaggedValue.

The UML extension mechanisms are intended for several purposes:

- To add new modeling elements for use in creating UML models.

- To define standard items that are not considered interesting or complex enough to be defined directly as UML metamodel elements.
- To define process-specific or implementation language-specific extensions.
- To attach arbitrary semantic and non-semantic information to model elements.

Although it is beyond the scope and intent of this document, it is also possible to extend the UML metamodel by explicitly adding new metaclasses and other meta constructs. This capability depends on unique features of certain UML-compatible modeling tools, or direct use of a meta-metamodel facility, such as the CORBA Meta Object Facility (MOF).

The most important of the built-in extension mechanisms is based on the concept of Stereotype. Stereotypes provide a way of classifying model elements at the object model level and facilitate the addition of "virtual" UML metaclasses with new metaattributes and semantics. The other built in extension mechanisms are based on the notion of property lists consisting of tags and values, and constraints. These allow users to attach additional properties and semantics directly to individual model elements, as well as to model elements classified by a Stereotype.

A stereotype is a UML model element that is used to classify (or mark) other UML elements so that they behave in some respects as if they were instances of new "virtual" or "pseudo" metamodel classes whose form is based on existing "base" classes. Stereotypes augment the classification mechanism based on the built in UML metamodel class hierarchy; therefore, names of new stereotypes must not clash with the names of predefined metamodel elements or other stereotypes. Any model element can be marked by at most one stereotype, but any stereotype can be constructed as a specialization of numerous other stereotypes.

A stereotype may introduce additional values, additional constraints, and a new graphical representation. All model elements that are classified by a particular stereotype ("stereotyped") receive these values, constraints, and representation. By allowing stereotypes to have associated graphical representations users can introduce new ways of graphically distinguishing model elements classified by a particular stereotype.

A stereotype shares the attributes, associations, and operations of its base class but it may have additional well-formedness constraints as well as a different meaning and attached values. The intent is that a tool or repository be able to manipulate a stereotyped element the same as the ordinary element for most editing and storage purposes, while differentiating it for certain semantic operations, such as well-formedness checking, code generation, or report writing.

Any modeling element may have arbitrary attached information in the form of a property list consisting of tag-value pairs. A tag is a name string that is unique for a given element that selects an associated arbitrary value. Values may be arbitrary but for uniform information exchange they should be represented as strings. The tag represents the name of an arbitrary property with the given value. Tags may be used to represent management information (author, due date, status), code generation information (optimizationLevel, containerClass), or additional semantic information required by a given stereotype.

It is possible to specify a list of tags (with default values, if desired) that are required by a particular stereotype. Such required tags serve as "pseudoattributes" of the stereotype to supplement the real attributes supplied by the base element class. The values permitted to such tags can also be constrained.

It is not necessary to stereotype a model element in order to give it individually distinct constraints or tagged values. Constraints can be directly attached to a model element (stereotyped or not) to change its semantics. Likewise, a property list consisting of tag-value pairs can be directly attached to any model element. The tagged values of a property list allow characteristics to be assigned to model elements on a flexible, individual basis. Tags are user-definable, certain ones are predefined and are listed in the Standard Elements appendix.

Constraints or tagged values associated with a particular stereotype are used to extend the semantics of model elements classified by that stereotype. The constraints must be observed by all model elements marked with that stereotype.

The following sections describe the abstract syntax, well-formedness rules, and semantics of the Extension Mechanisms package.

2.7.2 Abstract Syntax

The abstract syntax for the Extension Mechanisms package is expressed in graphic notation in Figure 2-14 on page 2-57.

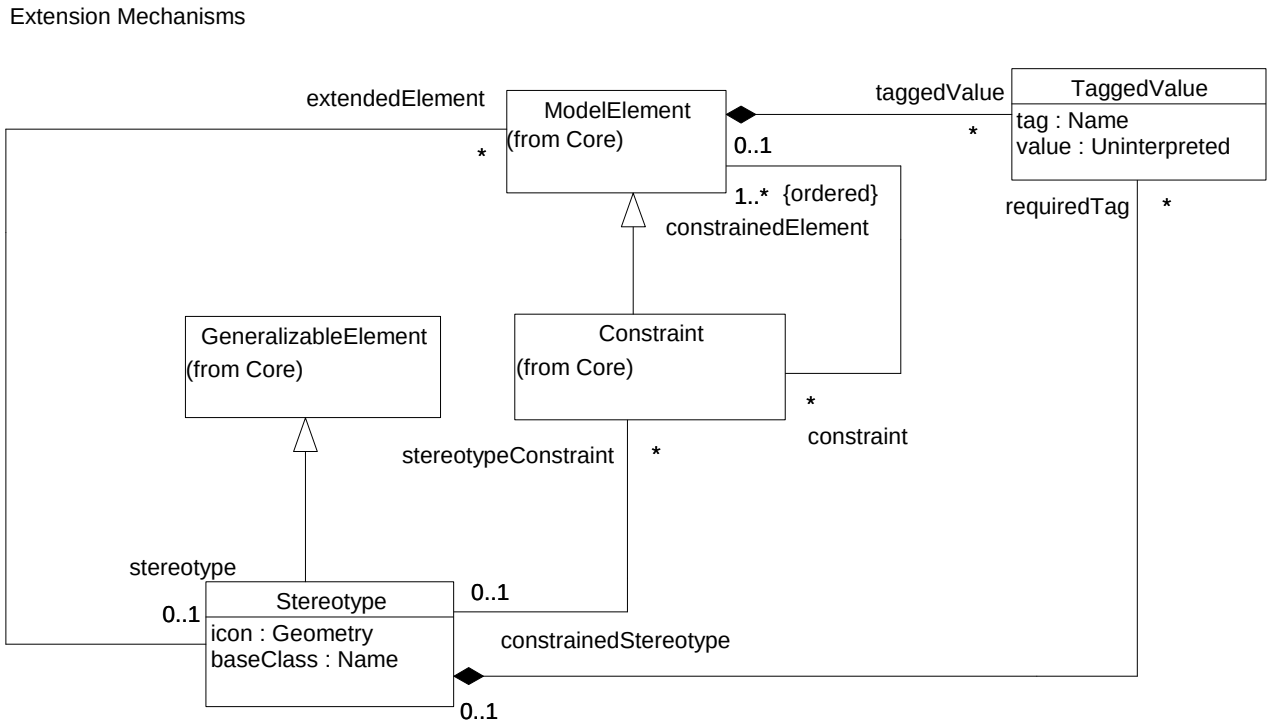


Figure 2-14 Extension Mechanisms

Constraint

The constraint concept allows new semantics to be specified linguistically for a model element. The specification is written as an expression in a designated constraint language. The language can be specially designed for writing constraints (such as OCL), a programming language, mathematical notation, or natural language. If constraints are to be enforced by a model editor tool, then the tool must understand the syntax and semantics of the constraint language. Because the choice of language is arbitrary, constraints are an extension mechanism.

In the metamodel, a Constraint directly attached to a ModelElement describes semantic restrictions that this ModelElement must obey. Also, any Constraints attached to a Stereotype apply to each ModelElement that bears the given Stereotype.

Attributes

body	A boolean expression defining the constraint. Expressions are written as strings in a designated language. For the model to be well formed, the expression must always yield a true value when evaluated for instances of the constrained elements at any time when the system is stable (i.e., not during the execution of an atomic operation).

Associations

constrainedElement	An ordered list of elements subject to the constraint. The constraint applies to their instances.
constrainedStereotype	An ordered list of stereotypes subject to the constraint. The constraint applies to instances of elements classified by the stereotypes.

Any particular constraint has either a constrainedElement link or a constrainedStereotype link but not both.

ModelElement (as extended)

Any model element may have arbitrary tagged values and constraints (subject to these making sense). A model element may have at most one stereotype whose base class must match the UML class of the modeling element (such as Class, Association, Dependency, etc.). The presence of a stereotype may impose implicit constraints on the modeling element and may require the presence of specific tagged values.

Associations

constraint	A constraint that must be satisfied for instances of the model element. A model element may have a set of constraints. The constraint is to be evaluated when the system is stable (i.e., not in the middle of an atomic operation).
stereotype	Designates at most one stereotype that further qualifies the UML class (the base class) of the modeling element. The stereotype does not alter the structure of the base class but it may specify additional constraints and tagged values. All constraints and tagged values on a stereotype apply to the model elements that are classified by the stereotype. The stereotype acts as a "pseudo metaclass" describing the model element.
taggedValue	An arbitrary property attached to the model element. The tag is the name of the property and the value is an arbitrary value. The interpretation of the tagged value is outside the scope of the UML metamodel. A model element may have a set of tagged values, but a single model element may have at most one tagged value with a given tag name. If the model element has a stereotype, then it may specify that certain tags must be present, providing default values.

Stereotype

The stereotype concept provides a way of classifying (marking) elements so that they behave in some respects as if they were instances of new "virtual" metamodel constructs. Instances have the same structure (attributes, associations, operations) as a similar non-stereotyped instance of the same kind. The stereotype may specify additional constraints and required tagged values that apply to instances. In addition, a stereotype may be used to indicate a difference in meaning or usage between two elements with identical structure.

In the metamodel, the Stereotype metaclass is a subtype of GeneralizableElement. TaggedValues and Constraints attached to a Stereotype apply to all ModelElements classified by that Stereotype. A stereotype may also specify a geometrical icon to be used for presenting elements with the stereotype.

Stereotypes are GeneralizableElements. If a stereotype is a subtype of another stereotype, then it inherits all of the constraints and tagged values from its stereotype supertype and it must apply to the same kind of base class. A stereotype keeps track of the base class to which it may be applied.

Attributes

baseClass	Species the name of a UML modeling element to which the stereotype applies, such as Class, Association, Refinement, Constraint, etc. This is the name of a metaclass, that is, a class from the UML metamodel itself rather than a user model class.

icon	The geometrical description for an icon to be used to present an image of a model element classified by the stereotype.

Associations

extendedElement	Designates the model elements affected by the stereotype. Each one must be a model element of the kind specified by the baseClass attribute.
stereotypeConstraint	Designates constraints that apply to elements bearing the stereotype.
requiredTag	Specifies a set of tagged values, each of which specifies a tag that an element classified by the stereotype is required to have. The value part indicates the default value for the tag-value, that is, the tag-value that an element will be presumed to have if it is not overridden by an explicit tagged value on the element bearing the stereotype. If the value is unspecified, then the element must explicitly specify a tagged value with the given tag.

TaggedValue

A tagged value is a (Tag, Value) pair that permits arbitrary information to be attached to any model element. A tag is an arbitrary name, some tag names are predefined as Standard Elements. At most, one tagged value pair with a given tag name may be attached to a given model element. In other words, there is a lookup table of values selected by tag strings that may be attached to any model element.

The interpretation of a tag is (intentionally) beyond the scope of UML, it must be determined by user or tool convention. It is expected that various model analysis tools will define tags to supply information needed for their operation beyond the basic semantics of UML. Such information could include code generation options, model management information, or user-specified additional semantics.

Attributes

tag	A name that indicates an extensible property to be attached to ModelElements. There is a single, flat space of tag names. UML does not define a mechanism for name registry but model editing tools are expected to provide this kind of service. A model element may have at most one tagged value with a given name. A tag is, in effect, a pseudoattribute that may be attached to model elements.
value	An arbitrary value. The value must be expressible as a string for uniform manipulation. The range of permissible values depends on the interpretation applied to the tag by the user or tool; its specification is outside the scope of UML.

Associations

taggedValue	A TaggedValue that is attached to a ModelElement.
requiredTag	ATaggedValue that is attached to a Stereotype. A particular TaggedValue can be attached to either a ModelElement or a Stereotype, but not both.

2.7.3 Well-Formedness Rules

The following well-formedness rules apply to the Extension Mechanisms package.

Constraint

[1] A Constraint attached to a Stereotype must not conflict with Constraints on any inherited Stereotype, or associated with the baseClass.

-- cannot be specified with OCL

[2] A Constraint attached to a stereotyped ModelElement must not conflict with any constraints on the attached classifying Stereotype, nor with the Class (the baseClass) of the ModelElement.

-- cannot be specified with OCL

[3] A Constraint attached to a Stereotype will apply to all ModelElements classified by that Stereotype and must not conflict with any constraints on the attached classifying Stereotype, nor with the Class (the baseClass) of the ModelElement.

-- cannot be specified with OCL

Stereotype

[1] Stereotype names must not clash with any baseClass names.

Stereotype.oclAllInstances->forAll(st | st.baseClass <> self.name)

[2] Stereotype names must not clash with the names of any inherited Stereotype.

```
self.allSupertypes->forAll(st : Stereotype | st.name <> self.name)
```

[3] Stereotype names must not clash in the (M2) meta-class namespace, nor with the names of any inherited Stereotype, nor with any baseClass names.

```
--  M2 level not accessible
```

[4] The baseClass name must be provided; icon is optional and is specified in an implementation specific way.

```
self.baseClass <> ''
```

[5] Tag names attached to a Stereotype must not clash with M2 meta-attribute namespace of the appropriate baseClass element, nor with Tag names of any inherited Stereotype.

```
--  M2 level not accessible
```

ModelElement

[1] Tags associated with a ModelElement (directly via a property list or indirectly via a Stereotype) must not clash with any metaattributes associated with the Model Element.

```
--  not specified in OCL
```

[2] A model element must have at most one tagged value with a given tag name.

```
self.taggedValue->forAll(t1, t2 : TaggedValue |
    t1.tag = t2.tag implies t1 = t2)
```

[3] (Required tags because of stereotypes) If T in modelElement.stereotype.required Tag.such that T.value = unspecified, then the modelElement must have a tagged value with name = T.name.

```
self.stereotype.requiredTag->forAll(tag |
        tag.value = Undefined implies self.taggedValue->exists(t |
            t.tag = tag.tag))
```

TaggedValue

No extra well-formedness rules.

2.7.4 Semantics

Constraints, stereotypes, and tagged values apply to model elements, not to instances. They represent extensions to the modeling language itself, not extensions to the runtime environment. They affect the structure and semantics of models. These concepts represent metalevel extensions to UML. However, they do not contain the full power of a heavyweight metamodel extension language and they are designed such that tools need not implement metalevel semantics to implement them.

Within a model, any user-level model element may have a set of constraints and a set of tagged values. The constraints specify restrictions on the instantiation of the model. An instance of a user-level model element must satisfy all of the constraints on its model element for the model to be well-formed. Evaluation of constraints is to be performed when the system is "stable," that is, after the completion of any internal operations when it is waiting for external events. Constraints are written in a designated constraint language, such as OCL, C++, or natural language. The interpretation of the constraints must be specified by the constraint language.

A user-level model element may have at most one tagged value with a given tag name. Each tag name represents a user-defined property applicable to model elements with a unique value for any single model element. The meaning of a tag is outside the scope of UML and must be determined by convention among users and model analysis tools.

It is intended that both constraints and tagged values be represented as strings so that they can be edited, stored, and transferred by tools that may not understand their semantics. The idea is that the understanding of the semantics can be localized into a few modules that make use of the values. For example, a code generator could use tagged values to tailor the code generation process and a process planning tool could use tagged values to denote model element ownership and status. Other modules would simply preserve the uninterpreted values (as strings) unchanged.

A stereotype refers to a baseClass, which is a class in the UML metamodel (not a user-level modeling element) such as Class, Association, Refinement, etc. A stereotype may be a subtype of one or more existing stereotypes (which must all refer the same baseClass, or baseClasses that derive from the same baseClass), in which case it inherits their constraints and required tags and may add additional ones of its own. As appropriate, a stereotype may add new constraints, a new icon for visual display, and a list of default tagged values.

If a user-level model element is classified by an attached stereotype, then the UML base class of the model element must match the base class specified by the stereotype. Any constraints on the stereotype are implicitly attached to the model element. Any tagged values on the stereotype are implicitly attached to the model element. If any of the values are unspecified, then the model element must explicitly define tagged values with the same tag name or the model is ill-formed. (This behaves as if a copy of the tagged values from the stereotype is attached to the model element, so that the default values can be changed). If the stereotype is a subtype of one or more other stereotypes, then any constraints or tagged values from those stereotypes also apply to the model element (because they are inherited by this stereotype). If there are any conflicts among multiple constraints or tagged values (inherited or directly specified), then the model is ill-formed.

2.7.5 Standard Elements

None.

2.7.6 Notes

From an implementation point of view, instances of a stereotyped class are stored as instances of the base class with the stereotype name as a property. Tagged values can and should be implemented as a lookup table (qualified association) of values (expressed as strings) selected by tag names (represented as strings).

Attributes of UML metamodel classes and tag names should be accessible using a single uniform string-based selection mechanism. This allows tags to be treated as pseudo-attributes of the metamodel and stereotypes to be treated as pseudo-classes of the metamodel, permitting a smooth transition to a full metamodeling capability, if desired. See Section 5.2.2, “Mapping of Interface Model into MOF” for a discussion of the relationship of the UML to the OMG Meta Object Facility (MOF).

2.8 Data Types

2.8.1 Overview

The Data Types package is the subpackage that specifies the different data types used by UML. This chapter has a simpler structure than the other packages, since it is assumed that the semantics of these basic concepts are well known.

2.8.2 Abstract Syntax

The abstract syntax for the Data Types package is expressed in graphic notation in Figure 2-15 on page 2-65.

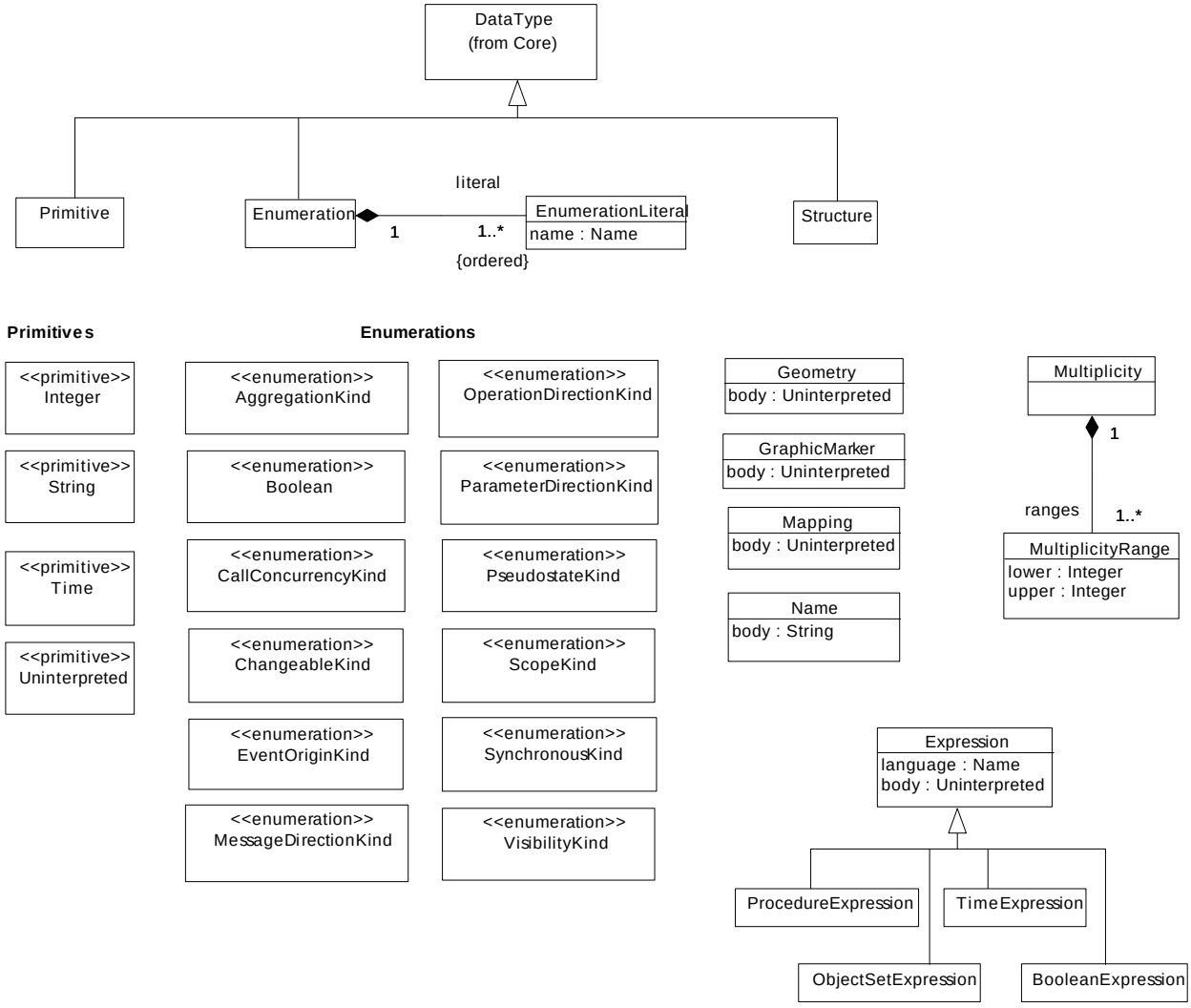


Figure 2-15 Data Types

In the metamodel, the data types are used for declaring the types of the classes' attributes. They appear as strings in the diagrams and not with a separate 'data type' icon. In this way, the sizes of the diagrams are reduced. However, each occurrence of a particular name of a data type denotes the same data type.

Note that these data types are the data types used for defining UML and not the data types to be used by a user of UML. The latter data types will be instances of the DataType metaclass defined in the metamodel.

AggregationKind

In the metamodel, AggregationKind defines an enumeration whose values are none, shared, and composite. Its value denotes what kind of aggregation an Association is.

Boolean

In the metamodel, Boolean defines an enumeration whose values are false and true.

BooleanExpression

In the metamodel, BooleanExpression defines a statement which will evaluate to an instance of Boolean when it is evaluated.

