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Kernel Modeling Language (KerML)

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0 Submission Introduction

0.1 Submission Overview

This document is the first of two documents submitted in response to the Systems Modeling Language (SysML®) v2 Request for Proposals (RFP) (ad/2017-11-04). This document defines a *Kernel Modeling Language (KerML)* that provides a syntactic and semantic foundation for creating application specific modeling languages. The second document specifies the *Systems Modeling Language (SysML)*, version 2.0, built on this foundation.

Even though both documents are being submitted together to fulfill the requirements of the RFP, the present document for KerML is proposed as a separate specification from SysML v2. KerML provides a common basis for creation of new modeling languages (or evolution of existing modeling languages). It moves beyond the syntactic interoperability offered by MOF to the possibility of diverse modeling languages that tailored to specific application while maintaining fundamental semantic interoperability.

Release note. The present document is an update to the initial submission document submitted to OMG in August 2020.

0.2 Submission Submitters

The following OMG member organizations are jointly submitting this proposed specification:

- 88Solutions Corporation
- Dassault Systèmes
- GfSE e.V.
- IBM
- INCOSE
- InterCax LLC
- Lockheed Martin Corporation
- MITRE
- Model Driven Solutions, Inc.
- PTC
- Simula Research Laboratory AS
- Thematrix

The submitters also thankfully acknowledge the support of over 60 other organizations that participated in the SysML v2 Submission Team (SST).

0.3 Submission - Issues to be discussed

6.7.1 Proposals shall describe a proof of concept implementation that can successfully execute the test cases that are required in 6.5.4.

The SST is developing a pilot implementation of the full KerML abstract syntax and textual concrete syntax. There have been four quarterly public releases of this pilot implementation so far, the last being the 2020-06 version released at the beginning of July 2020. However, since the conformance test suite has not been developed as of the time of this initial submission, it is not possible to formally demonstrate the conformance of the implementation to the proposed specification. Nevertheless, with few exceptions, this proposed specification describes the language as it has been implemented. For those specific areas in which the pilot implementation as of the 2020-06 release is known to not fully conform to the initial submission of the KerML specification, the deviations are identified in "implementation notes" in this document. The SST is currently planning on releasing the 2020-09 version of the pilot implementation as open source, at which time it is intended that the implementation be fully conformant with the initial submission of this specification.

6.7.2 Proposals shall provide a requirements traceability matrix that demonstrates how each requirement in the RFP is satisfied. It is recognized that the requirements will be evaluated in more detail as part of the submission process. Rationale should be included in the matrix to support any proposed changes to these requirements.

See subclause 0.4 in the proposed *Systems Modeling Language (SysML), Version 2.0* specification document submitted along with the present document.

6.7.3 Proposals shall include a description of how OMG technologies are leveraged and what proposed changes to these technologies are needed to support the specification.

As required in the SysML v2 RFP, the abstract syntax for KerML is defined as a model that is consistent with the OMG Meta Object Facility [MOF] as extended with MOF Support for Semantic Structures [SMOF] (see [7.1.4](#)). This also allows KerML models represented in the KerML abstract syntax to be interchange using OMG XML Metadata Interchange [XMI].

The OMG MOF standard has been used to define many OMG-standardized modeling languages, and the KerML language definition is also built on it. However, MOF and XMI only standardize the means for specifying the abstract syntax of a modeling language and interchanging models so specified. Even SMOF provides only limited additional support for the syntactic structures required for so-called "semantic" languages.

The goal of KerML is to go beyond this and to become a new OMG standard providing application-independent syntax *and semantics* for creating more specific modeling languages (as described further in [Clause 1](#)). This will allow not only syntactic interchange between modeling tools, but also semantic interoperability. The KerML specification is being submitted as part of the SysML v2 submission, because the SST has built SysML v2 on KerML in exactly this way.

0.4 Language Requirement Tables

See subclause 0.4 of the proposed *Systems Modeling Language (SysML), Version 2.0* specification document submitted along with the present document.

1 Scope

The Kernel Modeling Language (KerML) provides an application-independent syntax and semantics for creating more specific modeling languages. *Modeling languages* are for expressing *models* of some (real or virtual) system of interest. Subclause [6.1](#) outlines the relationship of modeling languages, models, and modeled systems.

The KerML *metamodel* includes concrete and abstract syntax for KerML (see [Clause 7](#)). The concrete syntax provides a notation for expressing system models, while the abstract syntax derived from it is given semantics. Application specific modeling languages can be build on KerML by extending the abstract syntax, specializing its semantics, with concrete syntaxes similar to or entirely different from KerML's.

The specification also includes *model libraries* expressed in KerML concrete syntax (see [Clause 8](#)). These capture typical semantic patterns (such as asynchronous transfers and state-based behavior) that can be reused by languages built on KerML. Specialized modeling languages can provide additional syntax for these libraries, tailored to their applications, with semantics based largely or entirely on the KerML libraries.

The circularity of KerML model libraries expressed in KerML itself is broken by the mathematical semantics of a small *core* subset of the language (see [7.3](#)). The parts of the metamodel built on the core have its mathematical semantics by specialization. This means the KerML libraries have this grounding, providing a consistent basis for mathematical reasoning about models based on these libraries.

2 Conformance

This specification defines the Kernel Modeling Language (KerML), a language used to construct *models* of (real or virtual, planned or imagined) things. The specification includes this document and the content of the machine-readable files listed on the cover page. If there are any conflicts between this document and the machine-readable files, the machine-readable files take precedence.

A *KerML model* shall conform to this specification only if it can be represented according to the syntactic requirements specified in [Clause 7](#). The model may be represented in a form consistent with the requirements for the KerML concrete syntax, in which case it can be parsed (as specified in [Clause 7](#)) into an abstract syntax form, or may be represented only in an abstract syntax form (see also [7.1.3](#) and [7.1.4](#)).

A *KerML modeling tool* is a software applications that creates, manages, analyzes, visualizes, executes or performs other services on KerML models. A tool can conform to this specification in one or more of the following ways.

1. *Abstract Syntax Conformance*. A tool demonstrating Abstract Syntax Conformance provides a user interface and/or API that enables instances of KerML abstract syntax metaclasses to be created, read, updated, and deleted. The tool must also provide a way to validate the well-formedness of models that corresponds to the constraints defined in the KerML metamodel. A well-formed model represented according to the abstract syntax is syntactically conformant to KerML as defined above. (See [Clause 7](#).)
2. *Concrete Syntax Conformance*. A tool demonstrating Concrete Syntax Conformance provides a user interface and/or API that enables instances of KerML concrete syntax notation to be created, read, updated, and deleted. Note that a conforming tool may also provide the ability to create, read, update and delete additional notational elements that are not defined in KerML. Concrete Syntax Conformance implies Abstract Syntax Conformance, in that creating models in the concrete syntax acts as a user interface for the abstract syntax. However, a tool demonstrating Concrete Syntax Conformance need not represent a model internally in exactly the form modeled for the abstract syntax in this specification. (See [Clause 7](#).)
3. *Semantic Conformance*. A tool demonstrating Semantic Conformance provides a demonstrable way to interpret a syntactically conformant model (as defined above) according to the KerML semantics, e.g., via model execution, simulation, or reasoning, when and only when such interpretations are possible. Semantic Conformance implies Abstract Syntax Conformance, in that the semantics for KerML are only defined on models represented in the abstract syntax. (See [Clause 7](#) and [Clause 8](#). See also [6.1](#) for further discussion of the interpretation of models and their syntactic and semantic conformance.)
4. *Model Interchange Conformance*. A tool demonstrating model interchange conformance can import and/or export syntactically conformant KerML models (as defined above) in one or more of the formats specified in [Clause 9](#).

Every conformant KerML modeling tool shall demonstrate at least Abstract Syntax Conformance and Model Interchange Conformance. In addition, such a tool may demonstrate Concrete Syntax Conformance and/or Semantic Conformance, both of which are dependent on Abstract Syntax Conformance.

For a tool to demonstrate any of the above forms of conformance, it is sufficient that the tool pass the relevant tests from the Conformance Test Suite specified in [Annex A](#).

3 Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this specification.

[Alf] *Action Language for Foundational UML (Alf)*, Version 1.1
<https://www.omg.org/spec/ALF/1.1>

[DOL] *Distributed Ontology, Model, and Specification Language*, Version 1.0
<https://www.omg.org/spec/DOL/1.0>

[MOF] *Meta Object Facility*, Version 2.5.1
<https://www.omg.org/spec/MOF/2.5.1>

[OCL] *Object Constraint Language*, Version 2.4
<https://www.omg.org/spec/OCL/2.4>

[SMOF] *MOF Support for Semantic Structures*, Version 1.0
<https://www.omg.org/spec/SMOF/1.0>

[SysAPI] *Systems Modeling Application Programming Interface (API) and Services*
(as submitted contemporaneously with this proposed KerML specification)

[UUID] *A Universally Unique Identifier (UUID) URN Namespace*
<https://tools.ietf.org/html/rfc4122>

[XMI] *XML Metadata Interchange*, Version 2.5.1
<https://www.omg.org/spec/XMI/2.5.1>

4 Terms and Definitions

There are no terms and definitions specific to this specification.

5 Symbols

There are no symbols defined in this specification.

6 Introduction

6.1 Language Architecture

Developing systems involves at least two kinds of specifications, one giving the intended effects of a system (requirements), and another determining how it will bring about those effects (design). Many designs might be developed and evaluated against the same requirements. A third kind of specification describes test procedures that check whether requirements are met by real or virtual systems built and operated according to some design. These cover common situations of system operation, but usually cannot cover all of them.

In the terms above, this specification serves as requirements for the KerML language, while implementations of it are analogous to designs. The specification includes a *metamodel* that defines how models are structured (syntax) and *model libraries* that specify how real or virtual things are constructed or operated according to those models (semantics). This language architecture enables two kinds of automatic testing of implementation conformance to this specification, as illustrated in [Fig. 1](#) (also see [Clause 2](#)).

1. *Syntactic conformance* is short for models conforming to metamodels. The example model in the middle left of [Fig. 1](#) is expressed in the syntax of KerML at the top (concrete and well as abstract syntax, see [7.1.1](#)), as shown by the upward arrow in the middle. KerML syntax is expressed in the Meta-Object Facility [MOF], enabling the model to be automatically checked for conformance to it.
2. *Semantic conformance* is short for real or virtual things conforming to models in the way they are constructed and during their operation (applies only to syntactically conformant models). Models expressed in KerML reuse elements of the KerML model libraries to give them semantics, as shown by the horizontal block arrow in [Fig. 1](#). These libraries give conditions for conformant things, as built or operated, which are augmented in the model as appropriate.

Semantic conformance helps people interpret models in the same way, because the models extend libraries expressed in a small (core) subset of the same language (as shown in the figure by the arrow at the top right). This subset is the first part of the language that engineers and tool builders learn, enabling them to inspect the libraries to understand the real or virtual effects of things built and operated according to models extending the libraries. More uniform model interpretation improves communication between everyone involved in modeling, including modelers and tool builders.

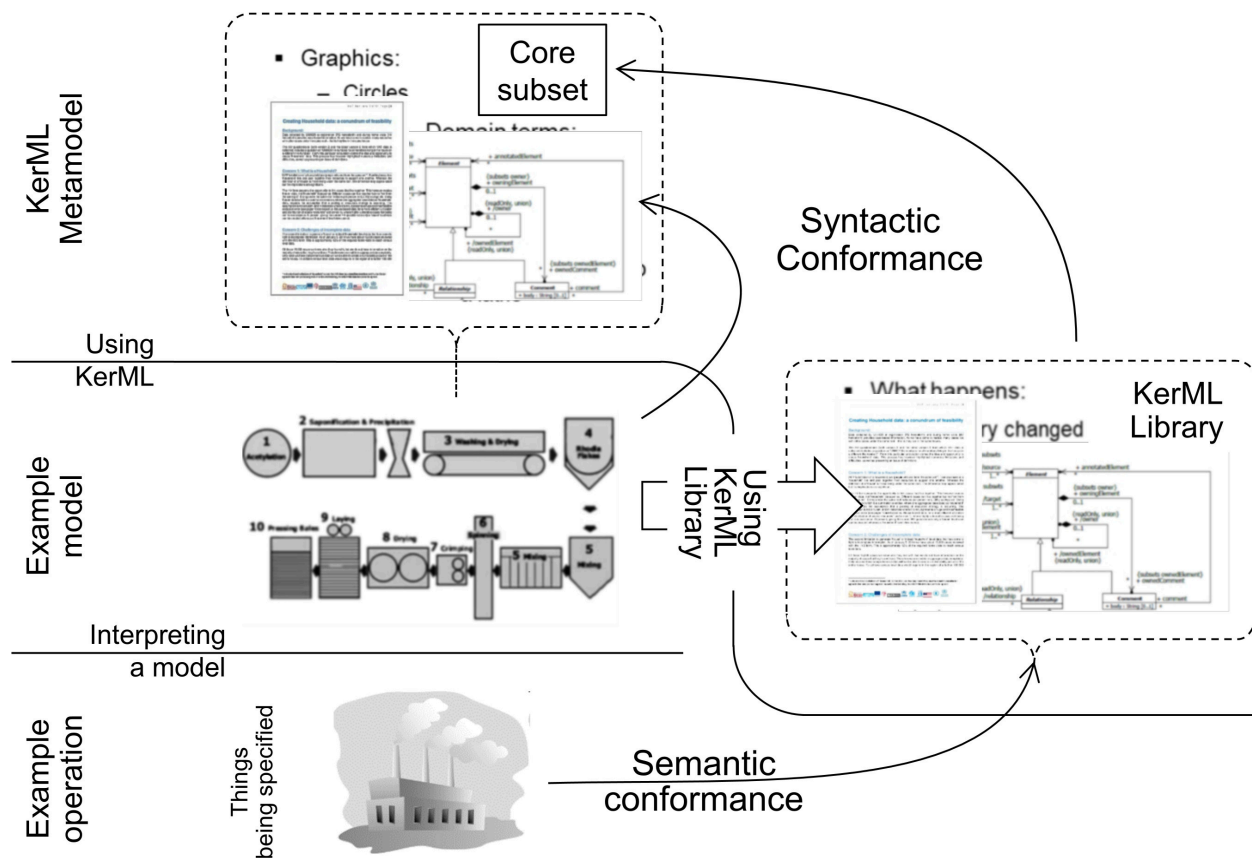


Figure 1. Syntactic and Semantic Conformance

6.2 Document Conventions

The following stylistic conventions apply to text about the [Clause 7](#) (Metamodel):

1. When names of metaclasses from the KerML abstract syntax are used as common nouns ("an Element", "multiple FeatureTypings") they refer to instances of the metaclass (in models). For example, "Elements can own other Elements" refers to instances of the metaclass Element that reside in models. When italicized or modified by "metaclass" they are proper nouns referring to a metamodel element, rather than its instances. For example, "The Element metaclass and *Relationship* are contained in the Root package." refers to metaclasses.
2. Names of properties of metaclasses appear in "code" font. When in regular (non-italic) style, they are common nouns referring the values of the properties (in models), pluralized where necessary, e.g., "the ownedRelatedElements of a Relationship". When italicized they are proper nouns referring to a metaelement, rather than its values.

The following stylistic conventions apply to text about the [Clause 8](#) (Model Library):

1. Convention 1 above applies to Types in the KerML library, where the instances are (real or virtual) things of that Type
2. Convention 2 above applies to KerML Features in the KerML Library, where the values are (real or virtual) things.

See [7.3](#) about instances (interpretations) of KerML Types and Features.

The following conventions apply to the Concrete Syntax subclauses in [Clause 7](#) for the KerML textual notation:

1. Textual notation appears in "code" font.
2. Keywords are appear in **boldface**, ("Features are declared using the **feature** keyword.")

3. Symbols (such as + and :>>) and short segments of textual notation (but longer than an individual name) may be written in-line in body text (without being code or bold).
4. Longer samples of textual notation are written in separate paragraphs, indented relative to body paragraphs.

The grammar of the textual Concrete Syntax and its mapping to the Abstract Syntax is expressed in a specialized *Extended Backus-Naur Form* (EBNF) notation described in [7.1.3](#).

Core mathematical semantics is expressed in the usual notation for first order logic, except:

1. Quantifiers can specify that variable values must be members of particular sets, rather than leaving this to the body of the statement ($\forall t_g \in V_T \dots$ is short for $\forall t_g \ t_g \in V_T \Rightarrow \dots$). The same set can be given once for multiple variables ($\forall t_g, t_s \in V_T \dots$ is short for $\forall t_g, t_s \ t_g \in V_T \wedge t_s \in V_T \Rightarrow \dots$).
2. Dots (.) appearing between property or feature names have the same meaning as in OCL, including implicit collections [OCL].

Mathematical terms used in the specification are defined in [7.3.1.2](#).

Submission Note. Paragraphs marked like this one are not part of the proposed specification. They are material that was not included at the time of the submission, or changes that are expected before the next revision. These notes will be removed in revised submissions as they are addressed.

Implementation Note. Paragraph marked like this one are not part of the proposed specification either. They identify areas which the proof-of-concept pilot implementation (being developed by the submission team) is not fully consistent with the proposed specification.

Release Note. Paragraphs marked like this one provide additional information on the status of updates to this specification document in releases since the initial submission.

6.3 Document Organization

The remainder of this document is organized into three major clauses.

- [Clause 7](#) specifies the Metamodel that defines the KerML language. The first subclause of this clause is an overview, with each following subclause describing succeeding layers of the metamodel. The subclause for each metamodel layer is then divided into an overview and a description of the metamodel elements for each package in the layer (see also [7.1.4](#)). Each package subclause describes the concrete syntax, abstract syntax and semantics of the elements in the package (except that the elements in the Root layer have not model-level semantics).
- [Clause 8](#) specifies the Kernel Model Library, which is a set of KerML models used to provide Kernel-layer semantics to user models. The first subclause of this clause is an overview, with each following subclause describing the elements in a single package in the Model Library, referred to as a *library model*.
- [Clause 9](#) describes each of the formats that can be used to provide standard interchange of KerML models between modeling tools.

In addition, [Annex A](#) defines the suite of conformance tests that may be used to demonstrate the conformance of a modeling tool to this specification (see also [Clause 2](#)).

6.4 Acknowledgements

This specification represents the work of many organizations and individuals. The Kernel Model Language concept, as developed for use with SysML v2, is based on earlier work of the KerML Working Group, which was led by:

- Conrad Bock, US National Institute of Standards and Technology (NIST)
- Charles Galey, Lockheed Martin Corporation

- Bjorn Cole, Lockheed Martin Corporation

The primary authors of this specification document and the syntactic and library models described in it are:

- Ed Seidewitz, Model Driven Solutions
- Conrad Bock, US National Institute of Standards and Technology (NIST)
- Bjorn Cole, Lockheed Martin Corporation

The specification was formally submitted for standardization by the following organizations:

- 88Solutions Corporation
- Dassault Systèmes
- GfSE e.V.
- IBM
- INCOSE
- InterCax LLC
- Lockheed Martin Corporation
- MITRE
- Model Driven Solutions, Inc.
- PTC
- Simula Research Laboratory AS
- Thematix

However, work on the specification was also supported by over 120 people in over 60 other organizations that participated in the SysML v2 Submission Team (SST). The following individuals had leadership roles in the SST:

- Manas Bajaj, InterCax LLC (API and services development lead)
- Yves Bernard, Airbus (profile development co-lead)
- Bjorn Cole, Lockheed Martin Corporation (metamodel development co-lead)
- Sanford Friedenthal, SAF Consulting (SST co-lead, requirements V&V lead)
- Charles Galey, Lockheed Martin Corporation (metamodel development co-lead)
- Karen Ryan, Siemens (metamodel development co-lead)
- Ed Seidewitz, Model Driven Solutions (SST co-lead, pilot implementation lead)
- Tim Weilkiens, oose (profile development co-lead)

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- Tyler Anderson, No Magic/Dassault Systèmes
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- John Watson, Lightstreet consulting

7 Metamodel

7.1 Metamodel Overview

7.1.1 General

This clause specifies the syntax and part of the semantics of KerML (the complete semantics depends on model libraries, see below). It includes the following:

1. *Concrete syntax* specifies the how the language appears to modelers. They construct and review models shown according to the concrete syntax. The textual concrete syntax is based on a *lexical structure*, as defined in [7.1.2](#). Subclause [7.1.3](#) then describes the conventions for defining the grammar for the concrete syntax based on this lexical structure.
2. *Abstract syntax* (metamodel) specifies linguistic terms and relations between them (as opposed to library terms) that are expressed in concrete syntax. These omit purely visual aspects of concrete syntax, such as placement of shapes in graphical notation, or delimiters in textual notation, which do not affect what modelers are trying to express. Abstract syntax facilitates construction of tools that focus on how modelers use linguistic terms, apart from how they appear visually. Concrete syntax is translated to abstract syntax by removing visual information (assuming both follow the specified syntaxes). Subclause [7.1.4](#) describes the conventions for defining abstract syntax.
3. *Semantics* specifies how to tell when actual or virtual systems conform to models in the way those systems are operated are constructed and during their operation (applies only to syntactically conformant models). As discussed in [6.1](#), a *core* subset of KerML abstract syntax is given a mathematical semantics. Semantics for the rest of KerML are specified by constraints on the use of KerML abstract syntax that require models to reuse of elements from the KerML model library, see [7.1.5](#).

The KerML metamodel is a taxonomy (repeated *layers* of specialization) of kinds of model elements (metaclasses), each of which includes the above facets. The taxonomy is divided into three layers (see [7.1.4](#)), from general to specific:

1. *Root* includes the most general syntactic constructs for structuring models, such as elements, relationships, and packaging, see [7.2](#). These constructs have no semantics (in the sense of [6.1](#)); this is added in specializations below.
2. *Core* includes the most general constructs that have semantics, based on *classification*, see [7.3](#). Some Core semantics is specified mathematically.
3. *Kernel* provides commonly needed modeling capabilities, such associations and behavior, see [7.4](#). Its additional semantics is specified entirely through model libraries.

7.1.2 Lexical Structure

7.1.2.1 Lexical Structure Overview

The *lexical structure* of the KerML textual notation defines how the string of characters in an input text is divided into a set of *input elements*. Such input elements can be categorized as *whitespace*, *notes*, or *tokens*.

Lexical analysis is the process of converting an input text into a corresponding stream of input elements. After lexical analysis, whitespace and notes are discarded and only tokens are retained for the subsequent step of parsing. Lexical analysis for KerML is essentially the same as is done for the processing of any typical textual programming language.

7.1.2.2 Line Terminators and White Space

```
LINE_TERMINATOR =  
    "\n"  
INPUT_CHARACTER =  
    !("\n")  
WHITE_SPACE =  
    ' ' | '\t' | '\f' | LINE_TERMINATOR
```

The input text can be divided up into lines separated by *line terminators*. A line terminator may be a single character (such as a line feed) or a sequence of characters (such as a carriage return/line feed combination). This specification does not require any specific encoding for a line terminator, but any encoding used must be consistent throughout any specific input text. Any characters in the input text that are not a part of line terminators are referred to as *input characters*.

A *white space* character is a space, tab, form feed or line terminator. Any contiguous sequence of white space characters can be used to separate tokens that would otherwise be considered to be part of a single token. It is otherwise ignored, with the single exception that a line terminator is used to mark the end of a single-line note (see [7.1.2.3](#)).

7.1.2.3 Notes and Comments

```
SINGLE_LINE_NOTE =  
    '/' '/' (!('\n' | '\r') !('\n' | '\r')*)? ('\r'? '\n')?;  
  
MULTILINE_NOTE =  
    '/' '/' '*' -> '*' /'  
  
REGULAR_COMMENT =  
    '/' '*' ! '*' -> '*' /';  
  
DOCUMENTATION_COMMENT =  
    '/' '*' '*' -> '*' /'
```

Notes and *comments* are used to annotate other elements of the input text. They have no computable semantics, but simply provide information useful to a human reader of the text. Notes and comments are lexically similar, but notes are not considered tokens and are, therefore, stripped from the input text and not parsed as part of the KerML concrete syntax. Comments, on the other hand, are parsed into Comment elements in the abstract syntax and are stored as part of the model represented by the input text. The lexical structure of comment text is described here. See [7.2.3](#) for the definition of the full syntax of Comment elements.

There are two kinds of notes:

1. A *single-line note* includes all the text from the initial characters "/" "/" up to the next line terminator or the end of the input text (whichever comes first), except that "/" "/" "*" begins a multi-line note rather than a single-line note.

```
// This is a single-line note and will be ignored
```

2. A *multiline note* includes all the text from the initial characters "/" "/" "*" to the final characters "*" /".


```

    /* This is a multiline note
       and will be ignored */

```

There are two kinds of comment text:

1. *Regular comment text* includes all the text from the initial characters "/*" to the final characters "*/", except that "/*" begins documentation comment text rather than regular comment text.

```

/* This is the text for a regular Comment to be included in the model.

   It can be on a single line or multiple lines. */

```

2. *Documentation comment text* includes all the text from the initial characters "/*" to the final characters "*/". Regular comment text can be used to specify an sort of Comment, but documentation comment text is used solely to specify Documentation Comments (see [7.2.3](#)).

```

/** This is text for a Comment included as Documentation in the model. */

```

7.1.2.4 Names

```

NAME =
    BASIC_NAME | UNRESTRICTED_NAME

BASIC_NAME =
    ('a'..'z'|'A'..'Z'|'_') ('a'..'z'|'A'..'Z'|'_'|'0'..'9')*

UNRESTRICTED_NAME =
    '\\' ( '\\' ('b'|'t'|'n'|'f'|'"'|'"'|'\\') | !('\\'|'\\') ) * '\\' ;

```

Lexically, a name is a sequence of characters that is used to identify some model Element. This identification may be inherent to the element or relative to some *namespace* that provides a context for resolution of the name to the referenced Element. In either case, there are two kinds of names:

1. A *basic name* is one that can be lexically distinguish in itself from other kinds of tokens. The initial character of a basic name must be one of a lowercase letter, an uppercase letter or an underscore. The remaining characters of a basic name are allowed to be any character allowed as an initial character plus any digit. However, a reserved keyword may not be used as a name, even though it has the form of a basic name (see [7.1.2.7](#)), including the Boolean literals **true** and **false**.

```

Vehicle
power_line

```

2. An *unrestricted name* provides a way to represent a name that contains any character. It is represented as a non-empty sequence of characters surrounded by single quotes. The characters within the single quotes may not include non-printable characters (including backspace, tab and newline). However, these characters may be included as part of the name itself through use of an escape sequence. In addition, the single quote character or the backslash character may only be included by using an escape sequence.

```

'+'
'circuits in line'
'On/Off Switch'

```

An *escape sequence* is a sequence of two text characters starting with the backslash as an escape character, which actually denotes only a single character (except for the newline escape sequence, which represents however many characters is necessary to represent an end of line in a specific implementation—see [7.1.2.2](#)). [Table 1](#) shows the meaning of the allowed escape sequences.

Table 1. Escape Sequences

Escape Sequence	Meaning
\'	Single Quote
\"	Double Quote
\b	Backspace
\f	Form Feed
\t	Tab
\n	Line Terminator
\\	Backslash

7.1.2.5 Numeric Literals

```

DECIMAL_VALUE =
    '0'..'9' ('0'..'9')*

EXPONENTIAL_VALUE =
    DECIMAL_VALUE ('e' | 'E') ('+' | '-')? DECIMAL_VALUE

```

A *decimal value* represents a an exact decimal (base 10) representation of a natural number—that is, a non-negative integer. It consists of a sequence of one or more decimal digits (that is, characters "0" through "9"). A decimal value may specify a natural literal, or it may be part of the specification of a real literal (see [Clause](#)). Note that a decimal literal does not include a sign, because negating a literal is an operator in the KerML Expression syntax.

```

0
1234

```

An *exponential value* is a decimal value followed by a base 10 exponential part delimited by the letter "e" or "E". An exponential value may be used in the specification of a real literal (see [Clause](#)). Note that a decimal point and fractional part are not included in the lexical structure of an exponential value. They are handled as part of the syntax of real literals.

```

5E3
2E-10
1E+3

```

Submission Note. For the revised submission, we may consider allowing other than decimal numeric literals, particularly the traditional binary, octal and hexadecimal.

7.1.2.6 String Values

```
STRING_VALUE =  
  '"' ( '\\ ' ( 'b' | 't' | 'n' | 'f' | 'r' | "'" | '"' | '\\ ' ) | ! ( '\\ ' | "'" ) ) * ' ' "
```

A *string value* lexically delimits a sequence of characters to be included in a String literal value (see [7.4.8](#)). The characters in the string value are surrounded by double quotes, within which escape characters resolve to their meaning as given in [Table 2](#). The empty string is represented by a pair of double quote characters with no other characters intervening between them.

7.1.2.7 Reserved Words

A *reserved keyword* is a token that has the lexical structure of a basic name but is not actually be used as a basic name. The following keywords are so reserved in KerML.

**about abstract all alias any as assoc behavior by binding bool class
classifier comment composite conjugates conjugation connector datatype
derived doc end element expr false feature featured first flow from
function generalization import id in inout interaction inv language
metadata nonunique null of ordered out package port portion predicate
private protected public readonly redefines redefinition relationship
rep specializes step stream subclass subset subsets subtype succession
then to true type typed typing**

7.1.2.8 Symbols

Symbols are non-name tokens composed entirely of characters that are not alphanumeric. There are two kinds of symbols:

1. *Punctuation* symbols have no meaning themselves, but are used to allow unambiguous separation between other tokens that do have meaning.
2. *Operator* symbols are distinguished notations in the KerML Expression sublanguage (see [7.4.8](#)) that map to particular library Functions.

Some symbols are made of multiple characters that may themselves individually be valid symbol tokens. Nevertheless, a multi-symbol token is not considered a combination of the individual symbol tokens. For example, “: :” is considered a single token, not a combination of two “:” tokens. Input characters shall be grouped from left to right to form the longest possible sequence of characters to be grouped into a single token. So “a : : b” would be analyzed into four tokens: “a”, “: :”, “:” and “b” (which, as it turns out, is not a valid sequence of tokens in the KerML textual concrete syntax).

Certain symbols can be used interchangeably with equivalent keywords. For convenience, these are referenced in the concrete syntax grammar using special lexical terminal names that match either the symbol or the corresponding keyword, as shown in [Table 2](#).

Table 2. Symbol/Keyword Pairs

Lexical Name	Symbol	Keyword
TYPED_BY	:	typed by
SPECIALIZES	:>	specializes

Lexical Name	Symbol	Keyword
SUBSETS	:>	subsets
REDEFINES	:>>	redefines
CONJUGATES	~	conjugates

7.1.3 Concrete Syntax

The *grammar* definition for the KerML textual concrete syntax defines how lexical tokens for an input text (see [7.1.2](#)) are grouped in order to construct an abstract syntax representation of a model (see [7.1.4](#)). The concrete syntax grammar definition uses an Extended Backus Naur Form (EBNF) notation (see [Table 3](#)) that includes further notations to describe how the concrete syntax maps to the abstract syntax (see [Table 4](#)).