ChangeableKind

In the metamodel, ChangeableKind defines an enumeration whose values are none, frozen, and addOnly. Its value denotes how an AttributeLink or LinkEnd may be modified.

Enumeration

In the metamodel, Enumeration defines a special kind of DataType whose range is a list of definable values, called EnumerationLiterals.

EnumerationLiteral

An EnumerationLiteral defines an atom (i.e., with no relevant substructure) that can be compared for equality.

Expression

In the metamodel, an Expression defines a statement which will evaluate to a (possibly empty) set of instances when executed in a context. An Expression does not modify the environment in which it is evaluated.

Geometry

In the metamodel, a Geometry denotes a position in space.

GraphicMarker

In the metamodel, GraphicMarker defines the presentation characteristics of view elements, such as color, texture, font, line width, shading, etc.

Integer

In the metamodel, an Integer is an element in the (infinite) set of integers (…-2, -1, 0, 1, 2…).

Mapping

In the metamodel, a Mapping is an expression that is used for mapping ModelElements. For exchange purposes, it should be represented as a String.

MessageDirectionKind

In the metamodel, MessageDirectionKind defines an enumeration whose values are activation and return. Its value denotes the direction of a Message.

Multiplicity

In the metamodel, a Multiplicity defines a non-empty set of non-negative integers. A set which only contains zero ({0}) is not considered a valid Multiplicity. Every Multiplicity has at least one corresponding String representation.

MultiplicityRange

In the metamodel, a MultiplicityRange defines a range of integers. The upper bound of the range cannot be below the lower bound.

Name

In the metamodel, a Name defines a token which is used for naming ModelElements. Each Name has a corresponding String representation.

ObjectSetExpression

In the metamodel, ObjectSetExpression defines a statement which will evaluate to a set of instances when it is evaluated. ObjectSetExpressions are commonly used to designate the target instances in an Action.

OperationDirectionKind

In the metamodel, OperationDirectionKind defines an enumeration whose values are provide and require. Its value denotes if an Operation is required or provided by a Classifier.

ParameterDirectionKind

In the metamodel, ParameterDirectionKind defines an enumeration whose values are in, inout, out, and return. Its value denotes if a Parameter is used for supplying an argument and/or for returning a value.

Primitive

A Primitive defines a special kind of simple DataType, without any relevant substructure.

ProcedureExpression

In the metamodel, ProcedureExpression defines a statement which will result in an instance of Procedure when it is evaluated.

PseudostateKind

In the metamodel, PseudostateKind defines an enumeration whose values are initial, deepHistory, shallowHistory, join, fork, branch, and final. Its value denotes the possible pseudo states in a state machine.

ScopeKind

In the metamodel, ScopeKind defines an enumeration whose values are classifier and instance. Its value denotes if the stored value should be an instance of the associated Classifier or the Classifier itself.

String

In the metamodel, a String defines a stream of text.

Structure

A Structure defines a special kind of DataType, that has a fixed number of named parts.

SynchronousKind

In the metamodel, SynchronousKind defines an enumeration whose values are synchronous and asynchronous. Its value denotes what kind of Message a CallAction will create when executed.

Time

In the metamodel, a Time defines a value representing an absolute or relative moment in time and space. A Time has a corresponding string representation.

TimeExpression

In the metamodel, TimeExpression defines a statement which will evaluate to an instance of Time when it is evaluated.

Uninterpreted

In the metamodel, an Uninterpreted is a blob, the meaning of which is domain-specific and therefore not defined in UML.

VisibilityKind

In the metamodel, VisibilityKind defines an enumeration whose values are public, protected, and private. Its value denotes how the element to which it refers is seen outside the enclosing name space.

2.8.3 Standard Elements

The predefined stereotypes, constraints and tagged values for the Data Types package are listed in Table 2-4 and defined in Appendix A - UML Standard Elements.

Table 2-4 Data Types - Standard Elements

Model Element	Stereotypes	Constraints	Tagged Values
DataType	«enumeration»		

Part 3 - Behavioral Elements

This section defines the superstructure for behavioral modeling in UML, the Behavioral Elements package. The Behavioral Elements package consists of four lower-level packages: Common Behavior, Collaborations, Use Cases, and State Machines.

2.9 Overview

Common Behavior specifies the core concepts required for behavioral elements. The Collaborations package specifies a behavioral context for using model elements to accomplish a particular task. The Use Case package specifies behavior using actors and use cases. The State Machines package defines behavior using finite-state transition systems.

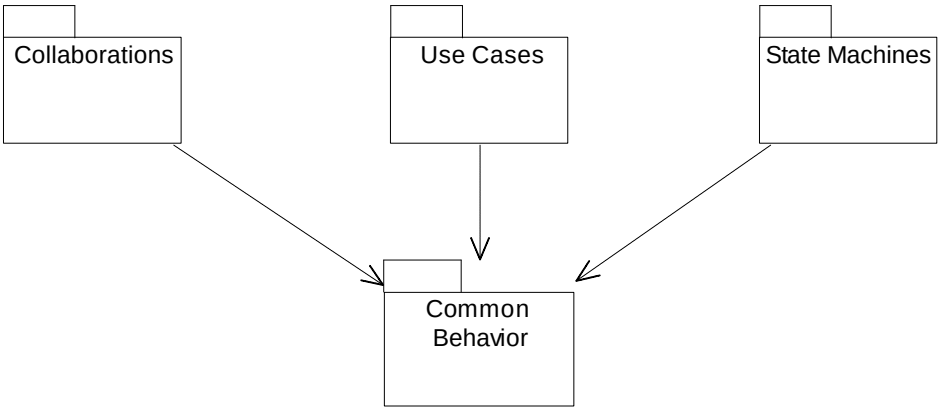


Figure 2-16 Behavioral Elements Package

2.10 Common Behavior

2.10.1 Overview

The Common Behavior package is the most fundamental of the subpackages that compose the Behavioral Elements package. It specifies the core concepts required for dynamic elements and provides the infrastructure to support Collaborations, State Machines and Use Cases.

The following sections describe the abstract syntax, well-formedness rules and semantics of the Common Behavior package.

2.10.2 Abstract Syntax

The abstract syntax for the Common Behavior package is expressed in graphic notation in the following figures. Figure 2-17 on page 2-71 shows the model elements that define Requests, which include Signals and Operations.

Common Behavior: Requests

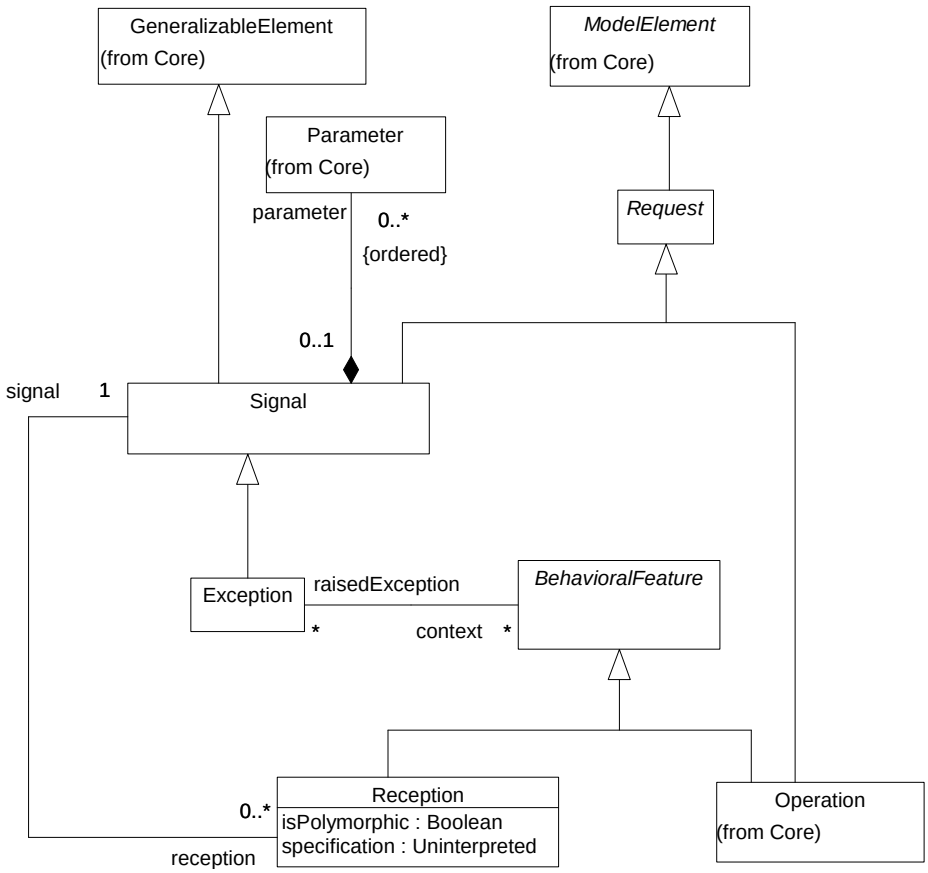


Figure 2-17 Common Behavior Requests

Figure 2-18 on page 2-72 illustrates the model elements that specify various actions, such as CreateAction, CallAction and SendAction.

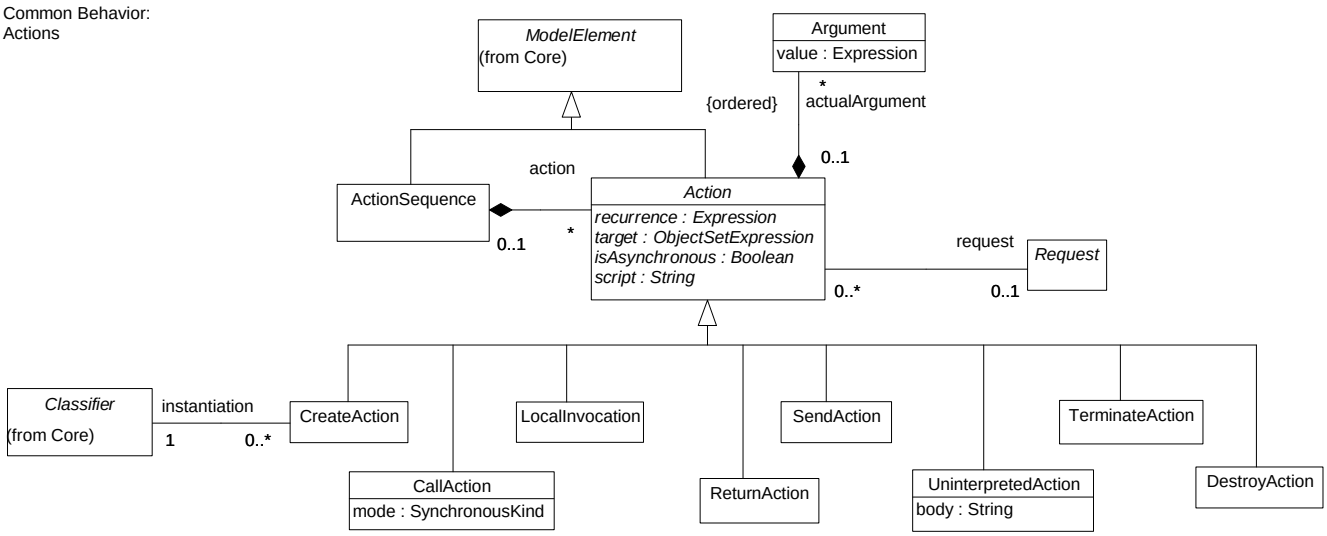


Figure 2-18 Common Behavior - Actions

Figure 2-19 on page 2-73 shows the model elements that define Instances and Links.

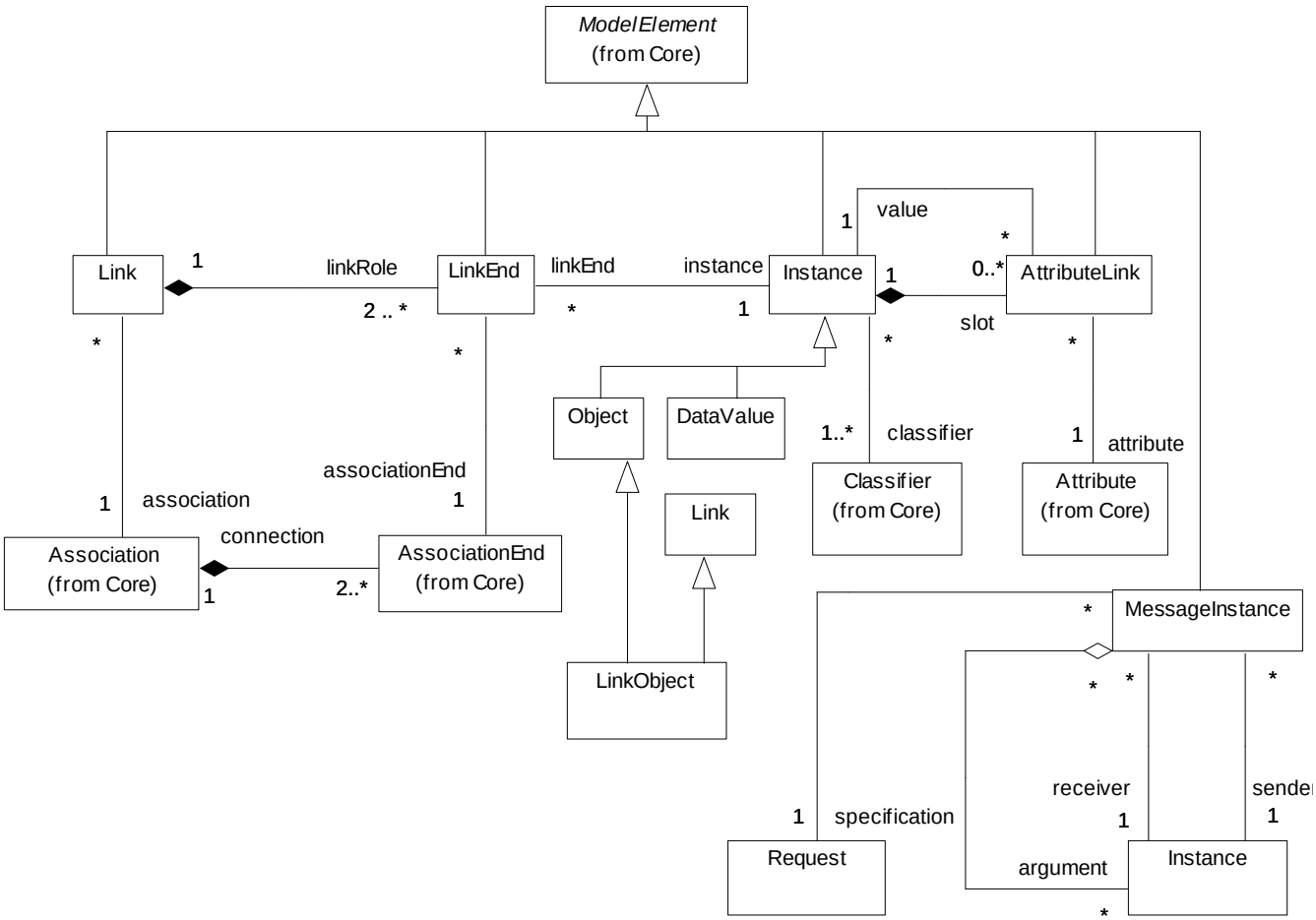


Figure 2-19 Common Behavior - Instances and Links

The following metaclasses are contained in the Common Behavior package.

Action

An action is a specification of an executable statement that forms an abstraction of a computational procedure that results in a change in the state of the model, realized by sending a message to an object or modifying a value of an attribute.

In the metamodel an Action is a part of an ActionSequence and may contain a specification of a target as well as a specification of the arguments (actual parameters) of the dispatched Request.

The target metaattribute is of type ObjectSetExpression which, when executed, resolves into zero or more specific Instances which are the intended recipients of the dispatched Request. Similarly, it is associated with a list of Arguments which at

runtime are resolved to the actual arguments of the Request. The recurrence metaattribute specifies how many times the resulted Request should be sent every time the Action is executed.

Action is an abstract metaclass.

Attributes

recurrence	An Expression stating how many times the Action should be performed.
target	An ObjectSetExpression which determines the target of the Action.

Associations

request	The specification of the Request being dispatched by the Action.
actualArgument	A sequence of Expressions which determines the actual arguments needed when evaluating the Action.

ActionSequence

An action sequence is a collection of actions.

In the metamodel an ActionSequence is an aggregation of Actions. It describes the behavior of the owning State or Transition.

Associations

action	A sequence of Actions performed sequentially as an atomic unit.

Argument

An argument represents the actual values passed to a dispatched request and aggregated within an action.

In the metamodel, an Argument is a part of an Action and contains a metaattribute, value, or type Expression.

Attributes

value	An Expression determining the actual Instance when evaluated.

AttributeLink

An attribute link is a named slot in an instance, which holds the value of an attribute.

In the metamodel AttributeLink is a piece of the state of an Instance and holds the value of an Attribute.

Associations

value	The Instance which is the value of the AttributeLink.
attribute	The Attribute from which the AttributeLink originates.

CallAction

A call action is an action resulting in an invocation of an operation on an instance. A call action can be synchronous or asynchronous, indicating whether the operation is invoked synchronously or asynchronously.

In the metamodel, the CallAction is a subtype of Action. The designated instance or set of instances is specified via the target expression, and the actual arguments are designated via the argument association inherited from Action. The resulting operation is specified by the dispatched Request, which in that case should be an Operation.

Attributes

mode	An enumeration which states if the dispatched Operation will be synchronous or asynchronous. • synchronous - indicates that the caller waits for the completion of the execution of the Operation. • asynchronous - Indicates that the caller does not wait for the completion of the execution of the Operation but continues immediately.

CreateAction

A create action is an action resulting a creation of an instance of some classifier.

In the metamodel, the CreateAction is a subtype of Action. The Classifier class is designated by the instantiation association of the CreateAction.

Associations

classifier	The Classifier of which an Instance will be created of when the CreateAction is performed.

DestroyAction

A destroy action is an action results in the destruction of an object specified in the action.

In the metamodel a DestroyAction is a subclass of Action. The designated object is specified by the target association of the Action.

DataValue

A data value is an instance with no identity.

In the metamodel DataValue is a subclass of Instance which cannot change its state, i.e. all Operations that are applicable to it are pure functions or queries. DataValues are typically used as attribute values.

Exception

An exception is a signal raised by behavioral features typically in case of execution faults. In the metamodel, Exception is derived from Signal. An Exception is associated with the BehavioralFeature that raises it.

Attributes

body	A description of the Exception in a format not defined in UML.

Associations

behavioralFeature	The set of BehavioralFeatures that raise the exception.

Instance

The instance construct defines an entity to which a set of operations can be applied and which has a state that stores the effects of the operations.

In the metamodel Instance is connected to at least one Classifier which declares its structure and behavior. It has a set of attribute values and is connected to a set of Links, both sets matching the definitions of its Classifiers. The two sets implements the current state of the Instance. Instance is an abstract metaclass.

Associations

attributeLink	The set of AttributeLinks that holds the attribute values of the Instance.
linkEnd	The set of LinkEnds of the connected Links that are attached to the Instance.
classifier	The set of Classifiers that declare the structure of the Instance.

Link

The link construct is a connection between instances.

In the metamodel Link is an instance of an Association. It has a set of LinkEnds that matches the set of AssociationEnds of the Association. A Link defines a connection between Instances.

Associations

association	The Association that is the declaration of the link.
linkRole	The sequence of LinkEnds that constitute the Link.

LinkEnd

A link end is an end point of a link.

In the metamodel LinkEnd is the part of a Link that connects to an Instance. It corresponds to an AssociationEnd of the Link's Association.

Associations

instance	The Instance connected to the LinkEnd.
associationEnd	The AssociationEnd that is the declaration of the LinkEnd..

LinkObject

A link object is a link with its own set of attribute values and to which a set of operations may be applied.

In the metamodel LinkObject is a connection between a set of Instances, where the connection itself may have a set of attribute values and to which a set of Operations may be applied. It is a subclass of both Object and Link.

LocalInvocation

A local invocation is a special type of action that invokes a local operation (an operation on "self"). This type of invocation takes place without the mediation of the state machine (i.e., it does not generate a call event). The invocation of a local utility procedure of an object is an example of a LocalInvocation. In contrast, a CallAction on "self" always results in an event.

In the metamodel, LocalInvocation is associated with the Operation that it invokes through the relationship to Request. The argument association specifies the arguments of the Operation are specified by the argument association. (inherited from Action).

MessageInstance

A message instance reifies a communication between two instances.

In the metamodel MessageInstance is an instance of a subclass of a Request, like Signal and Request. It has a sender, a receiver, and may have a set of arguments, all being Instances.

Associations

specification	The Request from which the MessageInstance originates.
sender	The Instance which sent the MessageInstance.
receiver	The Instance which receives the MessageInstance.
arguments	The sequence of Instances being the arguments of the MessageInstance.

Object

An object is an instance that originates from a class.

In the metamodel Object is a subclass of Instance and it originates from at least one Class. The set of Classes may be modified dynamically, which means that the set of features of the Object is changed during its life-time.

Reception

A reception is a declaration stating that a classifier is prepared to react to the receipt of a signal. The reception designates a signal and specifies the expected behavioral response. A reception is a summary of expected behavior. The details of handling a signal are specified by a state machine.

In the metamodel Reception is a subclass of BehavioralFeature and declares that the Classifier containing the feature reacts to the signal designated by the reception feature. The isPolymorphic attribute specifies whether the behavior is polymorphic or not; a true value indicates that the behavior is not always the same and may be affected by state or subclassing. The specification indicates the expected response to the signal.

Attributes

isPolymorphic	Whether the response to the Signal is fixed. If true, then the response may depend on state of the Classifier and may be overridden on subclasses. If false, then response to the signal is always the same, regardless of state of the Classifier, and it may not be overridden by subclasses.
specification	A description of the effects of the classifier receiving a signal, stated as an Expression.