Productions in the grammar formally result in the synthesis of classes in the abstract syntax and the population of their properties (see [Table 5](#)). Productions may also be parameterized, with the parameters typed by abstract syntax classes. Information passed in parameters during parsing allows a production to update the properties of the provided abstract syntax elements as a side-effect of the parsing it specifies. Some productions only update the properties of parameters, without synthesizing any new abstract syntax element.

Table 3. EBNF Notation Conventions

Lexical element	LEXICAL
Terminal element	'terminal'
Non-terminal element	NonterminalElement
Sequential elements	Element1 Element2
Alternative elements	Element1 Element2
Optional elements (zero or one)	Element ?
Repeated elements (zero or more)	Element *
Repeated elements (one or more)	Element +
Grouping	(Elements ...)

Table 4. Abstract Syntax Synthesis Notation

Variable assignment	<code>v = Element</code>	Assign the result of parsing the concrete syntax <code>Element</code> to the local variable <code>v</code> .
Property assignment	<code>x.p = Element</code>	Assign the result of parsing the concrete syntax <code>Element</code> to property <code>p</code> of the abstract syntax element denoted by <code>x</code> .
List property construction	<code>x.p += Element</code>	Add the result of parsing the concrete syntax <code>Element</code> to the list property <code>p</code> of the abstract syntax element denoted by <code>x</code> .
Boolean property assignment	<code>x.p ?= Element</code>	If the concrete syntax <code>Element</code> is parsed, then set the Boolean property <code>p</code> of the abstract syntax element denoted by <code>x</code> to true.

Non-parsing assignment	<pre>{ v = value } { x.p = value } { x.p += value } }</pre>	Assign (or add) the given <code>value</code> to the variable <code>v</code> or property <code>x.p</code> , without parsing any input.
Name resolution	<code>[QualifiedName]</code>	Parse a <code>QualifiedName</code> , then resolve that name to an <code>Element</code> reference (see 7.2.4.2.4) for use as a value in an assignment as above.
Operator resolution	<code>[['operator']]</code> <code>[[NAME]]</code>	Parse the operator name (given as a terminal symbol or a lexical <code>NAME</code>), then resolve it to the <code>Function</code> in the appropriate model library <code>Package</code> (as given in 7.4.8.2.1 or 7.4.8.2.2).

Table 5. Grammar Production Definitions

Synthetic production definition	<code>NonterminalElement :</code> <code>AbstractSyntaxElement</code> <code>= ...</code>	Define a production for the <code>NonterminalElement</code> that synthesizes the <code>AbstractSyntaxElement</code> .
Parameterized synthetic production definition	<code>NonterminalElement</code> <code>(p1 : Type1, p2 :</code> <code>Type2, ...) :</code> <code>AbstractSyntaxElement</code> <code>= ...</code>	Define a production for the <code>NonterminalElement</code> that synthesizes the <code>AbstractSyntaxElement</code> , with the given parameters named <code>p1</code> , <code>p2</code> , The types of the parameters must be abstract-syntax classes.
Parameterized updating production definition	<code>NonterminalElement</code> <code>(p1 : Type1, p2 :</code> <code>Type2, ...) = ...</code>	Define a production for the <code>NonterminalElement</code> that does not synthesize any new abstract-syntax element, but updates properties of its parameters. (Such a production must have at least one parameter.)

7.1.4 Abstract Syntax

The KerML metamodel is divided into three layers (see [7.1.1](#)), each in a top-level package, as shown in [Fig. 2](#). Each package publicly imports the one it depends on for more general metaelements, the Kernel package containing (as owned or imported members) all abstract syntax elements. Each package contains nested packages for the modeling areas it addresses.

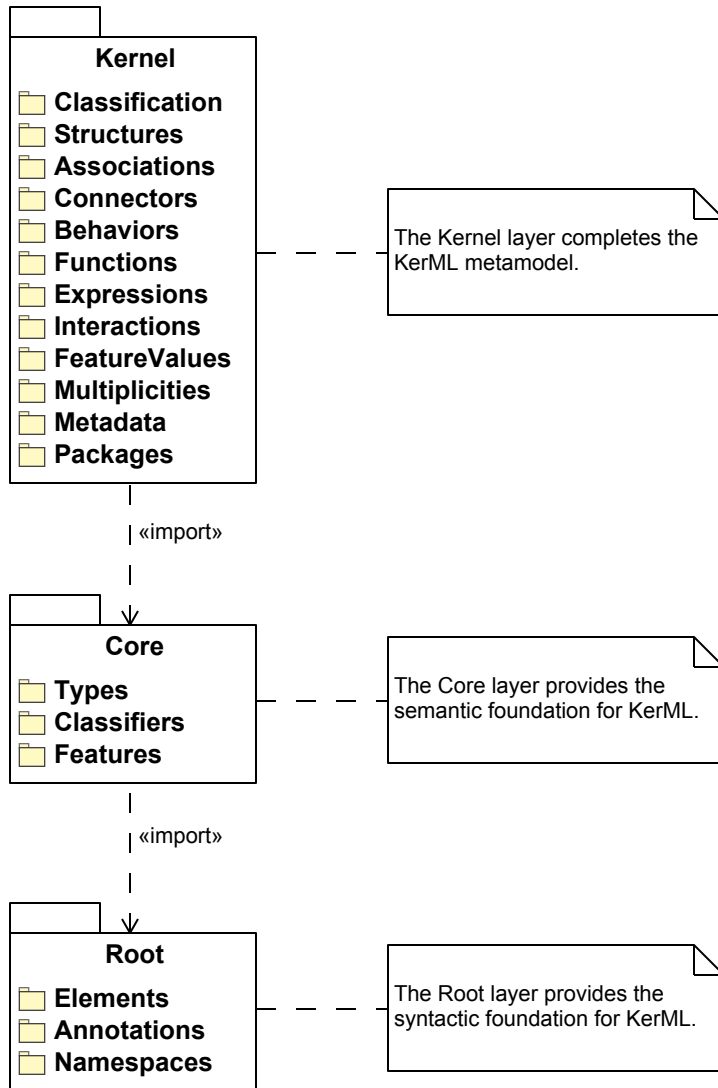


Figure 2. KerML Syntax Layers

Every metaclass in the KerML abstract syntax model is a direct or indirect subclass of the Element metaclass. Relationship is a particularly important direct subclass of Element. The KerML abstract syntax is designed so that models are represented as graphs of Elements connected by Relationships. The abstract syntax model rigorously follows the following convention: the only meta-associations that are not derived are those with Relationship metaclasses (that is Relationship or a subclass of it). All other associations between Elements are derived from such reified relationship classes.

[Fig. 3](#) shows the complete generalization hierarchy of metaclasses in the KerML abstract syntax, excluding Relationship metaclasses other than Association and Connector (and their subclasses). Association and Connector (and their subclasses) are the only kind of Types that are also Relationships. [Fig. 4](#) shows the hierarchy of Relationship metaclasses.

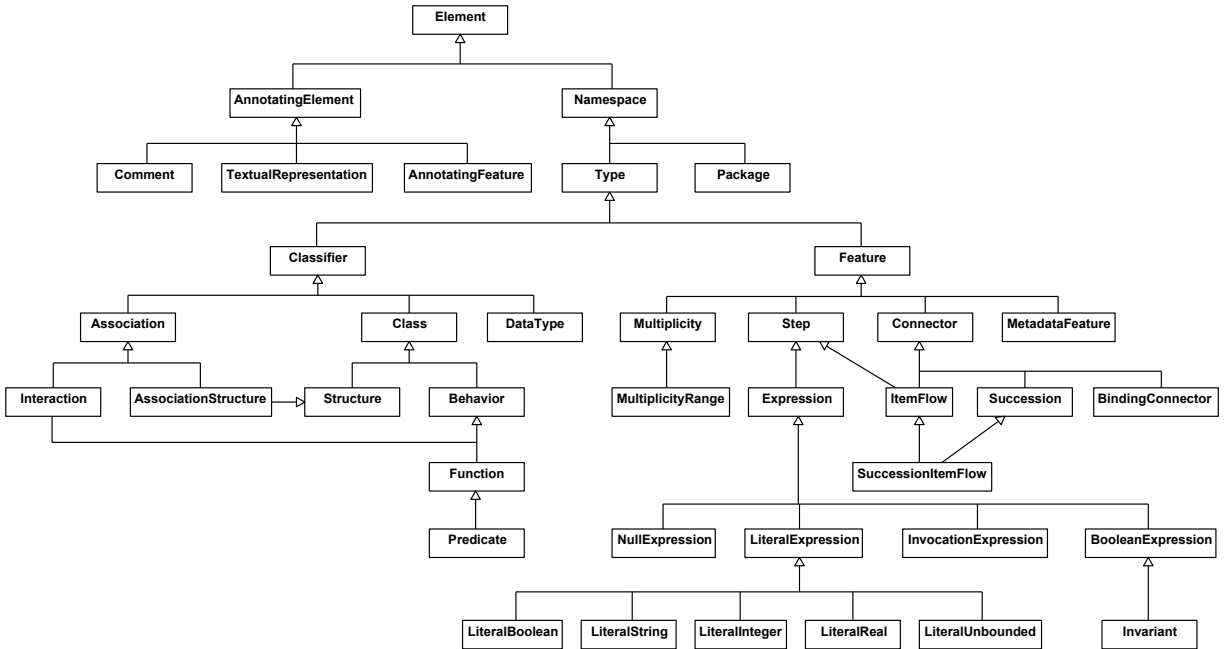


Figure 3. KerML Element Hierarchy

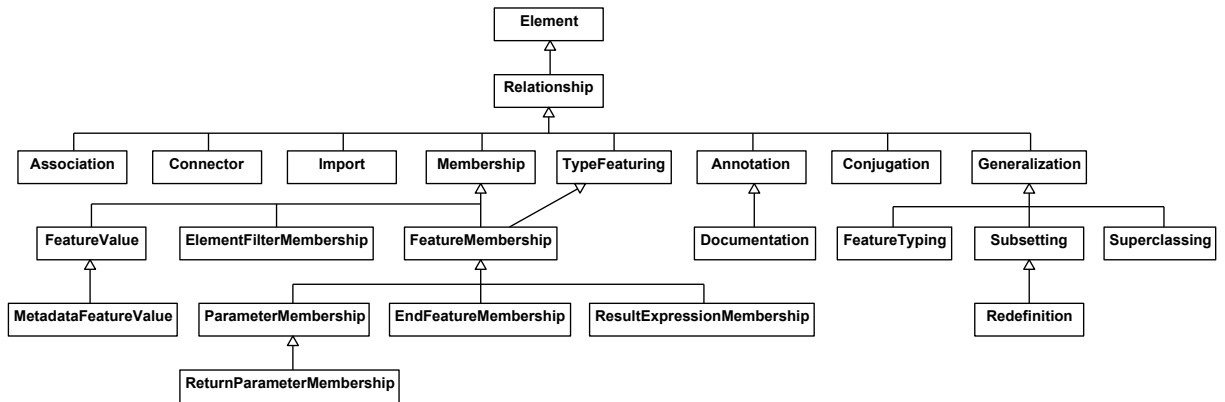


Figure 4. KerML Relationship Hierarchy

7.1.5 Semantics

KerML semantics is specified by a combination of mathematics and model libraries, as illustrated in [7.1.5](#). The left side of this diagram shows the abstract syntax packages corresponding to the three layers of the KerML metamodel. The right side shows the corresponding semantic layering.

The Root layer is purely syntactic and has no modeling semantics. The Core is grounded in mathematical semantics (based on [7.3.1.2](#)), supported by the *Base* package from the Kernel Model Library (see [8.2](#)). The Kernel layer is given semantics fully through its relationship to the Model Library (see [Clause 8](#)). The semantic specification for each Kernel sub-package summarizes constraints on Kernel abstract syntax elements that specify how the model library is used when models are constructed following the abstract syntax.

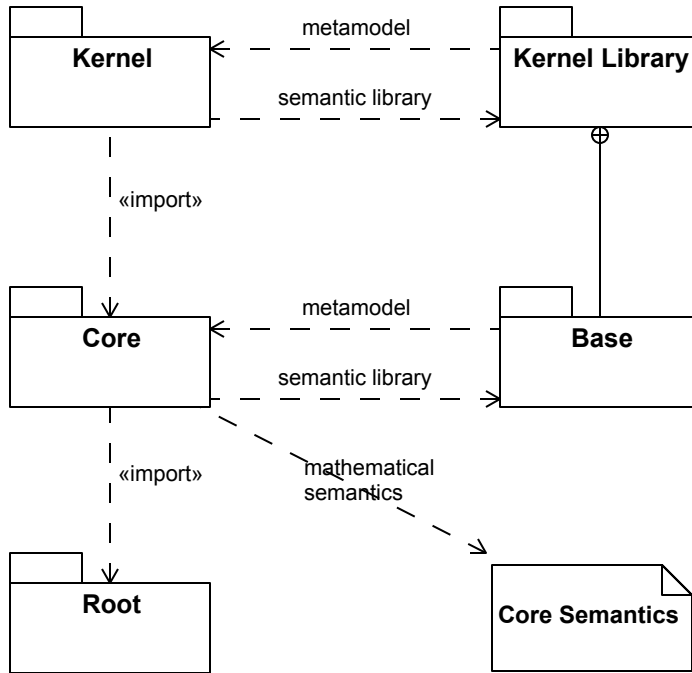


Figure 5. KerML Semantic Layers

7.2 Root

7.2.1 Root Overview

The Root layer contains the syntactic foundations of KerML. It includes constraints on the structure of models, but none of these affect the modeled systems as they are built or operate, that is, the elements have no semantics. This is added in the Core layer (see [7.3](#)), which extends Root.

Root provides the most general syntactic capabilities of the language: Elements and Relationships between them, Annotations of Elements, and Membership of Elements in Namespaces. Namespaces can assign unique names to Namespace members, but support multiple aliases per Element. They also support Import of Elements from other Namespaces, enabling an Element to have a different name when imported.

7.2.2 Elements

7.2.2.1 Elements Overview

Identification

Elements are the constituents of a model. Every Element has an `identifier` that shall be a Universally Unique Identifier (UUID) (as specified in [UUID]). Generally, the properties of an Element can change over its lifetime, but the `identifier` shall not change after the Element is created.

The Element metaclass is the most general metaclass in the KerML abstract syntax. Element is *not* abstract, and a model may include instances of Element that are not instances of any other subclass of Element. Such an instance may be refined in later of the versions of the model into a more specific modeling construct, by dynamically changing its metaclass to a more specific specialization of Element (see [SMOF]). In general, the metaclass of an

Element may change over its lifetime, but all Element instances with the same `identifier` value shall be considered versions of the same constituent model Element, regardless of their metaclass at any point in time.

An Element may also have additional identifiers, its `aliasIds`, which may be assigned for tool-specific purposes. This specification places no restrictions on the structure or uniqueness of `aliasIds` assigned by tools. It is a tool responsibility to manage any necessary uniqueness of such identifiers within or across models.

However, one of the `aliasIds`, the `humanId`, may be entered by the modeler. If given, the `humanId` for an Element has the lexical form of a name. However, an Element may be given different names relative to different Namespaces (see 7.2.4), while the `humanId` for an Element is the same in all contexts. Any `humanIds` of the `ownedElements` of a Namespace must be unique (see 7.2.4), but it is otherwise the responsibility of the modeler to maintain other structural or uniqueness properties for `humanIds` as appropriate to the model being created.

Relationships

Some Elements represent Relationships between other Elements, known as the `relatedElements` of the Relationship. In general terms, a model is constructed as a graph structure in which Relationships form the edges connecting non-Relationship Elements constituting the nodes. However, since Relationships are themselves Elements, it is also possible in KerML for a Relationship to be a `relatedElement` in a Relationship and for there to be Relationships between Relationships.

The `relatedElements` of a Relationship are divided into `source` and `target` Elements. A Relationship is said to be *directed* from its `source` Elements to its `target` Elements. It is allowed for a Relationship to have only `source` or only `target` Elements. However, by convention, an *undirected* Relationship is usually represented as having only `target` Elements.

A Relationship shall have at least two `relatedElements`. A Relationship with exactly two `relatedElements` is known as a *binary* Relationship. A *directed binary* Relationship is a binary Relationship in which one `relatedElement` is the `source` and one is the `target`. Most specializations of Relationship in the KerML abstract syntax restrict the specialized Relationship to be a directed binary Relationship (the principal exceptions being Association and Connector and their further specializations).

Ownership

One of the `relatedElements` of a Relationship may be the `owningRelatedElement` of the Relationship. If the `owningRelatedElement` of a Relationship is deleted from a model, then the Relationship shall also be deleted. Some of the `relatedElements` of a Relationship (which shall be distinct from the `owningRelatedElement`, if any) may also be designated as `ownedRelatedElements`. If a Relationship has `ownedRelatedElements`, then, if the Relationship is deleted from a model, all its `ownedRelatedElements` shall also be deleted.

The `ownedRelationships` of an Element are all those Relationships for which the Element is the `owningRelatedElement`. The `ownedElements` of an Element shall be all those Elements that are `ownedRelatedElements` of the `ownedRelationships` of the Element. The `owningRelationship` of an Element (if any) is the Relationship for which the Element is an `ownedRelatedElement`. An Element shall have no more than one `owningRelationship`. The owner of an Element (if any) shall be the `owningRelatedElement` of the `owningRelationship` of the Element.

The above deletion rules imply that, if an Element is deleted from a model, then all its `ownedRelationships` and `ownedElements` are also deleted. This may result in a further cascade of deletions until all deletion rules are satisfied. An Element that has no owner acts as the *root Element* of an *ownership tree structure*, such that all

Elements and Relationships in the structure are deleted if the root Element is deleted. Deleting any Element other than the root Element results in the deletion of the entire subtree below that Element.

It is a general design principle of the KerML abstract syntax that non-Relationship Elements are related only by reified instances of Relationships. All other meta-associations between Elements are derived from these reified Relationships. For example, the `owningRelatedElement/ownedRelationship` meta-association between an Element and a Relationship is fundamental to establishing the structure of a model. However, the `owner/ownedElement` meta-association between two Elements is derived, based on the Relationship structure between them.

7.2.2.2 Concrete Syntax

7.2.2.2.1 Elements

```
Identification (e : Element, m : Membership) =
    ( 'id' e.humanId = NAME )? ( m.memberName = NAME )?

Element (m : Membership) : Element =
    'element' Identification(this, m) ElementBody(this)

ElementBody (e : Element) =
    ';' | '{' OwnedElement(e) * '}'

OwnedElement (e : Element) =
    e.ownedRelationship += OwnedRelationship(e)
| e.ownedRelationship += OwnedDocumentation
| e.ownedRelationship += OwnedTextualRepresentationAnnotation
```

An Element in its simplest form, not representing any more specialized modeling construct, is notated using the keyword **element**. The declaration of an Element may also specify a `humanId` for it, as a lexical name preceded by the keyword **id**. Note that the notation does not have any provision or specifying the `identifier` or other `aliasIds` of an Element, since these are expected to be managed by the underlying modeling tooling.

```
element id e145;
```

If the Element is an `ownedMember` of a Namespace, then a name may also be given for the Element (after its `humanId`, if any). This name is actually the `memberName` of the Membership by which the Element is owned by the Namespace (see [7.2.4](#)).

```
element id '1.2.4' MyName;
```

Note that it is not required to specify either a `humanId` or a name for an Element. However, unless at least one of these is given, it is not possible to reference the Element from elsewhere in the textual concrete syntax.

In addition to the declaration notated as above, the representation for an Element may include a *body*, which is a list of owned Elements delimited by curly braces `{...}`. It is a general principle of the KerML textual concrete syntax that the representation of owned Elements are nested inside the body of the representation of the owning Element. In this way, when the notation for the owning Element is removed in its entirety from the representation of a model, the owned Elements are also removed.

It is possible to specify the following owned Elements as part of the body of an Element:

- Owned (generic) Relationships (see [7.2.2.2.2](#)), using the keyword **relationship**. The containing Element becomes the `owningRelatedElement` and sole source for the Relationship with one or more other Elements identified as target Elements.
- Owned Documentation Comments (see [7.2.3.2.1](#)), using the keyword **doc**. The containing Element becomes the `owningRelatedElement` for the Documentation Relationship to the Comment.
- Owned TextualRepresentations (see [7.2.3.2.1](#)), using the keyword **rep** or **language**. The containing Element becomes the `ownedRelatedElement` for the Annotation Relationship to the TextualRepresentation.

```

element id A {
    doc /* Element A is related to element B. */
    relationship to B;
}
element id B {
    language "HTML"
    /* <a href="https://plm.elsewhere.com/part?id="1234"/> */
}

```

7.2.2.2 Relationships

```
Relationship (m : Membership) : Relationship =
  'relationship' Identification(this, m)
  RelationshipRelatedElements(this)
  RelationshipBody(this, m)

OwnedRelationship (e : Element) : Relationship =
  'relationship' Identification(this, m)
  'to' RelationshipTargetList(this)
  RelationshipBody(this)
  { source += e }

RelationshipRelatedElements (r : Relationship) =
  'from' RelationshipSourceList(r) ( 'to' RelationshipTargetList(r) )?
  | 'to' RelationshipTargetList(r)

RelationshipSourceList (r : Relationship) =
  RelationshipSource(r) ( ',' RelationshipSource(r) )*

RelationshipSource (r : Relationship) =
  r.source += [QualifiedName]

RelationshipTargetList (r : Relationship) =
  RelationshipTarget(r) ( ',' r.target += RelationshipTarget(r) )*

RelationshipTarget (r : Relationship) =
  r.target += [QualifiedName]

RelationshipBody (r : Relationship, m : Membership) =
  ';' | '{' RelationshipOwnedElement(r, m)* '}'

RelationshipOwnedElement (r : Relationship) =
  r.ownedRelatedElement += OwnedRelatedElement
  | r.ownedRelationship += OwnedDocumentation
  | r.ownedRelationship += OwnedTextualRepresentationAnnotation

OwnedRelatedElement : Element =
  'element' ( humanId = NAME )? ElementBody
  | 'relationship' ( humanId = NAME )? RelationshipBody
```

A Relationship can be declared using the keyword **relationship**. As for a generic Element (see Elements above), a humanId and/or a name (if it is an ownedMember) may be specified for the Relationship. The (unowned) source Elements of the Relationship are then listed after the keyword **from**, while the target Elements are listed after the keyword **to**. It is allowable for a Relationship to have only source Elements or only target Elements, but there must be at least two Elements specified across the source and target lists (though some of the target Elements may be ownedRelatedElements, see below).

```
element id '1' A;
element id '2' B;
```

```

element id '3' C;
relationship id '4' R from '1' to B, C;

```

The top-level Elements of a model are implicitly declared within a *root* Namespace for their `humanIds` and `names` (see [7.2.4](#)). This allows for the identification of top-level Elements in the declaration of a Relationship, even without an explicit Namespace structure. However, when the model is organized into a Namespace structure, then Elements may be identified using qualified names according that structure (see [7.2.4](#) for the rules on the resolution of qualified names).

```

package P1 {
    element S;
}
package P2 {
    element T;
}
relationship from P1::S to P2::T;

```

A Relationship may have a body that specifies the following kinds of owned Elements of the Relationship:

- Owned (generic) Elements (see Elements above), using the keyword **element**. Such Elements become `ownedRelatedElements` of the containing Relationship (which are always target Elements).
- Owned (generic) Relationships, using the keyword, using the keyword **relationship**. Such Relationships become `ownedRelatedElements` of the containing Relationship, as for generic Elements.
- Owned Documentation Comments (see [7.2.3.2.1](#)), using the keyword **doc**, as for a generic Element (see Elements above).
- Owned TextualRepresentations (see [7.2.3.2.1](#)), using the keyword **rep** or **language**, as for a generic Element (see Elements above).

Note. The KerML concrete syntax does not provide any notation for a generic Relationship body to declare `ownedRelatedElements` of more specific kinds than listed above. A Namespace structure should be used instead to create a containment structure for more specific kinds of Elements (see [7.2.4](#)).

To specify that a Relationship has an `owningRelatedElement`, use the nested owned Relationship notation (see [7.2.2.2.1](#) above).

```

element A;
element B {
    relationship to A {
        element C; // Owned related element
        relationship to B; // Relationship as owned related Element
    }
}
relationship R from A to B {
    doc /* This relationship has no owned related Elements. */
}

```

7.2.2.3 Abstract Syntax

7.2.2.3.1 Overview

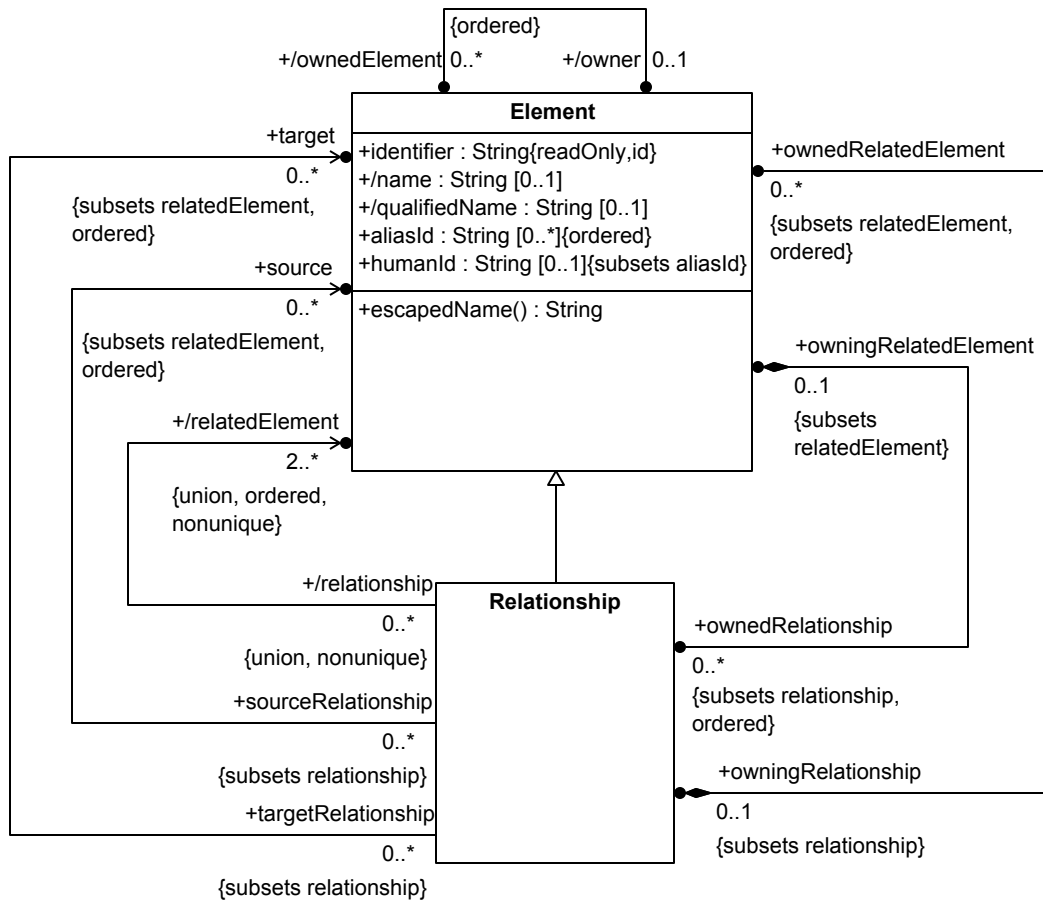


Figure 6. Elements

7.2.2.3.2 Element

Description

An Element is a constituent of a model that is uniquely identified relative to all other Elements. It can have Relationships with other Elements. Some of these Relationships might imply ownership of other Elements, which means that if an Element is deleted from a model, then so are all the Elements that it owns.

General Classes

No general classes.

Attributes

aliasId : String [0..*] {ordered}

Various alternative identifiers for this Element. Generally, these will be set by tools, but one of them (the humanId), in particular, may be set by the modeler.

/documentation : Documentation [0..*] {subsets ownedAnnotation, ordered}

The `ownedAnnotations` of this Element that are Documentation, for which the Element is the `annotatedElement`.

`/documentationComment : Comment [0..*] {subsets ownedElement, annotatingElement, ordered}`

The Comments that document this Element, derived as the `documentingComments` of the documentation of the Element.

`humanId : String [0..1] {subsets aliasId}`

An identifier for this Element that is set by the modeler. It is the responsibility of the modeler to maintain the uniqueness of this identifier within a model or relative to some other context. The `modeledId` essentially acts as an alias for an Element that is specifically tied to that Element, rather than being a name for it in the context of some explicit namespace.

`identifier : String`

The globally unique identifier for this Element. This is intended to be set by tooling, and it must not change during the lifetime of the Element.

`/name : String [0..1]`

The primary name of this Element. If the Element is owned by a Namespace, then its `name` is derived as the `memberName` of the `owningMembership` of the Element.

`/ownedAnnotation : Annotation [0..*] {subsets ownedRelationship, annotation, ordered}`

The `ownedRelationships` of this Element that are Annotations, for which this Element is the `annotatedElement`.

`/ownedElement : Element [0..*] {ordered}`

The Elements owned by this Element, derived as the `ownedRelatedElements` of the `ownedRelationships` of this Element.

`ownedRelationship : Relationship [0..*] {subsets relationship, ordered}`

The Relationships for which this Element is the `owningRelatedElement`.

`/ownedTextualRepresentation : TextualRepresentation [0..*] {subsets ownedElement, textualRepresentation}`

The `textualRepresentations` that are `ownedElements` of this Element.

`/owner : Element [0..1]`

The owner of this Element, derived as the `owningRelatedElement` of the `owningRelationship` of this Element, if any.

`owningMembership : Membership [0..1] {subsets owningRelationship}`

The `owningRelationship` of this Element, if that Relationship is a Membership.

`/owningNamespace : Namespace [0..1] {subsets namespace}`

The Namespace that owns this Element, derived as the membershipOwningNamespace of the owningMembership of this Element, if any.

owningRelationship : Relationship [0..1] {subsets relationship}

The Relationship for which this Element is an ownedRelatedElement, if any.

/qualifiedName : String [0..1]

The name of this Element, if it has one, qualified by the name of its owningNamespace, if it has one. The qualifiedName is represented in a form that is valid according to the KerML textual concrete syntax.

Operations

escapedName() : String

Return either the name of this Element, if this has the form of a basic name (or is null), or, otherwise, its representation as a restricted name that according to the lexical structure of the KerML textual notation (i.e., with special characters escaped and surrounded by single quote characters).

Constraints

elementName

[no documentation]

```
name = if owningNamespace = null then null
      else owningNamespace.nameOf(self) endif
```

elementDocumentation

[no documentation]

```
documentation = ownedAnnotation->selectByKind(Documentation)
```

elementOwnedElements

[no documentation]

```
ownedElement = ownedRelationship.ownedRelatedElement
```

elementQualifiedName

If the owningNamespace of this Element is a root Namespace, then the qualifiedName of the Element is the same as the (escaped) name of the Element. If the owningNamespace is not a root Namespace, and it has a qualifiedName, then the qualifiedName of this Element is constructed from the qualifiedName of the owningNamespace and the (escaped) name of the Element. Otherwise the qualifiedName of the Element is null.

```
qualifiedName =
  if owningNamespace = null then null
  else if owningNamespace.owner = null then escapedName()
  else if owningNamespace.qualifiedName = null then null
```



```

    else owningNamespace.qualifiedName + "::" + escapedName()
  endif endif endif

```

elementOwnedAnnotation

[no documentation]

```

ownedAnnotation = ownedRelationship->selectByKind(Annotation)->
  select(a | a.annotatedElement = self)

```

elementOwner

[no documentation]

```

owner = owningRelationship.owningRelatedElement

```

elementDocumentationComment

[no documentation]

```

documentationComment = documentation.documentingComment

```

7.2.2.3.3 Relationship

Description

A Relationship is an Element that relates two or more other Elements. Some of its `relatedElements` may be owned, in which case those `ownedRelatedElements` will be deleted from a model if their `owningRelationship` is. A Relationship may also be owned by another Element, in which case the `ownedRelatedElements` of the Relationship are also considered to be transitively owned by the `owningRelatedElement` of the Relationship.

The `relatedElements` of a Relationship are divided into `source` and `target` Elements. The Relationship is considered to be directed from the `source` to the `target` Elements. An undirected Relationship may have either all `source` or all `target` Elements.

A "relationship Element" in the kernel abstract syntax is generically any Element that is an instance of either Relationship or a direct or indirect specialization of Relationship. Any other kind of Element is a "non-relationship Element". It is a convention of the kernel abstract syntax that non-relationship Elements are *only* related via reified relationship Elements. Any meta-associations directly between non-relationship Elements must be derived from underlying reified Relationships.

General Classes

Element

Attributes

```

ownedRelatedElement : Element [0..*] {subsets relatedElement, ordered}

```

The `relatedElements` of this Relationship that are owned by the Relationship.

```

owningRelatedElement : Element [0..1] {subsets relatedElement}

```

The `relatedElement` of this Relationship that owns the Relationship, if any.

`/relatedElement : Element [2..*] {ordered, nonunique, union}`

The Elements that are related by this Relationship, derived as the union of the `source` and `target` Elements of the Relationship. Every Relationship must have at least two `relatedElements`.

`source : Element [0..*] {subsets relatedElement, ordered}`

The `relatedElements` from which this Relationship is considered to be directed.

`target : Element [0..*] {subsets relatedElement, ordered}`

The `relatedElements` to which this Relationship is considered to be directed.

Operations

No operations.

Constraints

No constraints.

7.2.3 Annotations

7.2.3.1 Annotations Overview

Annotations

An Annotation is a Relationship between an Element and an AnnotatingElement that provides additional information about the Element being annotated. Each Annotation is between a single AnnotatingElement and a single Element being annotated, but an AnnotatingElement may have multiple Annotation Relationships with different `annotatedElements`, and any Element may have multiple Annotations. The `annotatedElement` of an Annotation can optionally be the `owningRelatedElement` of the Annotation, in which case the `annotatedElement` is known as the `owningAnnotatedElement` and the Annotation is one of the `ownedAnnotations` of the `owningAnnotatedElement`.

Specific kinds of AnnotatingElements include Comments and TextualRepresentations. A further kind of AnnotatingElement, an AnnotatingFeature for user-defined metadata, is defined in the Kernel layer (see [7.4.12](#)).

Comments and Documentation

A Comment is an AnnotatingElement with a textual body that in some way describes its `annotatedElement`. A Comment that is related to its `annotatedElement` using the specialized Documentation Relationship has a special status of providing *documentation* for the `annotatedElement`. A Documentation Annotation shall be an `ownedAnnotation` of its `annotatedElement`. Further, the `documentingComment` of a Documentation shall be an `ownedRelatedElement` of the Documentation Relationship. This implies that the `documentationComments` of an Element (derived as the `documentingComments` of the owned documentation of the Element) are a subset of the `ownedElements` of the Element.

Textual Representation

A TextualRepresentation is an AnnotatingElement whose textual body represents the `annotatedElement` in a given language. In particular, if the named language is machine-parsable, then the body text should be legal

input text as defined for that language. The interpretation of the named language string shall be case insensitive. If the named language string matches one of the language names shown in [Table 6](#) (without regard to case), then the body text shall be syntactically legal according to the specification shown in the table. Other specifications may define specific language strings, other than those shown in [Table 6](#), to be used to indicate the use of languages from those specifications in KerML TextualRepresentations.

If the language of a TextualRepresentation is "kerml", then the body text shall be a legal representation of the representedElement in the KerML textual concrete syntax as defined in this specification. A conforming tool can use such a TextualRepresentation Annotation to record the original KerML concrete syntax text from which an Element was parsed. In this case, it is a tool responsibility to ensure that the body of the TextualRepresentation remains correct (or the Annotation is removed) if the annotated Element changes other than by re-parsing the body text.

For any other named language, the KerML specification does not define how the body text is to be semantically interpreted as part of the model being represented. In particular, a direct Element instance with a TextualAnnotation in a language other than KerML is essentially a semantically "opaque" Element specified in the other language. However, a conforming KerML tool may interpret such an element consistently with the specification of the named language.

Table 6. Standard Language Names

Language Name	Specification
kerml	Kernel Modeling Language (this specification)
ocl	Object Constraint Language [OCL]
alf	Action Language for fUML [Alf]

7.2.3.2 Concrete Syntax

7.2.3.2.1 Comments

```

Comment (m : Membership, e : Element) : Comment =
  ( 'comment' Identification(this, m)
    'about' annotation += Annotation
    { ownedRelationship += annotation }
  ( ',' annotation += Annotation
    { ownedRelationship += annotation } ) *
  | ( 'comment' Identification(this, m) ) ?
    annotation += ElementAnnotation(e)
    { ownedRelationship += annotation }
  )
  body = REGULAR_COMMENT

Annotation : Annotation =
  annotatedElement = [Qualified Name]

ElementAnnotation ( e : Element ) : Annotation =
  { annotatedElement = e }

```

The full declaration of a Comment begins with the keyword **comment**, optionally followed by a humanId and/or name (see [7.2.2.2.1](#)). One or more annotatedElements are then identified for the Comment after the keyword

about, indicating that the Comment has Annotation Relationships to each of the identified Elements. The body of the Comment is written lexically as regular comment text between `/*` and `*/` delimiters (see [7.2.2.1](#)).

```
element A;
element B;
comment Comment1 about A, B
    /* This is the comment body text. */
```

If the Comment is an `ownedMember` of a Namespace (see [7.2.4](#)), then the explicit identification of `annotatedElements` can be omitted, in which case the `annotatedElement` shall be implicitly the containing Namespace. Further, in this case, if no `humanId` or `name` is given for the Comment, then the **comment** keyword can also be omitted.

```
namespace N {
    comment C /* This is a comment about N. */

    /* This is also a comment about N. */
}
```

The actual body text of the Comment shall be extracted from the lexical regular comment token text as follows:

1. Remove the initial `/*` and final `*/` characters.
2. Remove any white space immediately after the initial `/*`, up to and including the first line terminator (if any).
3. On each subsequent line of the text:
 1. Strip initial white space other than line terminators.
 2. Then, if the first remaining character is `"*"`, remove it.
 3. Then, if the first remaining character is now a space, remove it.

For example, the lexical comment text in the following concrete syntax notation:

```
namespace CommentExample {
    /*
    * This is an example of multiline
    * comment text with typical formatting
    *    for readable display in a text editor.
    */
}
```

would result in the following body text in the Comment Element in the represented model:

```
This is an example of multiline
comment text with typical formatting
    for readable display in a text editor.
```

The body text of a Comment can include markup information (such as HTML), and a conforming tool may display such text as rendered according to the markup. However, marked up "rich text" for a Comment written using the KerML textual concrete syntax shall be stored in the Comment body in plain text including all mark up text, with all line terminators and white space included as entered, other than what is removed according to the rules above.

Submission Note. It is expected that the revised submission will provide a standard means for notating links to model elements from within Comments and a capability for the "transclusion" of certain textual information on model elements.

7.2.3.2.2 Documentation

```
OwnedDocumentation : Documentation =
    documentingComment = DocumentationComment

DocumentationComment : Comment =
    'doc' ( 'id' humanId = Name )? body = REGULAR_COMMENT

PrefixDocumentation : Documentation =
    documentingComment = PrefixDocumentationComment

PrefixDocumentationComment : Comment =
    ( 'doc' ( 'id' humanId = Name )? )? body = DOCUMENTATION_COMMENT
```

A documentation Comment is notated similarly to a regular Comment (see [7.2.3.2.1](#)), but using the keyword **doc** rather than **comment**. Since a documentation Comment is always an `ownedElement` of its `annotatedElement`, the notation of a documentation Comment is always nested within the notation of its owning Element, so there is no need to explicitly identify the `annotatedElement`. Further, since a documentation Comment is always owned via its Documentation Relationship, it cannot be an `ownedMember` of a Namespace and therefore cannot have a name specified for it. However, it can optionally be given a `humanId` (or separately given an alias via a non-owning Membership Relationship—see [7.2.4](#)).

```
element X {
    doc id X_Comment
        /* This is a documentation comment about X. */
    doc /* This is more documentation about X. */
}
```

If the Element being documented is the member of a Namespace, then a special notation can be used in which lexical documentation comment text (see [7.2.2.1](#)) is placed immediately *before* the notation of the Element being documented. If no `humanId` is specified for a documentation Comment of this form, then the keyword **doc** can also be omitted.

```
package P {

    /** This is a documentation comment about Q. */
    package Q;

}
```

Documentation comment text shall be processed following the same rules as for regular comment text (see above), except that the initial `"/**"` characters are removed, rather than just `"/**"`.

7.2.3.2.3 Textual Representation

```
OwnedTextualRepresentationAnnotation : Annotation =
  ownedRelatedElement += OwnedTextualRepresentation(this)

OwnedTextualRepresentation (a : Annotation) : TextualRepresentation =
  ( 'rep' ( humanId = NAME )? )?
  'language' language = STRING_VALUE body = REGULAR_COMMENT
  { annotation += a }

TextualRepresentation (m : Membership, e : Element) : TextualRepresentation =
  ( 'rep' Identification(this, m)
    'about' annotation += Annotation
  | ( 'rep' Identification(this, m) )?
    ElementAnnotation(e)
  )
  'language' language = STRING_VALUE body = REGULAR_COMMENT
```

A `TextualRepresentation` is notated similarly to a regular `Comment` (see [7.2.3.2.1](#)), but with the keyword **rep** used instead of **comment**. Similarly to a `Comment`, the **about** keyword can be used to specify the `representedElement` for the `TextualRepresentation`. However, only one `representedElement` may be identified for a `TextualRepresentation`. If the `TextualRepresentation` is an `ownedMember` of a `Namespace` (see [7.2.4](#)), then, if the `representedElement` is not identified explicitly, it shall by default be the containing `Namespace`. A `TextualRepresentation` declaration must also specify the `language` as a literal string following the keyword **language**. If the `TextualRepresentation` has no `humanId`, `name` or explicit `representedElement`, then the **rep** keyword can also be omitted.

```
class C {
  feature x: Real;
  inv x_constraint;
  rep inOCL about x_constraint language "ocl"
    /* self.x > 0.0 */
}
behavior setX(c : C, newX : Real) {
  language "alf"
    /* c.x = newX;
     * WriteLine("Set new x");
     */
}
```

The lexical comment text given for a `TextualRepresentation` shall be processed as for regular comment text (see above), and it is the result after such processing that is the `TextualRepresentation` `body` expected to conform to the named `language`.

Note. Since the lexical form of a comment is used to specify the `TextualRepresentation` `body`, it is not possible to include comments of a similar form in the `body` text.

Submission Note. The revised submission may include a means to allow nested comments.

7.2.3.3 Abstract Syntax

7.2.3.3.1 Overview

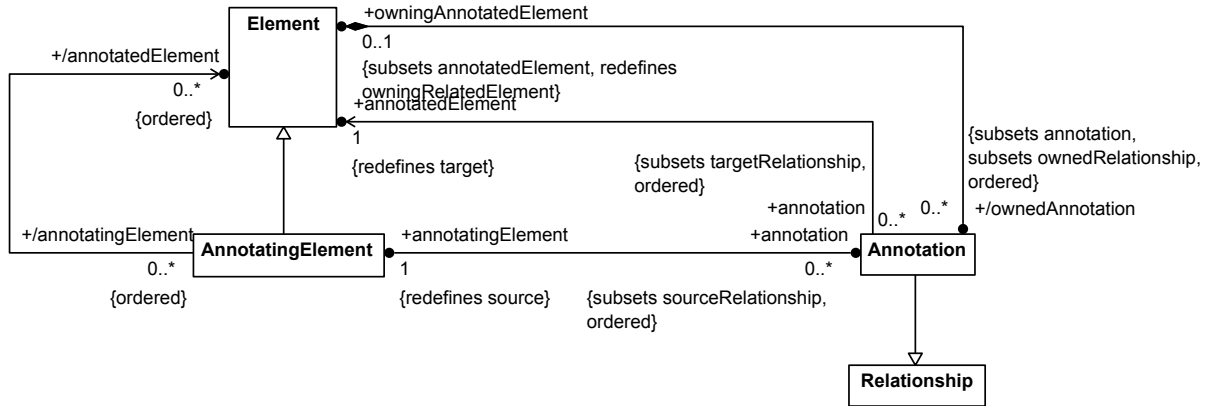


Figure 7. Annotation

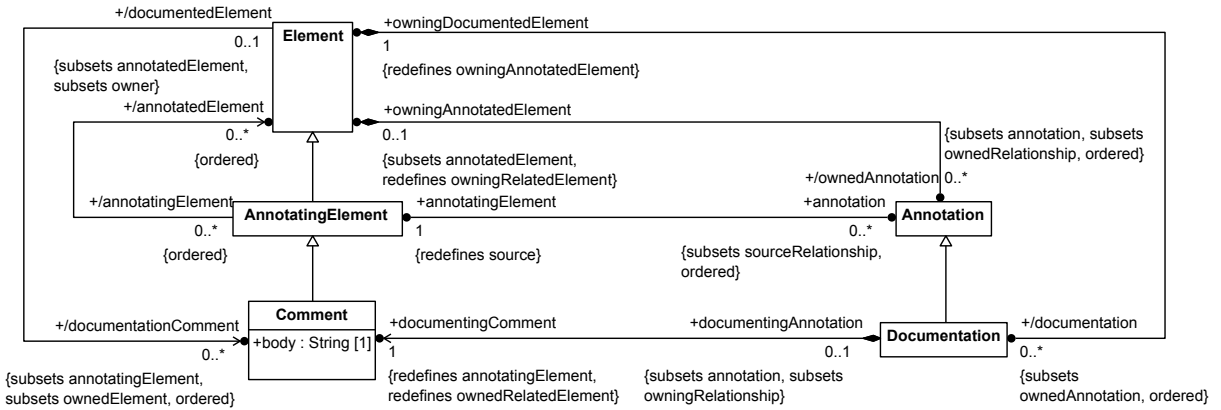


Figure 8. Comments

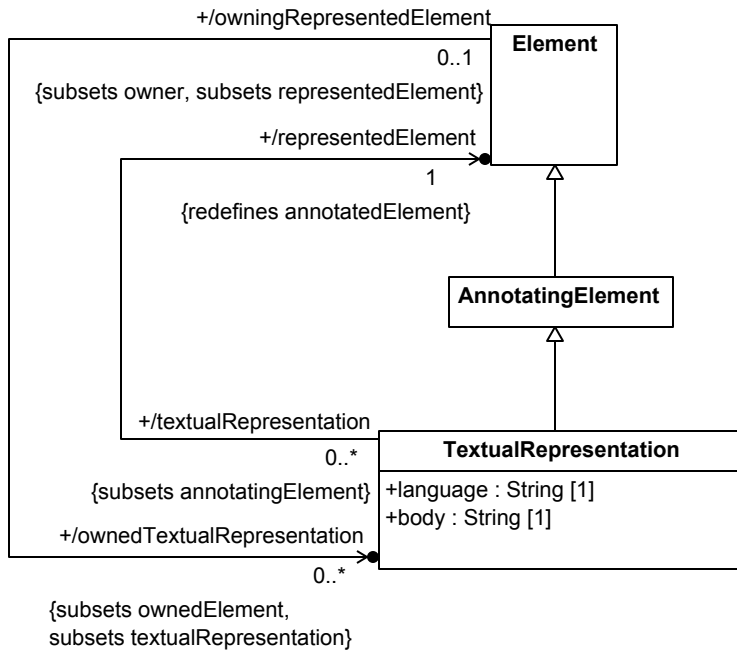


Figure 9. Textual Representation

7.2.3.3.2 AnnotatingElement

Description

An AnnotatingElement is an Element that provides additional description of or metadata on some other Element. An AnnotatingElement is attached to its annotatedElement by an Annotation Relationship.

General Classes

Element

Attributes

/annotatedElement : Element [0..*] {ordered}

The Elements that are annotated by this AnnotatingElement, derived as the annotatedElements of the annotations of this AnnotatingElement.

annotation : Annotation [0..*] {subsets sourceRelationship, ordered}

The Annotations that relate this AnnotatingElement to its annotatedElements.

Operations

No operations.

Constraints

annotatingElementAnnotatedElement

[no documentation]

```
annotatedElement = annotation  
.annotatedElement
```

7.2.3.3.3 Annotation

Description

An Annotation is a Relationship between an AnnotatingElement and the Element that is annotated by that AnnotatingElement.

General Classes

Relationship

Attributes

annotatedElement : Element {redefines target}

The Element that is annotated by the `annotatingElement` of this Annotation.

annotatingElement : AnnotatingElement {redefines source}

The AnnotatingElement that annotates the `annotatedElement` of this Annotation.

owningAnnotatedElement : Element [0..1] {subsets annotatedElement, redefines owningRelatedElement}

The `annotatedElement` of this Annotation, when it is also its `owningRelatedElement`.

Operations

No operations.

Constraints

No constraints.

7.2.3.3.4 Comment

Description

A Comment is AnnotatingElement whose `body` in some way describes its `annotatedElements`.

General Classes

AnnotatingElement

Attributes

body : String

The annotation text for the Comment.

Operations

No operations.

Constraints

No constraints.

7.2.3.3.5 Documentation

Description

Documentation is an Annotation whose `annotatingElement` is a Comment that provides documentation of the `annotatedElement`. Documentation is always an `ownedRelationship` of its `annotatedElement`.

General Classes

Annotation

Attributes

`documentingComment` : Comment {redefines `annotatingElement`, `ownedRelatedElement`}

The Comment, which is owned by the Documentation Relationship, that documents the `owningDocumentedElement` of this Documentation.

`owningDocumentedElement` : Element {redefines `owningAnnotatedElement`}

The `annotatedElement` of this Documentation, which must own the Relationship.

Operations

No operations.

Constraints

No constraints.

7.2.3.3.6 TextualRepresentation

Description

A TextualRepresentation is an AnnotatingElement that whose `body` represents the `representedElement` in a given `language`. The named `language` can be a natural language, in which case the `body` is an informal representation, or an artificial language, in which case the `body` is expected to be a formal, machine-parsable representation.

General Classes

AnnotatingElement

Attributes

`body` : String

A textual representation of the `representedElement` in the given `language`.

language : String

The natural or artificial language in which the `body` text is written.

`/representedElement` : Element {redefines `annotatedElement`}

The Element represented textually by this `TextualRepresentation`, which is its single `annotatedElement`.

Operations

No operations.

Constraints

No constraints.

7.2.4 Namespaces

7.2.4.1 Namespaces Overview

Memberships

A Namespace is an Element that contains other Elements via Membership Relationships with those Elements. The Namespace that is the `source` of a Membership Relationship shall also be its `owningRelatedElement`, known as the `membershipOwningNamespace` of the Membership. The `target` of a Membership can be any kind of Element, known as the `memberElement` of the Membership.

The Memberships for which a Namespace is the `membershipOwningNamespace` are the `ownedMemberships` of the Namespace. If the `memberElement` of an `ownedMembership` is an `ownedRelatedElement` of the Membership, then it is an `ownedMemberElement` of the Membership and an `ownedMember` of the Namespace. If an Element is the `ownedMemberElement` of a Membership, then that Membership is known as the `owningMembership` of the Element.

A Namespace may also have Import Relationships to other Namespaces. The Namespace that is the `source` of an Import Relationship shall also be its `owningRelatedElement`, known as the `importOwningNamespace` of the Import. The Namespace that is the `target` of an Import Relationship is known as the `importedNamespace` of the Import. The `importOwningNamespace` of an Import shall be different than its `importedNamespace`.

The visible Memberships of the `importedNamespace` of an Import shall become `importedMemberships` of the `importOwningNamespace`. The *visible* Memberships of a Namespace shall comprise at least the follow:

- All `ownedMemberships` of the Namespace with `visibility=public`.
- All `importedMemberships` of the Namespace that are derived from Import Relationships with `visibility=public`.

Subclasses of Namespace may define additional Memberships to be included in the set of visible Memberships of that kind of Namespace (for instance, the visible Memberships of a Type also include the `public inheritedMemberships` of the Type—see [7.3.2](#)).

A Namespace can also have `ownedMemberships` for which the `memberElement` is *not* owned. The union of the set of `unowned memberElements` of `ownedMemberships` and the set of `memberElements` (owned or unowned) of `importedMemberships` may be referred to as the complete set of *imported members* of the Namespace. The members of a Namespace comprise at least its `ownedMembers` and the complete set of its imported members.

A *root Namespace* is a Namespace that has no owner. The `ownedElements` of a root Namespace are known as *top-level Elements*. Any Element that is not a root Namespace shall have an `owner` and, therefore, must be in the ownership tree of a top-level Element of some root Namespace.

Note. The set of all Elements owned directly or indirectly by a root Namespace may be considered to be the representation of a single "model", though this term is not formally defined within KerML.

Naming

Each member of a Namespace can optionally be given one or more names *relative to* that Namespace. The names of a member of a Namespace shall consist of the `memberNames` specified for all the Memberships by which the member Element is related to the Namespace. Note that the same Element may be related to a Namespace by multiple Memberships, allowing the Element to have multiple, different names relative to that Namespace.

The name property of an Element is derived as the `memberName` of the `owningMembership` of the Element. All other names given to an Element are termed *aliases* for the Element.

The names of all the `ownedMembers` of a Namespace shall be distinct from each other. Further, if the `memberName` of any visible Membership of an `importedNamespace` conflicts with the name of any of `ownedMember` of the `importOwningNamespace`, or with the `memberName` of any visible Membership of the `importedNamespace` of any other Import, then that Membership shall be considered *hidden*, and it shall *not* be included in the set of `importedMemberships` of the `importOwningNamespace`.

As a result of the above rules, the `memberNames` of all `ownedMemberships` and `importedMemberships` will always be distinct from each other. Any subclass of Namespace that adds further kinds of Memberships (e.g., `inheritedMemberships` of Types—see [7.3.2](#)) shall maintain the property that the `memberNames` of all `memberships` of a Namespace are distinct from each other.

Release Note. The current rules for Membership distinguishability in a Namespace require that all `memberNames` be distinct from each other. It is expected that this will be loosened in the revised submission to allow overloading of behavioral Elements with the same name when these can be distinguished by having different parameter signatures.

Namespace is an Element that may itself be a named member of another Namespace. A *qualified name* of a named Namespace member includes both its *unqualified* `memberName` and the name of its containing Namespace, which may or may not be itself qualified. A qualified name of an Element has the form of a list of the `memberNames` of Namespace each relative to the previous one, followed by the unqualified `memberName` of the Element in the final Namespace. Since Namespace may themselves have aliases, it is possible for there to be multiple qualified names for an Element even if it does not itself have aliases. On the other hand, if a Namespace does not have any name, then its `members` will have no qualified names, even if they are themselves named.

Since a root Namespace cannot be contained in any other Namespace, it cannot have a name, at least as given within the KerML language. Any qualified name of an Element relative to a root Namespace always begins with the name of a member of the root Namespace, without regard to the (nameless) root Namespace itself.

Note. While a root Namespace cannot be given a name within KerML, it is expected that it would be named by what ever tooling or repository is used to manage KerML models. For the purposes of document-based model interchange, a root Namespace is the top-level element that can be interchanged as a single document (see Clause 9).

7.2.4.2 Concrete Syntax

7.2.4.2.1 Namespaces

```
RootNamespace : Namespace =
    NamespaceBodyElement(this) *

Namespace (m : Membership) : Namespace =
    NamespaceDeclaration(this, m) NamespaceBody(this)

NamespaceDeclaration (n : Namespace, m : Membership) : Namespace =
    'namespace' Identification(n, m)

NamespaceBody (n : Namespace) =
    ';' | '{' NamespaceBodyElement(p) * '}'
```

The *declaration* of a Namespace gives its identification, while the *body* of a Namespace specifies its contents.

The declaration of a root Namespace is implicit and no identification of it is provided in the KerML textual notation. Instead, the body of a root Namespace (i.e., a KerML "model") is given simply by the list of representations of its top-level elements, typically in a single textual document.

```
doc /* This is a model notated in KerML concrete syntax. */
element A {
    relationship B to C;
}
class C;
datatype D;
feature f: C;
package P;
```

A Namespace that is not a root Namespace, and does not represent any more specialized modeling construct (such as a Type—see [7.3.2](#)) is declared using the keyword **namespace**, optionally followed by a humanId and/or name (see [7.2.2.2.1](#)). The body of the Namespace is notated as a list of representations of the content of the Namespace delimited between curly braces { . . . }. If the Namespace is empty, then the body may omitted and the declaration ended instead with a semicolon.

```
namespace id '1.1' N1; // This is an empty namespace.
namespace id '1.2' N2 {
    doc /* This is an example of a namespace body. */
    class C;
    datatype D;
    feature f : C;
    namespace N3; // This is a nested namespace.
}
```

7.2.4.2.2 Namespace Bodies

```
NamespaceBodyElement (n : Namespace) =
  n.ownedRelationship += OwnedDocumentation
  | n.ownedRelationship += NamespaceMember(p)
  | n.ownedRelationship += Import

NamespaceMember (n : Namespace) : Membership
  ( ownedRelationship += PrefixDocumentation ) *
  ( visibility = BasicVisibilityIndicator ) ?
  ( NonFeatureNamespaceMember(this, n)
  | FeatureNamespaceMember(this) )

NonFeatureNamespaceMember (m : Membership, n : Namespace) =
  m.ownedMemberElement = NonFeatureElement(m, n)
  | ( 'alias' | 'import' ) m.memberElement = [Qualified Name]
    ( 'as' m.memberName = NAME ) ? ';'

FeatureNamespaceMember (m : Membership) =
  m.ownedMemberElement = FeatureElement(m)

Import : Import =
  ( ownedRelationship += PrefixDocumentation ) *
  ( visibility = BasicVisibilityIndicator ) ?
  'import' ( ImportedNamespace(this) |
            ImportedFilterPackage(this) )
  '::' ( '*' | isRecursive ?= '**' ) ';'

ImportedNamespace (i : Import) =
  i.importedNamespace = [Qualified Name]

ImportedFilterPackage (i : Import) :
  i.ownedRelatedElement += FilterPackage

FilterPackage : Package =
  ownedRelationship += FilterPackageImport
  ( ownedRelationship += FilterPackageMember ) +

FilterPackageImport : Import =
  ImportedNamespace (this)

FilterPackageMember : ElementFilterMembership =
  '[' condition = OwnedExpression ']'
  { visibility = 'private' }

BasicVisibilityIndicator : VisibilityKind =
  'public' | 'private'
```

Declaring an Element within the body of a Namespace denotes that the Element is an `ownedMember` of the Namespace—that is, that there is an `ownedMembership` of the Namespace with the Element as its `ownedMemberElement`. The name given for the Element (if any) becomes the `memberName` of the

Membership. The visibility of the Membership can also be specified by placing the keyword **public** or **private** before the Element declaration. If no visibility is specified, the default is **public**.

```
namespace N {
    public class C;
    private datatype D;
    feature f : C; // public by default
}
```

An alias for an Element is declared using the keyword **alias** followed by a qualified name (see below) identifying the Element, with the alias name given after the keyword **as**. This denotes an ownedMembership of the containing Namespace, with the identified Element as an unowned memberElement. The visibility of the Membership can be specified as for an ownedMember. The identified Element need not be an ownedMember of the Namespace containing the alias declaration, in which case the explicit alias name may be omitted, with the name of the Element then being the implicit alias name within the aliasing Namespace.

The keyword **import** can be used instead of **alias**. Typically, **import** is used when the aliased Element is not an ownedMember of the aliasing Namespace, while **alias** is used when giving another name to an Element within the same Namespace. However, the two forms are actually completely equivalent in meaning.

```
namespace N1 {
    class A;
    private alias A as B;
    public import P::C as CC;
    import N::D;
}
```

An ownedImport of a Namespace is denoted using the keyword **import** followed by a qualified name (see [7.2.4.2.4](#)) identifying the importedNamespace, followed by "::*". The visibility of the Import can be specified by placing the keyword **public** or **private** before the Import declaration. If no visibility is specified, the default is **public**.

```
namespace N2 {
    import N::*;
    private import N1::*;
}
```

If an importedNamespace is followed by "::*" instead of "::*", then the import shall be *recursive*. Such an import is equivalent to a regular import of importedNamespace, followed by further recursively importing each of the ownedMembers of the importedNamespace that are themselves Namespaces.

An Import may also be declared with one or more filterConditions, given as model-level evaluable Boolean Expressions (see [7.4.8](#)), listed after the importedNamespace specification, each surrounded by square brackets [...]. Such a filtered Import is equivalent to importing an implicit Package that then both imports the given importedNamespace and has all the given filterConditions. The effect is such that, for a filtered Import, Memberships shall be imported from the importedNamespace if and only if they satisfy all the given filterConditions. (While filtered Imports may be used in any Namespace, Packages and filterConditions are actually Kernel-layer concepts, because Expressions are only defined in that layer. See [7.4.13](#).)

```
namespace N3 {
    import Annotations::*;
```

```

    // Only import elements of NA that are annotated as Approved.
    import NA::*[@Approved];
}

```

A regular Comment (see [7.2.3.2](#)) declared within a Namespace body also becomes an `ownedMember` of the Namespace. If no `annotatedElements` are specified for the Comment, then, by default, the Comment is considered to be about the containing Namespace.

```

namespace N3 {
  class A;
  comment Comment1 about A
    /* This is a comment about class A. */

  comment Comment 2
    /* This is a comment about namespace N3. */

  /* This is also a comment about namespace N3. */
}

```

A Documentation Comment declared within a Namespace body (see [7.2.3.2](#)), however, is *not* an `ownedMember` of the Namespace. Instead, if it is a regular Comment, then it is owned via a Documentation Relationship by the containing Namespace. If it is a prefix Comment, then it is owned via a Documentation Relationship with the next Membership or Import declared in the Namespace lexically after the Comment.

```

namespace N4 {
  doc N4_Doc
    /* This is documentation about namespace N4. */

  /** This is documentation about member B. */
  /** This is more documentation about member B. */
  private class B;

  /** This is documentation about alias B1. */
  public alias B as B1;

  /** This is documentation about the import of N3. */
  import N3::*;
}

```


7.2.4.2.3 Namespace Elements

```
NonFeatureElement (m : Membership, n : Namespace) : Element =
  Element (m)
  | Relationship (m)
  | Comment (m, n)
  | TextualRepresentation (m, n)
  | AnnotatingFeature (m, n)
  | Namespace (m)
  | Type (m)
  | Classifier (m)
  | DataType (m)
  | Class (m)
  | Structure (m)
  | Association (m)
  | AssociationStructure (m)
  | Interaction (m)
  | Behavior (m)
  | Function (m)
  | Predicate (m)
  | Package (m)
  | Generalization (m)
  | Conjugation (m)
  | Superclassing (m)
  | FeatureTyping (m)
  | Subsetting (m)
  | Redefinition (m)
  | TypeFeaturing (m)

FeatureElement (m : Membership) : Feature =
  Feature (m)
  | Step (m)
  | Expression (m)
  | BooleanExpression (m)
  | Invariant (m)
  | Connector (m)
  | BindingConnector (m)
  | Succession (m)
  | ItemFlow (m)
  | SuccessionItemFlow (m)
```

A Namespace body can contain any kind of Element that can be represented in the KerML notation. These are syntactically divided into two sets: Feature Elements and non-Feature Elements. Feature Elements include Feature, as defined in the Core (see [7.3.4](#)), and the various specialized kinds of Features defined in the Kernel (see [7.4](#)). Non-Feature Elements include all constructs defined in the Root (see [7.2](#)), Type and Classifier as defined in the Core (see [7.3.2](#) and [7.3.3](#)), and Package and the various specialized kinds of Classifiers defined in the Kernel (see [7.4](#)). This division is convenient because, in the Core, Feature Elements may be related to Types using a specialized FeatureMembership Relationship, while non-Feature Elements are always related to Types using the same generic Membership Relationship used with non-Type Namespaces.