Associations

signal	The Signal that the Classifier is prepared to handle.

Request

A request is a specification of a stimulus being sent to instances. It can either be an operation or a signal.

In the metamodel a Request is an abstract subclass of BehavioralFeature.

ReturnAction

A return action is an action that results in returning a value to a caller.

In the metamodel ReturnAction values are represented as the arguments inherited from an Action.

SendAction

A send action is an action that results in the (asynchronous) sending of a signal. The signal can be directed to a set of receivers via objectSetExpression, or sent implicitly to an unspecified set of receivers, defined by some external mechanism. For example, if the signal is an exception, the receiver is determined by the underlying runtime system mechanisms.

In the metamodel SendAction is associated with the Signal by the request association inherited from Action. The actual arguments are specified by the argument association, inherited from Action.

Signal

A signal is a specification of an asynchronous stimulus communicated between instances. The receiving instance handles the signal by a state machine. Signal is a generalizable element and is defined independently of the classes handling the signal. A reception is a declaration that a class handles a signal, but the actual handling is specified by a state machine.

In the metamodel Signal is a subclass of Request that is dispatched by a SendAction. It is a GeneralizableElement, and aggregates a set of Parameters. A Signal is always asynchronous.

Associations

reception	A set of Receptions that indicate Classes prepared to handle the signal.

TerminateAction

A terminate action results in self-destruction of an object.

In the metamodel TerminateAction is a subclass of Action.

UninterpretedAction

An uninterpreted action represents all actions that are not explicitly reified in the UML

Taken to the extreme, any action is a call or raise on some instance (e.g., Smalltalk). However, in more practical terms, actions such as assignments and conditional statements can be captured as uninterpreted actions, as well as any other language specific actions that are neither call nor send actions

Attributes

body	The definition of the action.

2.10.3 Well-Formedness Rules

The following well-formedness rules apply to the Common Behavior package.

AttributeLink

[1] The type of the Instance must match the type of the Attribute.

self.value.classifier->includes(self.attribute.type)

CallAction

[1] The types and order of actual arguments for an Action must match the parameters of the Request.

```
(self.actualArgument->size > 0)
    implies (Sequence{1..self.actualArguments->size})->
        forAll (x |
            self.actualArgument->at(x).type =
            self.message.parameter->at(x).type)
```

Note: parameter refers to Signal or Operation (downcast)

[2] A CallAction must have exactly one target

```
self.target->size = 1
```

[3] The type of the dispatched Request should be Operation.

```
self.message->notEmpty
and
self.message.oclIsTypeOf(Operation)
```

CreateAction

[1] A CreateAction does not have a target expression.

```
self.target->isEmpty
```

DestroyAction

[1] A DestroyAction should not have arguments

```
self.actualArgument->size = 0
```

DataValue

[1] A DataValue originates from exactly one Classifier, which is a DataType.

```
(self.classifier->size = 1)
and
self.classifier.oclIsKindOf(DataType)
```

[2] A DataValue has no AttributeLinks.

```
self.slot->isEmpty
```

Instance

[1] The AttributeLinks matches the declarations in the Classifiers.

```
self.slot->forAll ( al |
    self.classifier->exists ( c |
        c.allAttributes->includes ( al.attribute ) ) )
```

[2] The Links matches the declarations in the Classifiers.

```
self.allLinks->forAll ( l |
    self.classifier->exists ( c |
        c.allAssociations->includes ( l.association ) ) )
```

[3] If two Operations have the same signature they must be the same.

```
self.classifier->forAll ( c1, c2 |
    c1.allOperations->forAll ( op1 |
        c2.allOperations->forAll ( op2 |
            op1.hasSameSignature (op2)  implies op1 = op2 ) ) )
```

[4] There are no name conflicts between the AttributeLinks and opposite LinkEnds.

```
self.slot->forAll( al |
    not self.allOppositeLinkEnds->exists( le | le.name = al.name ) )
and
self.allOppositeLinkEnds->forAll( le |
    not self.slot->exists( al | le.name = al.name ) )
```

[6] The number of associated Instances in one opposite LinkEnds must match the multiplicity of that AssociationEnd.

Additional operations

[1] The operation allLinks results in a set containing all Links of the Instance itself.

```
allLinks : set(Link);
allLinks = self.linkEnd->collect ( l | l.link )
```

[2] The operation allOppositeLinkEnds results in a set containing all LinkEnds of Links connected to the Instance with another LinkEnd.

```
allOppositeLinkEnds : set(Link);
allOppositeLinkEnds = self.allLinks->collect ( l |
    l.linkRole )->select ( le | le.instance <> self )
```

Link

[1] The set of LinkEnds must match the set of AssociationEnds of the Association.

```
Sequence {1..self.linkRole->size}->forAll ( i |
    self.linkRole->at (i).associationEnd = self.association.connection->at (i) )
```

[2] There are not two Links of the same Association which connects the same set of Instances in the same way.

```
self.association.instance->forAll ( l |
    Sequence {1..self.linkRole->size}->forAll ( i |
        self.linkRole.instance = l.linkRole.instance ) implies self = l )
```

LinkEnd

[1] The type of the Instance must match the type of the AssociationEnd.

self.instance.classifier->includes (self.associationEnd.type)

LinkObject

[1] One of the Classifiers must be the same as the Association.

self.classifier->includes(self.association)

[2] The Association must be a kind of AssociationClass.

self.association.oclIsKindOf(AssociationClass)

MessageInstance

[1] The type of the arguments must match the parameters of the Request.

```
self.argument->size = self.specification.parameter->size
and
Sequence {1..self.argument->size}->forAll ( i |
    self.argument->at (i).classifier->includes (
        self.specification.parameter->at (i).type ) )
-- Note: parameter refers to the parameter of the operation or signal
-- subclasses of request.
```

Object

[1] Each of the Classifiers must be a kind of Class.

self.classifier->forAll (c | c.oclIsKindOf(Class))

Signal

[1] A Signal is always asynchronous and is always an invocation.

self.isAsynchronous **and** self.direction = activation

Reception

[1] A Reception can not be a query.

not self.isQuery

Request

Additional operations

[1] The parameter of a Request is the parameter of the Signal or Operation.

parameter : set(Parameter);

```
parameter = if self.oclIsKindOf(Operation)
        then self.oclAsType(Operation).parameter
        else if self.oclIsKindOf(Signal)
            then self.oclAsType(Signal).parameter
            else Set {}
        endif endif
```

SendAction

[1] The types and order of actual arguments must match the parameters of the Request (Signal or Operation).

```
(self.actualArgument->size > 0)
    implies (Sequence{1..self.actualArgument->size}->
        forAll (x |
            self.actualArgument->at(x).type =
            self.message.parameters->at(x).type))
-- note: parameters apply to signal or operation (downcast)
```

[2] The type of the dispatched Request is a Signal.

```
self.message->notEmpty
and
self.message.oclIsKindOf (Signal)
```

[3] The target of an Exception should be empty (implicit)

```
self.message.oclIsKindOf(Exception) implies (self.target = NULL)
```

TerminateAction

[1] A TerminateAction should not have arguments.

```
self.actualArgument->size = 0
```

2.10.4 Semantics

This section provides a description of the semantics of the elements in the Common Behavior package.

Object and DataValue

An object is an instance that originates from a class, it is structured and behaves according to its class. All objects originating from the same class are structured in the same way, although each of them has its own set of attribute links. Each attribute link references an instance, usually a data value. The number of attribute links with the same name fulfills the multiplicity of the corresponding attribute in the class. The set may be modified according to the specification in the corresponding attribute (e.g.,

each referenced instance must originate from (a subtype of) the type of the attribute, and attribute links may be added or removed according to the changeable property of the attribute).

An object may have multiple classes (i.e., it may originate from several classes). In this case, the object will have all the features declared in all of these classes, both the structural and the behavioral ones. Moreover, the set of classes (i.e., the set of features that the object conforms to) may vary over time. New classes may be added to the object and old ones may be detached. This means that the features of the new classes are dynamically added to the object, and the features declared in a class which is removed from the object are dynamically removed from the object. No name clashes between attributes links and opposite link ends are allowed, and each operation which is applicable to the object should have a unique signature.

Another kind of instance is data value, which is an instance with no identity. Moreover, a data value cannot change its state-all operations that are applicable to a data value are queries and do not cause any side effects. Since it is not possible to differentiate between two data values that appear to be the same, it becomes more of a philosophical issue whether there are several data values representing the same value or just one for each value-it is not possible to tell. In addition, a data value cannot change its type.

Link

A link is a connection between instances. Each link is an instance of an association (i.e., a link connects instances of (subclasses of) the associated classifiers). In the context of an instance, an opposite end defines the set of instances connected to the instance via links of the same association and each instance is attached to its link via a link-end originating from the same association end. However, to be able to use a particular opposite end, the corresponding link end attached to the instance must be navigable. An instance may use its opposite ends to access the associated instances. An instance can communicate with the instances of its opposite ends and also use references to them as arguments or reply values in communications.

A link object is a special kind of link, it is at the same time also an object. Since an object may change it classes this is also true for a link object. However, one of the classes must always be an association class.

Request, Signal, Exception and Message Instance

A request is a specification of a communication between instances as a result of an instance performing certain kinds of actions: call action, raise action, destroy action, and return action.

Two kinds of requests exist: signal and operation. The former is used to trigger a reaction in the receiver in an asynchronous way and without a reply, and the latter is the specification of an operation, which can be either synchronous or asynchronous and may require a reply from the receiver to the sender. When an instance communicates with another instance a message instance is passed between the two instances. It has a sender, a receiver, and possibly a set of arguments according to the

specifying request. A signal may be attached to a classifier, which means that instances of the classifier will be able to receive that signal. This is facilitated by declaring a reception by the classifier.

An exception is a special kind of signal, typically used to signal fault situations. The sender of the exception aborts execution and execution resumes with the receiver of the exception, which may be the sender itself. Unlike other signals, the receiver is determined implicitly by the interaction sequence during execution and is not explicitly specified.

The reception of a message instance originating from a call action by an instance causes the invocation of an operation on the receiver. The receiver executes the method that is found in the full descriptor of the class that corresponds to the operation. The reception of a signal by an instance may cause a transition and subsequent effects as specified by the state machine for the classifier of the recipient. This form of behavior is described in the State Machines package. Note that the invoked behavior is described by methods and state machine transitions. Operations and Receptions merely declare that a classifier accepts a given Request but they do not specify the implementation.

Action

An action is a specification of a computable statement. Each kind of action is defined as a subclass of action. The following kinds of actions are defined:

- send action is an action in which a message instance is created that causes a signal event for the receiver(s).
- call action is an action in which a message instance is created that causes an operation to be invoked on the receiver.
- local invocation is an action that leads to the local execution of an operation.
- create action is an action in which an instance is created based on the definitions of the specified set of classifiers.
- terminate action is an action in which an instance causes itself to cease to exist.
- destroy action is an action in which an instance causes another instance to cease to exist.
- return action is an action that returns a value to a caller.
- uninterpreted action is an action that has no interpretation in UML.

Each action has a specification of the target object set, which resolves into zero or more instances when the action is executed. These instances are the recipients of a signal or an operation invocation. Each action also has a list of expressions, which resolve into a list of actual argument values when the action is executed. An action is always executed within the context of an instance.

An action may dispatch a request to another instance (e.g., call action, send action). The action specifies how the receiver and the arguments are to be evaluated for each dispatched instance of the request. Moreover, the action also specifies how many

message instances should be dispatched and if they should be dispatched sequentially or in parallel (recurrence). In a degenerated case, this could be used for specification of a condition, which must be fulfilled if the request is to be sent; otherwise, the request is neglected.

2.10.5 Standard Elements

The predefined stereotypes, constraints and tagged values for the Common Behavior package are listed in Table 2-5 and defined in Appendix A - UML Standard Elements.

Table 2-5 Common Behavior - Standard Elements

Model Element	Stereotypes	Constraints	Tagged Values
Instance			persistent
LinkEnd		association, global, local, parameter, self	
Request		broadcast, vote	

2.11 Collaborations

2.11.1 Overview

The Collaborations package is a subpackage of the Behavioral Elements package. It specifies the concepts needed to express how different elements of a model interact with each other from a structural point of view. The package uses constructs defined in the Foundation package of UML as well as in the Common Behavior package.

A Collaboration defines a specific way to use the Model Elements in a Model. It describes how different kinds of Classifiers and their Associations are to be used in accomplishing a particular task. The Collaboration defines a restriction of, or a projection of, a Model of Classifiers (i.e., what properties Instances of the participating Classifiers must have in a particular Collaboration). The same Classifier or Association can appear in several Collaborations, and also several times in one Collaboration, each time in a different role. In each appearance it is specified which of the properties of the Classifier or Association are needed in that particular usage. These properties are a subset of all the properties of that Classifier or Association. A set of Instances and Links conforming to the participants specified in the Collaboration cooperate when the specified task is performed. Hence, the Classifier structure implies the possible collaboration structures of conforming Instances. A Collaboration may be presented in a diagram, either showing the restricted views of the participating Classifiers and Associations, or by showing prototypical Instances and Links conforming to the restricted views.

Collaborations can be used for expressing several different things, like how use cases are realized, actor structures of ROOM, OORam role models, and collaborations as defined in Catalysis. They are also used for setting up the context of Interactions and for defining the mapping between the specification part and the realization part of a Subsystem.

An Interaction defined in the context of a Collaboration specifies the details of the communications that should take place in accomplishing a particular task. It describes which Requests should be sent and their internal order.

The following sections describe the abstract syntax, well-formedness rules and semantics of the Collaborations package.

2.11.2 Abstract Syntax

The abstract syntax for the Collaborations package is expressed in graphic notation in Figure 2-20.

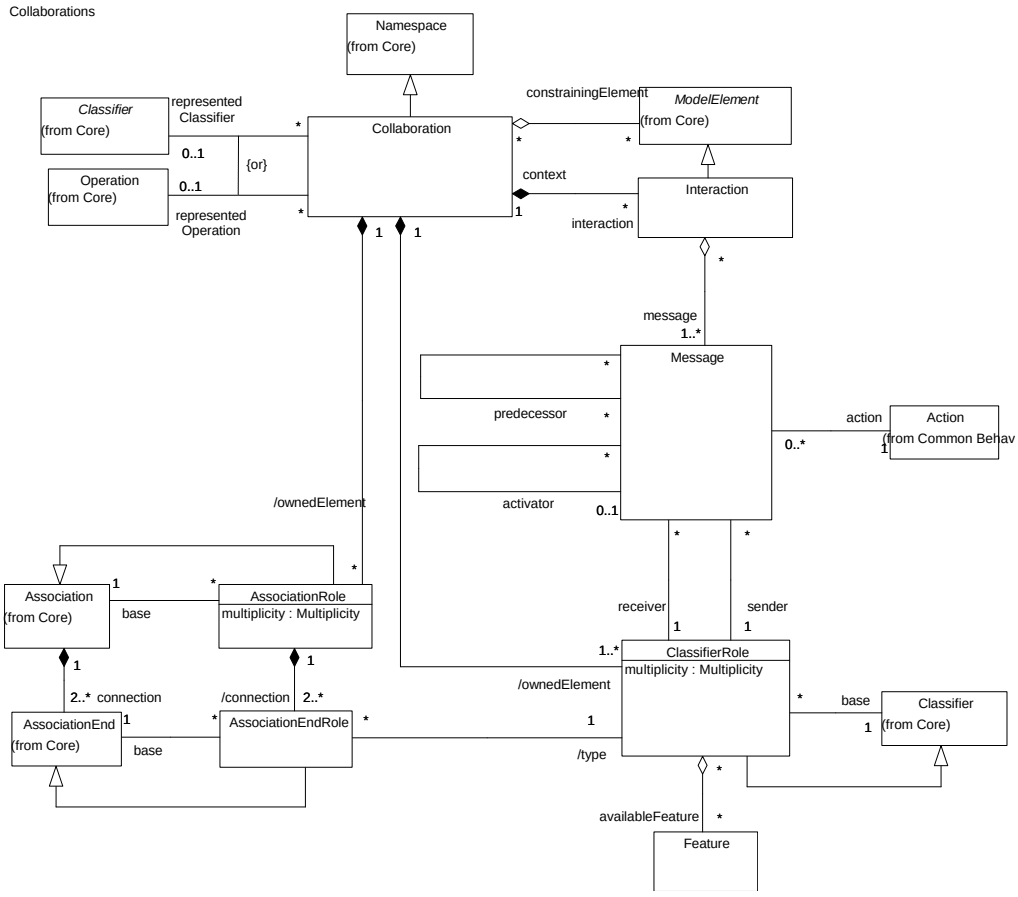


Figure 2-20 Collaborations

AssociationEndRole

An association-end role specifies an endpoint of an association as used in a collaboration.

In the metamodel, an AssociationEndRole is part of an AssociationRole and specifies the connection of an AssociationRole to a ClassifierRole. It is related to the AssociationEnd, declaring the corresponding part in an Association.

Attributes

multiplicity	The number of LinkEnds playing this role in a Collaboration.

Associations

base	An AssociationEndRole that is a projection of an AssociationEnd.

AssociationRole

An association role is a specific usage of an association needed in a collaboration.

In the metamodel an AssociationRole specifies a restricted view of an Association used in a Collaboration. An AssociationRole is a composition of a set of AssociationEndRoles corresponding to the AssociationEnds of its base Association.

Attributes

multiplicity	The number of Links playing this role in a Collaboration.

Associations

base	An AssociationRole that is a projection of an Association.

ClassifierRole

A classifier role is a specific role played by a participant in a collaboration. It specifies a restricted view of a classifier, defined by what is required in the collaboration.

In the metamodel a ClassifierRole specifies one participant of a Collaboration (i.e., a role Instances conform to). It declares a set of Features, which is a subset of those available in the base Classifier. The ClassifierRole may be connected to a set of AssociationRoles via AssociationEndRoles.

Attributes

multiplicity	The number of Instances playing this role in a Collaboration.

Associations

availableFeature	The subset of Features of the Classifier which is used in the Collaboration.
base	A ClassifierRole that is a projection of a Classifier.

Collaboration

A collaboration describes how an operation or a classifier, like a use case, is realized by a set of classifiers and associations used in a specific way. The collaboration defines a context for performing tasks defined by interactions.

In the metamodel, a Collaboration contains a set of ClassifierRoles and AssociationRoles, which represent the Classifiers and Associations that take part in the realization of the associated Classifier or Operation. The Collaboration may also contain a set of Interactions that are used for describing the behavior performed by Instances conforming to the participating ClassifierRoles.

A Collaboration specifies a view (restriction, slice, projection) of a model of Classifiers. The projection describes the required relationships between Instances that conform to the participating ClassifierRoles, as well as the required subset of the Features of these Classifiers. Several Collaborations may describe different projections of the same set of Classifiers. Hence, a Classifier can be a base for several ClassifierRoles.

A Collaboration may also reference a set of ModelElements, usually Classifiers and Generalizations, needed for expressing structural requirements, such as Generalizations required between the Classifiers themselves to fulfill the intent of the Collaboration.

Associations

constrainingElement	The ModelElements that add extra constraints, like Generalization and Constraint, on the ModelElements participating in the Collaboration.
interaction	The set of Interactions that are defined within the Collaboration.
ownedElement	(Inherited from Namespace) The set of roles defined by the Collaboration. These are ClassifierRoles and AssociationRoles.
representedClassifier	The Classifier the Collaboration is a realization of. (Used if the Collaboration represents a Classifier.)
representedOperation	The Operation the Collaboration is a realization of. Used if the Collaboration represents an Operation.)

Interaction

An interaction specifies the messages sent between instances performing a specific task. Each interaction is defined in the context of a collaboration.

In the metamodel an Interaction contains a set of Messages specifying the communication between a set of Instances conforming to the ClassifierRoles of the owning Collaboration.

Associations

context	The Collaboration which defines the context of the Interaction.
message	The Messages that specify the communication in the Interaction.

Message

A message defines how a particular request is used in an interaction.

In the metamodel a Message defines a particular usage of a Request in an Interaction. It specifies the roles of the sender and receiver as well as the dispatching Action. Furthermore, it defines the relative sequencing of Messages within the Interaction.

Associations

action	The specification of the Message.
activator	The Message that called the operation whose method contains the current Message.
receiver	The role of the Instance that receives the Message and reacts to it.
predecessor	The set of Messages whose completion enables the execution of the current Message. All of them must be completed before execution begins. Empty if this is the first message in a method.
sender	The role of the Instance that sends the Message and possibly receives a response.

2.11.3 Well-Formedness Rules

The following well-formedness rules apply to the Collaborations package.

AssociationEndRole

[1] The type of the ClassifierRole must conform to the type of the base AssociationEnd.

self.type = self.base.type

or

self.type.allSupertypes->includes (self.base.type)

[2] The type must be a kind of ClassifierRole.

self.type.oclIsKindOf (ClassifierRole)

AssociationRole

[1] The AssociationEndRoles must conform to the AssociationEnds of the base Association.