7.2.4.2.4 Name Resolution

```
QualifiedName =  
  NAME ( '::' NAME ) *
```

A qualified name is notated as a sequence of *segment names* separated by ":" punctuation. An *unqualified* name can be considered the degenerate case of a qualified name with a single segment name. A qualified name is used in the KerML textual concrete syntax to identify an Element that is being referred to in the representation of another Element. A qualified name used in this way does not appear in the corresponding abstract syntax—instead, the abstract syntax representation contains an actual reference to the identified Element. *Name resolution* is the process of determining the Element that is identified by a qualified name.

Qualified name resolution uses the Namespace memberships to map simple names to named Elements. Every Namespace other than a root Namespace is nested in a containing Namespace called its *owningNamespace*. A root Namespace has an implicit containing namespace known as its *global namespace*. The global namespace for a root Namespace includes all the visible Memberships of all other root Namespace that are *available* to the first Namespace, which shall include at least all the KerML Model Libraries (see [Clause 8](#)). A conforming tool can provide means for making additional Namespace available to a root Namespace, but this specification does not define any standard mechanism for doing so.

An Element considered to be *directly contained* in a Namespace if it is an *ownedElement* of the Namespace or if it is indirectly owned by the Namespace without any other intervening Namespace (e.g., if the Element is an *ownedRelatedElement* of a Relationship that is not a Membership but is an *ownedMember* of the Namespace). A Namespace defines a mapping from names to Elements directly contained in the Namespace, known as the *local resolution* of those names.

1. For each Element that is directly contained in a Namespace, the *humanId* of the Element locally resolves to that Element.
2. For each *membership* of a Namespace, the *memberName* of the Membership locally resolves to the *memberElement* of the Membership.

Note. If the Namespace is well formed, then there can be at most one Element that locally resolves to any given name.

The *visible resolution* of a name restricts the *memberships* in the second step to those that are visible outside the Namespace. Note that resolution of *humanIds* is not restricted by visibility.

In general, the *full resolution* of a simple name relative to a Namespace then proceeds as follows:

1. If the name locally resolves to an Element directly contained in the Namespace, then it fully resolves to that Element.
2. If there is no such Element, then:
 - If the Namespace is *not* a root Namespace, then the name resolution continues with the *owningNamespace* of the Namespace.
 - If the Namespace *is* a root Namespace, then the name resolution continues with the global namespace.

The resolution of a simple name in the global namespace proceeds as follows:

1. If there is a Membership in the global namespace that has an *ownedMemberElement* that has a *humanId* equal to the simple name, then the name resolves to that Element.

2. If there is a Membership in the global namespace that has a `memberName` equal to the simple name, then the name resolves to the `memberElement` of that Membership.
3. If there is no such Membership, then the name has no resolution.

Note. It is possible that there will be more than one Membership that resolves to a given simple name. In this case, one of these Memberships is chosen for the resolution of the name, with `humanId` resolution having priority over `memberName` resolution, but with which one is chosen not otherwise determined by this specification.

A qualified name is always used to identify an Element that is a `target` Element of some Relationship. The *context* Namespace is the nearest Namespace that directly or indirectly owns that Relationship. The *local namespace* for resolving the qualified name is then determined as follows:

- If the context Relationship is *not* a Membership or an Import, then the local namespace is the context Namespace.
- If the context Relationship *is* a Membership or an Import, then
 - If the context Namespace is *not* a root Namespace, then the local namespace is the `owningNamespace` of the context Namespace.
 - If the context Namespace *is* a root Namespace, then the local namespace is the global namespace for the context Namespace.

Note. Membership and Import Relationships are treated as a special case in order to avoid possible infinite recursion in the name resolution process.

The resolution of a qualified name begins with the full resolution of its first segment name with respect to the local namespace for the qualified name. If the qualified name has only one segment name, then the qualified name resolves to the resolution of its first segment name. Otherwise, each segment name of the qualified name, other than the last, must resolve to a Namespace that is the visible resolution of the name relative to the Namespace identified by the previous segment. The qualified name then resolves to the resolution of its last segment name.

Note. In the concrete syntax productions found in various other subclauses, the notation `[QualifiedName]` is used to signify that a `Qualified` Name shall be parsed, then that name shall be resolved into a reference to an Element, per the rules given in this subclause, and that reference shall be inserted into the abstract syntax as specified in the production, not the `Qualified` Name itself (see also [7.1.3](#), [Table 4](#)).

7.2.4.3 Abstract Syntax

7.2.4.3.1 Overview

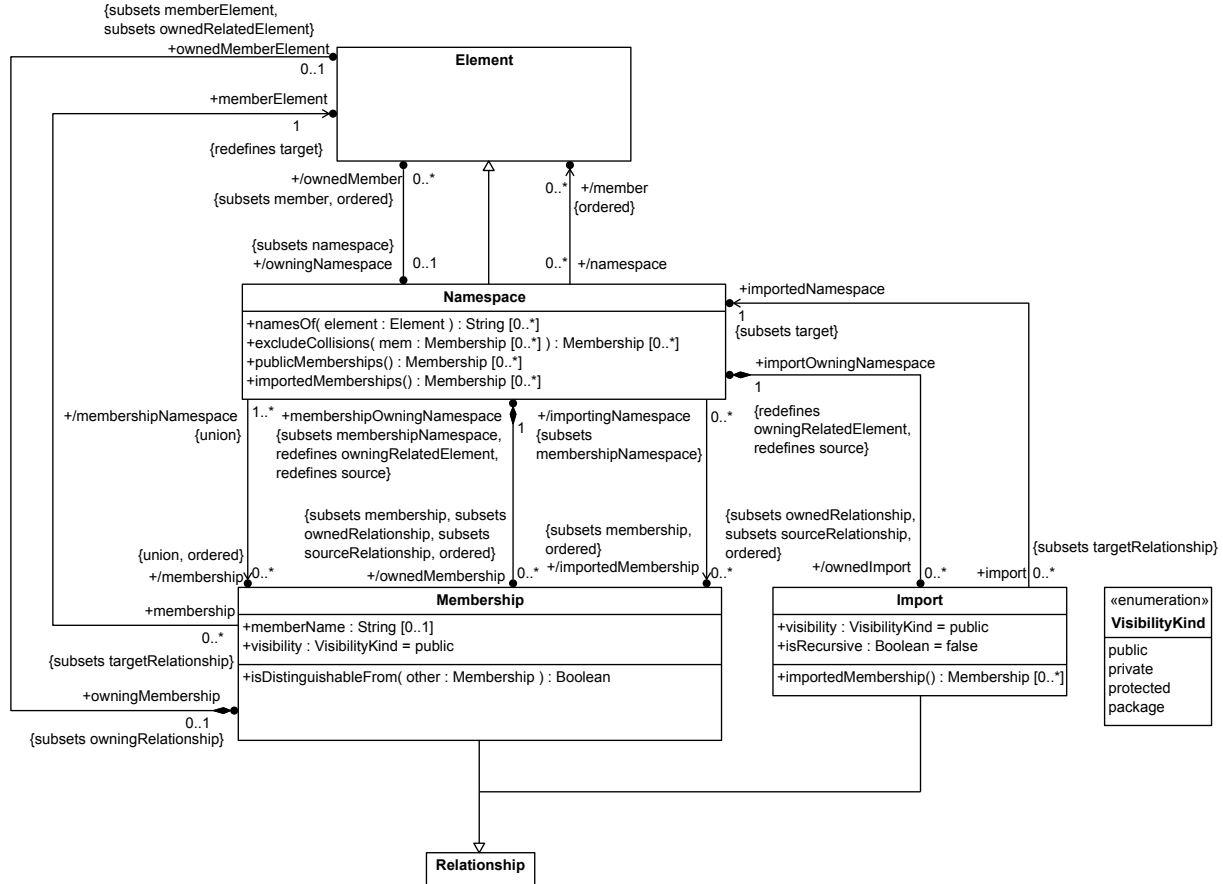


Figure 10. Namespaces

7.2.4.3.2 Import

Description

An Import is a Relationship between an importOwningNamespace and an importedNamespace in which the visible member Elements of the importedNamespace become imported members of the importOwningNamespace. An Import may be *public*, in which case the imported members are "re-exported" as publicly visible members of the importOwningNamespace, or it may be *private*, in which case the imported members are private to the importOwningNamespace.

General Classes

Relationship

Attributes

importedNamespace : Namespace {subsets target}

The Namespace whose visible members are imported by this Import.

importOwningNamespace : Namespace {redefines source, owningRelatedElement}

The Namespace into which members are imported by this Import, which must be the `owningRelatedElement` of the Import.

`isRecursive` : Boolean

Whether to recursively import Memberships from all visible, owned sub-namespaces of the `importedNamespace`.

`visibility` : VisibilityKind

Whether the imported members from this Import become public or private members of the `importOwningNamespace`.

Operations

`importedMembership()` : Membership [0..*]

Returns the Memberships of the `importedNamespace` whose `memberElements` are to become imported members of the `importOwningNamespace`. By default, this is the set of publicly visible Memberships of the `importedNamespace`, but this may be overridden in specializations of Import

Constraints

No constraints.

7.2.4.3.3 Membership

Description

Membership is a Relationship between a Namespace and an Element that indicates the Element is a member of (i.e., is contained in) the Namespace. The Membership may define a `memberName` for the Element as a member of the Namespace and specifies whether or not the Element is publicly visible as a member of the Namespace from outside the Namespace. The Element may be owned by the Namespace, in which case it is an `ownedMember` of the Namespace, or it may be referenced but not owned, in which case it is effectively individually imported into the Namespace.

General Classes

Relationship

Attributes

`memberElement` : Element {redefines target}

The Element that becomes a member of the `membershipOwningNamespace` due to this Membership.

`memberName` : String [0..1]

The name of the `memberElement` in `membershipOwningNamespace`.

`membershipOwningNamespace` : Namespace {subsets `membershipNamespace`, redefines `source`, `owningRelatedElement`}

The Namespace of which the `memberElement` becomes a member due to this Membership.

`ownedMemberElement` : `Element` [0..1] {subsets `memberElement`, `ownedRelatedElement`}

The `memberElement` of this `Membership` if it is owned by the `Membership` as an `ownedRelatedElement`.

`visibility` : `VisibilityKind`

Whether or not the `Membership` of the `memberElement` in the `membershipOwningNamespace` is publicly visible outside that `Namespace`. Unless the `membershipOwningNamespace` is a `Type`, `visibility` must be either `public` or `private`.

Operations

`isDistinguishableFrom(other : Membership)` : `Boolean`

Whether this `Membership` is distinguishable from a given other `Membership`. By default, this is true if the `memberName` of this `Membership` is either empty or is different the `memberName` of the other `Membership`, or if the metaclass of the `memberElement` of this `Membership` is different than the metaclass of the `memberElement` of the other `Membership`. But this may be overridden in specializations of `Membership`.

Constraints

No constraints.

7.2.4.3.4 Namespace

Description

A `Namespace` is an `Element` that contains other `Elements`, known as its `members`, via `Membership Relationships` with those `Elements`. Some of the `members` of a `Namespace` may be owned by the `Namespace`. The rest are imported into the `Namespace`, either as `unowned memberElements` of `owned Memberships` of the `Namespace` or via `Import Relationships` with other `Namespaces`.

A `Namespace` can provide names for its `members` via the `memberNames` specified by the `Memberships` in the `Namespace`. If a `Membership` specifies a `memberName`, then that is the name of the corresponding `memberElement` relative to the `Namespace`. Note that the same `Element` may be the `memberElement` of multiple `Memberships` in a `Namespace` (though it may be owned at most once), each of which may define a separate alias for the `Element` relative to the `Namespace`.

General Classes

`Element`

Attributes

`/importedMembership` : `Membership` [0..*] {subsets `membership`, ordered}

The `Memberships` in this `Namespace` that result from `Import Relationships` between the `Namespace` and other `Namespaces`. This excludes any `Membership` from one imported `Namespace` that would be indistinguishable from a `Membership` imported from another `Namespace` or from an `ownedMembership` of this `Namespace`.

`/member` : `Element` [0..*] {ordered}

The set of all `member Elements` of this `Namespace`, derived as the `memberElements` of all `memberships` of the `Namespace`.

/membership : Membership [0..*] {ordered, union}

All Memberships in this Namespace, defined as the union of ownedMemberships and importedMemberships.

/ownedImport : Import [0..*] {subsets sourceRelationship, ownedRelationship, ordered}

The ownedRelationships of this Namespace that are Imports, for which the Namespace is the importOwningNamespace.

/ownedMember : Element [0..*] {subsets member, ordered}

The owned members of this Namespace, derived as the ownedMemberElements of the ownedMemberships of the Namespace.

/ownedMembership : Membership [0..*] {subsets membership, sourceRelationship, ownedRelationship, ordered}

The ownedRelationships of this Namespace that are Memberships, for which the Namespace is the membershipOwningNamespace.

Operations

excludeCollisions(mem : Membership [0..*]) : Membership [0..*]

Exclude from the given set mem of Memberships those that would not be distinguishable from each other if imported into this Namespace.

importedMemberships() : Membership [0..*]

Derive the imported Memberships of this Namespace as the importedMembership of all

ownedImports

, excluding Memberships that have distinguishability collisions with each other or with any ownedMembership.

body: excludeCollisions(ownedImport.importedMembership()) ->
select(m1 | ownedMembership->forall(m2 | m1.isDistinguishableFrom(m2)))

namesOf(element : Element) : String [0..*]

Return the names of the given element as it is known in this Namespace.

publicMemberships() : Membership [0..*]

Return the publicly visible Memberships of this Namespace, which includes those ownedMemberships that are with a visibility of public and those importedMemberships that were imported via Import Relationships with a visibility of public.

Constraints

namespaceMembers

[no documentation]

```

member = membership.memberElement

namespaceOwnedMember

[no documentation]

ownedMember = ownedMembership.ownedMemberElement

namespaceOwnedMembership

[no documentation]

ownedMembership = ownedRelationship->selectByKind(Membership)

namespaceOwnedImport

[no documentation]

ownedImport = ownedRelationship->selectByKind(Import)

namespaceDistinguishability

[no documentation]

membership->forAll(m1 | membership->forAll(m2 | m1 <> m2 implies m1.isDistinguishableFrom(
namespaceImportedMembership

[no documentation]

importedMembership = importedMemberships()

```

7.2.4.3.5 VisibilityKind

Description

VisibilityKind is an enumeration whose literals specify the visibility of a Membership of an Element in a Namespace outside of that Namespace. Note that "visibility" specifically restricts whether an Element in a Namespace may be referenced by name from outside the Namespace and only otherwise restricts access to an Element as provided by specific constraints in the abstract syntax (e.g., preventing the import or inheritance of private Elements).

General Classes

No general classes.

Literal Values

package

Only valid if the owning Namespace of a Membership is a Type. Indicates that the Membership is visible to all Elements within the nearest enclosing Namespace that is not a Type to which it would have been visible if it had public visibility, but that it is not visible outside the nearest owning Namespace that is not a Type (or if there is no such Namespace).

private

Indicates a Membership is not visible outside its owning Namespace.

protected

Only valid for if the owning Namespace of a Membership is a Type. Indicates that the Membership is visible outside its owning Type only if inherited by direct or indirect specializations of the Type.

public

Indicates that a Membership is publicly visible outside its owning Namespace.

7.3 Core

7.3.1 Core Overview

7.3.1.1 General

The Core layer specializes the Root layer to add the minimum modeling constructs for specifying systems as they are build or operate (that have semantics). *Semantics* is about alignment of models and the things being modeled (real, simulated, or imagined things of any kind, including objects, links between them, and performances of behaviors). Models give conditions for how things should be (a specification of things), or for a model to be an accurate reflection of things (an explanation or record of things). See discussion in 6.1.

KerML specifies the alignment above by *classification*. Things being modeled are aligned with models when the model has elements that classify those things. Core introduces Type, the most general kind of model element that classifies things (real or simulated) when used in models. Classifiers are Types that classify things, such as cars, people, and processes being carried out, as well as how they are related by Features, including chains of relationships (for "nested" Features). Features are Types that classify just the (chains of) relationships. Classifiers include how things are related to enable them to be identified by those relationships. For example, cars owned by people who live a particular city might be required to be registered. These cars are identified by a chain of two relationships, first ownership of the car, then the residence of the owner.

Taxonomies are supported by Generalizations between Types (Superclassing for Classifiers, Subsetting and Redefinition for Features). Specialized Types classify all the things their more general Types do (via one or more Generalizations). This means things classified by a specialized Type have all the Features (via *features*) of its general Types (sometimes referred to as "inheriting" features from general to specific Types). FeatureTyping (the kinds of "values" a feature might have) is Generalization between a Feature and another Type.

The syntax and semantics for Types, Classifiers, and Features (see [7.3.3](#), [7.3.2](#), and [7.3.4](#), respectively) are described informally in their Overview subclauses, and then formally in their Concrete Syntax, Abstract Syntax, and Semantics subclauses. The mathematical term *universe* is used in the Overview subclauses, which is the set of all things potentially being modeled, separately from how they are related (see [7.3.1.2](#)).

7.3.1.2 Mathematical Preliminaries

The following are model theoretic terms, explained in terms of this specification:

- *Vocabulary*: Model elements conforming to abstract syntax and additional restrictions given in this subclause.
- *Universe*: All (real or virtual) things the vocabulary could possibly be about.
- *Interpretation*: The relationship between vocabulary and mathematical structures made of elements of the universe.

The *semantics* of KerML are restrictions on the interpretation relationship, given in this subclause and the Semantics subclauses. This subclause also defines the above terms for KerML. They are used by the mathematical semantics in the rest of the specification.

A vocabulary $V = (V_T, V_C, V_F)$ is a 3-tuple where:

- V_T is a set of types (model elements classified by Type or its specializations, see [7.3.2.3](#)).
- $V_C \subseteq V_T$ is a set of classifiers (model elements classified by Classifier or its specializations, see [7.3.3.3](#)), including at least *Base::Anything* from KerML model library, see [8.2](#).
- $V_F \subseteq V_T$ is a set of features (model elements classified by Feature or its specializations, see [7.3.4.3](#)), including at least *Base::things* from the KerML model library (see [8.2](#)).
- $V_T = V_C \cup V_F$

An interpretation $I = (\mathcal{A}, \cdot^T)$ for V is a 2-tuple where:

- \mathcal{A} is a non-empty set (*universe*), and
- \cdot^T is an (*interpretation*) function relating elements of the vocabulary to sets of sequences of elements of the universe. It has domain V_T and co-domain that is the power set of S , where

$$S = \cup_{i \in \mathbb{Z}^+} \mathcal{A}^i$$

S is the set of all n -ary Cartesian products of \mathcal{A} with itself, including 1-products, but not 0-products, which are called *sequences*. The Semantics subclauses give other restrictions on the interpretation function.

The phrase *result of interpreting* a model (vocabulary) element refers to sequences paired with the element by \cdot^T . This specification also refers to this as the *interpretation* of the model element, for short.

The function \cdot^{minT} specializes \cdot^T to the subset of sequences in an interpretation that have no others as tails, except when applied to *Anything*

$$\forall t \in \text{Type}, s_1 \in S \quad s_1 \in (t)^{minT} \equiv s_1 \in (t)^T \wedge (t \neq \text{Anything} \Rightarrow (\forall s_2 \in S \quad s_2 \in (t)^T \wedge s_2 \neq s_1 \Rightarrow \neg \text{tail}(s_2, s_1)))$$

The following functions, adapted from [DOL], Appendix F.4.1 (Semantic Conformance of UML With DOL, Preliminaries), operate on sequences:

- *length* is a synonym for DOL's *sequence-length*.

$$\forall s \quad \text{length}(s) \equiv \text{form:sequence-length}(s)$$

- *head* is true if the first sequence is the same as the second for some of it, starting at the beginnings of both, otherwise is false.

$$\begin{aligned} \forall s_1, s_2 \quad \text{head}(s_1, s_2) &\Rightarrow \text{form:Sequence}(s_1) \wedge \text{form:Sequence}(s_2) \\ \forall s_1, s_2 \quad \text{head}(s_1, s_2) &\equiv (\text{length}(s_1) \leq \text{length}(s_2)) \wedge \\ &(\forall p \in \mathbb{Z}^+ \quad p \geq 1 \wedge p \leq \text{length}(s_1) \Rightarrow \\ &(\forall x \text{ form:in-position-count}(s_1, p, x) = \text{form:in-position-count}(s_2, p, x))) \end{aligned}$$

- *tail* is true if the first sequence is the same as the second for some of it, ending at the ends of both, otherwise is false:

$$\begin{aligned} \forall s_1, s_2 \quad \text{tail}(s_1, s_2) &\Rightarrow \text{form:Sequence}(s_1) \wedge \text{form:Sequence}(s_2) \\ \forall s_1, s_2 \quad \text{tail}(s_1, s_2) &\equiv (\text{length}(s_1) \leq \text{length}(s_2)) \wedge \\ &(\forall h, p \in \mathbb{Z}^+ \quad (h = \text{length}(s_2) - \text{length}(s_1)) \wedge (p > h) \wedge (p \leq \text{length}(s_2) \Rightarrow \\ &(\forall x \text{ form:in-position-count}(s_1, p - h, x) = \text{form:in-position-count}(s_2, p, x)))) \end{aligned}$$

- *concat* is true if the first sequence has the second as head, the third as tail, and its length is the sum of the lengths of the other two, otherwise is false:

$$\begin{aligned} \forall s_0, s_1, s_2 \text{ concat}(s_0, s_1, s_2) &\Rightarrow \text{form:Sequence}(s_0) \wedge \text{form:Sequence}(s_1) \wedge \text{form:Sequence}(s_2) \\ \forall s_0, s_1, s_2 \text{ concat}(s_0, s_1, s_2) &\equiv (\text{length}(s_0) = \text{length}(s_1) + \text{length}(s_2)) \wedge \text{head}(s_1, s_0) \wedge \text{tail}(s_2, s_0) \end{aligned}$$

7.3.2 Types

7.3.2.1 Types Overview

Types

Type is the most general kind of model element in KerML that has semantics (in the sense of 6.1 and [7.3.1.2](#)). Types classify things in the modeled universe and/or (chains of) relationships between those things (see [7.3.1.1](#)). The set of things and (chains of) relationships classified by a Type is the *extent* of the Type, each member of which is an *instance* of the Type. Everything in the modeled universe and all (chains of) relationships between them are instances of the Type *Anything* in the Base model library (see [8.2](#)).

Note. Referring to things and (chains of) relationships between them collectively as instances is for clarity of explanation only. The mathematical semantics treats both as sequences (see [7.3.1.2](#) and the Semantics subclauses).

Types give conditions for what things must be in their extent and what must not be (*sufficient* and necessary conditions, respectively). The simplest conditions directly identify instances that must be in or not in the extent. Other conditions can give characteristics of instances indicating they must be in or not in the extent. For example, a type Car could require every instance in its extent (everything it classifies) to have four wheels, which means anything that does not have four wheels is not in its extent (necessary condition). It does not mean all four wheeled things are in the extent (are cars), however (necessary conditions are usually stated as what must be true of all instances in the extent, even though they only determine what is not). Alternatively, Car could require all four wheeled things to be in its extent (sufficient condition).

Conditions in KerML are always necessary and can be indicated as sufficient for all conditions of a Type as needed, whereupon the sufficient conditions are the negation of the necessary ones. For example, if Car requires all instances to be four wheeled (necessary), and then is also indicated as sufficient, its extent will include all four wheeled things and no others. The original (necessary) condition excludes everything not four wheeled, then indicating Car is sufficient brings in all four wheeled things. These conditions apply to all procedures that determine the extent of Types, including logical solvers, inference engines, and software.

A Type can also be *abstract*, which means that all instances of the Type must also be instances of at least one (possibly indirect) specialization of it (which must not be abstract, that is, must be *concrete*), see Generalization below.

Generalization

Generalizations are Relationships between a *specific* Type and a *general* one, indicating that all instances of the *specific* Type are instances of the *general* one (the extent of the *specific* Type is a subset of the extent of the *general* one, which might be the same set). This means instances of the *specific* Type have all the features of the *general* ones, referred to syntactically as *inheriting* features from general to specific Types, see below. It also enables Generalization Relationships to form cycles, which means all Types in the cycle have the same instances (same extent).

Classifiers and Features

Types divide into Classifiers and Features ([7.3.3](#) and [7.3.4](#), respectively). Classifiers classify things in the universe and how they are related, while Features classify only how they are related (see [7.3.4.1](#)). Types must be Classifiers or Features, but not both. However, they can generalize each other in models. Classifiers generalizing Features limit what things the Features can relate to, see FeatureTyping in [7.3.4.1](#). Classifiers generalized by Features can

have no instances, because Classifiers must include things in the modeled universe, regardless of how they are related, whereas Features cannot include those.

Note. Types as the union of Classifiers and Features is required by the mathematical semantics (see [7.3.1.2](#)), but not by the abstract syntax. This specification does not give semantics to Types that are not Classifiers or Features.

Membership in Types

Types are Namespaces, enabling them to have members via Membership Relationships to other Elements identified as their memberships (see [7.2.4](#)). These include `inheritedMemberships`, which are certain Memberships from the general Types of their owned Generalizations. The `memberNames` of all `inheritedMemberships` must be distinct from each other and from the `memberNames` of all owned Memberships. A Membership that would otherwise be imported is also hidden by an `inheritedMembership` of with the same `memberName`, just as in the case of an owned Membership (see [7.2.4.1](#)).

Except for name conflicts, as described above, the `inheritedMemberships` include all visible and protected Memberships of the general Types. *Protected* Memberships are all owned and inherited Memberships of the general Type whose visibility is the `VisibilityKind` `protected` (imported Memberships can never have `protected` visibility). This means `protected` Memberships are Memberships that are only visible to their owning Type and to (direct or indirect) specializations of it.

Note. Name conflicts due to inherited Memberships can be resolved by redefining them to give non-conflicting `memberNames` (see [7.3.4](#)).

Feature Membership

A `FeatureMembership` is a Relationship between a Type and a Feature that is both a kind of Membership and a kind of `FeatureTyping` (see [7.3.4.3.6](#)). The Features that are related to a Type via `FeatureMembership` Relationships, identified as the `features` of the Type, are not only members of the Type, they also have the Type as one of their `featuringTypes` (see [7.3.4](#)). `FeatureMembership` also defines a number of properties specific to a Feature due to its membership in each related Type, see [cf:`FeatureMembership.vlink`].

Multiplicity

The number of instances in the extent of a Type (*cardinality*) is constrained by its *multiplicity*. A Multiplicity is a Feature whose values are natural numbers that are the only ones allowed for the cardinality of its `featuringType` (every Multiplicity is the `feature` of exactly one Type). A Type can have at most one `feature` that is a Multiplicity, identified as its `multiplicity`. Cardinality for Classifiers is the number of things in the modeled universe classified by the it. For Features that are not an end Feature, cardinality is the number of values of the Feature for a specific instance of its `featuringTypes`.

Note. See [7.4.11](#) in Kernel for specifying numeric ranges for multiplicities, rather than each number separately as above.

An `EndFeatureMembership` is a `FeatureMembership` that specifies the `memberFeature` as an *end* Feature of the `owningType` of the `EndFeatureMembership`. `EndFeatureMembership` has exactly the same meaning as `FeatureMembership`, except that the semantics of Multiplicity is different for end Features. End Features are used primarily in the definition of Associations and Connectors (see [7.4.4](#) and [7.4.5](#), respectively).

Conjugation

Conjugation is a Relationship between two Types in which the `conjugatedType` inherits visible and protected Memberships from the `originalType`, except the direction of input and output Features is reversed. FeatureMemberships with direction `in` relative to the `originalType` are treated as having direction of `out` relative to the `conjugatedType`, and vice versa for direction `in` treated as `out`. FeatureMemberships with with no direction or direction `inout` in the `originalType` are inherited without change. Types can participate as `conjugatedTypes` in at most one Conjugation Relationship, and they shall not also be the `specific` Type in any Generalization relationship.

7.3.2.2 Concrete Syntax

7.3.2.2.1 Types

```
Type (m : Membership) : Type =
  ( isAbstract ?= 'abstract' )? 'type'
  TypeDeclaration(this, m) TypeBody(this)

TypeDeclaration (t : Type, m : Membership) =
  (t.isSufficient ?= 'all' )? Identification(t, m)
  ( t.ownedRelationship += MultiplicityMember )?
  ( SpecializationPart(t) | ConjugationPart(t) )+

SpecializationPart (t : Type) =
  SPECIALIZES t.ownedRelationship += OwnedGeneralization
  ( ',' t.ownedRelationship += OwnedGeneralization )*

ConjugationPart (t : Type) =
  CONJUGATES t.ownedRelationship += OwnedConjugation

MultiplicityMember : Membership =
  ownedMemberElement = Multiplicity

TypeBody (t : Type) =
  ';' | '{' TypeBodyElement(t)* '}'

TypeBodyElement (t : Type) : Type =
  t.documentation += OwnedDocumentation
  | t.ownedRelationship += NonFeatureTypeMember(t)
  | t.ownedRelationship += FeatureTypeMember
  | t.ownedRelationship += Import

NonFeatureTypeMember (t : Type) : Membership =
  TypeMemberPrefix(this) NonFeatureElement(this, t)

FeatureTypeMember : FeatureMembership =
  FeatureMember | EndFeatureMember

TypeMemberPrefix (m : Membership) =
  ( m.ownedRelationship += PrefixAnnotation )*
  ( m.visibility = VisibilityIndicator )?

VisibilityIndicator : VisibilityKind =
  BasicVisibilityIndicator | 'protected'
```

Similarly to the generic Namespace notation (see [7.2.4.2](#)), the representation of a Type includes a *declaration* and a *body*.