Sequence{ 1..(self.role->size) }->forAll (index |

self.role->at(index).base = self.base.connection->at(index))

[2] The endpoints must be a kind of AssociationEndRoles.

self.role->forAll(r | r.oclIsKindOf (AssociationEndRole))

ClassifierRole

[1] The AssociationRoles connected to the ClassifierRole must match a subset of the Associations connected to the base Classifier.

self.allAssociations->forAll(ar |

self.base.allAssociations->exists (a | ar.base = a))

[2] The Features of the ClassifierRole must be a subset of those of the base Classifier.

self.base.allFeatures->includesAll (self.availableFeature)

[3] A ClassifierRole does not have any Features of its own.

self.allFeatures->isEmpty

Collaboration

[1] All Classifiers and Associations of the ClassifierRoles and AssociationRoles in the Collaboration should be included in the namespace owning the Collaboration.

self.ownedElement->forAll (e |

(e.oclIsKindOf (ClassifierRole) **implies**

self.namespace.allContents->includes (e.oclAsType(ClassifierRole).base))

and

(e.oclIsKindOf (AssociationRole) implies

self.namespace.allContents->includes (e. oclAsType(AssociationRole).base)))

[2] All the constraining ModelElements should be included in the namespace owning the Collaboration.

self.constrainingElement->forAll (ce |

self.namespace.allContents->includes (ce))

[3] If a ClassifierRole or an AssociationRole does not have a name then it should be the only one with a particular base.

```
self.ownedElement->forAll ( p |
    (p.oclIsKindOf (ClassifierRole) implies
        p.name = '' implies
            self.ownedElement->forAll ( q |
                q.oclIsKindOf(ClassifierRole) implies
                    (p.oclAsType(ClassifierRole).base =
                        q.oclAsType(ClassifierRole).base implies p = q) ) )
and
    (p.oclIsKindOf (AssociationRole) implies
        p.name = '' implies
            self.ownedElement->forAll ( q |
                q.oclIsKindOf(AssociationRole) implies
                    (p.oclAsType(AssociationRole).base =
                        q.oclAsType(AssociationRole).base implies p = q) ) )
)
```

[4] A Collaboration may only contain ClassifierRoles and AssociationRoles.

```
self.ownedElement->forAll ( p |
    p.oclIsKindOf (ClassifierRole) or
    p.oclIsKindOf (AssociationRole) )
```

Interaction

[1] All Signals being bases of Messages must be included in the namespace owning the Interaction.

```
self.message->forAll ( m |
    m.base.oclIsKindOf(Signal) implies
                self.collaboration.namespace.allContents->includes (m.base) )
```

Message

[1] The sender and the receiver must participate in the Collaboration which defines the context of the Interaction.

```
self.interaction.context.ownedElement->includes (self.sender)
and
self.interaction.context.ownedElement->includes (self.receiver)
```

[2] The predecessors and the activator must be contained in the same Interaction.

```
self.predecessor->forAll ( p | p.interaction = self.interaction )
and
self.activator->forAll ( a | a.interaction = self.interaction )
```

[3] The predecessors must have the same activator as the Message.

self.allPredecessors->forAll (p | p.activator = self.activator)

[4] A Message cannot be the predecessor of itself.

not self.allPredecessors->includes (self)

Additional operations

[1] The operation allPredecessors results in the set of all Messages that precede the current one.

allPredecessors : Set(Message);

allPredecessors = self.predecessor->union (self.predecessor.allPredecessors)

2.11.4 Semantics

This section provides a description of the semantics of the elements in the Collaborations package. It is divided into two parts: Collaboration and Interaction.

Collaboration

In the following text the term instance of a collaboration denotes the set of instances that together participate in and perform one specific collaboration.

The purpose of a collaboration is to specify how an operation or a classifier, like a use case, is realized by a set of classifiers and associations. Together, the classifiers and their associations participating in the collaboration conform to the requirements of the realized operation or classifier. The collaboration defines a context in which the behavior of the realized element can be specified in terms of interactions between the participants of the collaboration. Thus, while a model describes a whole system, a collaboration is a slice, or a projection, of that model. It defines a subset of its contents, like classifiers and associations.

A collaboration may be presented at two different levels: specification level or instance level. A diagram presenting the collaboration at the specification level will show classifier roles and association roles, while a diagram at the instance level will present instances and links conforming to the roles in the collaboration.

In a collaboration it is specified what properties instances must have to be able to take part in the collaboration, i.e. each participant specifies the required set of features a conforming instance must have. Furthermore, the collaboration also states which associations must exist between the participants. Not all features of the participating classifiers and not all associations between these classifiers are always required in a particular collaboration. Because of this, a collaboration is not actually defined in terms of classifiers, but classifier roles. Thus, while a classifier is a complete description of instances, a classifier role is a description of the features required in a particular collaboration (i.e., a classifier role is a projection of a classifier in the sense that its features match a subset of the classifier's features). The represented classifier is referred to as the base classifier. Several classifier roles may have the same base

classifier, even in the same collaboration, but their features may be different subsets of the features of the classifier. These classifier roles then specify different roles played by (usually different) instances of the same classifier.

In a collaboration the association roles defines what associations are needed between the classifiers in this context. Each association role represents the usage of an association in the collaboration, and it is defined between the classifier roles that represents the associated classifiers. The represented association is called the base association of the association role.

An instance participating in a collaboration instance plays a specific role (i.e., conforms to a classifier role) in the collaboration. The number of instances that should play one specific role in one instance of a collaboration is specified by the classifier role (multiplicity). Different instances may play the same role but in different instances of the collaboration. Since all these instances play the same role, they must all conform to the classifier role specifying the role. Thus, every instance must have attribute values corresponding to the attribute specified by the classifier role, and must participate in links corresponding to the association roles connected to the classifier role. The instances may, of course, have more attribute values than required by the classifier role which would be the case if they originate from a classifier being a subtype of the required one. Furthermore, one instance may play different roles in different instances of one collaboration. The instance may, in fact, play multiple roles in the same instance of a collaboration.

If the collaboration represents an operation the context could also include things like parameters, attributes and classifiers contained in the classifier owning the operation, etc. The interactions then specify how the arguments, the attribute values, the instances etc. will cooperate to perform the behavior specified by the operation. A collaboration can be used to specify how an operation or a classifier, like a use case, is realized by a set of cooperating classifiers. In a collaboration representing an operation, the base classifiers are the operation’s parameter types together with the attribute types of the classifier owning the operation. When the collaboration represents a classifier, its base classifiers can be classifiers of any kind, like classes or subsystems.

How the instances conforming to a collaboration should interact to jointly perform the behavior of the realized classifier is specified with a set of interactions. The collaboration thus specifies the context in which these interactions are performed.

Two or more collaborations may be composed in order to refine a superordinate collaboration. For example, when refining a superordinate use case into a set of subordinate use cases, the collaborations specifying each of the subordinate use cases may be composed into one collaboration, which will be a (simple) refinement of the superordinate collaboration. The composition is done by observing that at least one instance must participate in both sets of collaborating instances. This instance has to conform to one classifier role in each collaboration. In the composite collaboration these two classifier roles are merged into a new one, which will contain all features included in either of the two original classifier roles. The new classifier role will, of course, be able to fulfill the requirements of both of the previous collaborations, so the instance participating in both of the two sets of collaborating instances will conform to the new classifier role.

A collaboration may be a specification of a template. There will not be any instances of such a template collaboration, but it can be used for generating ordinary collaborations, which may be instantiated. Template collaborations may have parameters that act like placeholders in the template. Usually, these parameters would be classifiers and associations, but other kinds of model elements can also be defined as parameters in the collaboration, like operation or signal. In a collaboration generated from the template these parameters are refined by other model elements that make the collaboration instantiable.

Moreover, a collaboration may have a set of constraining model elements, like constraints and generalizations perhaps together with some extra classifiers. These constraining model elements do not participate in the collaboration themselves. They are used for expressing extra constraints on the participating elements in the collaboration that cannot be covered by the participating roles themselves. For example, in a template it might be required that two of the classifiers must have a common ancestor or one classifier must be a subclass of another one. These kinds of requirements cannot be expressed with association roles, since they express the required links between participating instances. An extra set of model elements is therefore added to the collaboration.

Interaction

The purpose of an interaction is to specify the communication between a set of interacting instances performing a specific task. An interaction is defined within a collaboration (i.e., the collaboration defines the context in which the interaction takes place). The instances performing the communication specified by the interaction conform to the classifier roles of the collaboration.

An interaction specifies the execution of a set of message instances. These are partially ordered based on which execution thread they belong to. The execution starts by executing the first message instance of each thread after it has been dispatched. Within each thread the message instances are executed in a sequential order while message instances of different threads may be executed in parallel or in an arbitrary order.

A request is a specification of a communication between instances, such as a call action or a send action. The request states the name of the operation to be applied to or the event to be raised in the receiver as well as the arguments. Furthermore, it specifies the direction of the stimulus (i.e., whether it is an invocation of an operation or a reply) and whether or not it is an asynchronous stimulus. If it is asynchronous the instance will continue its execution immediately after sending the message instance, while it will be blocked and waiting for a reply if it is synchronous.

A message is a usage of a request in an interaction. It specifies the type of the sender and the type of the receiver as well as which messages should have been received and sent before the current one. Moreover, the message also specifies the expected response of the receiver (script), which should be in conformance with the specification of the corresponding operation of the receiver.

The interaction specifies the activator and predecessors of each message. The activator is the message that invoked the procedure of which the current message is a step. Every message except the initial message of an interaction has an activator. The predecessors are the set of messages that must be completed before the current message may be executed. The first message in a procedure has no predecessors. If a message has more than one predecessor, then it represents the joining of two threads of control. If a message has more than one successor (the inverse of predecessor), then it indicates a fork of control into multiple threads. The predecessors relationship imposes a partial ordering on the messages within a procedure, whereas the activator relationship imposes a tree on the activation of operations. Messages may be executed concurrently subject to the sequential constraints imposed by the predecessors and activator relationship.

Each message instance is dispatched by performing an action. The action specifies how the receiver and the arguments are to be evaluated for each dispatched instance of the message. Moreover, the action also specifies whether iteration or conditionality should be applied and whether iteration should be applied sequentially or in parallel (recurrence).

2.11.5 Standard Elements

None.

2.11.6 Notes

Pattern is a synonym for a template collaboration that describes the structure of a design pattern. Design patterns involve many nonstructural aspects, such as heuristics for their use and lists of advantages and disadvantages. Such aspects are not modeled by UML and may be represented as text or tables.

2.12 Use Cases

2.12.1 Overview

The Use Cases package is a subpackage of the Behavioral Elements package. It specifies the concepts used for definition of the functionality of an entity like a system. The package uses constructs defined in the Foundation package of UML as well as in the Common Behavior package.

The elements in the Use Cases package are primarily used to define the behavior of an entity, like a system or a subsystem, without specifying its internal structure. The key elements in this package are UseCase and Actor. Instances of use cases and instances of actors interact when the services of the entity are used. How a use case is realized in terms of cooperating objects, defined by classes inside the entity, can be specified with a Collaboration. A use case of an entity may be refined to a set of use cases of the elements contained in the entity. How these subordinate use cases interact can also be expressed in a Collaboration. The specification of the functionality of the system itself

is usually expressed in a separate use-case model (i.e., a Model stereotyped «useCaseModel»). The use cases and actors in the use-case model are equivalent to those of the system package.

The following sections describe the abstract syntax, well-formedness rules and semantics of the Use Cases package.

2.12.2 Abstract Syntax

The abstract syntax for the Use Cases package is expressed in graphic notation in Figure 2-21 on page 2-98.

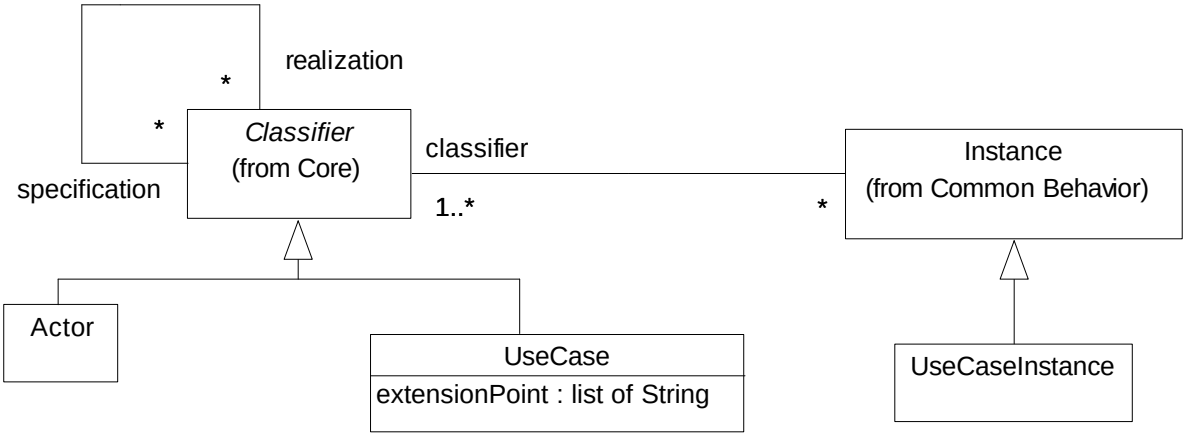


Figure 2-21 Use Cases

The following metaclasses are contained in the Use Cases package.

Actor

An actor defines a coherent set of roles that users of an entity can play when interacting with the entity. An actor has one role for each use case with which it communicates.

In the metamodel Actor is a subclass of Classifier. An Actor has a Name and may communicate with a set of UseCases, and, at realization level, with Classifiers taking part in the realization of these UseCases. An Actor may also have a set of Interfaces, each describing how other elements may communicate with the Actor.

An Actor may inherit other Actors. This means that the inheriting Actor will be able to play the same roles as the inherited Actor (i.e., communicate with the same set of UseCases) as the inherited Actor.

UseCase

The use case construct is used to define the behavior of a system or other semantic entity without revealing the entity's internal structure. Each use case specifies a sequence of actions, including variants, that the entity can perform, interacting with actors of the entity.

In the metamodel UseCase is a subclass of Classifier, containing a set of Operations and Attributes specifying the sequences of actions performed by an instance of the UseCase. The actions include changes of the state and communications with the environment of the UseCase.

There may be Associations between UseCases and the Actors of the UseCases. Such an Association states that instances of the UseCase and a user playing one of the roles of the Actor communicate with each other. UseCases may be related to other UseCases only by Extends and Uses relationships (i.e., Generalizations stereotyped «extends» or «uses»). An Extends relationship denotes the extension of the sequence of one UseCase with the sequence of another one, while Uses relationships denote that UseCases share common behavior.

The realization of a UseCase may be specified by a set of Collaborations (i.e., the Collaborations define how Instances in the system interact to perform the sequence of the UseCase).

Attributes

extensionPoint	A list of strings representing extension points defined within the use case. An extension point is a location at which the use case can be extended with additional behavior.

UseCaseInstance

A use case instance is the performance of a sequence of actions being specified in a use case.

In the metamodel UseCaseInstance is a subclass of Instance. Each method performed by a UseCaseInstance is performed as an atomic transaction (i.e., it is not interrupted by any other UseCaseInstance).

An explicitly described UseCaseInstance is called a scenario.

2.12.3 Well-FormednessRules

The following well-formedness rules apply to the Use Cases package.

Actor

[1] Actors can only have Associations to UseCases and Classes and these Associations are binary.

```
self.associations->forAll(a |
    a.connection->size = 2 and
    a.allConnections->exists(r | r.type.oclIsKindOf(Actor)) and
    a.allConnections->exists(r |
        r.type.oclIsKindOf(UseCase) or
        r.type.oclIsKindOf(Class)))
```

[2] Actors cannot contain any Classifiers.

```
self.contents->isEmpty
```

[3] For each Operation in an offered Interface the Actor must have a matching Operation.

```
self.specification.allOperations->forAll (interOp |
self.allOperations->exists ( op | op.hasSameSignature (interOp) ) )
```

UseCase

[1] UseCases can only have binary Associations.

```
self.associations->forAll(a | a.connection->size = 2)
```

[2] UseCases can not have Associations to UseCases specifying the same entity.

```
self.associations->forAll(a |
    a.allConnections->forAll(s, o|
    s.type.specificationPath->isEmpty and o.type.specificationPath->isEmpty
    or
    (not s.type.specificationPath->includesAll(o.type.specificationPath) and
    not o.type.specificationPath->includesAll(s.type.specificationPath))
    ))
```

[3] A UseCase can only have «uses» or «extends» Generalizations.

```
self.generalization->forAll(g |
    g.stereotype.name = 'Uses' or g.stereotype.name = 'Extends')
```

[4] A UseCase cannot contain any Classifiers.

```
self.contents->isEmpty
```

[5] For each Operation in an offered Interface the UseCase must have a matching Operation.

```
self.specification.allOperations->forAll (interOp |
    self.allOperations->exists ( op | op.hasSameSignature (interOp) ) )
```

Additional operations

[1] The operation specificationPath results in a set containing all surrounding Namespaces that are not instances of Package.

```
specificationPath : Set(Namespace)
```

```
specificationPath = self.allSurroundingNamespaces->select(n |
    n.oclIsKindOf(Subsystem) or n.oclIsKindOf(Class))
```

UseCaseInstance

No extra well-formedness rules.

2.12.4 Semantics

This section provides a description of the semantics of the elements in the Use Cases package, and its relationship to other elements in the Behavioral Elements package.

Actor

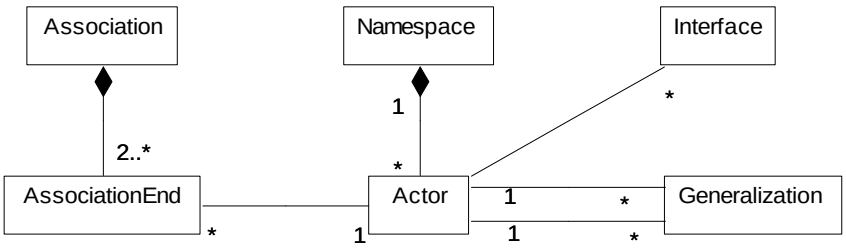


Figure 2-22 Actor Illustration

Actors model parties outside an entity such as a system, a subsystem, or a class which interact with the entity. Each actor defines a coherent set of roles users of the entity can play when interacting with the entity. Every time a specific user interacts with the entity, it is playing one such role. An instance of an actor is a specific user interacting with the entity. Any instance that conforms to an actor can act as an instance of the actor. If the entity is a system the actors represent both human users and other systems. Some of the actors of a lower level subsystem or a class may coincide with actors of the system, while others appear inside the system. The roles defined by the latter kind of actors are played by instances of classifiers in other packages or subsystems, where in the latter case the classifier may belong to either the specification part or the contents part of the subsystem.

Since an actor is outside the entity, its internal structure is not defined but only its external view as seen from the entity. Actor instances communicate with the entity by sending and receiving message instances to and from use case instances and, at realization level, to and from objects. This is expressed by associations between the actor and the use case or class.

Furthermore, interfaces can be connected to an actor, defining how other elements may interact with the actor.

Two or more actors may have commonalities (i.e., communicate with the same set of use cases in the same way). This commonality is expressed with generalizations to another (possibly abstract) actor, which models the common role(s). An instance of an heir can always be used where an instance of the ancestor is expected.

UseCase

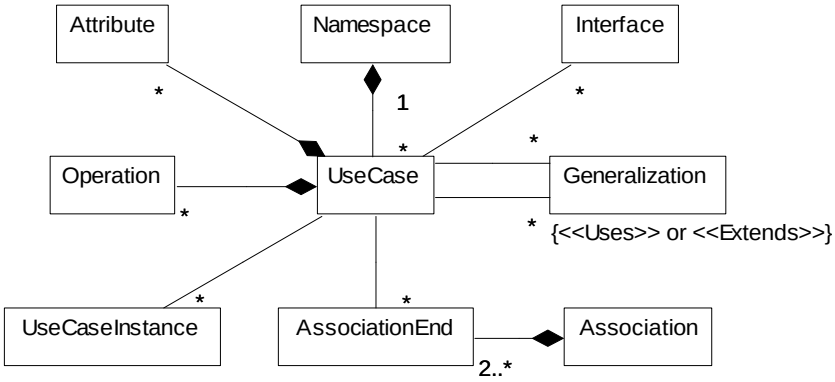


Figure 2-23 UseCase Illustration

In the following text the term entity is used when referring to a system, a subsystem, or a class and the term model element or element denotes a subsystem or a class.

The purpose of a use case is to define a piece of behavior of an entity without revealing the internal structure of the entity. The entity specified in this way may be a system or any model element that contains behavior, like a subsystem or a class, in a model of a system. Each use case specifies a service the entity provides to its users (i.e., a specific way of using the entity). It specifies a complete sequence initiated by a user (i.e., the interactions between the users and the entity as well as the responses performed by the entity) as they are perceived from the outside. A use case also includes possible variants of this sequence (e.g., alternative sequences, exceptional behavior, error handling etc.). The complete set of use cases specifies all different ways to use the entity (i.e., all behavior of the entity is expressed by its use cases). These use cases can be grouped into packages for convenience.

From a pragmatic point of view, use cases can be used both for specification of the (external) requirements on an entity and for specification of the functionality offered by an (already realized) entity. Moreover, the use cases also indirectly state the requirements the specified entity poses on its users (i.e., how they should interact so the entity will be able to perform its services).

Since users of use cases always are external to the specified entity, they are represented by actors of the entity. Thus, if the specified entity is a system or a subsystem at the topmost level (i.e., a top-package, the users of its use cases are modeled by the actors of the system). Those actors of a lower level subsystem or a class that are internal to the system are often not explicitly defined. Instead, the use cases relate directly to model elements conforming to these implicit actors (i.e., whose

instances play these roles in interaction with the use cases). These model elements are contained in other packages or subsystems, where in the subsystem case they may be contained in the specification part or the contents part. The distinction between actor and conforming element like this is often neglected; thus, they are both referred to by the term actor.

There may be associations between use cases and actors, meaning that the instances of the use case and the actor communicates with each other. One actor may communicate with several use cases of an entity (i.e., the actor may request several services of the entity) and one use case communicates with one or several actors when providing its service. Note that two use cases specifying the same entity cannot communicate with each other since each of them individually describes a complete usage of the entity. Moreover, use cases always use signals when communicating with actors outside the system, while it may use other communication semantics when communicating with elements inside the system.

The interaction between actors and use cases can be defined with interfaces. The interface then defines a subset of the entire interaction defined in the use case. Different interfaces offered by the same use case need not be disjoint.