A Type is declared using the keyword **type**, optionally followed by a nameId and/or name. In addition, a Type declaration defines either one or more ownedGeneralizations for the Type (for notation, see [7.3.2.2.2](#)) or a conjugator for the Type (for notation, see [7.3.2.2.3](#)).

A Type is specified as abstract (`isAbstract = true`) by placing the keyword **abstract** before the keyword **type**. A Type is specified as sufficient (`isSufficient = true`) by placing the keyword **all** after the keyword **type**. (This notational placement of the **abstract** and **all** keywords is also consistent in the notation for Classifiers and Features.)

```
abstract type A specializes Base::Anything;
type all x specializes A, Base::things;
```

The multiplicity of a Type is specified after any identification of the Type, between square brackets [...] (see also [7.4.11](#) on MultiplicityRanges).

```
// This Type has exactly one instance.
type Singleton[1] specializes Base::Anything;
```

The body of a Type is specified as for a generic Namespace, by listing the members between curly braces {...} (see [7.2.4.2](#)). However, unlike non-Type Namespaces, Types can have protected members. A protected member is indicated using the keyword **protected**, instead of **public** or **private**. In addition, Features that are declared as ownedMembers of a Type are automatically considered to be ownedFeatures of the Type, related by FeatureMemberships (see [7.3.2.2.4](#)).

```
type Super specializes Base::Anything {
  private namespace N {
    type Sub specializes Super;
  }
  protected feature f : N::Sub;
}
```

7.3.2.2.2 Generalization

```
Generalization (m : Membership) : Generalization =
  ( 'generalization' Identification(this, m) )?
  'subtype' specific = [QualifiedName]
  SPECIALIZES general = [QualifiedName] ';'

OwnedGeneralization : Generalization =
  general = [QualifiedName]
```

A Generalization Relationship is declared using the keyword **generalization**, optionally followed by a humanId and/or a name. The qualified name of the specific Type is then given after the keyword **subtype**, followed by the qualified name of the general Type after the keyword **specializes**. The symbol `:>` can be used interchangeably with the keyword **specializes**.

```
generalization Gen subtype A specializes B;
generalization subtype x :> Base::things;
```

If no humanId or name is given, then the keyword **generalization** may be omitted.

```
subtype C specializes A;
subtype C specializes B;
```

An ownedGeneralization of a Type is defined as part of the declaration of the Type, rather than in a separate declaration, by including the qualified names of the general Type in a list after the keyword **specializes** (or the symbol :>).

```
type C specializes A, B;
type f :> Base::things;
```

7.3.2.2.3 Conjugation

```
Conjugation (m : Membership) =
  'conjugation' Identification(this, m)
  'type' conjugatedType = [QualifiedName]
  CONJUGATES originalType = [QualifiedName] ';'

OwnedConjugation : Conjugation =
  originalType = [QualifiedName]
```

A Conjugation Relationship is declared using the keyword **conjugation**, followed by a humanId and/or a name. The qualified name of the conjugatedType is then given after the keyword **type**, followed by the qualified name of the originalType after the keyword **conjugates**. The symbol ~ can be used interchangeably with the keyword **conjugates**.

```
type Original specializes Base::Anything {
  in feature Input;
}
type Conjugate1 specializes Base::Anything;
type Conjugate2 specializes Base::Anything;
conjugation c1 type Conjugate1 conjugates Original;
conjugation c2 type Conjugate2 ~ Original;
```

An ownedConjugator for a Type is defined as part of the declaration of the Type, rather than in a separate declaration, by including the qualified name of the originalType after the keyword **conjugates** (or the symbol ~).

```
type Conjugate1 conjugates Original;
type Conjugate2 ~ Conjugate1;
```

A Type can be the conjugatedType of at most one Conjugation Relationship. A conjugatedType shall not have any ownedGeneralizations.

7.3.2.2.4 Feature Membership

```
FeatureMember : FeatureMembership =
  TypeMemberPrefix(this) FeatureMemberFlags(this)
  ( ownedMemberFeature = FeatureElement(this)
  | 'feature'? ( memberName = NAME )?
  | 'is' memberFeature = [QualifiedName] ';'
  )

EndFeatureMember : EndFeatureMembership =
  TypeMemberPrefix(this) 'end' FeatureMemberFlags(this)
  ownedMemberFeature = FeatureElement(this)

FeatureMemberFlags (m : FeatureMembership) =
  ( m.direction = FeatureDirection )?
  ( m.isComposite ?= 'composite' | m.isPortion ?= 'portion' )?
  ( m.isReadOnly ?= 'readonly' )? ( m.isDerived ?= 'derived' )?
  ( m.isPort ?= 'port' )?

FeatureDirection : FeatureDirectionKind =
  'in' | 'out' | 'inout'
```

The body of a Type contains declarations of the Elements that are the members of of the Type, just as in the generic notation for a Namespaces (see [7.2.4](#)). However, unlike a non-Type Namespace, a Type can be the `featuringType` of those of its members that are Features. The features of a Type are declared in two ways:

- A Feature declared directly in the body of a Type automatically becomes an `ownedFeature` of that Type (see [7.3.4.2](#)).
- A non-owned feature of a Type is declared using the same feature keyword used to declare an `ownedFeature`, but with the qualified name of the Feature given after the keyword **is**. Such a declaration may also include a `memberName` for the Feature relative to the `featuringType`. If no explicit `memberName` is given, then the name of the Feature (if any) is used as the implicit default.

As kinds of Types, the above also applies to the bodies of Classifiers (see [7.3.3](#)) and Features (see [7.3.4.2](#)). A Feature may also be an imported into a Type like an other Element (see [7.2.4.2.1](#)), in which case it is related to the importing Type by a regular Membership, not a FeatureMembership, and, so, does not become one of the features of the Type.

```
feature person : Person;
classifier Person {
  feature age : ScalarValues::Integer; // This Feature member is owned.
  feature parent[2] is person;         // This Feature member is not owned.
  import person as personAlias;        // This is not a FeatureMembership.
}
```

Whether a Feature member is owned or not, there are a number of additional properties of its FeatureMembership that can be flagged by adding specific keywords to its declaration. If present these are always specified in the following order, after any visibility indicator:

1. **in**, **out**, **inout** – Specifies that the FeatureMembership has the indicated direction.

2. **composite** or **portion** – Specifies either `isComposite = true` or `isPortion = true` (specifying both is not allowed).
3. **readonly** – Specifies `isReadOnly = true`.
4. **derived** – Specifies `isDerived = true`.
5. **port** – Specifies `isPort = true`.

Implementation Note. The notations for **readonly** and **derived** have not been implemented yet.

```
classifier Fuel {  
    portion feature fuelPortion : Fuel;  
}  
classifier Tank {  
    port feature fillPort {  
        in feature fuelFlow: Fuel;  
    }  
    composite feature fuel : Fuel;  
}
```

A Feature can also be declared to be an `endFeature` (that is, related to the Type by an `EndFeatureMembership`) using the keyword **end**, which is placed before the above flag keywords (if any). Any kind of Type can have `endFeatures`, but they are mostly used in Associations (see [7.4.4](#)) and Connectors (see [7.4.5](#)).

```
assoc VehicleRegistration {  
    end feature owner[1] : Person;  
    end feature vehicle[*] : Vehicle;  
}
```

7.3.2.3 Abstract Syntax

7.3.2.3.1 Overview

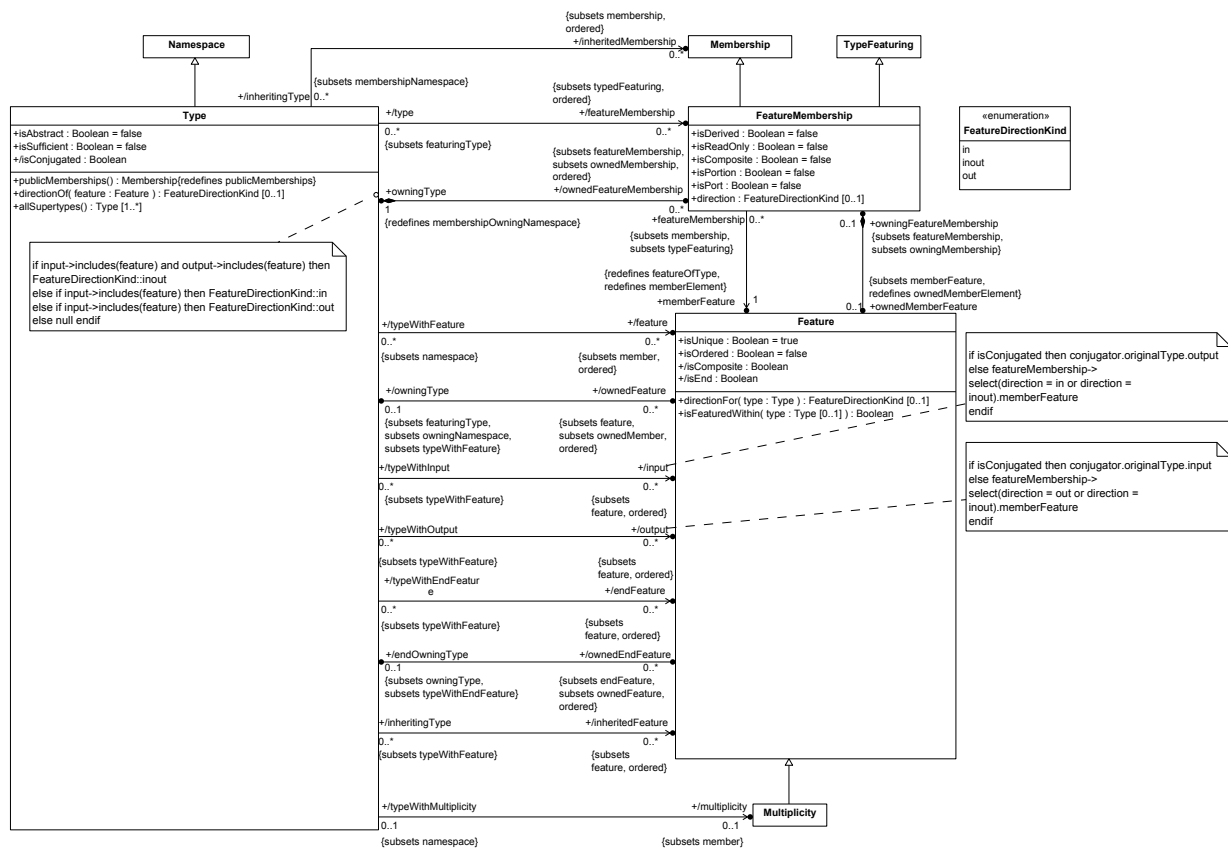


Figure 11. Types

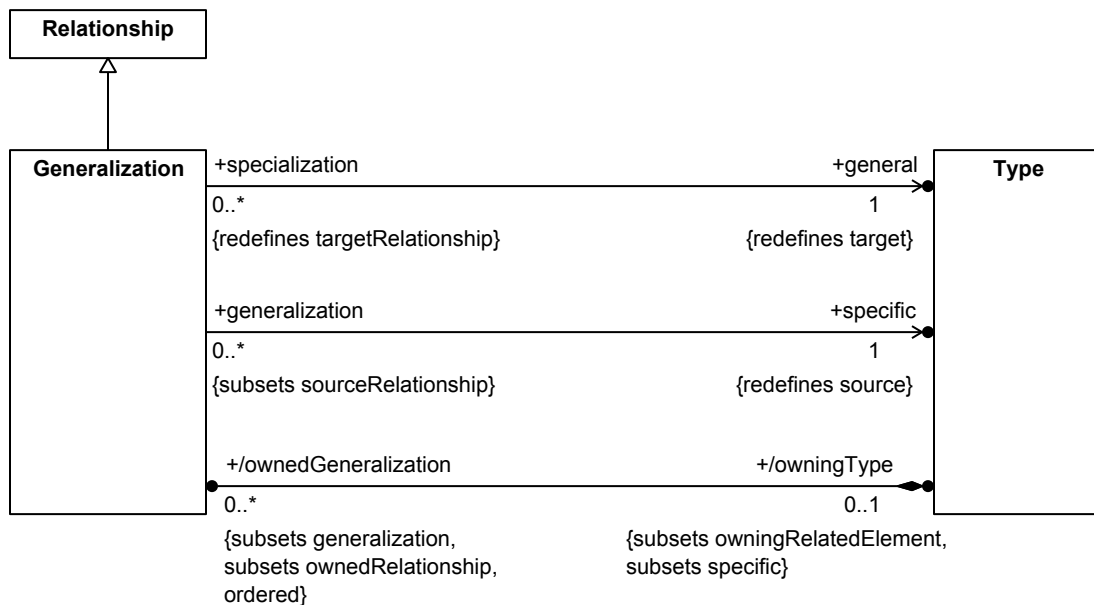


Figure 12. Generalization

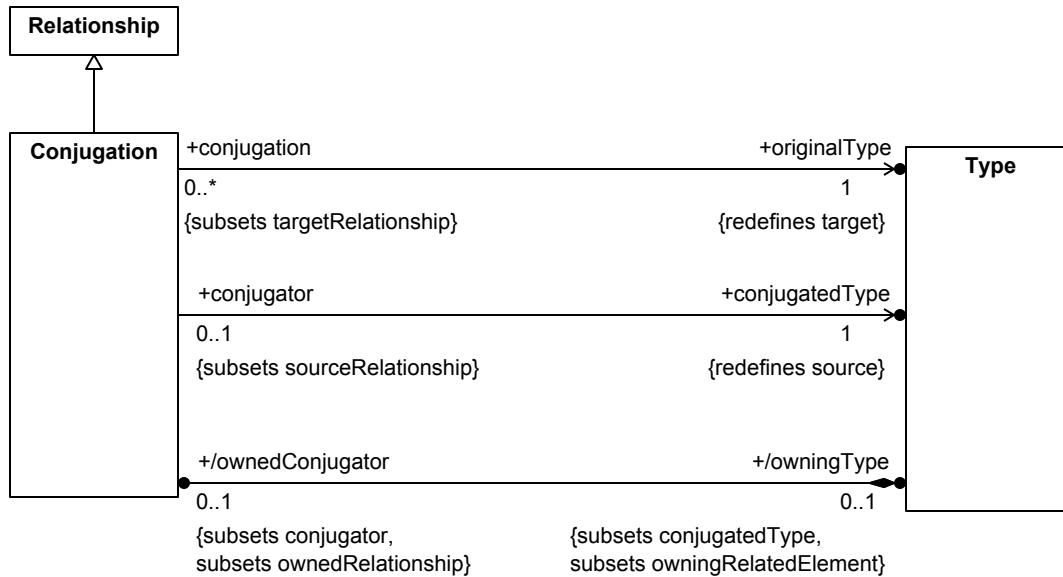


Figure 13. Conjugation

7.3.2.3.2 Conjugation

Description

Conjugation is a Relationship between two types in which the `conjugatedType` inherits all the Features of the `originalType`, but with all input and output Features reversed. That is, any Features with a `FeatureMembership` with *direction in* relative to the `originalType` are considered to have an effective direction of *out* relative to the `conjugatedType` and, similarly, Features with *direction out* in the `originalType` are considered to have an effective direction of *in* in the `originalType`. Features with *direction inout*, or with no direction, in the `originalType`, are inherited without change.

A Type may participate as a `conjugatedType` in at most one Conjugation relationship, and such a Type may not also be the *specific* Type in any Generalization relationship.

General Classes

Relationship

Attributes

`conjugatedType : Type {redefines source}`

The Type that is the result of applying Conjugation to the `originalType`.

`originalType : Type {redefines target}`

The Type to be conjugated.

`/owningType : Type [0..1] {subsets conjugatedType, owningRelatedElement}`

The `conjugatingType` of this Type that is also its `owningRelatedElement`.

Operations

No operations.

Constraints

No constraints.

7.3.2.3.3 EndFeatureMembership

Description

An EndFeatureMembership is a FeatureMembership that specifies the `memberFeature` as an `endFeature` of the `owningType` of the EndFeatureMembership. EndFeatureMembership has exactly the same meaning as FeatureMembership, except that the semantics of Multiplicity is different for `endFeatures`.

An `endFeature` is always considered to map each domain entity to a single co-domain entity, whether or not a Multiplicity is given for it. If a Multiplicity is given for an `endFeature`, rather than giving the co-domain cardinality for the Feature as usual, it specifies a cardinality constraint for *navigating* across the `endFeatures` of the `featuringType` of the end Feature. That is, if a Type has n `endFeatures`, then the Multiplicity of any one of those end Features constrains the cardinality of the set of values of that Feature when the values of the other $n-1$ end Features are held fixed.

General Classes

FeatureMembership

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.3.2.3.4 FeatureDirectionKind

Description

FeatureDirectionKind enumerates the possible kinds of `direction` that a Feature may be given as a member of a Type.

General Classes

No general classes.

Literal Values

in

Values of the Feature on each instance of its domain are determined externally to that instance and used internally.

inout

Values of the Feature on each instance are determined either as *in* or *out* directions, or both.

out

Values of the Feature on each instance of its domain are determined internally to that instance and used externally.

7.3.2.3.5 FeatureMembership

Description

FeatureMembership is a Membership for a Feature in a Type that is also a TypeFeaturing Relationship between the Feature and the Type.

General Classes

Membership
TypeFeaturing

Attributes

direction : FeatureDirectionKind [0..1]

Determines how values of the Feature are determined or used, see FeatureDirectionKind.

isComposite : Boolean

Whether the values of the Feature can exist after the instance of the domain no longer does.

isDerived : Boolean

Whether the values of the Feature can always be computed from the values of other Features.

isPort : Boolean

Whether the Feature is visible externally to instances of the Feature's domain.

isPortion : Boolean

Whether the values of the Feature are contained in the space and time of instances of the Feature's domain.

isReadOnly : Boolean

Whether the values of the Feature can change over the lifetime of an instance of the domain.

memberFeature : Feature {redefines memberElement, featureOfType}

The Feature that this FeatureMembership relates to its owningType, making it a feature of the owningType.

ownedMemberFeature : Feature [0..1] {subsets memberFeature, redefines ownedMemberElement}

A memberFeature that is owned by this FeatureMembership and hence an ownedFeature of the owningType.

owningType : Type {redefines membershipOwningNamespace}

The Type that owns this FeatureMembership.

Operations

No operations.

Constraints

No constraints.

7.3.2.3.6 Generalization

Description

Generalization is a Relationship between two Types that requires all instances of the `specific` type to also be instances of the `general` Type (i.e., the set of instances of the `specific` Type is a *subset* of those of the `general` Type, which might be the same set).

General Classes

Relationship

Attributes

general : Type {redefines target}

A Type with a superset of all instances of the `specific` Type, which might be the same set.

/owningType : Type [0..1] {subsets specific, owningRelatedElement}

The Type that is the `specific` Type of this Generalization and owns it as its `owningRelatedElement`.

specific : Type {redefines source}

A Type with a subset of all instances of the `general` Type, which might be the same set.

Operations

No operations.

Constraints

generalizationSpecificNotConjugated

The `specific` Type of a Generalization cannot be a conjugated Type.

not specific.isConjugated

7.3.2.3.7 Multiplicity

Description

A Multiplicity is a Feature whose co-domain is a set of natural numbers that includes the number of sequences determined below, based on the kind of `typeWithMultiplicity`:

- Classifiers: minimal sequences (the single length sequences of the Classifier).
- Features: sequences with the same feature-pair head. In the case of Features with Classifiers as domain and co-domain, these sequences are pairs, with the first element in a single-length sequence of the domain Classifier (head of the pair), and the number of pairs with the same first element being among the Multiplicity co-domain numbers.

Multiplicity co-domains (in models) can be specified by Expression that might vary in their results. If the `typeWithMultiplicity` is a Classifier, the domain of the Multiplicity shall be *Anything*. If the `typeWithMultiplicity` is a Feature, the Multiplicity shall have the same domain as the `typeWithMultiplicity`.

General Classes

Feature

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.3.2.3.8 Type

Description

A Type is a Namespace that is the most general kind of Element supporting the semantics of classification. A Type may be a Classifier or a Feature, defining conditions on what is classified by the Type (see also the description of `isSufficient`).

General Classes

Namespace

Attributes

`/endFeature` : Feature [0..*] {subsets feature, ordered}

All `features` related to this Type by `EndFeatureMemberships`.

`/feature` : Feature [0..*] {subsets member, ordered}

The `memberFeatures` of the `featureMemberships` of this Type.

`/featureMembership` : FeatureMembership [0..*] {subsets typedFeaturing, ordered}

All `FeatureMemberships` that have the Type as source. Each `FeatureMembership` identifies a Feature of the Type.

/inheritedFeature : Feature [0..*] {subsets feature, ordered}

All the memberFeatures of the inheritedMemberships of this Type.

/inheritedMembership : Membership [0..*] {subsets membership, ordered}

All Memberships inherited by this Type via Generalization or Conjugation.

/input : Feature [0..*] {subsets feature, ordered}

All features related to this Type by FeatureMemberships that have direction in or inout.

isAbstract : Boolean

Indicates whether instances of this Type must also be instances of at least one of its specialized Types.

/isConjugated : Boolean

Indicates whether this Type has an ownedConjugator. (See Conjugation.)

isSufficient : Boolean

Whether all things that meet the classification conditions of this Type must be classified by the Type.

(A Type gives conditions that must be met by whatever it classifies, but when isSufficient is false, things may meet those conditions but still not be classified by the Type. For example, a Type *Car* that is not sufficient could require everything it classifies to have four wheels, but not all four wheeled things would need to be cars. However, if the type *Car* were sufficient, it would classify all four-wheeled things.)

/multiplicity : Multiplicity [0..1] {subsets member}

The one member (at most) of this Type that is a Multiplicity, which constrains the cardinality of the Type. A multiplicity can be owned or inherited. If it is owned, the multiplicity must redefine the multiplicity (if it has one) of any general Type of a Generalization of this Type.

/output : Feature [0..*] {subsets feature, ordered}

All features related to this Type by FeatureMemberships that have direction out or inout.

/ownedConjugator : Conjugation [0..1] {subsets ownedRelationship, conjugator}

A Conjugation owned by this Type for which the Type is the originalType.

/ownedEndFeature : Feature [0..*] {subsets endFeature, ownedFeature, ordered}

All endFeatures of this Type that are ownedFeatures.

/ownedFeature : Feature [0..*] {subsets feature, ownedMember, ordered}

The ownedMemberFeatures of the ownedFeatureMemberships of this Type.

/ownedFeatureMembership : FeatureMembership [0..*] {subsets ownedMembership, featureMembership, ordered}

The `ownedMemberships` of this Type that are `FeatureMemberships`, for which the Type is the `owningType`. Each such `FeatureMembership` identifies a feature of the Type.

`/ownedGeneralization : Generalization [0..*] {subsets generalization, ownedRelationship, ordered}`

The `ownedRelationships` of this Type, for which the Type is the `specific Type`.

Operations

`allSupertypes() : Type [1..*]`

post: `result = let g : Bag = generalization.general in
g->union(g->collect(allSupertypes()))->flatten()->asSet()->including(self)`

`directionOf(feature : Feature) : FeatureDirectionKind [0..1]`

If the given feature is a feature of this type, then return its direction relative to this type, taking conjugation into account.

`publicMemberships() : Membership`

Constraints

`typeOwnedConjugator`

[no documentation]

```
let ownedConjugators: Sequence(Conjugator) =  
    ownedRelationship->selectByKind(Conjugation) in  
    ownedConjugators->size() = 1 and  
    ownedConjugator = ownedConjugators->at(1)
```

`typeOwnedGeneralizations`

[no documentation]

```
ownedGeneralization = ownedRelationship->selectByKind(Generalization)->  
    select(g | g.special = self)
```

`typeOwnedFeatureMembership`

[no documentation]

```
ownedFeatureMembership = ownedRelationship->selectByKind(FeatureMembership)
```

`typeMultiplicity`

The multiplicity of this Type is all its features that are `Multiplicities`. (There must be at most one.)

```
multiplicity = feature->select(oclIsKindOf(Multiplicity))
```

7.3.2.4 Semantics

Required Generalizations to Model Library

See Required Relationships to Model Library in [7.3.3.4](#).

Type Semantics

The interpretation of Types in a model shall satisfy the following rules:

1. All sequences in the interpretation of a Type are in the interpretations of its generalizing Types.

$$\forall t_g, t_s \in V_T \quad t_g \in t_s.\text{generalization.general} \Rightarrow (t_s)^T \subseteq (t_g)^T$$

7.3.3 Classifiers

7.3.3.1 Classifiers Overview

Classifiers

Classifiers are Types that classify things in the modeled universe, regardless of how Features relate them, as well how they are related by Features ([7.3.4.1](#)). (See Classifiers and Features in [7.3.2.1](#) about how they are related.)

Superclassing

Superclassing is a kind of Generalization that restricts its `specific` and `general` Types to be Classifiers, identifying them as `subclass` and `superclass`, respectively. The `subclass` can omit any instances of the extent of the `superclass` that would be inconsistent with the semantics of Classifier (see [7.3.3.4](#)).

7.3.3.2 Concrete Syntax

7.3.3.2.1 Classifiers

```
Classifier (m : Membership) : Classifier =
  ( isAbstract ?= 'abstract' ) 'classifier'
  ClassifierDeclaration(this, m) TypeBody(this)

ClassifierDeclaration (t : Type, m : Membership)
  ( t.isSufficient ?= 'all' )? Identification(t, m)
  ( t.ownedRelationship += MultiplicityMember )?
  ( SuperclassingPart(t) | ConjugationPart(t) )?

SuperclassingPart (t : Type) =
  SPECIALIZES t.ownedRelationship += OwnedSuperclassing
  ( ',' t.ownedRelationship += OwnedSuperclassing )*
```

The notation for a Classifier is the same as the generic notation for a Type, except using the keyword **classifier** rather than **type**. However, any general Types referenced in a **specializes** list must be Classifiers, and the Generalizations defined are specifically Superclassings. A Classifier is also not required to have any `ownedSuperclassings` explicitly specified. If no explicit Superclassing is given for a Classifier, and the Classifier is not conjugated, then the Classifier is given a default Superclassing to the most general base Classifier *Anything* from the *Base* model library (see [8.2](#)).

```

classifier Person { // Default superclass is Base::Anything.
    feature age : ScalarValues::Integer;
}
classifier Child specializes Person;

```

The declaration of a Classifier may also specify that the Classifier is a `conjugatedType` (see [7.3.2.2](#)), in which case the `originalType` must also be a Classifier.

```

classifier FuelInPort {
    in feature fuelFlow : Fuel;
}
classifier FuelOutPort conjugates FuelInPort;

```

7.3.3.2.2 Superclassing

```

Superclassing (m : Membership) =
    ( 'generalization' Identification(this, m) )?
    'subclass' subclass = [QualifiedName]
    SPECIALIZES superclass = [QualifiedName] ';'

OwnedSuperclassing : Superclassing =
    superclass = [QualifiedName]

```

A Superclassing Relationship is declared using the keyword **generalization**, optionally followed by a `humanId` and/or a name. The qualified name of the subclass is then given after the keyword **subclass**, followed by the qualified name of the superclass after the keyword **specializes**. The symbol `:>` can be used interchangeably with the keyword **specializes**.

```

generalization Super subclass A specializes B;
generalization subclass B :> A;

```

If no `humanId` or name is given, then the keyword **generalization** may be omitted.

```

subclass C specializes A;
subclass C specializes B;

```

An `ownedSuperclassing` of a Classifier is defined as part of the declaration of the Classifier, rather than in a separate declaration, by including the qualified name of the superclass in a list after the keyword **specializes** (or the symbol `:>`).

```

classifier C specializes A, B;

```

7.3.3.3 Abstract Syntax

7.3.3.3.1 Overview

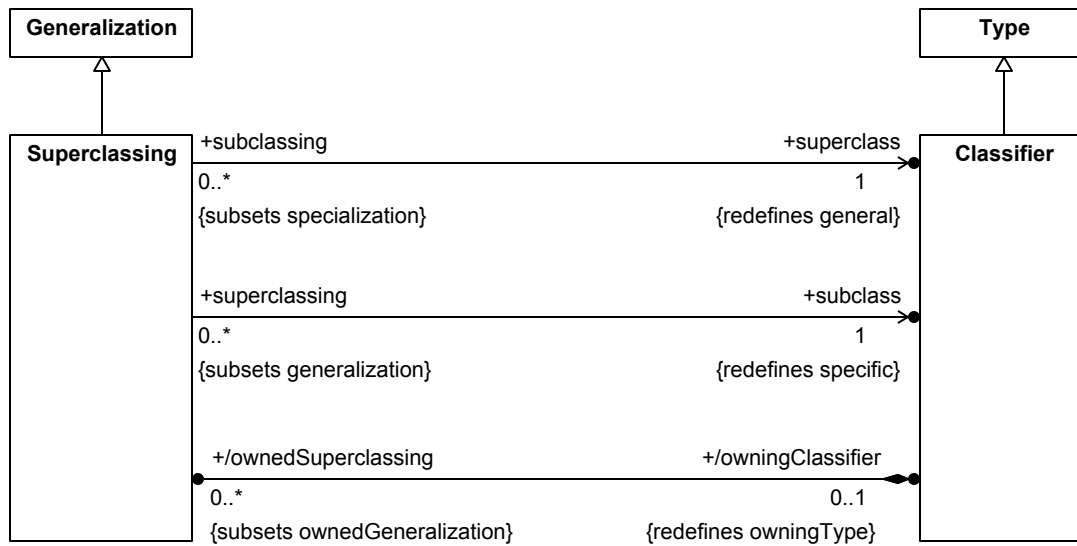


Figure 14. Classifiers

7.3.3.3.2 Classifier

Description

A Classifier is a Type for model elements that classify:

- Things (in the universe) regardless of how Features relate them. These are sequences of exactly one thing (sequence of length 1).
- How the above things are related by Features. These are sequences of multiple things (length > 1).

Classifiers that classify relationships (sequence length > 1) must also classify the things at the end of those sequences (sequence length =1). Because of this, Classifiers specializing Features cannot classify anything (any sequences).

General Classes

Type

Attributes

/ownedSuperclassing : Superclassing [0..*] {subsets ownedGeneralization}

The ownedGeneralizations of this Classifier that are Superclassings, for which the Classifier is the subclass.

Operations

No operations.

Constraints

classifierOwnedSuperclassings

[no documentation]

```
ownedSuperclassing = ownedGeneralization->intersection(superclassing)
```

classifierSpecializesAnything

[no documentation]

```
allSupertypes()->includes(Kernel Library::Anything)
```

classifierMultiplicityDomain

If a Classifier has a multiplicity, then the multiplicity shall have no featuringTypes (meaning that its domain is implicitly *Base::Anything*).

```
multiplicity <> null implies multiplicity.featureingType->isEmpty()
```

7.3.3.3 Superclassing

Description

Superclassing is Generalization in which both the `specific` and `general` Types are Classifiers. This means all instances of the specific Classifier are also instances of the general Classifier.