A use-case instance is a performance of a use case, initiated by a message from an instance of an actor. As a response to the message the use-case instance performs a sequence of actions as specified by the use case, like sending messages to actor instances, not necessarily only the initiating one. The actor instances may send new messages to the use-case instance and the interaction continues until the instance has responded to all input and does not expect any more input, when it ends. Each method performed by a use-case instance is performed as an atomic transaction (i.e., it is not interrupted by any other use-case instance).

A use case can be described in plain text, using operations, in activity diagrams, by a state-machine, or by other behavior description techniques, such as pre-and post conditions. The interaction between the use case and the actors can also be presented in collaboration diagrams.

In the case where subsystems are used to model the package hierarchy, the system can be specified with use cases at all levels, since use cases can be used to specify each subsystem and each class. A use case specifying one model element is then refined into a set of smaller use cases, each specifying a service of a model element contained in the first one. The use case of the whole is said to be superordinate to its refining use cases, which in turn are subordinate to the first one. The functionality specified by each superordinate use case is completely traceable to its subordinate use cases. Note, though, that the structure of the container element is not revealed by the use cases, since they only specify the functionality offered by the element. All subordinate use cases of a specific superordinate use case cooperate to perform the superordinate one. Their cooperation is specified by collaborations and may be presented in collaboration diagrams. All actors of a superordinate use case appear as actors of subordinate use cases. Moreover, the cooperating subordinate use cases are actors of each other. Furthermore, the interfaces of a superordinate use case are traceable to the interfaces of those subordinate use cases that communicate with actors that are also actors of the superordinate use case.

The environment of subordinate use cases is the model element containing the model elements specified by these use cases. Thus, from a bottom-up perspective, interaction of subordinate use cases results in a superordinate use case (i.e., a use case of the container element).

Use cases of classes are specified in terms of the operations of the classes, since a service of a class in essence is the invocation of the operations of the class. Some use cases may consist of the application of only one operation, while others may involve a set of operations, possibly in a well-defined sequence. One operation may be needed in several of the services of the class, and will therefore appear in several use cases of the class.

The realization of a use case depends on the kind of model element it specifies. For example, since the use cases of a class are specified by means of operations, they are realized by the corresponding methods, while the use cases of a subsystem are realized by the elements contained in the subsystem. Since a subsystem does not have any behavior of its own, all services offered by a subsystem must be a composition of services offered by elements contained in the subsystem (i.e., eventually by classes). These elements will collaborate and jointly perform the behavior of the specified use case. One or a set of collaborations describes how the realization of a use case is made. Hence, collaborations are used for specification of both the refinement and the realization of a use case.

The usage of use cases at all levels imply not only a uniform way of specification of functionality at all levels, but also a powerful technique for tracing requirements at the system package level down to operations of the classes. The propagation of the effect of modifying a single operation at the class level all the way up to the behavior of the system package is managed in the same way.

Commonalities between use cases are expressed with uses relationships (i.e., generalizations with the stereotype «uses»). The relationship means that the sequence of behavior described in a used use case is included in the sequence of another use case. The latter use case may introduce new pieces of behavior anywhere in the sequence as long as it does not change the ordering of the original sequence. Moreover, if a use case has several uses relationships, its sequence will be the result of interleaving the used sequences together with new pieces of behavior. How these parts are combined to form the new sequence is defined in the using use case.

An extends relationship (i.e., a generalization with the stereotype «extends») defines that a use case may be extended with some additional behavior defined in another use case. The extends relationship includes both a condition for the extension and a reference to an extension point in the related use case (i.e., a position in the use case where additions may be made). Once an instance of a use case reaches an extension point to which an extends relationship is referring, the condition of the relationship is evaluated. If the condition is fulfilled, the sequence obeyed by the use-case instance is extended to include the sequence of the extending use case. Different parts of the extending use case sequence may be inserted at different extension points in the original sequence. If there is still only one condition (i.e., if the condition of the extends relationship is fulfilled at the first extension point), then the entire extending behavior is inserted in the original sequence.

Note that the two kinds of relationships described above can only exist between use cases specifying the same entity. The reason for this is that the use cases of one entity specify the behavior of that entity alone (i.e., all use-case instances are performed entirely within that entity). If a use case would have a uses or extends relationship to a use case of another entity, the resulting use-case instances would involve both entities, resulting in a contradiction. However, uses and extends relationships can be defined from use cases specifying one entity to use cases of another one if the first entity has a generalization to the second one, since the contents of both entities are available in the first entity.

As a first step when developing a system, the dynamic requirements of the system as a whole can be expressed with use cases. The entity being specified is then the whole system, and the result is a separate model called a use-case model (i.e., a model with the stereotype «useCaseModel»). Next, the realization of the requirements is expressed with a model containing a system package, probably a package hierarchy, and at the bottom a set of classes. If the system package (i.e., the representation of the system as a whole in the model) is modeled by applying the «topLevelPackage» stereotype to the subsystem construct, its abstract behavior is naturally the same as that of the system. Thus, if use cases are used for the specification part of the system package, these use cases are equivalent to those in the use-case model of the system (i.e., they express the same behavior but possibly slightly differently structured). In other words, all services specified by the use cases of a system package, and only those, define the services offered by the system. Furthermore, if several models are used for modeling the realization of a system (e.g., an analysis model and a design model) the set of use cases of all system packages and the use cases of the use-case model must be equivalent.

2.12.5 Standard Elements

See Appendix A - UML Standard Elements for definitions of the «extends», «extends», and «useCaseModel» stereotypes.

2.12.6 Notes

A pragmatic rule of use when defining use cases is that each use case should yield some kind of observable result of value to (at least) one of its actors. This ensures that the use cases are complete specifications and not just fragments.

2.13 State Machines

2.13.1 Overview

The State Machine package is a subpackage of the Behavioral Elements package. It specifies a set of concepts that can be used for modeling behavior through finite state-transition systems. It is defined as an elaboration of the Foundation package. The State Machine package also depends on concepts that are defined in the Common Behavior package, enabling integration with the other subpackages in Behavioral Elements.

The metamodel described supports an object variant of statecharts. Statecharts are characterized by a number of conceptual shortcuts, such as hierarchical states, concurrent states, history, and branch nodes, which, in combination, achieve a significant compaction of specifications over most other state-based formalisms. In a sense, all other finite-state machine models can be considered as constrained versions of statecharts (e.g., Mealy machines or state-event matrices).

State machines can be used in two different ways. In one case, the state machine may specify complete behavior of its context, typically a class. In that case requestors send requests to the owner of a state machine. and the state machine receiving an event determines what the effect will be by attaching actions to transitions, from which complete specifications of operations can be derived.

In the second case, the state machine may be used as a protocol specification, showing the order in which operations may be invoked on a type. Transitions are triggered by call events and their actions invoke the desired operation. This means that a caller is allowed to invoke the operation at that point. The protocol state machine does not specify actions that specify the behavior of the operation itself, but shows a change of state determining which operations can be invoked next.

In addition to defining state machines, the metamodel also defines the core semantics of activity models. Statecharts and activity models share many elements, and hence are based on the same metamodel. Activity models are a subtype of state models that use most of the concepts that apply to state machines.

The following sections describe the abstract syntax, well-formedness rules, and semantics of the State Machines package.

2.13.2 Abstract Syntax

The abstract syntax for the State Machines package is expressed in graphic notation in the following figures. Figure 2-24 on page 2-107 shows the main model elements that define state machines, which include States, Events and Transitions.

State Machines: Main

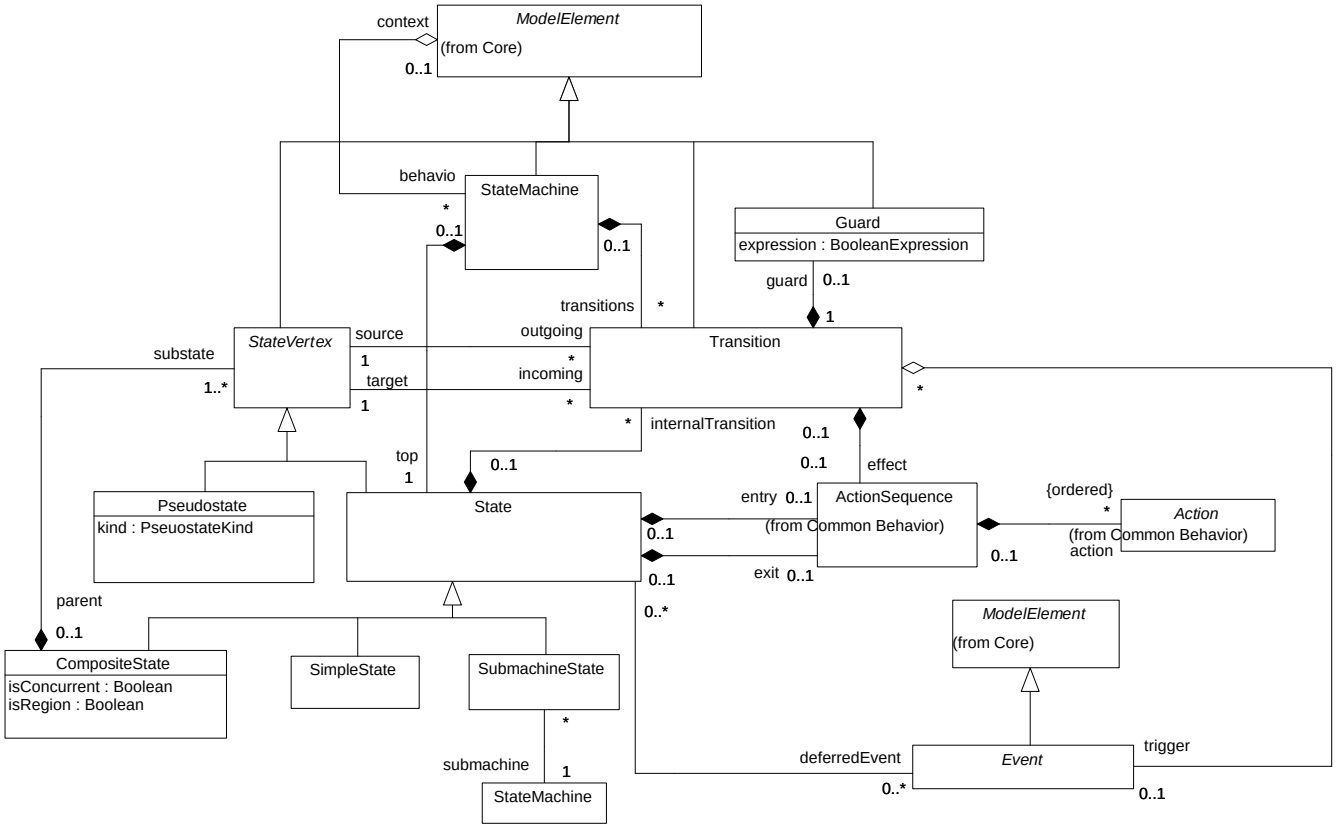


Figure 2-24 State Machines - Main

Figure 2-25 on page 2-108 shows model elements that are specializations of Events.

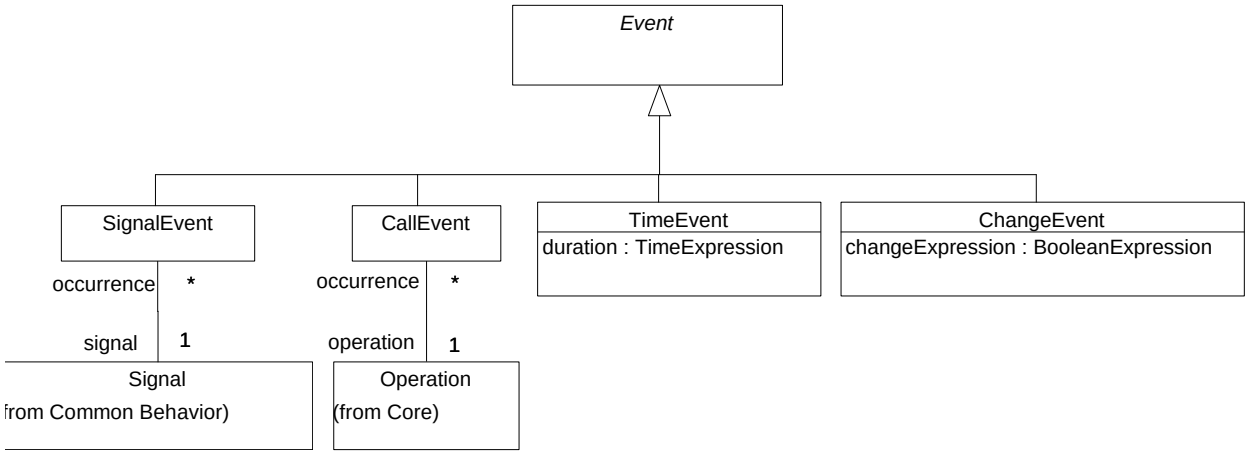


Figure 2-25 State Machines - Events

CallEvent

A call event is the reception of a request to invoke an operation. The expected result is the execution of the operation.

In the metamodel CallEvent is a subclass of Event, which is the abstract meta-class representing all event types that trigger a transition in the state machine.

Two special cases of CallEvent are the object creation event and the object destruction event.

Associations

operation	Designates the operation whose invocation is requested.

ChangeEvent

A change event is an event that is generated when one or more attributes or relationships change value according to an explicit expression.

A change event is never raised by an explicit change event action. Instead, it is a consequence of the execution of one or more actions that modify the values of elements that are referenced in the boolean expression. The corresponding change event is actually raised by the underlying run-time system that detects that the condition has changed to true

A change event functions as a trigger for transitions, and must not be confused with a guard. When a change event occurs, a guard can still block any transition that would otherwise be triggered by that change.

In the metamodel ChangeEvent is a subclass of Event, which is the abstract class that represents all events that trigger a StateMachine.

Attributes

changeExpression	A boolean expression that indicates when a ChangeEvent occurs.

CompositeState

A composite state is a state that consists of substates.

In the metamodel a CompositeState is a subclass of State that contains one or more substates that are subtypes of StateVertex.

Associations

substate	Designates a set of States that constitute the substates of a CompositeState. Each substate is uniquely owned by its parent CompositeState.

Attributes

isConcurrent	A boolean value that specifies the decomposition semantics. If this attribute is true, then the composite state is decomposed directly into two or more orthogonal conjunctive components (usually associated with concurrent execution). If this attribute is false, then there are no direct orthogonal components in the composite. This means that exactly one of the substates can be active at a given instant (i.e., sequential execution).
isRegion	A derived boolean value that indicates whether a CompositeState is a substate of a concurrent state. If it evaluates to true, then the CompositeState is a substate of a concurrent state.

Event

An event is the specification of a significant occurrence that has a location in time and space. An instance of an event can lead to the activation of a behavioral feature in an object.

It is important to distinguish between an event, which is a static specification for a dynamically occurring concept, from an actual instance of an event as a result of program execution. The class Event represents the type of an event. An instance of an event is not modeled explicitly in the metamodel.

In the metamodel an Event is a subclass of ModelElement and is the part of a Transition that represents its trigger.

Guard

A guard condition is a boolean expression that may be attached to a transition in order to determine whether that transition is enabled or not.

The guard is evaluated when an event occurrence triggers the transition. Only if the guard is true at the time the event is presented to the state machine will the transition actually take place. Guards should be pure expressions without side effects. Guard expressions with side effects may lead to unpredictable results.

In the metamodel Guard is a ModelElement so it can be substituted in refined state machines.

Attributes

expression	A boolean expression that specifies the guard condition.

PseudoState

A pseudo state is an abstraction of different types of nodes in the state machine graph which represent transient points in transition paths from one state to another (e.g., branch and fork points). Pseudo states are used to construct complex transitions from simple transitions. For example, by combining a transition entering a fork pseudo state with a set of transitions exiting the fork pseudo state, we get a complex transition that leads to a set of target states.

In the metamodel PseudoState is a subclass of StateVertex, which generalizes all statechart nodes.

Attributes

kind	Determines the type of the PseudoState and can be one of initial, deepHistory, shallowHistory, join, fork, branch, or final.

SignalEvent

A SignalEvent represents events that result from the reception of a signal by an object.

In the metamodel SignalEvent is a subclass of Event.

Associations

signal	Designates the Signal whose reception by the state owner may trigger a Transition.

SimpleState

A SimpleState is a state that does not have substates.

In the metamodel a SimpleState is a subclass of State that does not have any additional features. It is included solely for symmetry with CompositeState.

State

A State is a condition or situation during the life of an object during which is satisfies some condition, performs some activity, or waits for some event. A state models a dynamic situation in which, typically, one or more (implicit or explicit) conditions hold.

In the metamodel, a State is a subclass of StateVertex, thereby inheriting the fundamental features of incoming and outgoing transitions associated with state vertices.

Associations

deferredEvent	A list of Events. The effect of whose occurrence during the State is postponed until the owner enters a State in which they are not deferred, at which time they may trigger Transitions as if they had just occurred.
entry	An optional ActionSequence that is executed when the State is entered. These Actions are atomic, may not be avoided, and precede any internal activity or Transitions.
exit	An optional ActionSequence that is executed when the State is exited. These Actions are atomic, may not be avoided, and follow any internal activity or Transitions.
internalTransition	A set of Transitions that occur entirely within the State. If one of their triggers is satisfied, then the action is performed without changing State. This means that the entry or exit condition of the State will not be invoked. These Transitions apply even if the StateMachine is in a nested region and they leave it in the same State.
deferredEvent	An association that specifies the Events to be deferred if received within the State. Multiplicity '*..*' indicates that a State can defer multiple Events, and an Event can be deferred by multiple States.

StateMachine

A state machine is a behavior that specifies the sequences of states that an object or an interaction goes through during its life in response to events, together with its responses and actions. The behavior is specified as a traversal of a graph of state nodes interconnected by one or more joined transition arcs. The transitions are triggered by series of event instances.

In the metamodel a StateMachine is composed of States and Transitions. The ModelElement role provides the context for the StateMachine. A common case of the context relation is where a StateMachine is designated to specify the lifecycle of the Classifier. The StateMachine has a composition aggregation to a State that represents the top state and a set of Transitions. As a consequence the StateMachine owns its Transitions and its top State, but nested states are transitively owned through their parent States.

Associations

context	An association to a ModelElement constrained to be a Classifier or a BehavioralFeature. The owning ModelElement is the element whose behavior is specified by the StateMachine. The ModelElement may contain multiple StateMachines (although for many purposes one suffices). Each StateMachine is owned by one ModelElement.
top	Designates the top level State directly owned by the StateMachine. Other States are owned by the parent composite states. The multiplicity is 1, there must be one State designated as the top State. The rest of the StateMachine is an expansion of this CompositeState.
transitions	Associates the StateMachine with its Transitions. Note that internal Transitions are owned by the State and not by the StateMachine. All other Transitions which are essentially relationships between States are owned by the StateMachine. Multiplicity is ‘0..*’.

StateVertex

A StateVertex is an abstraction of a node in a statechart graph. In general, it can be the source or destination of any number of transitions.

In the metamodel a StateVertex is a subclass of ModelElement.

Associations

outgoing	Specifies the transitions departing from the vertex.
incoming	Specifies the transitions entering the vertex.

SubmachineState

A SubmachineState represents a nested state machine. A nested state machine is semantically equivalent to a composite state, but facilitates reuse and modularity in the form of an independent nested state machine.

In the metamodel a SubmachineState is a subclass of State.

Associations

submachine	Represents the substate machine.

TimeEvent

A TimeEvent is a subtype of Event for modeling event instances resulting from the expiration of a deadline.

In the metamodel a time event can specify a trigger of a transition, which by default denotes the time elapsed since the current state was entered.

Attributes

duration	Specifies the corresponding time deadline.

Transition

A Transition is a relationship between a source state vertex and a target state vertex. It may be part of a compound transition, which takes the state machine from one state configuration to another, representing the complete response of the state machine to a particular event instance for a given source state configuration.

In the metamodel Transition is a subclass of ModelElement that participates in various relationships with other state machine metaclasses.

Associations

trigger	Specifies the single Event which activates it.
guard	Predicate that must evaluate to true at the instant the Transition is triggered.
effect	Specifies an ActionSequence to be performed when the Transition fires.
source	Designates the StateVertex affected by firing the Transition. If the StateVertex is in the source state and the trigger of the Transition is satisfied, then it fires, performs its Actions, and the StateMachine enters the target State.
target	Designates the StateVertex that results from a firing of the Transition when the StateMachine was originally in the source State. After the firing the StateMachine is in the target State.

2.13.3 Well-FormednessRules

The following well-formedness rules apply to the State Machines package.

CompositeState

[1] A composite state can have at most one initial vertex

self.subState->select (v | v.oclType = Pseudostate)->
    select(p : Pseudostate | p.kind = #initial)->size <= 1

[2] A composite state can have at most one deep history vertex

self.subState->select (v | v.oclType = Pseudostate)->
    select(p : Pseudostate | p.kind = #deepHistory)->size <= 1

[3] A composite state can have at most one shallow history vertex

self.subState->select(v | v.oclType = Pseudostate)->
    select(p : Pseudostate | p.kind = #shallowHistory)->size <= 1

[4] There have to be at least two composite substates in a concurrent composite state

(self.isConcurrent) **implies**
    (self.subState->select (v | v.oclIsKindOf(CompositeState))->size >= 2)

Guard

[1] A guard should not have side effects

LocalInvocation

[1] A local invocation has no target

self.target->size = 0

PseudoState

[1] An initial vertex can have at most one outgoing transition and no incoming transitions

(self.kind = #initial) **implies**
    ((self.outgoing->size <= 1) and (self.incoming->isEmpty))

[2] A final pseudo state cannot have outgoing transitions

(self.kind = #final) **implies** (self.outgoing->isEmpty)

[3] History vertices can have at most one outgoing transition

((self.kind = #deepHistory) **or** (self.kind = #shallowHistory)) **implies**
    (self.outgoing->size <= 1)

[4] A join vertex must have at least two incoming transitions and exactly one outgoing transition

(self.kind = #join) **implies**

((self.outgoing->size = 1) and (self.incoming->size >= 2))

[5] A fork vertex must have at least two outgoing transitions and exactly one incoming transition

(self.kind = #fork) **implies**

((self.incoming->size = 1) **and** (self.outgoing->size >= 2))

[6] A branch vertex must have one incoming transition segment and at least two outgoing transition segments with guards.