General Classes

Generalization

Attributes

`/owningClassifier : Classifier [0..1] {redefines owningType}`

The more general Classifier in the pair linked by Superclassing and that owns the relationship.

`subclass : Classifier {redefines specific}`

The more specific Classifier in the pair linked by Superclassing.

`superclass : Classifier {redefines general}`

The more general Classifier in the pair linked by Superclassing.

Operations

No operations.

Constraints

No constraints.

7.3.3.4 Semantics

Required Generalizations to Model Library

1. All Types shall directly or indirectly specialize *Base::Anything* (see [8.2.2.1](#)), including Classifiers (implied by Rule 2 below combined with the definition of \cdot^T in [7.3.1.2](#)).

Classifier Semantics

The interpretation of the Classifiers in a model shall satisfy the following rules:

1. If the interpretation of a Classifier includes a sequence, it also includes the 1-tail of that sequence.

$$\forall c \in V_C, s_1 \in S \quad s_1 \in (c)^T \Rightarrow (\forall s_2 \in S \quad \text{tail}(s_2, s_1) \wedge \text{length}(s_2) = 1 \Rightarrow s_2 \in (c)^T)$$

2. The interpretation of the Classifier *Anything* includes all sequences of all elements of the universe.

$$(\text{Anything})^T = S$$

7.3.4 Features

7.3.4.1 Features Overview

Features

A Feature is a Type that classifies how things in the modeled universe are related, including by chains of relationships. Relations between things can themselves be treated as things, allowing relations between relations (recurring as many times as needed). A Feature relates instances in the intersection of the extents of its `featuringTypes` (the *domain*) with instances in the intersection of the extents of its `types` (the *co-domain*). The domain of Features with no `featuringTypes` is the Type *Anything* from the Base model library (see [7.3.2.1](#) and [8.2](#)). (See Classifiers and Features in [7.3.2.1](#) about how they are related.)

Type Featuring

TypeFeaturing is a Relationship between a Feature and a Type that is a `featuringType` of the Feature. The `ownedTypeFeaturings` of a Feature are those TypeFeaturings for which the Feature is a `featureOfType` and which are owned by the Feature. A FeatureMembership is a kind of TypeFeaturing that also makes the Feature a member of the `featuringType` (see [7.3.2](#)). FeatureMemberships are always owned by the `featuringType`.

Feature Typing

FeatureTyping is a kind of Generalization that restricts its `specific` Type to be a Feature, identifying it as `typedFeature`, while its `general` Type is not restricted, but identified by `type` (which must be a Classifier or another Feature, see Classifiers and Features in [7.3.2.1](#)). FeatureTyping can form cycles of Features to mean the extents of Features are the same, like any Generalization, but a Classifier in the cycle will make it unsatisfiable (see Generalization, and Classifiers and Features, in [7.3.2.1](#)).

The `ownedTypings` of a Feature are those FeatureTypes for which the Feature is a `typedFeature` and which are owned by the Feature. The `types` of a Feature are the union of the `types` of all its `ownedTypings` with all the `types` of the `subsettingFeatures` of the Feature (see Subsetting below), excluding any Types that directly or indirectly generalize any others.

Subsetting

Subsetting is a kind of Generalization that restricts its *specific* and *general* Types to be Features, identifying them as `subsettingFeature` and `subsettingFeature`, respectively. Any aspect of the `subsettingFeature` can be restricted relative to `subsettingFeature` as, such as the (co)domain and multiplicity (see below).

Redefinition

Redefinition is a kind of Subsetting that requires the things identified by (values of) the `redefinedFeature` and the `redefiningFeature` (specialized from `subsettingFeature` and `subsettingFeature`, respectively) to be the same on each instance (separately) of the domain of the `redefiningFeature`. This means any restrictions on the values of `redefiningFeature` relative to `redefinedFeature`, such as on the (co)domain or multiplicity, also apply to the values of `redefinedFeature` (on each instance of the domain of the `redefiningFeature`), and vice versa.

Redefinition also requires the `owningType` of the `redefiningFeature` to (indirectly) specialize the `owningType` (or `Anything`) of the `redefinedFeature` (`redefiningType`), and to *not* inherit the `redefinedFeature` into its namespace. This enables the `redefiningFeature` to have the same name as the `redefinedFeature` if desired. However, the absence of the `redefiningFeature` from namespace of the `redefiningType` does not prevent it from having values on instances of that Type, see above.

Mathematical Semantics

Types are interpreted as sequences of one or more things from the modeled universe, where each thing in the sequence is related to the next by a Feature. Classifier interpretations include sequences of length 1, as well as longer sequences ending in the things in their 1-sequences ("navigations" to those things). These longer sequences are interpretations of Features. Feature sequences can be divided in two, beginning with an interpretation of its domain, and ending with an interpretation of its co-domain (its *value*). In the simplest case, a Feature has exactly one `featuringType` and exactly one `type`, both of which are Classifiers. The interpretations of such a Feature are pairs (sequences of length 2) of a thing from a 1-sequence of the `featuringType` and a thing from a 1-sequence of the `type`. Interpretations of the `type` Classifier includes the Feature pairs ("navigations" to the last thing in the sequence). This way of interpreting Classifiers enables FeatureTyping to be a kind of Generalization that restricts the Feature interpretations to sequences that end (lead to) 1-sequences of its `type`. Features can also have Features as their `featuringType` or `type`. ("nested" features). In this case, the sequences will be longer than 2.

7.3.4.2 Concrete Syntax

7.3.4.2.1 Features

```
Feature (m : Membership) : Feature =
  ( isAbstract ?= 'abstract' )? 'feature'?
  FeatureDeclaration(this, m) ValuePart(this)?
  TypeBody(this)

FeatureDeclaration (f : Feature, m : Membership) =
  ( f.isSufficient ?= 'all' )? Identification(f, m)
  ( FeatureSpecializationPart(f) | ConjugationPart(f) )?
  TypeFeaturingPart(f)?

TypeFeaturingPart(f : Feature) =
  'featured' 'by' f.ownedRelationship += OwnedTypeFeaturing
  ( ',' f.ownedTypeFeaturing += OwnedTypeFeaturing )*

FeatureSpecializationPart(f : Feature) =
  FeatureSpecializationPart(f)+ MultiplicityPart(f)? FeatureSpecialization(f)*
  | MultiplicityPart(f) FeatureSpecialization(f)*

MultiplicityPart (f : Feature) =
  f.ownedRelationship += MultiplicityMember
  ( f.isOrdered ?= 'ordered' ( !f.isUnique ?= 'nonunique' )?
  | !f.isUnique ?= 'nonunique' ( isOrdered ?= 'ordered' )? )?

FeatureSpecialization (f : Feature) =
  Typings(f) | Subsettings(f) | Redefinitions(f)

Typings (f : Feature) =
  TypedBy(f) ( ',' f.ownedRelationship += OwnedFeatureTyping )*

TypedBy (f : Feature) =
  TYPED_BY f.ownedRelationship += OwnedFeatureTyping

Subsettings (f : Feature) =
  Subsets(f) ( ',' f.ownedRelationship += OwnedSubsetting )*

Subsets (f : Feature) =
  SUBSETS f.ownedRelationship += OwnedSubsetting

Redefinitions (f : Feature) =
  Redefines(f) ( ',' f.ownedRelationship += OwnedRedefinition )*

Redefines (f : Feature) =
  REDEFINES ownedRelationship += OwnedRedefinition
```

The notation for a Feature is similar to the generic notation for a Type (see [7.3.2.2.1](#)), except using the keyword **feature** rather than **type**. Further, a Feature can have any of three kinds of Generalization: FeatureTyping (see [7.3.4.2.3](#)), Subsetting (see [7.3.4.2.4](#)) and Redefinition (see [7.3.4.2.5](#)). In general, clauses for the different kinds of Generalization can appear in any order in a Feature declaration.

```

feature x typed by A, B subsets f redefines g;

// Equivalent declaration:
feature x redefines g typed by A subsets f typed by B;

```

If no Subsetting (or Redefinition) is explicitly specified for a Feature, and the Feature is not conjugated, then the Feature is given a default Subsetting of the most general base Feature *things* from the *Base* model library (see [8.2](#)). This is true even if a FeatureTyping is given for the Feature.

```

abstract feature person : Person; // Default subsets Base::things.
feature child subsets person;

```

The declaration of a Feature may also specify that the Feature is a conjugatedType (see [7.3.2.2.3](#)), in which case the originalType must also be a Feature.

```

classifier Tanks {
  port feature fuelInPort {
    in feature fuelFlow : Fuel;
  }
  port feature fuelOutPort ~ fuelInPort;
}

```

As for any Type, the multiplicity of a Feature can be given in square brackets [...] after any identification of the Feature. However, the multiplicity for a Feature can also be placed *after* one or more initial Generalization clauses in the Feature declaration. In particular, this allows a notation style for multiplicity consistent with that used in previous modeling languages. It is also useful when redefining a Feature without giving an explicit name (see [7.3.4.2.5](#)).

```

feature parent[2] : Person;
feature mother : Person[1] :> parent;

```

In addition, if an explicit multiplicity is given for a Feature, then that can be followed by either or both of the following keywords (in either order):

- **nonunique** – Specifies `isUnique = false` (the default is true).
- **ordered** – Specifies `isOrdered = true`.

A Feature that is an ownedFeature of a Type automatically has that type as a featuringType (because FeatureMembership is a kind of TypeFeaturing, see [7.3.2](#)). In addition to or instead of this, a list of featuringTypes can be included in the declaration of a Feature, preceded by the keyword **featured by** and following any ownedGeneralizations.

```

classifier Vehicle;
classifier PoweredComponent;
feature engine : Engine featured by Vehicle, PoweredComponent;

```

7.3.4.2.2 Type Featuring

```
TypeFeaturing (m : Membership) : TypeFeaturing =  
  'featuring' ( Identification(this, m) 'of')?  
  featureOfType = [QualifiedName]  
  'by' featuringType = [QualifiedName] ';'

OwnedTypeFeaturing : TypeFeaturing =  
  featuringType = [QualifiedName]
```

A TypeFeaturing Relationship is declared using the keyword **featuring**, optionally followed by a `humanId` and/or a name and the keyword **of**. The qualified name of the `featureOfType` is then given, followed by the qualified name of the `featuringType` after the keyword **featured by**.

```
featuring f1 of f featured by A;  
featuring g featured by B;
```

An `ownedTypeFeaturing` is defined as part of the declaration of the Feature, rather than in a separate declaration, by including the qualified name of the `featuringType` in a list after the keyword **featured by**.

```
feature f featured by A, B;
```

7.3.4.2.3 Feature Typing

```
FeatureTyping (m : Membership) : FeatureTyping =  
  ( 'generalization' Identification(this, m) )?  
  'typing' typedFeature = [QualifiedName]  
  TYPE_OF type = [QualifiedName] ';'

OwnedFeatureTyping : FeatureTyping =  
  type = [QualifiedName]
```

A FeatureTyping Relationship is declared using the keyword **generalization**, optionally followed by a `humanId` and/or a name. The qualified name of the `typedFeature` is then given after the keyword **typing**, followed by the qualified name of the type after the keyword **typed by**. The symbol `:` can be used interchangeably with the keyword **typed by**.

```
generalization t1 typing f typed by B;  
generalization t2 typing g : A;
```

An `ownedTyping` is defined as part of the declaration of the Feature, rather than in a separate declaration, by including the qualified name of the type in a list after the keyword **typed by** (or the symbol `:`).

```
feature f typed by A, B;
```

7.3.4.2.4 Subsetting

```
Subsetting (m : Membership) : Subsetting =
  ( 'generalization' Identification(this, m) )?
  'subset' subsettingFeature = [QualifiedName]
  SUBSETS subsettingFeature = [QualifiedName] ';'

OwnedSubsetting : Subsetting =
  subsettingFeature = [QualifiedName]
```

A Subsetting Relationship is declared using the keyword **generalization**, optionally followed by a `humanId` and/or a name. The qualified name of the `subsettingFeature` is then given after the keyword **subset**, followed by the qualified name of the `subsettingFeature` after the keyword **subsets**. The symbol `>` can be used interchangeably with the keyword **subsets**.

```
generalization Sub subset parent subsets person;
generalization subset mother subsets parent;
```

If no `humanId` or name is given, then the keyword **generalization** may be omitted.

```
subset rearWheels subsets wheels;
subset rearWheels subsets driveWheels;
```

An ownedSubsetting of a Feature is defined as part of the declaration of the Feature, rather than in a separate declaration, by including the qualified name of the `subsettingFeature` in a list after the keyword **subsets** (or the symbol `>`).

```
feature rearWheels subsets wheels, driveWheels;
```

If a `subsettingFeature` is ordered, then the `subsettingFeature` must also be ordered. If the `subsettingFeature` is unordered, then the `subsettingFeature` will be unordered by default, unless explicitly flagged as ordered.

```
feature anyWheels[*] : Wheels;
classifier Automobile {
  composite feature wheels[4] ordered subsets anyWheels;
  composite feature driveWheels[2] ordered subsets wheels; // Must be ordered.
}
```

If a `subsettingFeature` is unique, then the `subsettingFeature` must not be specified as non-unique. If the `subsettingFeature` is non-unique, then the `subsettingFeature` will still be unique by default, unless specifically flagged as nonunique.

```
feature urls[*] nonunique : URL;
classifier Server {
  feature accessibleURLs subsets urls; // Unique by default.
  feature visibleURLs subset accessibleURLs; // Cannot be nonunique.
}
```

7.3.4.2.5 Redefinition

```
Redefinition (m : Membership) : Redefinition =
  ( 'generalization' Identification(this, m) )?
  'redefinition' redefiningFeature = [QualifiedName]
  REDEFINES redefinedFeature = [QualifiedName] ';'

OwnedRedefinition : Redefinition =
  redefinedFeature = [QualifiedName]
```

A Redefinition Relationship is declared using the keyword **generalization**, optionally followed by a humanId and/or a name. The qualified name of the redefiningFeature is then given after the keyword **redefinition**, followed by the qualified name of the redefinedFeature after the keyword **redefines**. The symbol `>>` can be used interchangeably with the keyword **redefines**.

```
generalization Redef redefinition LegalRecord::guardian redefines parent;
generalization redefinition Vehicle::vin redefines RegisteredAsset::identifier;
```

If no humanId or name is given, then the keyword **generalization** may be omitted.

```
redefinition Vehicle::vin redefines RegisteredAsset::identifier;
redefinition Vehicle::vin redefines legalIdentification;
```

An ownedRedefinition of a Feature is defined as part of the declaration of the Feature, rather than in a separate declaration, by including the qualified name of the redefinedFeature in a list after the keyword **redefines** (or the symbol `>>`).

```
feature vin redefines RegisteredAsset::identifier, legalIdentification;
```

The resolution of the qualified names of redefinedFeatures given in a Feature declared in the body of a Type shall follow the following special rules:

1. Resolve the qualified name beginning with the public and protected members of the local namespace of the general Types from each Generalization of the owningType.
2. If exactly one resolution is found, and the resolving Element is a Feature, then that is the resolution of the name for the redefinedFeature. Otherwise there is no resolution.

Note that the local namespace of the owningType is *not* included in the name resolution for redefinedFeatures in this way. Since redefinedFeatures are not inherited, they would not be included in the local namespace of the owning Type and, therefore, could not be referenced by an unqualified name. Despite this, the above special rules allow such a reference, because the name resolution begins with the namespaces of the general Types of the owningType, one of which must contain the redefinedFeature.

```
classifier RegisteredAsset {
  feature identifier : Identifier;
}
classifier Vehicle : RegisteredAsset { // Owing Type.
  feature vin redefines identifier; // Legal even though "identifier" is not inher
}
```

If a name is not given in the declaration of a Feature with an `ownedRedefinition`, then, rather than the Feature having no name, it is implicitly given the same name as that of the `redefiningFeature` of its first `ownedRedefinition`, if any (which may itself be an implicit name, if the `redefinedFeature` is itself a `redefiningFeature`). (This is useful for constraining a `redefinedFeature`, while maintaining the same naming.)

```

classifier WheeledVehicle {
    composite feature wheels[1..*] : Wheel;
}
classifier MotorizedVehicle specializes WheeledVehicle {
    composite feature redefines wheels[2..4];
}
classifier Automobile specializes MotorizedVehicle {
    composite feature redefines wheels[4] : AutomobileWheel;
}

```

The restrictions on the specification of the ordering and uniqueness of a `subsettingFeature` (see [7.3.4.2.4](#)) also apply to a `redefiningFeature`.

7.3.4.3 Abstract Syntax

7.3.4.3.1 Overview

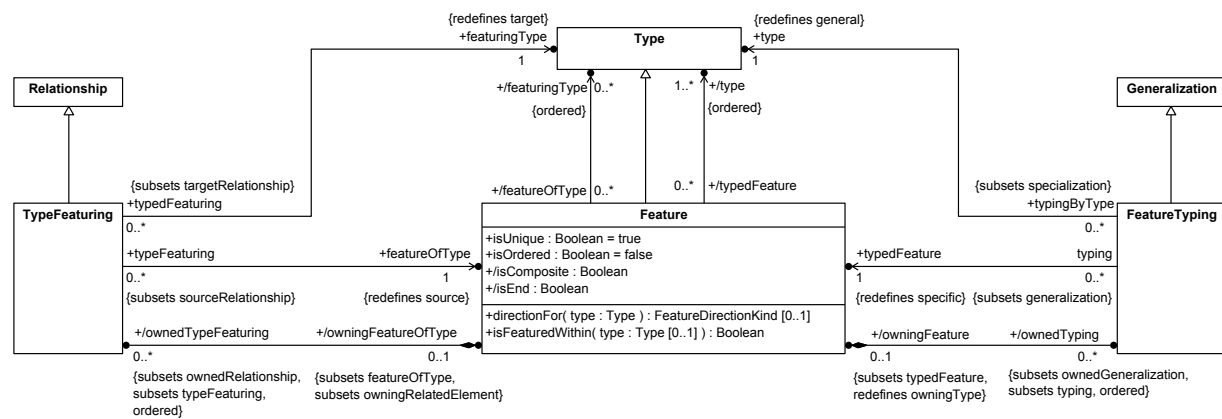


Figure 15. Features

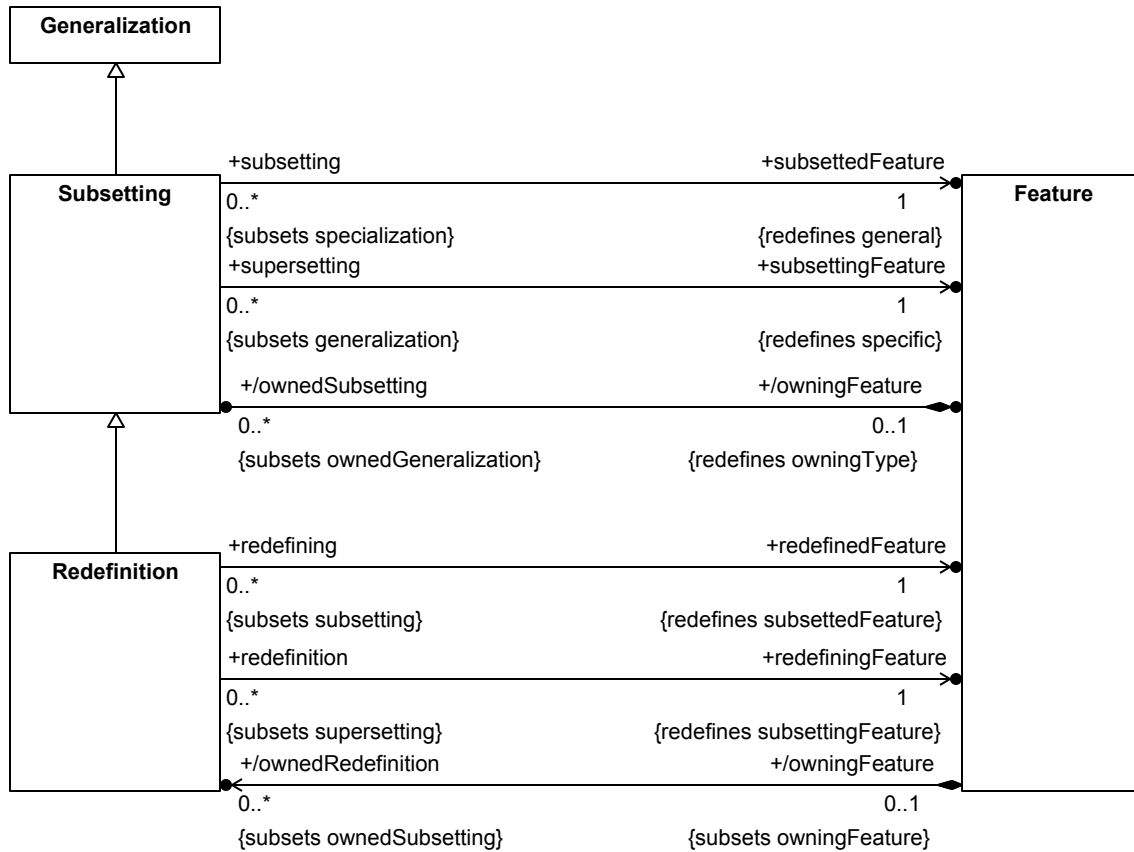


Figure 16. Subsetting

7.3.4.3.2 Feature

Description

A Feature is a Type that classifies sequences of multiple things (in the universe). These must concatenate a sequence drawn from the intersection of the Feature's *featuringTypes* (*domain*) with a sequence drawn from the intersection of its *types* (*co-domain*, *range*), treating (co)domains as sets of sequences. The domain of Features that do not have any *featuringTypes* is the same as if it were the library Type Anything. A Feature's *types* include at least Anything, which can be narrowed to other Classifiers by Redefinition.

In the simplest cases, a Feature's *featuringTypes* and *types* are Classifiers, its sequences being pairs (length = 2), with the first element drawn from the Feature's domain and the second element from its co-domain (the Feature "value"). Examples include cars paired with wheels, people paired with other people, and cars paired with numbers representing the car length.

Since Features are Types, their *featuringTypes* and *types* can be Features. When both are, Features classify sequences of at least four elements (length > 3), otherwise at least three (length > 2). The *featuringTypes* of *nested* Features are Features.

General Classes

Type

Attributes

/endOwningType : Type [0..1] {subsets typeWithEndFeature, owningType}

The Type that is related to this Feature by an EndFeatureMembership in which the Feature is an ownedMemberFeature.

/featuringType : Type [0..*] {ordered}

Types that feature this Feature, such that any instance in the domain of the Feature must be classified by all of these Types, including at least all the featuringTypes of its ownedTypeFeaturings.

/isComposite : Boolean

Whether the Feature is a composite feature of its featuringType, as given by whether isComposite is true for its owningFeatureMembership (see also FeatureMembership).

/isEnd : Boolean

Whether or not the owningFeatureMembership is an EndFeatureMembership, requiring a different interpretation of the multiplicity of the Feature. (See also EndFeatureMembership.)

isOrdered : Boolean

Whether an order exists for the values of this Feature or not.

isUnique : Boolean

Whether or not values for this Feature must have no duplicates or not.

/ownedRedefinition : Redefinition [0..*] {subsets ownedSubsetting}

The ownedSubsettings of this Feature that are Redefinitions, for which the Feature is the redefiningFeature.

/ownedSubsetting : Subsetting [0..*] {subsets ownedGeneralization}

The ownedGeneralizations of this Feature that are Subsettings, for which the Feature is the subsettingFeature.

/ownedTypeFeaturing : TypeFeaturing [0..*] {subsets ownedRelationship, typeFeaturing, ordered}

The ownedRelationships of this Feature that are TypeFeaturings, for which the Feature is the featureOfType.

/ownedTyping : FeatureTyping [0..*] {subsets ownedGeneralization, typing, ordered}

The ownedGeneralizations of this Feature that are FeatureTypings, for which the Feature is the typedFeature.

owningFeatureMembership : FeatureMembership [0..1] {subsets owningMembership, featureMembership}

The FeatureMembership that owns this Feature as an ownedMemberFeature, determining its owningType.

/owningType : Type [0..1] {subsets typeWithFeature, owningNamespace, featuringType}

The Type that is the owningType of the owningFeatureMembership of this Type.

/type : Type [1..*] {ordered}

Types that restrict the values of this Feature, such that the values must be instances of all the types. The types of a Feature are derived from its ownedFeatureTypings and the types of its ownedSubsettings.

Operations

directionFor(type : Type) : FeatureDirectionKind [0..1]

Return the directionOf this Feature relative to the given type.

body: type.directionOf(self)

isFeaturedWithin(type : Type [0..1]) : Boolean

Return whether this Feature has the given type as a direct or indirect featuringType. If type is null, then check if this Feature is implicitly directly or indirectly featured in *Base::Anything*.

body: type = null and feature.featuringType->isEmpty() or
type <> null and feature.featuringType->includes(type) or
feature.featuringType->exists(t |
t.ocIsKindOf(Feature) and
t.ocIsAsType(Feature).isFeaturedWithin(type))

Constraints

featureOwnedTyping

[no documentation]

ownedTyping = ownedGeneralization->selectByKind(FeatureTyping)

featureTypes

[no documentation]

type = typing.type

featureOwnedSubsettings

[no documentation]

ownedSubsetting = ownedGeneralization->selectByKind(Subsetting)

featureIsEnd

[no documentation]

isEnd = owningFeatureMembership <> null and owningFeatureMembership.ocIsKindOf(EndFeature)

featureIsComposite

[no documentation]

```
isComposite = owningFeatureMembership <> null and owningFeatureMembership.isComposite
```

```
featureOwnedRedefinitions
```

```
[no documentation]
```

```
ownedRedefinition = ownedSubsetting->selectByKind(Redefinition)
```

```
featureMultiplicityDomain
```

If a Feature has a multiplicity, then the `featuringTypes` of the multiplicity must be the same as those of the Feature itself.

```
multiplicity <> null implies multiplicity.featuringType = featuringType
```

```
featureClassifiesthings
```

```
[no documentation]
```

```
allSupertypes()->includes(Kernel Library::things)
```

```
featureOwnedTypeFeaturing
```

```
[no documentation]
```

```
ownedTypeFeaturing = ownedRelationship->selectByKind(TypeFeaturing)->  
    select(tf | tf.featureOfType = self)
```

```
unnamed1
```

```
[no documentation]
```

7.3.4.3.3 FeatureTyping

Description

FeatureTyping is Generalization in which the `specific` Type is a Feature. This means the set of sequences of the (specific) `typedFeature` is a subset of the set of sequences of the (general) `type`. In the simplest case, the `type` is a Classifier, whereupon the `typedFeature` subset has sequences ending in things (in the modeled universe) in single-length sequences of the Classifier.

General Classes

Generalization

Attributes

```
/owningFeature : Feature [0..1] {subsets typedFeature, redefines owningType}
```

The Feature that owns this FeatureTyping (which must also be the `typedFeature`).

```
type : Type {redefines general}
```

The Type that is being applied by this FeatureTyping.

typedFeature : Feature {redefines specific}

The Feature that has its Type determined by this FeatureTyping.

Operations

No operations.

Constraints

No constraints.

7.3.4.3.4 Redefinition

Description

Redefinition specializes Subsetting to require the `redefinedFeature` and the `redefiningFeature` to have the same values (on each instance of the domain of the `redefiningFeature`). This means any restrictions on the `redefiningFeature`, such as `type` or `multiplicity`, also apply to the `redefinedFeature` (on each instance of the `owningType` of the `redefiningFeature`), and vice versa. The `redefinedFeature` might have values for instances of the `owningType` of the `redefiningFeature`, but only as instances of the `owningType` of the `redefinedFeature` that happen to also be instances of the `owningType` of the `redefiningFeature`. This is supported by the constraints inherited from Subsetting on the domains of the `redefiningFeature` and `redefinedFeature`. However, these constraints are narrowed for Redefinition to require the `owningTypes` of the `redefiningFeature` and `redefinedFeature` to be different and the `redefinedFeature` to not be imported into the `owningNamespace` of the `redefiningFeature`. This enables the `redefiningFeature` to have the same name as the `redefinedFeature` if desired.

General Classes

Subsetting

Attributes

redefinedFeature : Feature {redefines subsettedFeature}

The Feature that is redefined by the `redefiningFeature` of this Redefinition.

redefiningFeature : Feature {redefines subsettingFeature}

The Feature that is redefining the `redefinedFeature` of this Redefinition.

Operations

No operations.

Constraints

No constraints.

7.3.4.3.5 Subsetting

Description

Subsetting is Generalization in which the `specific` and `general` Types that are Features. This means all values of the `subsettingFeature` (on instances of its domain, i.e., the intersection of its `featuringTypes`) are values of the `subsettedFeature` on instances of its domain. To support this, the domain of the `subsettingFeature` must be the same or specialize (at least indirectly) the domain of the `subsettingFeature` (via Generalization), and the range (intersection of a Feature's types) of the `subsettingFeature` must specialize the range of the `subsettingFeature`. The `subsettingFeature` is imported into the `owningNamespace` of the `subsettingFeature` (if it is not already in that namespace), requiring the names of the `subsettingFeature` and `subsettingFeature` to be different.

General Classes

Generalization

Attributes

`/owningFeature : Feature [0..1] {redefines owningType}`

The Feature that owns this Subsetting relationship, which must also be its `subsettingFeature`.

`subsettedFeature : Feature {redefines general}`

The Feature that is subsetted by the `subsettingFeature` of this Subsetting.

`subsettingFeature : Feature {redefines specific}`

The Feature that is a subset of the `subsettedFeature` of this Subsetting.

Operations

No operations.

Constraints

No constraints.

7.3.4.3.6 TypeFeaturing

Description

A `TypeFeaturing` is a Relationship between a Type and a Feature that is featured by that Type. Every instance in the domain of the `featureOfType` must be classified by the `featuringType`. This means that sequences that are classified by the `featureOfType` must have a prefix subsequence that is classified by the `featuringType`.

General Classes

Relationship

Attributes

`featureOfType : Feature {redefines source}`

The Feature that is featured by the `featuringType`.

`featuringType : Type {redefines target}`

The Type that features the `featureOfType`.

`/owningFeatureOfType : Feature [0..1] {subsets featureOfType, owningRelatedElement}`

The Feature that owns this TypeFeaturing and is also the `featureOfType`.

Operations

No operations.

Constraints

No constraints.

7.3.4.4 Semantics

Required Generalizations to Model Library

1. All Features shall directly or indirectly specialize specialize `Base:things` (see [8.2.2.5](#)) (implied by Rule 1 and 2 below combined with the definition of \cdot^T in [7.3.1.2](#)).

Feature Semantics

The interpretation of the Features in a model shall satisfy the following rules:

1. The interpretations of features must have length greater than one.

$$\forall s \in S, f \in V_F \quad s \in (f)^T \Rightarrow \text{length}(s) > 1$$

2. The interpretation of the Feature `things` is all sequences of length greater than one.

$$(\text{things})^T = \{ s \mid s \in S \wedge \text{length}(s) > 1 \}$$

See other rules below.

Features interpreted as sequences of length two or more can be treated as if they were interpreted as sets of ordered pairs (binary relations), where the first and second elements of each pair are from the domain and co-domain of the Feature, respectively (see [7.3.4.1](#)). The predicate `featurePair` below determines whether two sequences can be treated in this way.