(self.kind = #branch) **implies**

((self.incoming->size = 1) **and**

((self.outgoing->size >= 2) **and** self.outgoing->forAll(t |

t.guard->size = 1)))

StateMachine

[1] A StateMachine is aggregated within either a classifier or a behavioral feature.

self.context.oclIsKindOf(BehavioralFeature) **or** self.context.oclIsKindOf(Classifier)

[2] A top state is always a composite.

self.top.oclIsTypeOf(CompositeState)

[3] A top state cannot have parents

self.top.parent->isEmpty

[4] The top state cannot be the source or target of a transition.

(self.top.outgoing->isEmpty) **and** (self.top.incoming->isEmpty)

[5] There can be no history vertices in the top state.

self.top.substate->select(oclIsTypeOf(Pseudostate))->

forAll (p : Pseudostate |

not (p.kind = #shallowHistory) **and not** (p.kind = #deepHistory))

[6] If a StateMachine describes a behavioral feature, it contains no triggers of type CallEvent, apart from the trigger on the initial transition (see OCL for Transition [8]).

self.context.oclIsKindOf(BehavioralFeature) **implies**

self.transitions->reject(

source.oclIsKindOf(Pseudostate) **and**

source.oclAsType(Pseudostate).kind= #initial).trigger->isEmpty

Transition

[1] A fork segment should not have guards or triggers.

self.source.oclIsKindOf(Pseudostate) **implies**

((self.source.oclAsType(Pseudostate).kind = #fork) **implies**

((self.guard->isEmpty) **and** (self.trigger->isEmpty)))

[2] A join segment should not have guards or triggers.

self.target.oclIsKindOf(Pseudostate) **implies**
((self.target.oclAsType(Pseudostate).kind = #join) **implies**
((self.guard->isEmpty) **and** (self.trigger->isEmpty)))

[3] A fork segment should always target a state.

self.source.oclIsKindOf(Pseudostate) **implies**
((self.source.oclAsType(Pseudostate).kind = #fork) **implies**
(self.target.oclIsKindOf(State)))

[4] A join segment should always originate from a state.

self.target.oclIsKindOf(Pseudostate) **implies**
((self.target.oclAsType(Pseudostate).kind = #join) **implies**
(self.source.oclIsKindOf(State)))

[5] A branch segment must not have a trigger.

self.source.oclIsKindOf(Pseudostate) **implies**
(((self.source.oclAsType(Pseudostate).kind = #branch) **or**
(self.source.oclAsType(Pseudostate).kind = #deepHistory) **or**
(self.source.oclAsType(Pseudostate).kind = #shallowHistory) **or**
(self.source.oclAsType(Pseudostate).kind = #initial)) **implies**
(self.trigger->isEmpty))

[6] Join segments should originate from orthogonal states.

self.target.oclIsKindOf(Pseudostate) **implies**
((self.target.oclAsType(Pseudostate).kind = #join) **implies**
(self.source.parent.isConcurrent))

[7] Fork segments should target orthogonal states.

self.source.oclIsKindOf(Pseudostate) **implies**
((self.source.oclAsType(Pseudostate).kind = #fork) **implies**
(self.target.parent.isComposite))

[8] An initial transition at the topmost level may have a trigger with the stereotype "create." An initial transition of a StateMachine modeling a behavioral feature has a CallEvent trigger associated with that BehavioralFeature. Apart from these cases, an initial transition never has a trigger.

self.source.oclIsKindOf(Pseudostate) **implies**
((self.source.oclAsType(Pseudostate).kind = #initial) **implies**
(self.trigger->isEmpty **or**
((self.source.parent = self.stateMachine.top) **and**
(self.trigger.stereotype.name = 'create')) **or**
(self.stateMachine.context.oclIsKindOf(BehavioralFeature) **and**
self.trigger.oclIsKindOf(CallEvent) **and**

```
                                    (self.trigger.oclAsType(CallEvent).operation =
                                                        self.stateMachine.context))
                ))
self.source.oclIsKindOf(Pseudostate) implies
        ((self.source.kind = #initial) implies
                (self.trigger.isEmpty or
                ((self.source.parent = self.StateMachine.top) and
                                    (self.trigger.stereotype.name = 'create')) or
                (self.StateMachine.context.oclIsKindOf(BehaviouralFeature) and
                                    self.trigger.oclIsKindOf(CallEvent) and
                                    (self.trigger.operation = self.StateMachine.context))
                ))
```

2.13.4 Semantics

This section describes the execution semantics of state machines. For convenience, the semantics are described using an operational style; that is, they are expressed in terms of the operations of a hypothetical machine that implements a state machine specification. In the general case, the key components of this abstract machine are:

- an events queue which accepts incoming event instances,
- a dispatcher which selects and de-queues event instances for processing, and
- an event processor which processes dispatched event instances according to the general semantics of UML state machines and the specific form of the state machine in question. Because of that, this component is simply referred to as "the state machine" in the following text.

This is for reference purposes only and is not meant to imply that individual realizations must conform to this structure. For example, the role of the event dispatcher might be played by some other object that simply invokes an operation on the object.

Understanding the dynamic semantics of state machines requires an understanding of the complex relationships between individual metaclasses. Therefore, the bulk of the description of the dynamic semantics of state machine is included in the context of the state machine metaclass.

StateMachine

The software context that assumes that a state machine reacts to an event applied to it by some external object.

Event processing by a state machine is partitioned into steps, each of which is caused by an event instance directed to the state machine.

The fundamental semantics assumes that events are processed in sequence, where each event stimulates a run-to-completion (RTC) step. The next external event is dispatched to the state machine after the previous RTC step has completed. This assumption simplifies the transition function of the state machine since the incoming event is processed only after the state machine has reached a well-defined (stable) state configuration.

The practical meaning of these semantics is thread protection, allowing the state machine to safely complete its RTC step without concern about being interrupted in mid-transition by a subsequent event. This may be implemented by a thread event-loop reading events from a queue (in case of active classes) or as a monitor (in case of a passive class).

It is possible to define state machine semantics by allowing the RTC steps to be applied concurrently to the orthogonal regions of a composite state, rather than to the whole state machine. This would allow the event serialization constraint to be relaxed. However, such semantics are quite subtle and difficult to implement. Therefore, the dynamic semantics as defined in this document are based on the precept that an RTC step applies to the entire state machine. This satisfies most practical purposes.

Run-to-completion processing

Once an event instance is dispatched, it may result in one or multiple transitions being enabled for firing. (Only transitions that triggered by the corresponding event type can be enabled). By default, if no transition is enabled, the event is discarded without any effect. An event can be deferred to be processed later if specified as a deferred event in one of the active states. Deferred events semantics are described in a following section.

In case where one or more transitions are enabled, the state machine selects a subset and fires them, moving the state machine from one active state configuration to a new active state configuration. This basic transformation is called a step. The transitions that fire are determined by the transition selection function described below. Actions that result from taking the transition may cause event instances to be generated for this and other objects.

If these actions are synchronous then the transition freezes until the invoked objects complete their own run. Each orthogonal bottom-level component can fire at most one transition as a result of the event instance dispatch. Conflicting transitions (described below) will not fire in the same step. When all orthogonal regions have finished executing the transition, the event instance is consumed, and the step terminates.

The order in which selected transitions fire is not defined. It is based on an arbitrary traversal that is not explicitly defined by the state machine formalism.

Completion transitions and completion events

A completion transition is a transition without a trigger (a guard is possible). The completion transition is typically taken upon the completion of actions of its source state.

After reacting to an event occurrence, the state machine may reach a state configuration where some of the states have outgoing completion transitions (transient configurations). Such a configuration is considered non-stable.

In this case further steps are taken until the state machine reaches a stable state configuration (i.e., no more transitions are enabled). Completion transitions are triggered by completion events, which are dispatched to the state machine whenever a transient configuration is encountered. Completion events are dispatched in a series of steps until a stable configuration is reached completing the RTC step initiated by the event instance. At this point, control returns to the dispatcher and a new event instance can be dispatched.

It is possible for a state machine to never reach a stable configuration. (A practical solution to overcome such cases in an implementation of this semantics, is to set a limit on the maximal number of steps allowed before the state machine is to reach a stable configuration.)

An event instance can arrive at a state machine that is frozen in the middle of an RTC step from some other object within the same thread, in a circular fashion. This event instance can be treated by orthogonal components of the state machine that are not frozen along transitions at that time.

Step semantics

Informally, the semantics of a step involve the execution of a maximal set of non-conflicting transitions from an active, current state configuration. (Note that this section is based on the dynamic semantics sections of State, CompositeState, and Transition.)

Transition selection

Transition selection specifies which subset of the enabled transitions will fire. The following sections discuss the two major considerations that affect transition selection: conflicts and priorities.

Conflicts

In a given state, it is possible for several transitions to be enabled within a state machine. The issue then is which ones can be fired simultaneously without contradicting (conflicting with) each other. For example, if there are two transitions originating from a state s, one labeled e[c1] and the other e[c2], and if both [c1] and [c2] are true, then only one transition can fire.

Two transitions are said to conflict if they both exit the same state, or, more precisely, that the intersection of the set of states they exit is non-empty. The intuition is that only ‘concurrent’ transitions may be fired simultaneously. This constraint guarantees that the new active state configuration resulting from executing the set of transitions is well formed.

An internal transition in a state conflicts only with transitions that cause an exit from that state.

Priorities

Priorities resolve transition conflicts, but not all of them. We use the state hierarchy to define priorities among conflicting transitions. By definition, a transition emanating from a substate has higher priority than a conflicting transition emanating from any of the containing states.

The priority of a transition is defined based on its source state. Join transitions get the priority according to their lowest source state.

If t1 is a transition whose source state is s1, and t2 has source s2, then:

- If s1 is a substate of s2, then t1 has higher priority than t2.
- If s1 and s2 are not hierarchically related, then there is no priority defined between t1 and t2.

Note – other policies are also possible. In classical statecharts, the priority is reversed: parent states imply higher priorities than nested states. However, in the object context inner states are more specialized than their ancestors, and therefore override them.)

Selecting transitions

The set of transitions that will fire is the maximal set that satisfies the following conditions:

- All transitions in the set are enabled.
- There are no conflicts within the set.
- There is no transition outside the set that has higher priority than a transition in the set. Intuitively, the ones with higher priorities are in the set and the ones with lower priorities are left out.

This definition is not written algorithmically, but can be easily implemented by a greedy selection algorithm, with a straightforward traversal of the active state configuration. Active states are traversed bottom up, where transitions originating from each state are evaluated. This traversal guarantees that the priority principle is not violated. The only non-trivial issue is resolving transition conflicts across orthogonal states on all levels. This is resolved by "locking" each orthogonal state once a transition inside any one of its components is fired. The bottom-up traversal and the orthogonal state locking together guarantee a proper selection set.

Deferred events

Each of the states in the active states configuration may specify a set of deferred events. In case where no transition is enabled following an event dispatch, if the event is specified to be deferred by any of the active configuration states, it is considered pending.

An event instance is pending as long as its event is deferred by the active configuration. Following an RTC step where the state machine reaches a configuration in which the event is not deferred, the event instance is ready to be dispatched again.

Note – it is the responsibility of the dispatching mechanism to serialize the events to be dispatched in a sequence, since the step semantics is assumes a single event dispatch. Therefore, if following an RTC-step more than a single pending event becomes ready (or an external event has occurred) it is guaranteed that there is no conflict.

State

A state can be active or inactive during execution. A state becomes active when it is entered as a result of some transition, and becomes inactive if it is exited as a result of a transition.

A state can be exited and entered as a result of the same transition (e.g., self transition).

Whenever a state is entered, it executes its entry action sequence. Whenever a state is exited, it executes its exit action sequence.

CompositeState

Legal state configuration

Every active composite state during execution must follow the legal active state configuration with respect to its substates. This means that the following constraints are always met during execution (except for transition execution period which is transient):

- If the composite state is not a concurrent state, exactly one of its substates is active.
- If the composite state is concurrent, all of its substates (regions) are active.

To avoid violation of the legal configuration constraints during execution, the dynamic semantics upon entering and exiting composite states is defined such that a well-formed state machine always satisfies them.

Entering a composite state

Entering a non-concurrent composite state

Upon entering a composite state the entry action sequence executes similar to simple state.

- default entry: If the transition hits the edge of the composite state, then the default (initial) transition executes to enter one of the substates of the composite state. Note that initial transitions must always be enabled (in case of branches). A disabled initial transition is an ill-defined execution state and its handling is an implementation issue.
- explicit entry: If the transition "passes through" the state towards one of its substates, then the explicit substate becomes active, and recursively follows the entering procedure.

- history entry: if the transition is entering a history pseudo state of a composite state, the active substate is determined as the most recent active substate prior to the entry. If it is the first time the state is entered, then the active substate is determined by the transition outgoing from the history pseudo state. If no such transition is specified, the situation is illegal and its resolution is implementation dependent. The active substate determined by history proceeds with its default entry.
- deep history entry: similar to history, but the active substate also executes deep history entry (recursively)

Entering a concurrent composite state

Whenever a concurrent composite state is entered, each one of its substates (the "regions") are also entered, either by default or explicitly. If the transition hits the edge of the composite state, then all the regions are default entered. If the transition explicitly enters one or more regions (fork), these regions are entered explicitly and the others by default.

Exiting a composite state

Exiting non-concurrent state

The active substate(s) is exited (recursively). After exiting the active substate, the exit action is executed.

Exiting a concurrent state

Each one of the regions is exited. Following that, the exit actions are executed.

Pseudostate

A Pseudostate represents family of nodes in the state machine that are attached to states and transitions as compositional elements that carry additional semantics.

A Pseudostate can be one of the following:

- initial represents a default vertex that is the source for a single transition to the "default" state. There can be at most one initial vertex in a composite state or state machine.
- deepHistory is a vertex that is used to represent, in shorthand form, the most recent active configuration of a state and its substates. A composite state can have at most one deep history vertex. A transition coming into the history vertex is equivalent to a transition coming into the most recent active configuration of a state and the transitive closure of all its substates. A transition originating from the history connector leads to the default history state. This transition is taken in case no history exists and a transition to history is taken.
- shallowHistory is a vertex that is used to represent, in shorthand form, the most recent active configuration of a state but not its substates. A composite state can have at most one shallow history vertex. A transition coming into the shallow

history vertex is equivalent to a transition coming into the most recent active substate of a state. (Note that a state can have both deepHistory and shallowHistory transitions.)

- join vertices combine several transition segments coming from source vertices in different orthogonal components. The segments entering a join vertex cannot have guards.
- fork vertices connect an incoming transition to two or more orthogonal target vertices. The segments outgoing from a fork vertex must not have guards.
- branch vertices split a single segment into two or more transition branches labeled by guards. The guards determine which of the branches are enabled. A predefined guard denoted "else" may be defined for at most one branch. This branch is enabled if all the guards labeling the other branches are false.
- final represents a simple state with some additional semantics. Unlike all other pseudo states, this is not a transient state. When the final state is entered, its parent composite state is terminated, or that it satisfies the termination condition. In case that the parent of the final state is the top state, the entire statechart terminates, and this implies the termination of "life" of the entity that the statechart specifies. If the statechart specifies the behavior of a classifier, it implies the "termination" of that instance. In case that the parent state of the final state is not the top state, it simply means that the terminate transitions are enabled.

A terminate transition is a transition is a transition outgoing a non-pseudo state which does not have a label (event or guard). It is enabled if its source state has reached a final state.

SubmachineState

A submachine state is an organizational concept and does not introduce additional behavioral semantics. The submachine state facilitates reuse of state machine segments similar to the way procedures and templates are used in conventional programming language. A submachine state also facilitates decomposition of complex state machines into a set of simpler machine.

The semantics of a submachine state is equivalent to the semantics of replacing the submachine state with the state machine related by the submachine association, where the top state of the submachine merges with the submachine state, resulting in a composite state. Therefore, it is possible that the submachine state has entry or exit actions and/or internal transitions, they are attached to the resulting CompositeState.

A submachine state may also be thought of as a state machine "subroutine", in which one machine "calls" another machine and then "returns" to the original machine.

Transitions

Transitions vs. compound transitions

In the general case a transition represents a fragment of a compound transition. A compound transition is a cluster of simple transitions connected by join, fork, and branch transitions. In case of branch nodes, only one segment is selected for each branch, based on the guard. The dynamic semantics specify the execution of a compound transition, which is atomic in terms of execution (join, fork, and branch are pseudostates, not states).

Note that a compound transition can have at most one trigger, since join, fork and branch segments cannot have triggers.

A transition that fires always leads from one legal state configuration to another legal state configuration. Transitions originating from a composite state, once fired, always cause exiting the composite state and its constituents.

High-level ("interrupt") transitions

Transitions originating from composite states are sometimes referred to as "high-level" transitions or "interrupts." Once selected to fire (as explained below), they result in exiting of all the internal substates and executing their exit actions. Note however, that since the state machine semantics are run-to-completion, strictly speaking they are not really interrupts, but rather generalized or "group" transitions. (The term "interrupt" stems from classical statecharts where so-called "do activities" of states would be aborted as a result of high-level transitions.)

Enabled (compound) transitions

A transition is enabled if both of the following hold:

- All source states of the transition are in the current active state configuration. A completion transition (without a trigger) requires its source state to be in the termination state, in case it is a composite state.
- The trigger matches the event instance posted to the state machine. Null triggers match any event, in particular completion event. A specialized event matches a trigger based on a generalized event.
- There is a path of transition segments from the source to the target states, along which all the guards are satisfied (transition without guards are always satisfied). If more than one path is possible, only one is selected (non-deterministically).

Note that guards are evaluated prior to the invocation of any action related to the transition.

Since guards are not interpreted, their evaluation may include expressions causing side effects. Guards causing side effects are considered bad practice, since their evaluation strategy, in terms of when guards are evaluated and in which order, is not defined and is a function of the implementation.

(Compound) Transition execution

Transition execution semantics are defined such that the resulting state configuration is always a legal one. This principle is especially important once we deal with transitions entering/exiting boundaries of concurrent states.

LCA, main source, and main target

Every compound transition causes the exit of one (composite) state, and proper entering of another composite state. These two states are designated as the main source and the main target of the transition.

The Least Common Ancestor (LCA) state of a transition is the lowest state that contains all the explicit source states and explicit target states of the compound transition. In case of branch segments, only the states related to the selected path are considered explicit targets ("dead" branches are not considered).

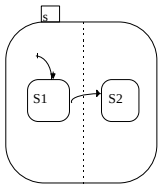
The main source is a direct substate of the LCA that contains the explicit sources. The main target is a substate of the LCA that contains the explicit targets.

Examples:

1. The common simple case: A transition t between two simple states s1 and s2, in a composite state s.

   Here LCA(t) is s, the main source is s1 and the main target is s2.

2. A more esoteric case: An unstructured transition from one region to another.



   Here LCA(t) is the parent of s, the main source is s and the main target is s.

Transition execution sequence

Once a transition is enabled and is selected to fire, the following steps are carried out in order:

- The main source state is properly exited (as defined in the composite states exiting semantics above).
- Actions are executed in sequence following their linear order along the segments of the transition: The "closer" the action to the source state, the earlier it is executed.
- The main target state is properly entered (as defined in the composite state entry semantics above).

2.13.5 Standard Elements

The predefined stereotypes, constraints and tagged values for the State Machines package are listed in Table 2-6 and defined in Appendix A - UML Standard Elements.

Table 2-6 State Machines - Standard Elements

Model Element	Stereotypes	Constraints	Tagged Values
Event	«create» «destroy»		

2.13.6 Notes

Example: Modeling Class Behavior

In the software that is implemented as a result of a state modeling design, the state machine may or may not be actually visible in the (generated or hand-crafted) code. The state machine will not be visible if there is some kind of run-time system that supports state machine behavior. In the more general case, however, the software code will contain specific statements that implement the state machine behavior.

A C++ example is shown below.

```
class bankAccount {
private:
int balance;
public;
void deposit (amount)
{
 if (balance > 0) balance = balance + amount' // no change
 else
 balance = balance + amount - 1; // $1 charge for the transaction
}
void withdrawal (amount) {
if (balance>0) balance = balance - amount ;
}
}
```

In the above example, the class has an abstract state manifested by the balance attribute, controlling the behavior of the class. This is modeled by the state machine in Figure 2-26 on page 2-128.

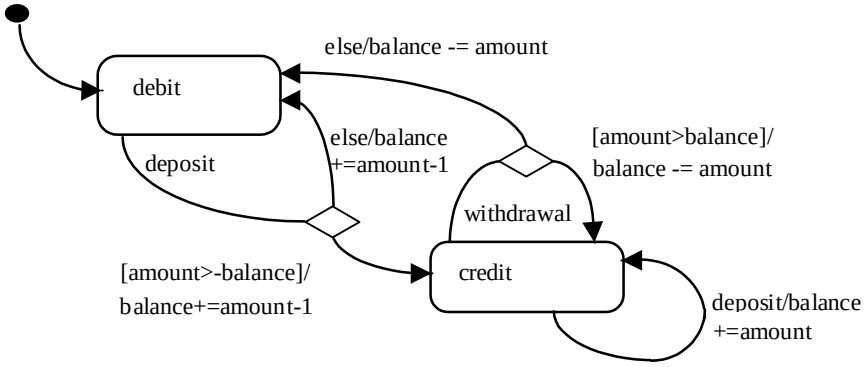


Figure 2-26 State Machine for Modeling Class Behavior

Since state machines describe behaviors of generalizable elements, primarily classes, state machine refinement is used capture the relationships between the corresponding state machines. The refinement mechanism itself is part of the Auxiliary Elements package, and define general refinement relationships between arbitrary model composites.

Example: State machine refinement

Since state machines describe behaviors of generalizable elements, primarily classes, state machine refinement is used capture the relationships between the corresponding state machines. The refinement relationships are facilitated by the refinement metaclass defined in the auxiliary elements package. State machines use refinement in three different mappings, specified by the mapping attribute of the refinement meta-class. The mappings are refinement, substitution, and deletion.

To illustrate state machine refinement, consider the following example where one state machine attached to a class denoted ‘Supplier,’ is refined by another state machine attached to a class denoted as ‘Client.’

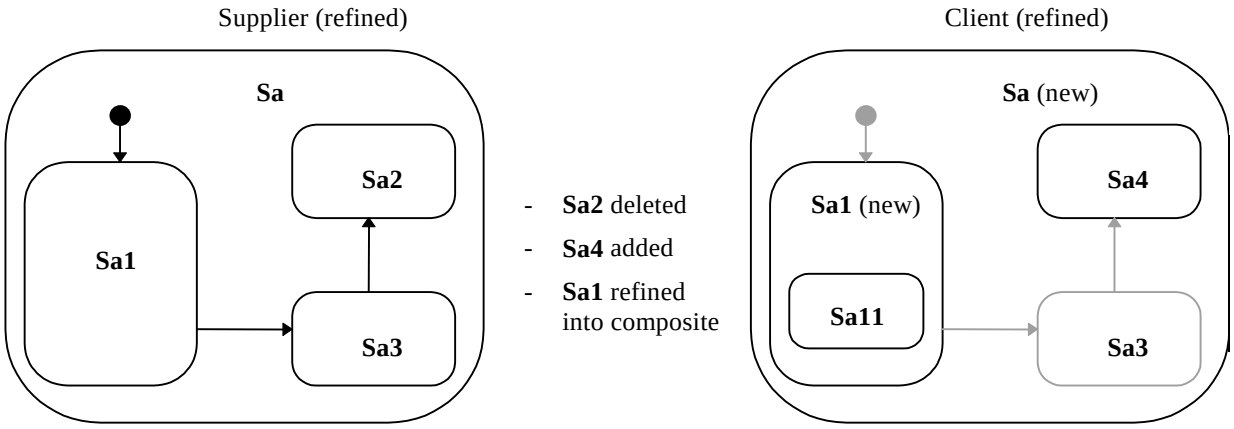


Figure 2-27 State Machine Refinement Example

In the example above, the client state (Sa(new)) in the subclass substitutes the simple substate (Sa1) by a composite substate (Sa1(new)). This new composite substate has a component substate (Sa11). Furthermore, the new version of Sa1 deletes the substate Sa2 and also adds a new substate Sa4. Substate Sa3 is inherited and is therefore common to both versions of Sa. For clarity, we have used a gray shading to identify components that have been inherited from the original. (This is for illustration purposes and is not intended as a notational recommendation.)

It is important to note that state machine refinement as defined here does not specify or favor any specific policy of state machine refinement. Instead, it simply provides a flexible mechanism that allows subtyping, (behavioral compatibility), inheritance (implementation reuse), or general refinement policies.

We provide a brief discussion of potentially useful policies that can be implemented with the state machine refinement mechanism. These policies could be indicated by attaching standard stereotypes (i.e., «subtype» and «inherits») to the refinement relationship between state machines.

Subtyping

The refinement policy for subtyping is based on the rationale that the subtype preserves the pre/post condition relationships of applying events/operations on the type, as specified by the state machine. The pre/post conditions are realized by the states, and the relationships are realized by the transitions. Preserving pre/post conditions guarantee the substitutability principle.

States and transitions are only added, not deleted. Refinement is interpreted as follows:

- A refined State has the same outgoing transitions, but may add others, and a different set of incoming transitions. It may have a bigger set of substates, and it may change its concurrency property from false to true.

- A refined Transition may go to a new target state which is a substate of the state specified in the base class. This comes to guarantee the post condition specified by the base class.
- A refined Guard has the same guard condition, but may add disjunctions. This guarantees that pre-conditions are weakened rather than strengthened.
- A refined ActionSequence contains the same actions (in the same sequence), but may have additional actions. The added actions should not hinder the invariant represented by the target state of the transition.

(Strict) Inheritance

The rationale behind this policy is to encourage reuse of implementation rather than preserving behavior. Since most implementation environment utilize strict inheritance (i.e. features can be replaced or added, but not deleted), the inheritance policy follows this line by disabling refinements which may lead to non-strict inheritance once the state machine is implemented.

States and transitions can be added. Refinement is interpreted as follows:

- A refined State has some of the same incoming transitions (i.e., drop some, add some) but a greater or bigger set of outgoing transitions. It may have more substates, and may change its concurrency attribute.
- A refined Transition may go to a new target state but should have the same source.
- A refined Guard has may have a different guard condition
- A refined ActionSequence contains some of the same actions (in the same sequence), and may have additional actions

General Refinement

In this most general case, states and transitions can be added and deleted (i.e., ‘null’ refinements). Refinement is interpreted without constraints (i.e., there are no formal requirements on the properties and relationships of the refined state machine element and the refining element):

- A refined State may have different outgoing and incoming transitions (i.e., drop all, add some)
- A refined Transition may leave from a different source and go to a new target state
- A refined Guard has may have a different guard condition
- A refined ActionSequence need not contain the same actions (or it may change their sequence), and may have additional actions

The refinement of the composite state in the example above is an illustration of general refinement.

It should be noted that if a type has multiple supertype relationships in the structural model, then the default state machine for the type consists of all the state machines of its supertypes as orthogonal state machine regions. This may be explicitly overridden through refinement if required.

Classical statecharts

The major difference between classical (Harel) statecharts and object state machines result from the external context of the state machine. Object state machines primarily come to represent behavior of a type. Classical statechart specify behaviors of processes. The following list of differences result from the above rationale:

- Events carry parameters, rather than being primitive signals
- Call events (operation triggers) are supported to model behaviors of types
- Event conjunction is not supported, and the semantics is given in respect to a single event dispatch, to better match the type context as opposed to a general system context.
- Classical statecharts have an elaborated set of predefined actions, conditions and events which are not mandated by object state machines, such as entered(s), exited(s), true(condition), tr!(c) (make true), fs!(c).
- Operations are not broadcast but can be directed to an object-set.
- The notion of activities (processes) does not exist in object state machines. Therefore all predefined actions and events that deal with activities are not supported, as well as the relationships between states and activities.
- Transition compositions are constrained for practical reasons. In classical statecharts any composition of pseudo states, simple transitions, guards and labels is allowed.
- Object state machine support the notion of synchronous communication between state machines.
- Actions on transitions are executed in their given order.
- Classical statecharts are based on the zero-time assumption, meaning transitions take zero time to execute. The whole system execution is based on synchronous steps where each step produces new events that will be processed at the next step. In OO state machines, this assumptions are relaxed and replaced with these of software execution model, based on threads of execution and that execution of actions do take time.

2.13.7 Activity Models

Activity models define an extended view of the State Machine package. State machines and activity models are both essentially state transition systems, and share many metamodel elements. This section describes the concepts in the State Machine package that are specific to activity models. It should be noted that the activity models

extension has few semantics of its own. It should be understood in the context of the State Machine package, including its dependencies on the Foundation package and the Common Behavior package.

An activity model is a special case of a state machine model that is used to model processes involving one or more classifiers. **Most of the states in such a model are action states that represent atomic actions, i.e., states that invoke actions and then wait for their REVIEWER: PLEASE FINISH THIS SENTENCE**. Transitions into action states are triggered by events, which can be

- the completion of a previous action state,
- the availability of an object in a certain state,
- the occurrence of a signal; or
- the satisfaction of some condition.

By defining a small set of additional subtypes to the basic state machine concepts, the well-formedness of activity models can be defined formally, and subsequently mapped to the dynamic semantics of state machines. In addition, the activity specific subtypes eliminate ambiguities that might otherwise arise in the interchange of activity models between tools.

2.13.7.1 Abstract Syntax

The abstract syntax for activity models is expressed in graphic notation in Figure 2-1 on page 2-133.

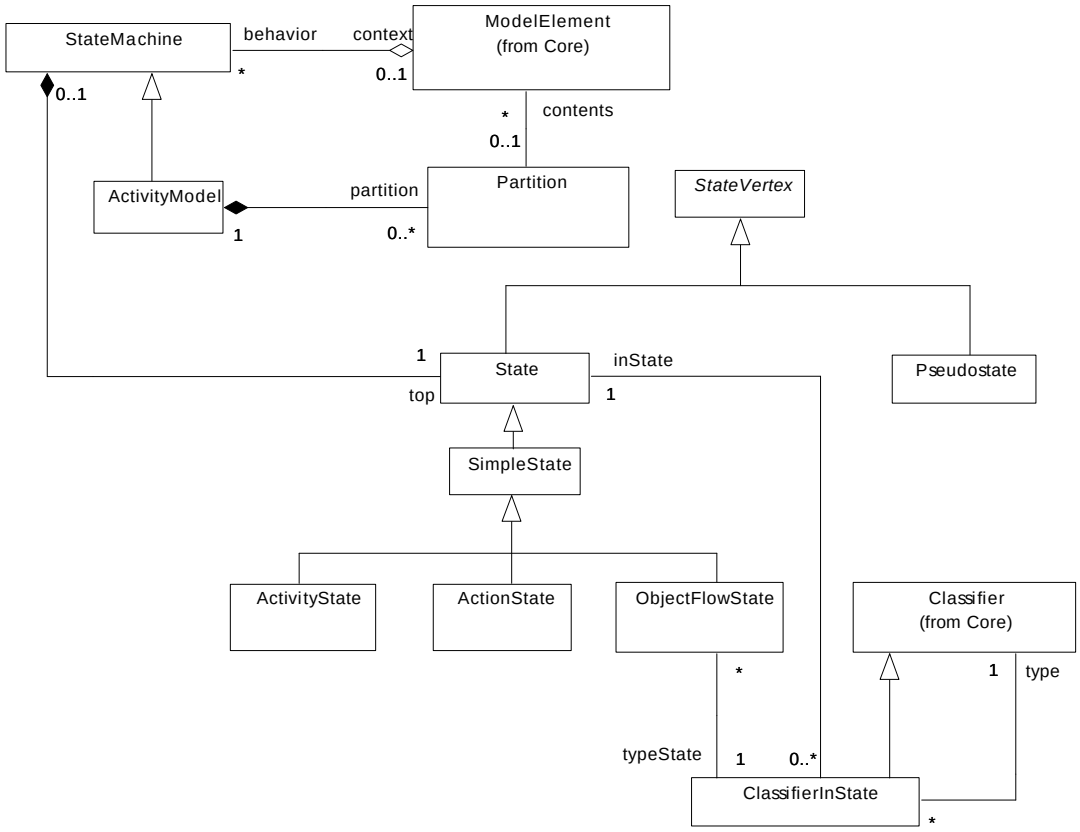


Figure 2-1 Activity Models

ActivityModel

An activity model is a special case of a state machine that defines a computational process in terms of the control-flow and object-flow among its constituent actions. It does not extend the semantics of state machines but it does define shorthand forms that are convenient for modeling computational processes.

The primary basis for ActivityModels is to describe a state model of an activity or process involving one or more Classifiers. ActivityModels can be attached to Packages, Classifiers (including UseCases) and BehavioralFeatures. Most of the States in an activity model are ActionStates (i.e., states in which an action is being performed, typically the execution operations). As in any state machine, if an outgoing transition is not explicitly triggered by an event then it is implicitly triggered by the completion of the contained actions. An ActivityState represents structured subactivity that has some duration and internally consists of a set of actions. That is, an ActivityState is a "hierarchical action" with an embedded activity submodel that ultimately resolves to individual actions.

Ordinary "wait states" can be included to model situations in which the computation waits for an external event. Branches, forks, and joins may also be included to model decisions and concurrent activity.

ActivityModels include the concept of Partitions to organize states according to various criteria, such as the real-world organization responsible for their performance.

Activity modeling can be applied in the context of organizational modeling for business process engineering and workflow modeling. In this context, events often originate from ‘outside’ the system (e.g., ‘customer call’). Activity models can also be applied to system modeling to specify the dynamics of operations and system level processes when a full interaction model is not needed.

Associations

partition	A set of Partitions each of which contains some of the model elements of the model.

ActionState

An action state represents the execution of an atomic action, typically the invocation of an operation.

An ActionState is a SimpleState with an entry action whose only exit Transition is triggered by the implicit event of completing the execution of the entry action. The state therefore corresponds to the execution of the entry action itself and the outgoing Transition is activated as soon as the action has completed its execution.

An ActionState may perform more than one Action as part of its entry ActionSequence. An ActionState may not have an exit transition, internal transitions, or external transitions triggered by anything other than the implicit action completion event.

Associations

entry	(Inherited from State) Specifies the invoked actions.

ActivityState

An activity state represents the execution of a non-atomic sequence of steps that has some duration (i.e., internally it consists of a set of actions and possibly waiting for events). That is, an activity state is a "hierarchical action," where an associated sub-activity model is executed.

An ActivityState is a SubmachineState that executes a nested activity model. When an input transition to the ActivityState is triggered, execution begins with the initial state of the nested ActivityModel. The outgoing Transition of an ActivityState is enabled when the final state of the nested ActivityModel is reached (i.e., when it completes its execution).

The semantics of an ActivityState are equivalent to the model obtained by statically substituting the contents of the nested model as a composite state replacing the activity state.

Associations

submachine	(Inherited from SubmachineState) Designates an activity model that is conceptually nested within the activity state. The activity state is conceptually equivalent to a CompositeState whose contents are the states of the nested ActivityModel. The nested activity model must have an initial state and a final state.

ClassifierInState

A classifier in state characterizes instances of a given classifier for a particular state. In an activity model, it may be input and/or output to an action through an object flow state.

ClassifierInState is a subtype of Classifier and may be used in static structural models and collaborations (e.g., it can be used to show associations that are only relevant when objects of a class are in a given state).

Associations

type	Designates a Classifier that characterizes instances.
inState	Designates a State that characterizes instances. The state must be a valid state of the corresponding Classifier.

ObjectFlowState

An object flow state defines an object flow between actions in an activity model. It signifies the availability of an instance of a classifier in a given state, usually as the result of an operation. This state indicates that an instance of the given class having the given state is available when the state is occupied.

The generation of an object by an action in an ActionState may be modeled by an ObjectFlowState that is triggered by the completion of the ActionState. The use of the object in a subsequent ActionState may be modeled by connecting the output transition of the ObjectFlowState as an input transition to the ActionState. Generally each action places the object in a different state that is modeled as a distinct ObjectFlowState.

Associations

typeState	Designates the class (or other classifier) and state of the object.

Partition

A partition is a mechanism for dividing the states of an activity model into groups. Partitions often correspond to organizational units in a business model. They may be used to allocate characteristics or resources among the states of an activity model.

Associations

contents	Specifies the states that belong to the partition. They need not constitute a nested region.

It should be noted that Partitions do not impact the dynamic semantics of the model but they help to allocate properties and actions for various purposes.

PseudoState

A pseudo state is an abstraction of different types of nodes in a state machine graph which function as transient points in transitions from one state to another, such as branching and forking.

Final PseudoStates are used for modeling hierarchical activities. A transition to a final PseudoState within an ActivityModel can be used to indicate completion of a sub-ActivityModel such that execution is resumed at the superstate level (i.e. outgoing superstate transitions will be activated). A nested activity model must have both an initial state and a final state or states.

2.13.7.2 Well-Formedness Rules

ActivityModel

[1] An ActivityModel specifies the dynamics of

(i) a Package, or

(ii) a Classifier (including UseCase), or

(iii) a BehavioralFeature.

(self.context.oclIsTypeOf(Package) **xor**
self.context.oclIsKindOf(Classifier) **xor**
self.context.oclIsKindOf(BehavioralFeature))

[2] An ActivityModel that specifies the dynamics of a BehavioralFeature or that is nested has exactly one initial State, representing the invocation of the BehavioralFeature or subactivity.

ActionState

[1] An ActionState has exactly one outgoing Transition.

```
self.outgoing->size = 1
```

[2] An ActionState has a non-empty Entry ActionSequence.

```
self.entry.action->size > 0
```

[3] An ActionState does not have an internal Transition or an Exit ActionSequence.

```
self.internalTransition->size = 0 and self.exit->size = 0
```

ObjectFlowState

[1] The ClassifierInState of the ObjectFlowState is the type of an input Parameter to an Operation invoked in the ActionStates which have the ObjectFlowState on an incoming Transition.

```
self.outgoing.target->select(oclIsTypeOf(ActionState)).
        invoked.parameter->select(
                kind = #in or kind = #inout).type->includes(self.typeState.type)
```

[2] The ClassifierInState of the ObjectFlowState is the type of an output Parameter of an Operation invoked in the ActionStates which have the ObjectFlowState on an outgoing Transition.

```
self.incoming.source->select(oclIsTypeOf(ActionState)).
        invoked.parameter->select(
                kind = #out or kind = #inout or kind = #return).
                        type->includes(self.typeState.type)
```

PseudoState

[1] In ActivityModels, Transitions incoming to (and outgoing from) join and fork PseudoStates have as sources (targets) any StateVertex. That is, joins and forks are syntactically not restricted to be used in combination with CompositeStates, as is the case in StateMachines.

```
self.stateMachine.oclIsTypeOf(ActivityModel) implies
    ((self.kind = #join or self.kind = #fork) implies
        (self.incoming->forAll(source.oclIsKindOf(SimpleState) or
          source.oclIsTypeOf(PseudoState)) and
        (self.outgoing->forAll(source.oclIsKindOf(SimpleState) or
          source.oclIsTypeOf(PseudoState)))))
```

[2] All of the paths leaving a fork must eventually rejoin in a subsequent join or joins. Furthermore, if there are multiple layers of joins they must be well nested. Therefore the concurrency structure of an activity model is in fact equally restrictive as that of an ordinary state machine, even though the composite states need not be explicit.

2.13.7.3 Semantics

ActivityModel

The dynamic semantics of activity models can be expressed in terms of state machines. This means that the process structure of activities formally must be equivalent to orthogonal regions (in composite states). That is, transitions crossing between parallel paths (or threads) are not allowed. As such, an activity specification that contains 'unconstrained parallelism' as is used in general activity models is considered 'incomplete' in terms of UML.

All events that are not relevant in a state must be deferred so they are consumed when become relevant. This is facilitated by the general deferral mechanism of state machines.

ActionState

As soon as the incoming transition of an ActionState is triggered (either through a single transition or through an conjunction of transitions connected to a 'join'), its entry action starts executing. Once the entry action has finished executing, the action is considered completed. Hence, formally, an activated action state signifies that the execution of an action is ongoing. When the action is complete then the outgoing transition (either a simple transition or a 'fork') is enabled.

ObjectFlowState

The activation of an ObjectFlowState signifies that an instance of the associated Classifier is available in a specified State (i.e., a state change has occurred as a result of a previous operation). This may enable a subsequent action state that requires the instance as input. The execution of the action consumes the value. If the ObjectFlowState leads into a join pseudostate, then the ObjectFlowState remains activated until the other predecessors of the join have completed.

Unless there is an explicit 'fork' that creates orthogonal object states, only one of an ObjectFlowState's outgoing transitions will fire, based on the activation of the first ActionState that requires it as input. The invocation of the ActionState will generally result in a state change of the object, resulting in a new ObjectFlowState.

2.13.7.4 Notes

Object-flow states in activity models are a specialization of the general dataflow aspect of process models. Object-flow activity models extend the semantics of standard dataflow relationships in three areas:

1. The operations in action states in activity models are operations of classes or types (e.g., ‘Trade’ or ‘OrderEntryClerk’). They are not hierarchical ‘functions’ operating on a dataflow.
2. The ‘contents’ of object flow states are typed. They are not unstructured data definitions as in data stores.
3. The state of the object flowing as input and output between operations is defined explicitly. It is the event of the availability of an object in a specific state that forms a trigger for the operation that requires the object as input. Object flow states are not stateless, passive data definitions as are data stores.

Part 4 - General Mechanisms

2.14 Model Management

This section defines the mechanisms of general applicability to models. This version of UML contains one general mechanisms package, Model Management. The Model Management package specifies how model elements are organized into models, packages, and systems.

2.14.1 Overview

The Model Management package is a subpackage of the Behavioral Elements package. It defines Model, Package, and Subsystem elements that serve mainly as grouping units for other ModelElements. The package uses constructs defined in the Foundation package of UML as well as in the Common Behavior package.

Packages are used within a Model to group ModelElements. A Subsystem is a special kind of Package with an additional specification of the behavior offered by ModelElements in the Subsystem.

In this section the term modeled system denotes the physical entity being modeled with UML (i.e., the term is not one of the constructs in the modeling language). It can denote a computer system, like a seat assignment system, a banking system, or a telephone exchange system. It can also describe business processes, like a sales process, or a development process. An analogy with the construction of houses would be that house would correspond to modeled system, while blue print would correspond to model, and element used in a blue print would correspond to model element in UML.

The following sections describe the abstract syntax, well-formedness rules, and semantics of the Model Management package.

2.14.2 Abstract Syntax

The abstract syntax for the Model Management package is expressed in graphic notation in Figure 2-1.