Two sequences are a *feature pair* of a Feature if and only if the interpretation of the Feature includes a sequence s_0 such that following are true:

- The first sequence is a proper head of s_0 and is in the minimal interpretation of all `featuringTypes` of the Feature.
- The second sequence is a proper tail of s_0 and is in the minimal interpretations of all `types` of the Feature.

$$\begin{aligned} \forall s_1, s_2 \in S, f \in V_F \quad & \text{featurePair}(s_1, s_2, f) \equiv \\ & \exists s_0 \in S \quad s_0 \in (f)^T \wedge \text{concat}(s_0, s_1, s_2) \wedge \\ & (\forall t_1 \in V_T \quad t_1 \in f.\text{featuringType} \Rightarrow s_1 \in (t_1)^{\text{min}^T}) \wedge \\ & (\forall t_2 \in V_T \quad t_2 \in f.\text{type} \Rightarrow s_2 \in (t_2)^{\text{min}^T}) \end{aligned}$$

The interpretation of the Features in a model shall satisfy the following rules:

3. All sequences in an interpretation of a Feature have a non-overlapping head and tail that are feature pairs of the Feature.

$$\forall s_0 \in S, f \in V_F \ s_0 \in (f)^T \Rightarrow \exists s_1, s_2 \in S \ \text{head}(s_1, s_0) \wedge \text{tail}(s_2, s_0) \wedge (\text{length}(s_0) \geq \text{length}(s_1) + \text{length}(s_2)) \wedge \text{featurePair}(s_1, s_2, f)$$

4. Values of `redefiningFeatures` are the same as the values of their `redefinedFeatures` restricted to the domain the `redefiningFeature`.

$$\forall f_g, f_s \in V_F \ f_g \in f_s.\text{redefinedFeature} \Rightarrow (\forall s_1 \in S \ (\forall f_{t_s} \in V_T \ f_{t_s} \in f_s.\text{featuringType} \Rightarrow s_1 \in (f_{t_s})^{\text{minT}}) \Rightarrow (\forall s_2 \in S \ (\text{featurePair}(s_1, s_2, f_s) \equiv \text{featurePair}(s_1, s_2, f_g))))$$

5. The multiplicity of a Feature includes the cardinality of its values.

$$\forall s_1 \in S, f \in V_F \ \#\{s_2 \mid \text{featurePair}(s_1, s_2, f)\} \in (f.\text{multiplicity})^T$$

7.4 Kernel

7.4.1 Kernel Overview

The Kernel layer completes the KerML metamodel. It specializes Core to add application-independent modeling capabilities beyond basic classification. These distinguish structure (things and limits on how they change over time) from processes (how things change over time). Structural elements include Classes and DataTypes (kinds of things), Associations between them, and Connectors (usages of Associations). Processing elements include Behaviors that coordinate other Behaviors via Steps (usages of Behaviors). Specialized processing elements include Functions, which are Behaviors that always yield a single result, and Expressions (usages of Functions), as well as Interactions, which combine Behaviors and Associations, and ItemFlows (Connectors using Interactions).

The Kernel adds semantics beyond the Core by specifying how model elements reuse the Kernel Model Library (see [Clause 8](#)). These are specified as constraints in the metamodel. The simplest reuse is specialization (direct or indirect). For example, Classes must subclass *Object* from the *Objects* library model, while Features typed by Classes must subset *objects*. Similarly, Behaviors must subclass the *Performance* from the *Performances* library model, while Steps (Features typed by Behaviors) must subset *performances*. Sometimes more complicated reuse patterns are needed. For example, binary Associations (with exactly two ends) specialize *BinaryLink* from the library, and additionally require the ends of the Association redefine the *source* and *target* ends of *BinaryLink*.

The semantics of the library models are ultimately grounded in the Core semantics, so, specializing a base Type from an appropriate library model gives the required semantics to each syntactic category of elements in the Kernel. In the remainder of [7.4](#), these semantic requirements are formally described in the Semantics subclause for each of the abstract syntax packages in the Kernel layer.

The textual concrete syntax provides modelers a compact way to use the abstract syntax. It includes keywords that translate to patterns of using abstract syntax and libraries. The syntactic constructs in the Kernel act as "syntactic markers" for semantic patterns tying Kernel semantics to the Core. In this way, Kernel is a syntactic and semantic extension of the Core. It is an example of how other modeling languages can be built on KerML by further extending and specializing the Kernel metamodel.

7.4.2 Classification

7.4.2.1 Classification Overview

Classifiers in Kernel are divided into DataTypes, Classes, and Associations. DataTypes and Classes are specified in this subclause, while Associations are described in [7.4.4](#). DataTypes classify things in the universe such that they are *distinguished* only by their relations to other things via Features, while Classes classify things that can be distinguished without regard to those relationships. This means DataTypes cannot also be Classes, or share instances with them.

Data Types

DataTypes are Classifiers that classify *DataValues* (see [8.2.2.2](#)) and how they are related by Features to (other) things in the modeled universe. *DataValues* are distinguishable when they differ in how they are related to other things. Since change over time means changing relationships, *DataValues* are outside of time (and space, compare to [8.4](#)).

However, *DataValues* for some DataTypes are directly identified (*enumerated*), in which case they are distinguishable regardless of their relationship to other things. Such DataTypes include the *primitive types* defined in the Kernel Model Library *ScalarValues* package (see [8.11](#)), and any subtypes of those.

Classes

Classes are Classifiers that classify *Occurrences* (see [8.4.2.5](#)) and how they are related by Features to (other) things in the modeled universe. Relations between *Occurrences* can change over time, modeled as Features relating *timeSlices* of them, which are also *Occurrences*, or as *LinkObjects* existing between them for limited time (see [8.5.2.3](#)). Portions of an *Occurrence* are classified the same as the *Occurrence* (or more specialized).

7.4.2.2 Concrete Syntax

7.4.2.2.1 Data Types

```
DataType (m : Membership) : DataType =
  ( isAbstract ?= 'abstract' )? 'datatype'
  ClassifierDeclaration(this, m) TypeBody(this)
```

A DataType is declared as a Classifier (see [7.3.3.2.1](#)), using the keyword **datatype**. If no `ownedSuperclassing` is explicitly given for the DataType, then it is implicitly given a default Superclassing to the DataType *DataValue* from the *Base* model library (see [8.2](#)).

Either all of the types of a Feature shall be DataTypes, or none of them shall be. If they are all DataTypes, and no `ownedSubsetting` or `ownedRedefinition` is explicitly given in the Feature declaration, then the Feature is implicitly given a default Subsetting to the Feature *dataValues* from the *Base* model library (see [8.2](#)).

```
datatype IdNumber specializes ScalarValues::Integer;
datatype Reading { // Subtypes Base::DataValue by default
  feature sensorId : IdNumber; // Subsets Base::dataValues by default.
  feature value : ScalarValues::Real;
}
```

7.4.2.2.2 Classes

```
Class (m : Membership) : Class =  
  ( isAbstract ?= 'abstract' )? 'class'  
  ClassifierDeclaration(this, m) TypeBody(this)
```

A Class is declared as a Classifier (see [7.3.3.2.1](#)), using the keyword **class**. If no `ownedSuperclassing` is explicitly given for the Class, then it is implicitly given a default Superclassing to the Class *Occurrence* from the *Occurrences* model library (see [8.4](#)).

Either all of the types of a Feature shall be Classes, or none of them shall be. If they are all Classes, and no `ownedSubsetting` or `ownedRedefinition` is explicitly given in the Feature declaration, then the Feature is implicitly given a default Superclassing to the Feature *occurrences* from the *Occurrences* model library (see [8.4](#)), unless at least one of the types is an AssociationStructure, in which case the default Superclassing shall be as specified in [7.4.4.2](#).

```
class Situation { // Specializes Occurrences::Occurrence by default.  
  feature condition : ConditionCode;  
  feature soundAlarm : ScalarValues::Boolean;  
}  
class SituationStatusMonitor specializes StatusMonitor {  
  feature currentSituation[*] : Situation; // Subsets Occurrences::occurrences by d  
}
```

7.4.2.3 Abstract Syntax

7.4.2.3.1 Overview

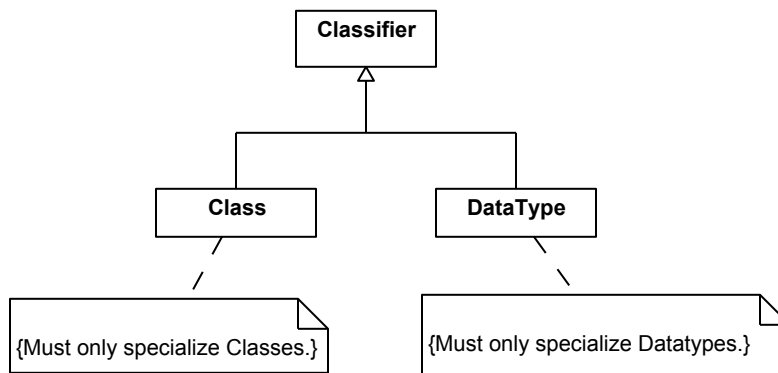


Figure 17. Classification

7.4.2.3.2 Class

Description

A Class is a Classifier of things (in the universe) that can be distinguished without regard to how they are related to other things (via Features). This means multiple things classified by the same Class can be distinguished, even when they are related other things in exactly the same way.

General Classes

Classifier

Attributes

No attributes.

Operations

No operations.

Constraints

classClassifiesOccurrence

[no documentation]

```
allSupertypes() -> includes (Kernel Library::Occurrence)
```

7.4.2.3.3 DataType

Description

A `DataType` is a Classifier of things (in the universe) that can only be distinguished by how they are related to other things (via Features). This means multiple things classified by the same `DataType`

- Cannot be distinguished when they are related to other things in exactly the same way, even when they are intended to be about the same thing.
- Can be distinguished when they are related to other things in different ways, even when they are intended to be about the same thing.

General Classes

Classifier

Attributes

No attributes.

Operations

No operations.

Constraints

datatypeClassifiesDataValue

[no documentation]

```
allSupertypes() -> includes (Kernel Library::DataValue)
```

7.4.2.4 Semantics

Required Generalizations to Model Library

1. `DataTypes` shall (indirectly) specialize `Base::DataValue` (see [8.2.2.2](#)).

2. Features typed by DataTypes shall (indirectly) subset *Base::dataValues* (see [8.2.2.3](#)).
3. Classes shall (indirectly) specialize *Occurrences::Occurrence* (see [8.4.2.5](#)).
4. Features typed by Classes shall (indirectly) subset *Occurrences::occurrences* (see [8.4.2.6](#)).

DataType Semantics

For all the things at the end of sequences in the interpretation of a DataType, the heads of sequences ending in that thing shall be the same as heads of sequences ending in the other things.

Class Semantics

For all the things at the end of sequences in the interpretation of a Class, the heads of sequences ending in that thing shall be different than the heads of sequences ending in the other things.

7.4.3 Structures

7.4.3.1 Structure Overview

Structures are Classes that classify *Objects* (see [8.5](#)) that are *Occurrences* in space and time, but are primarily structural in nature, as opposed to the *Performances* of Behaviors (see [8.6](#)). While an *Object* is not itself behavioral, it may be involved in and acted on by the *Performances* of Behaviors, and it may be the performer of some of them.

7.4.3.2 Concrete Syntax

```
Structure (m : Membership) : Structure =
  ( isAbstract ?= 'abstract' )? 'struct'
  ClassifierDeclaration(this, m) TypeBody(this)
```

A Structure is declared as a Classifier (see [7.3.3.2.1](#)), using the keyword **struct**. If no *ownedSuperclassing* is explicitly given for the Structure, then it is implicitly given a default Superclassing to the Structure *Object* from the *Objects* model library (see [8.5](#)).

Either all of the types of a Feature shall be Structures, or none of them shall be. If they are all Structures, and no *ownedSubsetting* or *ownedRedefinition* is explicitly given in the Feature declaration, then the Feature is implicitly given a default Superclassing to the Feature *objects* from the *Objects* model library (see [8.5](#)), unless at least one of the types is an AssociationStructure, in which case the default Superclassing shall be as specified in [7.4.4.2](#).

```
struct Sensor { // Specializes Objects::Object by default.
  feature id : IdNumber;
  feature currentReading : ScalarValues::Real;
  step updateReading { ... } // Performed behavior
}
struct SensorAssembly specializes Assembly {
  composite feature sensors[*] : Sensor; // Subsets Objects::objects by default.
}
```

7.4.3.3 Abstract Syntax

7.4.3.3.1 Overview

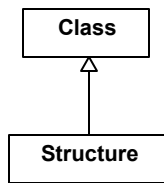


Figure 18. Structures

7.4.3.3.2 Structure

Description

A Structure is a Class of objects in the modeled universe that are primarily structural in nature. While an Object is not itself behavioral, it may be involved in and acted on by Behaviors, and it may be the performer of some of them.

General Classes

Class

Attributes

No attributes.

Operations

No operations.

Constraints

structureClassifiesObject

[no documentation]

```
allSupertypes()->includes(Kernel Library::Object)
```

7.4.3.4 Semantics

Required Generalizations to Model Library

1. Structures shall directly or indirectly specialize *Objects::Object* (see [8.5.2.5](#)).
2. Features typed by Structures shall directly or indirectly subset *Objects::objects* (see [8.5.2.6](#)).

7.4.4 Associations

7.4.4.1 Associations Overview

Associations are Classifiers that classify *Links* (see [8.3.2.3](#)) between things in the modeled universe, and how they are related by Features to those (other) things. At least two ownedFeatures of an Association must be endFeatures (see [7.3.2.1](#)), its associationEnds. Associations with exactly two associationEnds classify *BinaryLinks* (see [8.3.2.1](#)), and are called binary Associations. An Association is also a Relationships between the types of its associationEnds, which are its relatedTypes. *Links* are between

instances of an Association's `relatedTypes`. The features of Associations that are not `endFeatures` characterize *Links* separately from the linked things.

AssociationStructures are both Associations and Classes, which classify *LinkObjects* that are both *Links* and *Objects*. Unlike *Links*, *LinkObjects* occupy time and space, like other *Objects*, with `non-endFeature` features having values that are potentially different things over time. However, the values of the `endFeatures` of *LinkObjects* do not change over time (though the value of an `endFeature` can be an *Occurrence* whose `Features` have values values change over time).

7.4.4.2 Concrete Syntax

```
Association (m : Membership) : Association =
  ( isAbstract ?= 'abstract' )? 'assoc'
  ClassifierDeclaration(this, m) TypeBody(this)

AssociationStructure (m : Membership) : AssociationStructure =
  ( isAbstract ?= 'abstract' )? 'assoc' 'struct'
  ClassifierDeclaration(this, m) TypeBody(this)
```

An Association is declared as a Classifier (see [7.3.3.2.1](#)), using the keyword **assoc**. If no `ownedSuperclassing` is explicitly given for the Association, then it is implicitly given a default Superclassing to either the Association *BinaryLink* (if it is a binary Association) or the Association *Link* (otherwise), both of which are from the *Links* library model (see [8.3](#)).

If an Association has `ownedSuperclassings` whose superclasses are Associations, then these superclass Associations shall all have the same number of `associationEnds`. The subclass Association shall then have no more `owned associationEnds` than its superclass Associations. Each `owned associationEnd` of the subclass Association shall redefine an `associationEnd` of each of the superclass Associations. If no redefinition is given explicitly for an `associationEnd`, then it shall be considered to implicitly redefine the `associationEnd` at the same position, in order, of each `superClass` Association (including implicit defaults).

```
assoc Ownership { // Specializes Objects::BinaryLink by default.
  feature valuationOnPurchase : MonetaryValue;
  end feature owner[1..*] : LegalEntity; // Redefines BinaryLink::source.
  end feature ownedAsset[*] : Asset;      // Redefines BinaryLink::target.
}
assoc SoleOwnership specializes Ownership {
  end feature owner[1]; // Redefines Ownership::owner.
  // ownedAsset is inherited.
}
```

An AssociationStructure is declared like a regular Association, but using the keyword **assoc struct**. If no `ownedSuperclassing` is explicitly given for the AssociationStructure, then it is implicitly given a default Superclassing to either the AssociationStructure *BinaryLinkObject* (if it is a binary AssociationStructure) or the AssociationStructure *LinkObject* (otherwise), both of which are from the *Objects* library model (see [8.5](#)). The same rules on `associationEnds` specified above for Associations also apply to AssociationStructures. An AssociationStructure may specialize an Association that is not an AssociationStructure, but all specializations of an AssociationStructure shall be AssociationStructures.

```

assoc struct ExtendedOwnership specializes Ownership {
    // The values of this feature may change over time.
    feature revaluations[*] ordered : MonetaryValue;
}

```

An Association shall not have any composite features if it is not an AssociationStructure. If an AssociationStructure is not binary, then none of its endFeatures shall be composite. A binary AssociationStructure shall have at most one composite endFeature.

```

assoc struct Assembling {
    end feature assembly[1] : Component;
    end composite feature parts[*] : Component;
}

```

If a Feature has one or more Associations as types, then these Associations shall all have the same number of associationEnds. If the Feature defines owned endFeatures in its body, then it shall have more than the number of associationEnds of its Association types. The owned endFeatures of such a Feature shall follow the same rules for redefinition of the associationEnds of its Association types as given above for the redefinition of the associationEnds of superclass Associations by a subclass Association.

If a Feature declaration has no explicit ownedSubsettings or ownedRedefinitions, and any of its types are binary Associations, then the Feature is implicitly given a default Subsetting to the Feature *binaryLinks* from the *Links* model library (see [8.3](#)) or to the Feature *binaryLinkObjects* from the *Objects* model library (see [8.5](#)), if any of the Associations are AssociationStructures. If some of the types are Associations, but not binary Associations, then it is given a default Subsetting to the Feature *links* from the *Links* model library (see [8.3](#)) or to the Feature *linkObjects* from the *Objects* model library (see [8.5](#)), if any of the Associations are AssociationStructures

7.4.4.3 Abstract Syntax

7.4.4.3.1 Overview

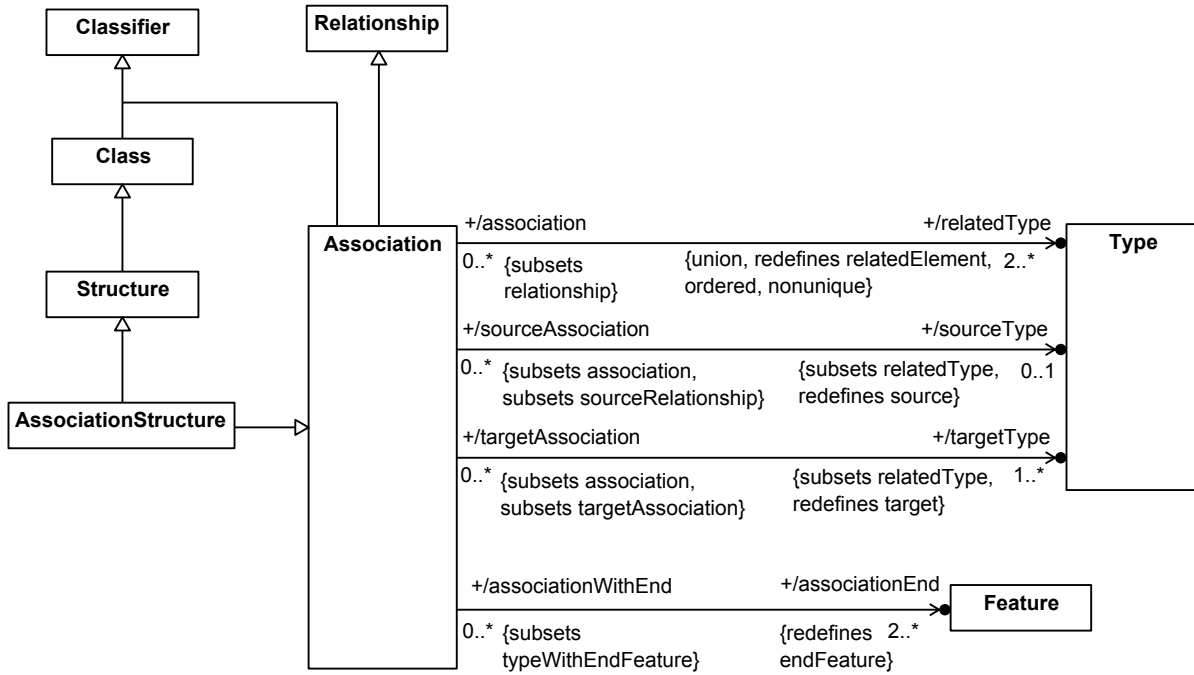


Figure 19. Associations

7.4.4.3.2 Association

Description

An Association is a Relationship and a Class to enable classification of links between things (in the universe). The co-domains of the `associationEnd` Features are one of the `relatedTypes`, as co-domain and participants (linked things) of an Association identify each other.

General Classes

Relationship
Classifier

Attributes

`/associationEnd : Feature [2..*] {redefines endFeature}`

The `features` of the Association that identifying the things that can be related by it. An Association must have at least two `associationEnds`. When it has exactly two, the Association is called a *binary* Association.

`/relatedType : Type [2..*] {redefines relatedElement, ordered, nonunique, union}`

The `types` of the `endFeatures` of the Association, which are the `relatedElements` of the Association considered as a Relationship.

`/sourceType : Type [0..1] {subsets relatedType, redefines source}`

The source `relatedType` for this Association. If this is a binary Association, then the `sourceType` is the first `relatedType`, and the first `associationEnd` of the Association must redefine the `source` Feature of the Association *BinaryLink* from the Kernel Library. If this Association is not binary, then it has no `sourceType`.

`/targetType : Type [1..*] {subsets relatedType, redefines target}`

The target `relatedTypes` for this Association. This includes all the `relatedTypes` other than the `sourceType`. If this is a binary Association, then the `associationEnds` corresponding to the `relatedTypes` must all redefine the `target` Feature of the Association *BinaryLink* from the Kernel Library.

Operations

No operations.

Constraints

AssociationLink

[no documentation]

```
let numend : Natural = associationEnd->size() in
  allSupertypes()->includes(
    if numend = 2 then Kernel Library::BinaryLink
    else Kernel Library::Link)
```

AssociationStructureIntersection

[no documentation]

```
oclIsKindOf(Structure) = oclIsKindOf(AssociationStructure)
```

associationRelatedTypes

[no documentation]

```
relatedTypes = associationEnd.type
```

7.4.4.3.3 AssociationStructure

Description

General Classes

Structure
Association

Attributes

No attributes.

Operations

No operations.

Constraints

associationStructureClassifiesLinkOccurrence

[no documentation]

```
allSupertypes() -> includes (Kernel Library::LinkOccurrence)
```

7.4.4.4 Semantics

Required Generalizations to Model Library

1. Associations shall directly or indirectly specialize *Links::Link* (see [8.3.2.3](#)).
2. Every associationEnd of an Association shall directly or indirectly subset *Links::participant*.
3. Associations with exactly two associationEnds shall directly or indirectly specialize *Links::BinaryLink* (see [8.3.2.1](#)).
4. Features typed by Associations shall directly or indirectly specialize *Links::links* (see [8.3.2.4](#)).
5. Features typed by Associations with exactly two associationEnds shall directly or indirectly specialize *Links::binaryLinks* (see [8.3.2.2](#)).
6. AssociationStructures shall directly or indirectly specialize *Objects::LinkObject* (see [8.5.2.3](#)).
7. Features typed by AssociationStructures shall directly or indirectly specialize *Objects::linkObjects* (see [8.5.2.4](#)).

Association Semantics

Association associationEnds are given a special semantics compared to other members.

An N-ary Association of the form

```
assoc A {  
    end feature e1;  
    end feature e2;  
    ...  
    end feature eN;  
}
```

is semantically equivalent to the Core model

```
classifier A specializes Links::Link {  
    end feature e1 subsets Links::Link::participant;  
    end feature e2 subsets Links::Link::participant;  
    ...  
    end feature eN subsets Links::Link::participant;  
}
```

The general semantics for the multiplicity of an endFeature is such that, even if a multiplicity other than 1..1 is specified, the Feature is required to effectively have multiplicity 1..1 relative to the *Link*. The *Link* instance for an Association is a tuple of participants, each one of which is a value of an endFeature of the Association. Note that the Feature *Link::participant* is declared **readonly**, meaning that the participants in a link cannot change once the link is created.

If an associationEnd has a multiplicity specified other than 1..1, then this shall be interpreted as follows: For an Association with N associationEnds, consider the i -th associationEnd e_i . The multiplicity, ordering and uniqueness constraints specified for e_i apply to each set of instances of the Association that have the same (singleton) values for each of the $N-1$ associationEnds other than e_i .

For example, each instance of the Association

```
assoc Ternary {
  end feature a[1];
  end feature b[0..2];
  end feature c[*] nonunique ordered;
}
```

consists of three participants, one value for each of the associationEnds *a*, *b* and *c*. The multiplicities specified for the associationEnds then assert that:

1. For any specific values of *b* and *c*, there must be exactly one instance of *Ternary*, with the single value allowed for *a*.
2. For any specific values of *a* and *c*, there may be up to two instances of *Ternary*, all of which must have different values for *b* (default uniqueness).
3. For any specific values of *a* and *b*, there may be any number of instance of *Ternary*, which are ordered and allow repeated values for *c*.

Submission Note. The special semantics for the multiplicity of Features with EndFeatureMembership is under discussion. It will be finalized in a revised submission.

If an Association has an ownedSuperclassing to another Association, then its associationEnds redefine the associationEnds of the superclass Association. In this case, the subclass Association will indirectly specialize Link through a chain of Superclassings, and each of its associationEnds will indirectly subset Links::participant through a chain of redefinitions and a subsetting.

Binary Association Semantics

Following the usual rules for the associationEnds of a specialized Association, the first associationEnd of the binary Association will redefine BinaryLink::source and the second associationEnd of the binary Association will redefine BinaryLink::target. The Association BinaryLink specializes *Link* and the Features BinaryLink::source and BinaryLink::target subset Link::participant. Therefore, the semantics for binary Associations are consistent with the semantics given above for Associations in general. In addition, the equivalent core model for a binary Association adds implicit nested *navigation* Features to each of the associationEnds of the Association, as described below.

A binary Association of the form

```
assoc A {
  end feature e1;
  end feature e2;
}
```

is semantically equivalent to the Core model

```
classifier A specializes Links::BinaryLink {
  end feature e1 redefines Links::BinaryLink::source {
    feature e2 = A::e2(e1);
  }
  end feature e2 redefines Links::BinaryLink::target {
    feature e1 = A::e2(e2);
  }
}
```

As shown above, the added navigation Feature for each end has the same name as the (effective) name of the *other* end. If the name of a navigation Feature is the same as an inheritable Feature from the `ownedGeneralizations` of the containing `associationEnd`, then the navigation Feature shall redefine that otherwise inherited Feature. The notation $A : : e2 (e1)$ means "all values of the end $e2$ of all instances of A that have the given value for the end $e1$ ". Therefore, for each value of $A : : e1$, $A : : e1 : : e2$ gives the values of $e2$ that have $e1$ at the other end, that is, it defines a *navigation* across A from $e1$ to $e2$. The meaning of $A : : e2 : : e1$ is similar.

Submission Note. The model for navigation across binary Associations is still under discussion and will be finalized in a revised submission.

AssociationStructure Semantics

An AssociationStructure has the same semantics as given above for Associations in general, except that, rather than specializing `Links::Link`, it specializes `Objects::LinkObject`, which in turn specializes `Object`, giving AssociationStructures the semantics of Structures (see [7.4.3.4](#)) as well as Associations.

7.4.5 Connectors

7.4.5.1 Connectors Overview

Connectors

Connectors are Features that are typed by Associations (see [7.4.4](#)), identifying (having values that are) Links (see [8.3.2.3](#)). The values (Links) of a Connector are restricted to those that are

1. classified by the `types` of its `associationEnds`, regardless of the domain of the Connector.
2. identified by its `relatedFeatures` for each instance of the domain of the Connector.

Connectors are also Relationships between their `relatedFeatures`.

All Associations typing a Connector shall have the same number of `associationEnds`, which shall also be the number of `owned endFeatures` of the Connector, its `connectorEnds`. Each `connectorEnd` redefines one `associationEnd` from each type and subsets one of the `relatedFeatures` of the Connector. Connectors typed by binary Associations are called binary Connectors.

Connectors can be described as "instance-specific" Associations (usages of Associations), because their links are limited to be between things identified by instances of the Connector's domain. For consistency, this requires that each `relatedFeature` of a Connector must have some `featuringType` of the Connector as a direct or indirect `featuringType` (where a Feature with no `featuringType` is treated as if the Classifier `Base::Anything` was its `featuringType`). This condition is automatically satisfied if a Connector has an `ownedType` for which its `relatedFeatures` are either direct or nested features. Otherwise, explicit `ownedTypeFeaturing` (see [7.3.4](#)) should be used to ensure that the Connector has a sufficiently general domain.

For example, an Association may be used to model an *Engine* powering *Wheels*. A Connector, however, would be used to model the fact that an *Engine* only powers *Wheels* in the same *Car*, not in another *Car* (as would be allowed with only the Association). Further, if the *Car* directly owns the Connector, then the Connector meets the required consistency condition with its `relatedElements` even if the connected *Wheels* are not directly features of the *Car* but are, say, nested in *wheelAssemblies* of the *Car*.

Binding Connectors

BindingConnectors are binary Connectors that require their `sourceFeature` and `targetFeature` to identify the same things (have the same values) on each instance of its domain. They are typed by `SelfLink` (which only links things in the modeled universe to themselves, see [8.3.2.5](#)) and have end multiplicities of exactly 1. This

requires a SelfLink to exist between each thing identified by the `sourceFeature` and one thing identified by `targetFeature`, and vice-versa.

Since the interpretations of DataTypes are disjoint from those of Classes and Behaviors (see [7.4.2](#) and [7.4.6](#)), a Feature typed by DataTypes shall only be bound to another Feature typed by DataTypes. In the determination of the equivalence of such Features, indistinguishable data values shall be considered equivalent.

The binding of Features typed by Classes (or Behaviors) to another Feature typed by Classes (or Behaviors) indicates that the same objects (or performances) play the roles represented by each of the `relatedFeatures`.

BindingConnectors are used with FeatureValues (see [7.4.10](#)).

Successions

Successions are binary Connectors that require their `sourceFeature` and `targetFeature` to identify *Occurrences* that are ordered in time. They are typed by the Association *Objects::HappensBefore* from the model library (see [8.4.2.1](#)), which links Occurrences that happen completely separately in time, with the Connector's `sourceFeature` being the *earlierOccurrence* and the `targetFeature` being the *laterOccurrence*.