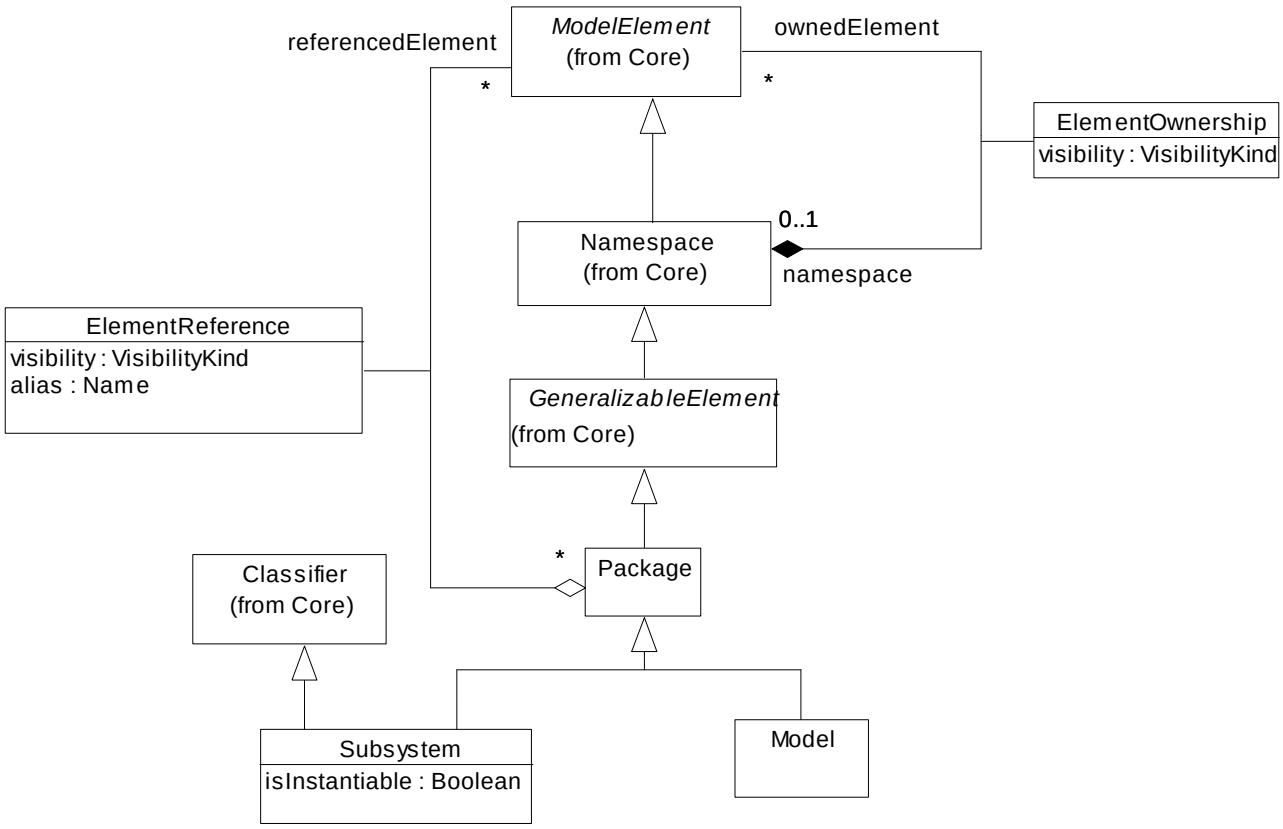


Figure 2-1 Model Management

ElementReference

An element reference defines the visibility and alias of a model element referenced by a package.

In the metamodel an ElementReference reifies the relationship between a Package and a ModelElement. It defines the alias for the ModelElement inside the Package and the visibility of the ModelElement relative to the Package.

Attributes

alias	The alias defines a local name of the referenced ModelElement, to be used within the Package.
visibility	Each referenced ModelElement is either public, protected, or private relative to the referencing Package.

Associations

No extra associations.

Model

A model is an abstraction of a modeled system, specifying the modeled system from a certain viewpoint and at a certain level of abstraction. A model is complete in the sense that it fully describes the whole modeled system at the chosen level of abstraction and viewpoint.

In the metamodel, Model is a subclass of Package. It contains a containment hierarchy of ModelElements that together describe the modeled system. A Model also contains a set of ModelElements, like Actors, which represents the environment of the system, together with their interrelationships, such as Dependencies and Generalizations, and Constraints.

Different Models can be defined for the same modeled system, specifying it from different viewpoints, like a logical model, a design model, a use-case model, etc. Each Model is self-contained within its viewpoint of the modeled system and within the chosen level of abstraction.

Attributes

No extra attributes.

Associations

No extra associations.

Package

A package is a grouping of model elements.

In the metamodel, a Package is a GeneralizableElement. A Package contains ModelElements like Packages, Classifiers, and Associations. A Package may also contain Constraints and Dependencies between ModelElements of the Package.

A Package may have «import» dependencies to other Packages, allowing ModelElements in the other Packages to be used by ModelElements in the first Package. The ModelElements available in a Package are those owned by the Package

together with those referenced (i.e., owned by other, imported Packages). Furthermore, each ModelElement of a Package has a visibility relative to the Package stating if the ModelElement is visible outside the Package or to a specialization of the Package.

Attributes

No extra attributes.

Associations

referencedElement	A Package references ModelElements in other imported Packages.

Subsystem

A subsystem is a grouping of model elements, of which some constitute a specification of the behavior offered by the other contained model elements.

In the metamodel, Subsystem is a subclass of both Package and Classifier, whose Features are all Operations. The contents of a Subsystem is divided into two subsets: 1) specification elements and 2) realization elements. The former provides, together with the Operations of the Subsystem, a specification of the behavior contained in the Subsystem, while the ModelElements in the latter subset jointly provide a realization of the specification.

The specification elements are UseCases together with their offered Interfaces, Constraints and relationships. The realization elements are Classes and Subsystems together with their associated Interfaces, Constraints, and relationships. The relationship between the specification elements and the realization elements is defined with a set of Collaborations.

Attributes

isInstantiable	States whether a Subsystem is instantiable or not. If true, then the instances of the model elements within the subsystem form an implicit composition to an implicit subsystem instance, whether or not it is actually implemented.

Associations

No extra associations.

2.14.3 Well-Formedness Rules

The following well-formedness rules apply to the Model Management package.

ElementReference

No extra well-formedness rules.

Model

No extra well-formedness rules.

Package

[1] A Package may only own or reference Packages, Subsystems, Classifiers, Associations, Generalizations, Dependencies, Constraints, Collaborations, Messages,and Stereotypes.

```
self.contents->forAll ( c |
        c.oclIsKindOf(Package)or
        c.oclIsKindOf(Subsystem)  or
        c.oclIsKindOf(Classifier)or
        c.oclIsKindOf(Association)or
        c.oclIsKindOf(Generalization)or
        c.oclIsKindOf(Dependency)or
        c.oclIsKindOf(Constraint)or
        c.oclIsKindOf(Collaboration)or
        c.oclIsKindOf(Message)or
        c.oclIsKindOf(Stereotype) )
```

[2] No referenced element (excluding Association) may have the same name or alias as any element owned by the Package or one of its supertypes.

```
self.allReferencedElements->reject( re |
    re.oclIsKindOf(Association) )->forAll( re |
        (re.elementReference.alias <> '' implies
            not (self.allContents - self.allReferencedElements)->reject( ve |
                ve.oclIsKindOf (Association) )->exists ( ve |
                    ve.name = re.elementReference.alias))
        and
        (re.elementReference.alias = '' implies
            not (self.allContents - self.allReferencedElements)->reject ( ve |
                ve.oclIsKindOf (Association) )->exists ( ve |
                    ve.name = re.name) ) )
```

[3] Referenced elements (excluding Association) may not have the same name or alias.

```
self.allReferencedElements->reject( re |
    not re.oclIsKindOf (Association) )->forAll( r1, r2 |
        (r1.elementReference.alias <> '' and r2.elementReference.alias <> '' and
            r1.elementReference.alias = r2.elementReference.alias implies r1 = r2)
        and
        (r1.elementReference.alias = '' and r2.elementReference.alias = '' and
            r1.name = r2.name implies r1 = r2)
```

```
        and
        (r1.elementReference.alias <> '' and r2.elementReference.alias = '' implies
            r1.elementReference.alias <> r2.name))
```

[4] No referenced element (Association) may have the same name or alias combined with the same set of associated Classifiers as any Association owned by the Package or one of its supertypes.

```
self.allReferencedElements->select( re |
    re.oclIsKindOf(Association) )->forAll( re |
        (re.elementReference.alias <> '' implies
            not (self.allContents - self.allReferencedElements)->select( ve |
                ve.oclIsKindOf(Association) )->exists( ve : Association |
                    ve.name = re.elementReference.alias
                    and
                    ve.connection->size = re.connection->size and
                    Sequence {1..re.connection->size}->forAll( i |
                        re.connection->at(i).type = ve.connection->at(i).type ) ) )
        and
        (re.elementReference.alias = '' implies
            not (self.allContents - self.allReferencedElements)->select( ve |
                not ve.oclIsKindOf(Association) )->exists( ve : Association |
                    ve.name = re.name
                    and
                    ve.connection->size = re.connection->size and
                    Sequence {1..re.connection->size}->forAll( i |
                        re.connection->at(i).type = ve.connection->at(i).type ) ) ) )
```

[5] Referenced elements (Association) may not have the same name or alias combined with the same set of associated Classifiers.

```
self.allReferencedElements->select ( re |
    re.oclIsKindOf (Association) )->forAll ( r1, r2 : Association |
        (r1.connection->size = r2.connection->size and
        Sequence {1..r1.connection->size}->forAll ( i |
            r1.connection->at (i).type = r2.connection->at (i).type and
        r1.elementReference.alias <> '' and r2.elementReference.alias <> '' and
            r1.elementReference.alias = r2.elementReference.alias implies r1 = r2))
        and
        (r1.connection->size = r2.connection->size and
         Sequence {1..r1.connection->size}->forAll ( i |
             r1.connection->at (i).type = r2.connection->at (i).type and
          r1.elementReference.alias = '' and r2.elementReference.alias = '' and
             r1.name = r2.name implies r1 = r2))
        and
```

```
(r1.connection->size = r2.connection->size and
Sequence {1..r1.connection->size}->forAll ( i |
    r1.connection->at (i).type = r2.connection->at (i).type and
r1.elementReference.alias <> '' and r2.elementReference.alias = '' implies
    r1.elementReference.alias <> r2.name)))
```

[6] The referenced elements of a Package are the public elements of imported Packages, transitively.

```
self.referencedElement = self.requirement->select (d |
    d.stereotype.name = 'import').supplier.oclAsType(Package).allVisibleElements
```

[7] A Package imports all its owned Packages.

```
self.requirement->select (s |
    s.stereotype.name = 'import').supplier->includesAll(
        self.ownedElement->select ( e | e.oclIsKindOf (Package)
```

Additional Operations

[1] The operation contents results in a Set containing the ModelElements owned by or imported by the Package.

```
contents : Set(ModelElement)
contents = self.ownedElement->union(self.referencedElement)
```

[2] The operation allReferencedElements results in a Set containing the ModelElements referenced by the Package or one of its supertypes.

```
allReferencedElements : Set(ModelElement)
allReferencedElements = self.referencedElement->union(
    self.supertype.oclAsType(Package).allReferencedElements->select( re |
        re.elementReference.visibility = #public or re.elementReference.visibility = #protected))
```

Subsystem

[1] For each Operation in an Interface offered by a Subsystem, the Subsystem itself or at least one contained UseCase must have a matching Operation.

```
self.specification.allOperations->forAll(interOp |
    self.allOperations->union(self.allSpecificationElements.allOperations)->exists
        ( op | op.hasSameSignature(interOp) ) )
```

[2] The Features of a Subsystem may only be Operations.

```
self.feature->forAll(f | f.oclIsKindOf(Operation))
```

[3] Each Operation must be realized by a Collaboration.

```
not self.isAbstract implies self.allOperations->forAll( op |
    self.allContents->select(c |
        c.oclIsKindOf(Collaboration) )->exists(c : Collaboration|
                                    c.representedOperation = op ) )
```

[4] Each specification element must be realized by a Collaboration.

```
not self.isAbstract implies self.allSpecificationElements->forAll( s |
    self.allContents->select(c |
        c.oclIsKindOf(Collaboration) )->exists(c : Collaboration|
            c.representedClassifier = s ) )
```

Additional Operations

[1] The operation allSpecificationElements results in a Set containing the ModelElements specifying the behavior of the Subsystem.

```
allSpecificationElements : Set(UseCase)
allSpecificationElements = self.allContents->select(c | c.oclIsKindOf(UseCase) )
```

2.14.4 Semantics

Package

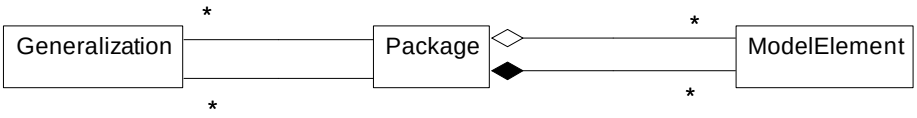


Figure 2-2 Package Illustration

The purpose of the package construct is to provide a general grouping mechanism. A package cannot be instantiated, thus it has no runtime semantics. In fact, its only semantics is to define a namespace for its contents. The package construct can be used for element organization of any purpose; the criteria to use for grouping elements together into one package are not defined within UML.

A package owns a set of model elements, with the implication that if the package is removed from the model, so are the elements owned by the package. Elements owned by the same package must have unique names within the package, although elements in different packages may have the same name.

There may be relationships between elements contained in the same package, but not a priori between an element in one package and an element outside that package. In other words, elements outside a package are by default not available to elements inside the package. There are two ways of making them available inside the package: 1) by importing their containing packages or 2) by defining generalizations to these other packages.

An import dependency (a Dependency with the stereotype «import») from one package to another means that the first package references all the elements with sufficient visibility in the second package. Referenced elements are not owned by the package; however, they may be used in associations, generalizations, attribute types, and other relationships. A package defines the visibility of its contained elements to be private, protected, or public. Private elements are not available at all outside the containing package. Protected elements are available only to packages with generalizations to the

containing package, and public elements are available also to importing packages. Note that the visibility mechanism does not restrict the availability of an element to peer elements in the same package.

When an element is referenced by a package it extends the namespace of that package. It is possible to give a referenced element an alias so that it will not conflict with the names of the other elements in the namespace, including other referenced elements. The alias will be the name of that element in the namespace. The element will not appear under both the alias and its original name. If an element is not given an alias, then it must be identified using its pathname (i.e., the concatenation of the names of the enclosing packages starting with the top-most package). Furthermore, an element may have the same or a more restrictive visibility in a package referencing it than it has in the package owning it (e.g., an element that is public in one package may be protected or private to a package referencing the element).

A package importing another package references all the public contents of the namespace defined by the imported package, including elements of packages imported by the imported package. This implies that import of packages is transitive, more specifically in the following sense: Assume package A imports package B, which in turn imports package C, then the public elements of C which are public in B are also available to A.

Packages are automatically imported by their containing package. Because of the recursiveness of import, even elements contained within several levels of packages are available, according to the visibility of contained elements. The visibility of an element contained within several levels of packages is the most restrictive of the visibilities of all containing packages.

A package can have generalizations to other packages. This means that the public and protected elements owned or referenced by a package are also available to its heirs, and can be used in the same way as any element referenced by the heirs themselves. Elements made available to another package by the use of a generalization appear under their real names, not under aliases. Moreover, they have the same visibility in the heir as they have in the owning package.

A package can be used to define a framework, consisting of patterns in the form of collaborations where (some of) the base elements are the parameters of the patterns. Apart from that, a framework package is described as an ordinary package.

Subsystem

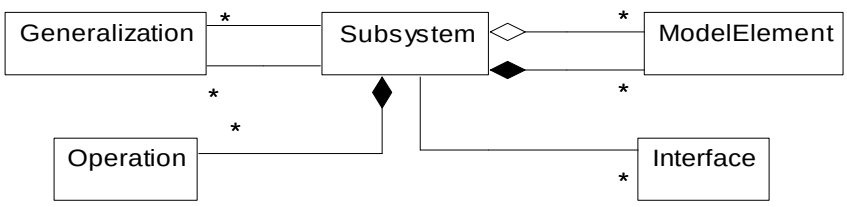


Figure 2-3 Subsystem Illustration

The purpose of the subsystem construct is to provide a grouping mechanism with the possibility to specify the behavior of the contents. A subsystem may or may not be instantiable. A non-instantiable subsystem merely defines a namespace for its contents. The contents of a subsystem have the same semantics as that of a package, thus it consists of ownedElements and referencedElements, with unique names or aliases within the subsystem.

The contents of a subsystem is divided into two subsets: 1) specification elements and 2) realization elements. The specification elements are used for giving an abstract specification of the behavior offered by the realization elements.

The specification of a subsystem consists of the specification subset of the contents together with the subsystem's features (operations). It specifies the behavior performed jointly by instances of classifiers in the realization subset, without revealing anything about the contents of this subset. The specification is made in terms of use cases and/or operations, where use cases are used to specify complete sequences performed by the subsystem (i.e., by instances of its contents) interacting with its surroundings, while operations only specify fragments. Furthermore, the specification part of a subsystem also includes constraints, relationships between the use cases, etc.

A subsystem has no behavior of its own. All behavior defined in the specification of the subsystem is jointly offered by the elements in the realization subset of the contents. In general, since they are classifiers, subsystems can appear anywhere a classifier is expected. The general interpretation of this is that since the subsystem itself cannot be instantiated or have any behavior of its own, the requirements posed on the subsystem in the context where it occurs is fulfilled by its contents. The same is true for associations (i.e., any association connected to a subsystem is actually connected to one of the classifiers it contains).

The correspondence between the specification part and the realization part of a subsystem is specified with a set of collaborations, at least one for each operation of the subsystem and for each contained use case. Each collaboration specifies how instances of the realization elements cooperate to jointly perform the behavior specified by the use case or operation (i.e., how the higher level of abstraction is transformed into the lower level of abstraction). A message instance received by an instance of a use case (higher level of abstraction) corresponds to an instance conforming to one of the classifier roles in the collaboration receiving that message instance (lower level of abstraction). This instance communicates with other instances conforming to other classifier roles in the collaboration, and together they perform the behavior specified by the use case. All message instances that can be received and sent by instances of the use cases are also received and sent by the conforming instances, although at a lower level of abstraction. Similarly, application of an operation of the subsystem actually means that a message instance is sent to a contained instance which then performs a method.

Importing subsystems is done in the same way as packages, using the visibility property to define whether elements are public, protected, or private to the subsystem.

A subsystem can have generalizations to other subsystems. This means that the public and protected elements in the contents of a subsystem are also available to its heirs. In a concrete (i.e., non-abstract) subsystem all elements in the specification, including

elements from ancestors, must be completely realized by cooperating realization elements, as specified with a set of collaborations. This may not be true for abstract subsystems.

Subsystems may offer a set of interfaces. This means that for each operation defined in an interface, the subsystem offering the interface must have a matching operation, either as a feature of the subsystem itself or of a use case. The relationship between interface and subsystem is not necessarily one-to-one. A subsystem may realize several interfaces and one interface may be realized by more than one subsystem.

A subsystem can be used to define a framework, consisting of patterns in the form of collaborations where (some of) the base elements are the parameters of the patterns. Furthermore, the specification of a framework subsystem may also be parameterized.

Model

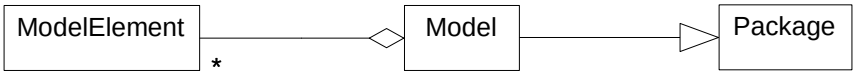


Figure 2-4 Model Illustration

The purpose of a model is to describe the modeled system at a certain level of abstraction and from a specific viewpoint, such as a logical or a behavioral view of the modeled system.

A model describes the modeled system completely in the sense that it covers the whole modeled system, although only those aspects relevant within the chosen level of abstraction and viewpoint are represented in the model. The model consists of a containment hierarchy where the top-most package represents the boundary of the modeled system.

The model may also contain model elements describing relevant parts of the system's environment. The environment may be modeled by actors and their interfaces. These model elements and the model elements representing the modeled system may be associated with each other. Such associations are owned either by the model or by the top-most package. The contents of a model is the transitive closure of its owned model elements, like packages, classifiers, and relationships.

Relationships between model elements in different models have no impact on the model elements' meaning in their containing models because of the self-containment of models. Note that even if inter-model relationships do not express any semantics in relation to the models, they may have semantics in relation to the reader or in deriving model elements as part of the overall development process.

A model may be a specialization of another model. This implies that all elements in the ancestor are also available in the specialized model under the same name as in the ancestor.

2.14.5 Standard Elements

The predefined stereotypes, constraints, and tagged values for the Model Management package are listed in Table 2-7 and defined in Appendix A - UML Standard Elements.

Table 2-7 Model Management - Standard Elements

Model Element	Stereotypes	Constraints	Tagged Values
Model	«useCaseModel»		
Package	«facade» «framework» «stub» «system» «topLevelPackage»		

2.14.6 Notes

Because this is a logical model of the UML, distribution or sharing of models between tools is not described.

The visibility of an element in an importing package/subsystem may be more restrictive than its visibility in the owning namespace. This is useful for example when a namespace makes parts of its contents public to the surrounding namespace, but these elements are not available to the outside of the surrounding namespace.

In UML, there are three different ways to model a group of elements contained in another element; by using a package, a subsystem, or a class. Some pragmatics on their use include:

- Packages are used when nothing but a plain grouping of elements is required.
- Subsystems provide grouping suitable for top-down development, since the requirements on the behavior of their contents can be expressed before the realization of this behavior is defined. The specification of a subsystem may also be seen as a provider of "high level APIs" of the subsystem.
- Classes are used when the container itself should be instantiable, so that it is possible to define composite objects.