7.4.5.2 Concrete Syntax

7.4.5.2.1 Connectors

```
Connector (m : Membership) : Connector :
  ( isAbstract ?= 'abstract' )? 'connector'
  ConnectorDeclaration(this, m) TypeBody(this)

ConnectorDeclaration (c : Connector, m : Membership) : Connector =
  BinaryConnectorDeclaration(c, m) | NaryConnectorDeclaration(c, m)

BinaryConnectorDeclaration (c : Connector, m : Membership) : Connector =
  ( FeatureDeclaration(c, m)? 'from' | c.isSufficient ?= 'all' 'from'? )?
  c.ownedRelationship += ConnectorEndMember 'to'
  c.ownedRelationship += ConnectorEndMember

NaryConnectorDeclaration (c : Connector, m : Membership) : Connector =
  FeatureDeclaration(c, m)
  '(' c.ownedRelationship += ConnectorEndMember ','
  c.ownedRelationship += ConnectorEndMember
  ( ',' c.ownedRelationship += ConnectorEndMember ) * ')'

ConnectorEndMember : EndFeatureMembership :
  ( memberName = NAME '=>' )? ownedMemberFeature = ConnectorEnd

ConnectorEnd : Feature :
  ownedRelationship += OwnedSubsetting ( ownedRelationship += MultiplicityMember )?
```

A Connector is declared as a Feature (see [7.3.4.2](#)) using the keyword **connector**. In addition, a Connector declaration includes a list of qualified names of the `relatedFeatures` of the Connector, between parentheses (...), after the regular Feature declaration part and before the body of the Connector (if any). If no `ownedSubsetting` or `ownedRedefinition` is explicitly given, then the Connector is implicitly given a

default Subsetting to the Feature *binaryLinks* from the *Links* model library (see [8.3](#)), if it is a binary Connector, or to the Feature *links* from the *Links* model library, if it is not a binary Connector and none of its types are AssociationStructures. If at least one of the types of a Connector is an AssociationStructure, then the default Subsetting is *linkObjects* from the *Objects* model library (see [8.5](#)) instead of *links*, and, if it is a binary Connector, the default is to subset both *linkObjects* and *binaryLinks*.

```
// Specializes Objects::LinkObject and Link::BinaryLink by default.
assoc struct Mounting {
    end feature mountingAxle[1] : Axle;
    end feature mountedWheel[2] : Wheel;
}

struct WheelAssembly {
    composite feature axle[1] : Axle;
    composite feature wheels[2] : Wheel;

    // Subsets Objects::linkObjects and Links::binaryLinks by default.
    connector mount[2] : Mounting (axle, wheels);
}
```

By default, the `connectorEnds` of a Connector are declared in the same order as the `associationEnds` of the types of the Connector. However, if the Connector has a single type, then the `relatedFeatures` can be given in any order, with each `relatedFeature` paired with an `associationEnd` of the type using a notation of the form `e => f`, where `e` is the name of an `associationEnd` and `f` is the qualified name of a `relatedFeature`. In this case, the name of each `associationEnd` shall appear exactly once in the list of `connectorEnds` declarations.

```
struct WheelAssembly {
    composite feature axle[0..1] : Axle;
    composite feature wheels[0..2] : Wheel;
    connector mount[2] : Mounting (
        mountedWheel => wheels,
        mountingAxle => axle);
}
```

A special notation can be used for a binary Connector, in which the source `relatedFeature` is referenced after the keyword **from**, and the target `relatedFeature` is referenced after the keyword **to**.

```
struct WheelAssembly {
    composite feature axle[1] : Axle;
    composite feature wheels[2] : Wheel;
    connector mount[2] : Mounting from axle to wheels;
}
```

If a binary Connector declaration includes only the `relatedFeatures` part, then the keyword **from** can be omitted.

```
struct WheelAssembly {
    composite feature axle[1] : Axle;
    composite feature wheels[2] : Wheel;
    connector axle to wheels;
}
```

If a binary Connector has a single type, then the names of the associationEnds of the type can also be used in the declaration of the connectorEnds in the special notation for binary Connectors. However, since the connectorEnds are always declared in order from source to target in this notation, the associationEnd names given must match those from the type in the order they are declared for that type.

```
struct WheelAssembly {
  composite feature axle[1] : Axle;
  composite feature wheels[2] : Wheel;
  connector mount[2] : Mounting
    from mountingAxle => axle
    to mountedWheel => wheels;
}
```

In any of the above notations, a multiplicity can be specified for a connectorEnd, after the qualified name of the relatedFeature for that end. In this case, the given multiplicity redefines the multiplicity that would otherwise be inherited from the associationEnd corresponding to the connectorEnd.

```
struct WheelAssembly {
  composite feature halfAxles[2] : Axle;
  composite feature wheels[2] : Wheel;

  // Connects each one of the halfAxles to a different one of the wheels.
  connector mount : Mounting from halfAxles[1] to wheels[1];
}
```

7.4.5.2.2 Binding Connectors

```
BindingConnector : BindingConnector =
  ( isAbstract ?= 'abstract' )? 'binding'
  BindingConnectorDeclaration TypeBody

BindingConnectorDeclaration (b : BindingConnector) =
  ( FeatureDeclaration(b) 'of' | isSufficient ?= 'all' 'of'? )?
  b.ownedRelationship += ConnectorEndMember '='
  b.ownedRelationship += ConnectorEndMember
```

A BindingConnector is declared as a Feature (see [7.3.4.2](#)) using the keyword **binding**. In addition, a BindingConnector declaration gives, after the keyword **of**, the qualified names of the two relatedFeatures of that are bound by the BindingConnector, separated by the symbol =, after the regular Feature declaration part and before the body of the BindingConnector (if any). If no ownedSubsetting or ownedRedefinition is explicitly given, then the BindingConnector is implicitly given a default Subsetting to the Feature *selfLinks* from the *Links* model library (see [8.3](#)). Note that, due to this default subsetting, if no type is explicitly given for a BindingConnector, then it will implicitly have the type *SelfLink* (the type of *selfLinks*).

```
struct WheelAssembly {
  composite feature fuelTank {
    out feature fuelFlowOut : Fuel;
  }

  composite feature engine {
    in feature fuelFlowIn : Fuel;
  }
}
```

```

    }

    // Subsets Links::selfLinks by default.
    binding fuelFlowBinding of
        fuelTank::fuelFlowOut = engine::fuelFlowIn;
}

```

If a BindingConnector declaration includes only the relatedFeatures part, then the keyword **of** can be omitted.

```

struct WheelAssembly {
    composite feature fuelTank {
        out feature fuelFlowOut : Fuel;
    }

    composite feature engine {
        in feature fuelFlowIn : Fuel;
    }

    binding fuelTank::fuelFlowOut = engine::fuelFlowIn;
}

```

The connectorEnds of a BindingConnector always have multiplicity 1..1.

7.4.5.2.3 Successions

```

Succession (m : Membership) : Succession =
    ( isAbstract ?= 'abstract' )? 'succession'
    SuccessionDeclaration(this, m) TypeBody(this)

SuccessionDeclaration (s : Succession, m : Membership) : Succession :
    ( FeatureDeclaration(s, m)? 'first' | s.isSufficient ?= 'all' 'first'? )?
    s.ownedRelationship += ConnectorEndMember 'then'
    s.ownedRelationship += ConnectorEndMember

```

A Succession is declared as a Feature (see [7.3.4.2](#)) using the keyword **succession**. In addition, the Succession declaration gives the qualified name of the source relatedFeature after the keyword **first** and the qualified name of the target relatedFeature after the keyword **then**. If no ownedSubsetting or ownedRedefinition is explicitly given, then the Connector is implicitly given a default Subsetting to the Feature *successions* from the *Objects* model library (see [8.5](#)). Note that, due to this default subsetting, if no type is explicitly given for a Succession, then it will implicitly have the type *HappensBefore* (the type of *successions*).

```

behavior TakePicture {
    composite step focus : Focus;
    composite step shoot : Shoot;
    succession controlFlow first focus then shoot;
}

```

If a Succession declaration includes only the relatedFeatures part, then the keyword **first** can be omitted.

```

behavior TakePicture {
    composite step focus : Focus;
    composite step shoot : Shoot;
    succession focus then shoot;
}

```

As for connectorEnds on regular Connectors, constraining multiplicities can also be defined for the connectorEnds of Successions.

```

behavior TakePicture {
    composite step focus[*] : Focus;
    composite step shoot[1] : Shoot;
    // A focus may be preceded by a previous focus.
    succession focus[0..1] then focus[0..1];
    // A shoot must follow a focus.
    succession focus[1] then shoot[0..1];
    // After a shoot, the behavior is done.
    succession shoot then done;
}

```

7.4.5.3 Abstract Syntax

7.4.5.3.1 Overview

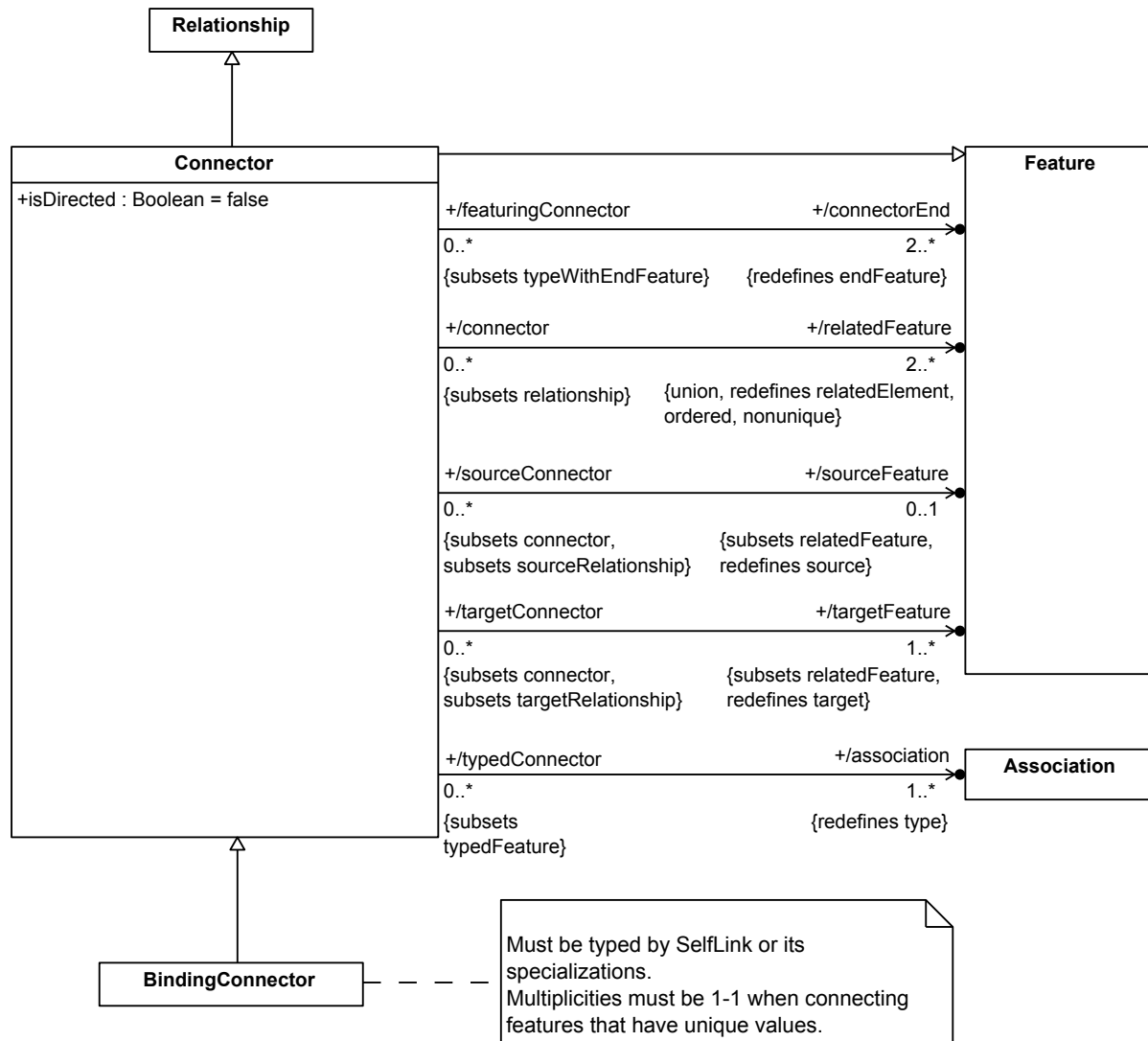


Figure 20. Connectors

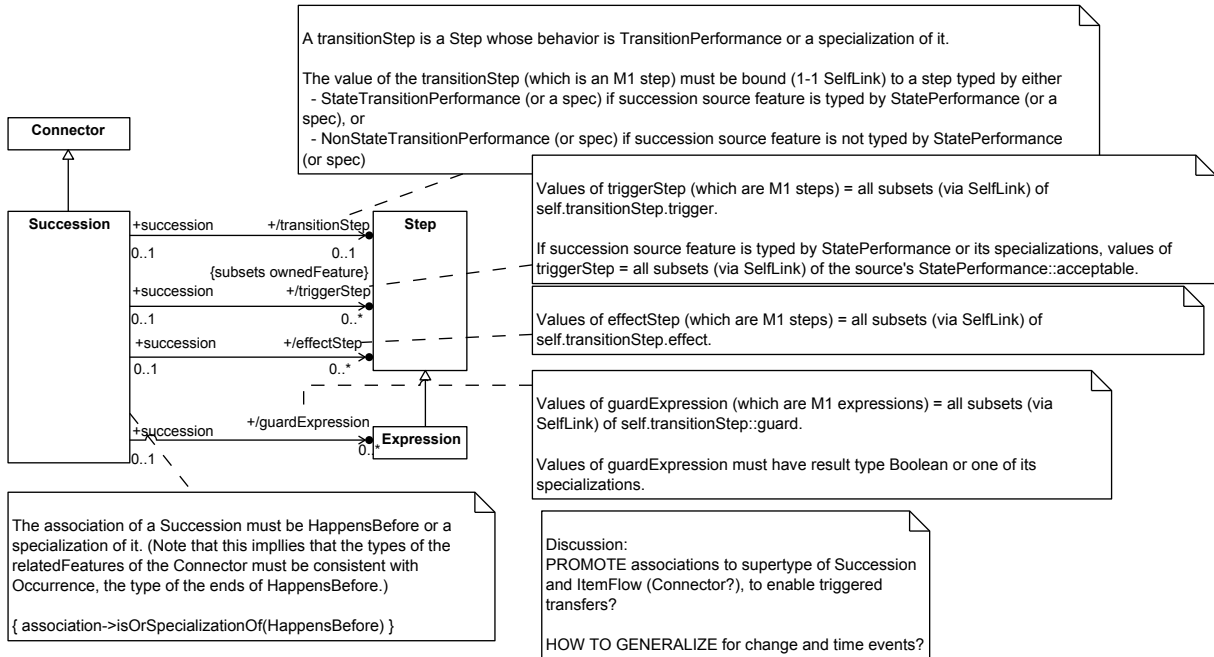


Figure 21. Successions

7.4.5.3.2 Binding Connector

Description

A Binding Connector is a binary Connector that requires its `relatedFeatures` to identify the same things (have the same values).

General Classes

Connector

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.4.5.3.3 Connector

Description

A Connector is a usage of Associations, with links restricted to instances of the Type in which it is used (domain of the Connector). Associations restrict what kinds of things might be linked. The Connector further restricts these links to between values of two Features on instances of its domain.

General Classes

Relationship
Feature

Attributes

/association : Association [1..*] {redefines type}

The Associations that type the Connector.

/connectorEnd : Feature [2..*] {redefines endFeature}

These are the ends of the Connector, which show what Features it relates. The connectorEnds of a Connector are the features of the Connector that redefine the end Features of the Connector association.

isDirected : Boolean

Whether or not the Connector should be considered to have a direction from source to target.

/relatedFeature : Feature [2..*] {redefines relatedElement, ordered, nonunique, union}

The Features that are related by this Connector considered as a Relationship, derived as the subsetting Features of the connectorEnds of the Connector.

/sourceFeature : Feature [0..1] {subsets relatedFeature, redefines source}

The source relatedFeature for this Connector. If this is a binary Connector, then the sourceFeature is the first relatedFeature, and the first end Feature of the Connector must redefine the source Feature of the Connector binaryLinks from the Kernel Library. If this Connector is not binary, then it has no sourceFeature.

/targetFeature : Feature [1..*] {subsets relatedFeature, redefines target}

The target relatedFeatures for this Connector. This includes all the relatedFeatures other than the sourceFeature. If this is a binary Connector, then the end Feature corresponding to the targetFeature must redefine the target Feature of the Connector binaryLinks from the Kernel Library.

Operations

No operations.

Constraints

connectorEndRedefinition

For each association of a Connector, each associationEnd must be redefined by a different connectorEnd of the Connector.

```
association->forall(a |
    a.associationEnd->forall(ae |
        connectorEnd->one(ce |
            ce.ownedRedefinition.redefinedFeature->includes(ae)))
```

connectorTargetFeature

The `targetFeatures` of a `Connector` are the `relatedFeatures` other than the `sourceFeature`.

```
targetFeature =  
    if sourceFeature = null then relatedFeature  
    else relatedFeature->excluding(sourceFeature)  
    endif
```

`connectorConnectorEnd`

The `connectorEnds` of a `Connector` are its `endFeatures`.

```
connectorEnd = feature->select(isEnd)
```

`connectorRelatedFeatures`

The `relatedFeatures` of a `Connector` are the subsetted `Features` of its `connectorEnds`.

```
relatedFeature = connectorEnd.ownedSubsetting.subsettedFeature
```

`connectorFeaturingType`

Each `relatedFeature` of a `Connector` must have some `featuringType` of the `Connector` as a direct or indirect `featuringType` (where a `Feature` with no `featuringType` is treated as if the `Classifier Base::Anything` was its `featuringType`).

```
relatedFeature->forall(f |  
    if featuringType->isEmpty() then f.isFeaturedWithin(null)  
    else featuringType->exists(t | f.isFeaturedWithin(t))  
    endif)
```

`connectorSourceFeature`

If this is a binary `Connector`, then the `sourceFeature` is the first `relatedFeature`. If this `Connector` is not binary, then it has no `sourceFeature`.

```
sourceFeature =  
    if relatedFeature->size() = 2 then relatedFeature->at(1)  
    else null  
    endif
```

7.4.5.3.4 Succession

Description

A `Succession` is a binary `Connector` that requires its `relatedFeatures` to happen separately in time. A `Succession` must be typed by the Association *HappensBefore* from the Kernel Model Library (or a specialization of it).

General Classes

`Connector`

Attributes

/effectStep : Step [0..*]

Steps that represent occurrences that are side effects of the transitionStep occurring.

/guardExpression : Expression [0..*]

Expressions that must evaluate to true before the transitionStep can occur.

/transitionStep : Step [0..1] {subsets ownedFeature}

A Step that is typed by the Behavior *TransitionPerformance* (from the Model Library) that has this Succession as its *transitionLink*.

/triggerStep : Step [0..*]

Steps that map incoming events to the timing of occurrences of the transitionStep. The values of triggerStep subset the list of acceptable events to be received by a Behavior or the object that performs it.

Operations

No operations.

Constraints

No constraints.

7.4.5.4 Semantics

Required Generalizations to Model Library

1. Connectors shall directly or indirectly specialize *Links::links* (see [8.3.2.4](#)), which means they shall be typed by Associations ([7.4.4.3.2](#)).
2. Connectors with exactly two relatedFeatures shall directly or indirectly specialize *Links::binaryLinks* (see [8.3.2.2](#)).
3. Connectors with at least one type that is an AssociationStructure shall directly or indirectly specialize *Objects::linkObjects* (see [8.5.2.4](#)).
4. BindingConnectors shall directly or indirectly specialize *Links::selfLink* (see [8.3.2.6](#)), which means they shall be directly or indirectly typed by *SelfLink* (see [8.3.2.5](#)).
5. Successions shall (indirectly) specialize *Occurrences::successions* (see [7.4.5.3.4](#)), which means they shall be directly or indirectly typed by *HappensBefore* (see [8.4.2.1](#)).

Connector Semantics

An N-ary Connector of the form

```
connector c : A (f1, f2, ... fN);
```

is semantically equivalent to the Core model

```
feature c : A subsets Links::links {  
  end feature e1 redefines A::e1 subsets f1;  
  end feature e2 redefines A::e2 subsets f2;  
  ...  
}
```

```

    end feature eN redefines A::eN subsets fN;
}

```

where e_1, e_2, \dots, e_N are the names of `associationEnds` of the Association A , in the order they are defined in A . If explicit multiplicities are given for the `connectorEnds`, then these become the multiplicities of the endFeatures in the equivalent core model. (If A is an `AssociationStructure`, then `Links::link` is replaced by `Objects::LinkObjects`, above and in the following.)

If the named notation is used for pairing `connectorEnds` to `associationEnds`:

```

connector c : A (e_f1 => f1, e_f2 => f2, ... e_fN => fN);

```

then the model is similar:

```

feature c : A subsets Links::links {
    end feature e_f1 redefines A::e_f1 subsets f1;
    end feature e_f2 redefines A::e_f2 subsets f2;
    ...
    end feature e_fN redefines A::e_fN subsets fN;
}

```

where the $e_{f1}, e_{f2}, \dots, e_{fN}$ are again names of `associationEnds` of the Association A , but now not necessarily in the order in which they are defined in A .

The semantic model of a binary Connector is just that of an N -ary Connector with $N = 2$. In particular, if no type is explicitly declared for a binary Connector, then its `connectorEnds` simply redefine the *source* and *target* ends of the Association *BinaryLink*, which are inherited by the Feature *binaryLinks*.

A binary Connector of the form

```

connector c : A from f1 to f2;

```

is semantically equivalent to

```

feature c : A subsets Links::binaryLinks {
    end feature source redefines Objects::binaryLinks::source subsets f1;
    end feature target redefines Objects::binaryLinks::target subsets f2;
}

```

If A is an `AssociationStructure`, then the equivalent Feature also subsets `Objects::linkObjects`.

Binding Connector Semantics

`BindingConnectors` are typed by *SelfLinks*, which have two `associationEnds` that subset each other, meaning they identify the same things (have the same values, see [8.3.2.5](#)). This applies to `BindingConnector` `connectorEnds` also by redefining the `associationEnds` of *SelfLink*.

A `BindingConnector` of the form

```

binding f1 = f2;

```

is semantically equivalent to the Core model

```

feature subsets Links::selfLinks {
    end feature self redefines Objects::selfLinks::self subsets f1;
    end feature myself redefines Objects::selfLinks::myself subsets f2;
}

```

where *selfLinks* is typed by *SelfLink* and, so, inherits the endFeatures *self* and *myself*.

Succession Semantics

Successions are typed by *HappensBefore*, which require the *Occurrence* identified by (value of) its first associationEnd (earlierOccurrence) to precede the one identified by its second (laterOccurrence, see [8.4.2.1](#)). This applies to Succession connectorEnds also by redefining the associationEnds of *HappensBefore*.

A Succession of the form

```

succession first f1 then f2;

```

is semantically equivalent to the Core model

```

feature subsets Occurrences::successions {
    end feature earlierOccurrence
        redefines Occurrences::successions::earlierOccurrence subsets f1;
    end feature laterOccurrence
        redefines Occurrences::successions::laterOccurrence subsets f2;
}

```

where *succession* is typed by *HappensBefore* and, so, inherits the endFeatures *earlierOccurrence* and *laterOccurrence*.

7.4.6 Behaviors

7.4.6.1 Behaviors Overview

Behaviors

Behaviors are Classes that classify *Performances* (see [8.6](#)), and how they are related to (other) things in the modeled universe. *Performances* are one kind of *Occurrence*, things that occupy time and space (see [8.4.2.5](#) and Classes in [7.4.2.1](#)), the other being *Objects* (see [8.5.2.5](#)). Behaviors can coordinate other Behaviors (see Steps below), generate effects on *Objects* involved in them (including their existence and relation to other things), and/or to produce some result before their *Performance* is completed.

Behavior features identified as parameters are those that specify which *Occurrences* might change their values as the Behavior is carried out:

- *Performances* of the Behavior itself (direction=out)
- Other *Occurrences* outside of it (direction=in)
- Or both (direction=inout).

where *direction* is a Feature of a ParameterMembership, a kind of FeatureMembership, that always has a value, defaulting to in.

Steps

Steps are Features that are typed by Behaviors (their behaviors), identifying (having values that are) *Performances* (see [8.6](#)). The features of a Behavior that are Steps (the steps of the Behavior) specify a

refinement of the *Performance* of the Behavior into the *Performances* represented by each of the steps. They can be connected by Successions to order their values (which are kinds of *Occurrences*) in time (see [7.4.5](#)). They can also be connected by ItemFlows (see [7.4.9](#)), to model things flowing between parameters (out or inout to in or inout).

Steps can inherit the parameters of their behaviors or define owned parameters to augment or redefine those of their behaviors. They can also have nested Steps to augment or redefine the steps inherited from their behaviors.

7.4.6.2 Concrete Syntax

7.4.6.2.1 Behaviors

```
Behavior (m : Membership) : Behavior =
  ( isAbstract ?= 'abstract ')? 'behavior'
  BehaviorDeclaration(this, m) TypeBody(this)

BehaviorDeclaration (b : Behavior, m : Membership) =
  ClassifierDeclaration(b, m) ParameterList(b)?

ParameterList (t : Type) =
  '(' ( t.ownedRelationship += ParameterMember
    ( ',' t.ownedRelationship += ParameterMember )* )? ')'

ParameterMember : ParameterMembership =
  ( direction = FeatureDirection )?
  ownedMemberParameter = ParameterDeclaration(this)

ParameterDeclaration(m : Membership) : Feature =
  FeatureParameterDeclaration(m)
  | StepParameterDeclaration(m)
  | ExpressionParameterDeclaration(m)
  | BooleanExpressionParameterDeclaration(m)

FeatureParameterDeclaration (m : Membership) : Feature =
  'feature'? ( f.isSufficient ?= 'all' )? Identification(this, m)
  ParameterSpecializationPart(this)

StepParameterDeclaration (m : Membership) : Step =
  'step' ( f.isSufficient ?= 'all' )? Identification(this, m)
  ParameterSpecializationPart(this)

ExpressionParameterDeclaration (m : Membership) : Expression =
  'expr' ( f.isSufficient ?= 'all' )? Identification(this, m)
  ParameterSpecializationPart(this)

BooleanExpressionParameterDeclaration (m : Membership) : BooleanExpression =
  'bool' ( f.isSufficient ?= 'all' )? Identification(this, m)
  ParameterSpecializationPart(this)

ParameterSpecializationPart (f : Feature) =
  ParameterSpecialization(f)* MultiplicityPart(f)? ParameterSpecialization(f)*

ParameterSpecialization (f : Feature) =
  TypedBy(f) | Subsets(f) | Redefines(f)
```

A Behavior is declared as a Classifier (see [7.3.3.2.1](#)), using the keyword **behavior**. If no `ownedSuperclassing` is explicitly given for the Behavior, then it is implicitly given a default Superclassing to the Behavior *Performance* from the *Performances* library model (see [8.6](#)).

After the Classifier declaration part (including any `ownedSuperclassings`), the Behavior declaration can include a list of owned parameter declarations, surrounded by parentheses (...). A parameter is declared as a

Feature (see [7.3.4.2.1](#)), but the feature keyword is optional. A parameter may also be declared as and Step (see [7.4.6.2.2](#)), Expression (see [7.4.7.2.2](#)) or BooleanExpression (see [7.4.7.2.4](#)) by using the appropriate keyword (**step**, **expr** or **bool**), but without any explicit parameter list for them.

The declaration of a parameter can be preceded by a direction keyword (**in**, **out** or **inout**). If no direction is given explicitly, then the parameter has direction **in** by default. Other flag keywords (**abstract**, **composite**, **portion**, **readonly**, **derived**, **port**) shall not be used with a parameter declaration.

```
// Specializes Objects::Performance by default.
behavior TakePicture (in scene : Scene, out picture : Picture);

behavior RunTest(
    step test : TestProcedure, feature testArtifact : artifact,
    out feature verdict : Verdict);
```

If a Behavior has ownedSuperclassings whose superclasses are Behaviors, then each of the ownedParameters of the subclass Behavior shall, in order, redefine the parameter at the same position of each of the superclass Behaviors. The redefining parameters shall have the same direction as the redefined parameters.

```
behavior A ( in a1, out a2);
behavior B ( in b1, out b2);
behavior C specializes A, B
    ( c1 redefines a1 redefines b1, out c2 redefines a2 redefines b2 );
```

If there is a single superclass Behavior, then the subclass Behavior can declare fewer owned parameters than the superclass Behavior, inheriting any additional parameters from the superclass (which are considered to be ordered after any owned parameters). If there is more than one superclass Behavior, then every parameter from every superclass must be redefined by an owned parameter of the subclass. If every superclass parameter is redefined, then the subclass Behavior may also declare additional parameters, ordered after the redefining parameters. If no redefinitions are given explicitly for a parameter, then the parameter shall be given ownedRedefinitions of superclass parameters sufficient to meet the previously stated requirements.

```
behavior A1 :> A ( in aa ); // aa redefines A::a1, A::a2 is inherited.
behavior B1 :> B ( in, out, inout b3); // Redefinitions are implicit.
behavior C1 :> A1, B1 (in c1, out c2, inout c3);
```

Steps (see [7.4.6.2.2](#)) declared in the body of a Behavior are the owned steps of the containing Behavior. A Behavior can also inherit or redefine non-private steps from any superclass Behaviors.

```
behavior Focus (in scene : Scene, out image : Image );
behavior Shoot (in image : Image, out picture : Picture);
behavior TakePicture (in scene : Scene, out picture : Picture) {
    composite step focus : Focus (in scene, out image);
    composite step shoot : Shoot (in image, out picture);
}
```

The body of a Behavior is like any other Type body: it contains a list of declarations of members of the Behavior treated as a Namespace. Though the performance of a Behavior takes place over time, the order in which its steps are declared has no implication for temporal ordering of the performance of those steps. Any restriction on temporal order, or any other connections between the steps, must be modeled explicitly.

```

behavior TakePicture (in scene : Scene, out picture : Picture) {
    binding focus::scene = scene;
    composite step focus : Focus (in scene, out image);
    succession focus then shoot;
    composite stream focus::image to shoot::image;
    composite step shoot : Shoot (in image, out picture);
    binding picture = focus::picture;
}

```

7.4.6.2.2 Steps

```

Step (m : Membership) : Step =
    ( isAbstract ?= 'abstract' )? 'step'
    StepDeclaration(this, m) TypeBody(this)

StepDeclaration (s : Step, m : Membership) =
    FeatureDeclaration(s, m) ( ValuePart(s) | StepParameterList(s) )?

StepParameterList (t : Type) =
    '(' ( t.ownedRelationship += StepParameterMember
        ( ',' t.ownedRelationship += StepParameterMember )* )? ')'

StepParameterMember : ParameterMembership =
    ( direction = FeatureDirection )?
    ownedMemberParameter = StepParameter(this)

StepParameter (m : Membership) : Feature =
    ParameterDeclaration(m) ValuePart(this)?

```

A Step is declared as a Feature (see [7.3.4.2](#)) using the keyword **step**. If no ownedSubsetting or ownedRedefinition is explicitly given, then the Step is implicitly given a default Subsetting to the Feature *performances* from the *Performances* library model (see [8.6](#)). Following the Feature declaration part, a Step declaration can include *either* a FeatureValue (see [7.4.10](#)) or a parameter list, declared in the same way as for a Behavior (see [Clause](#)).

```

step focus : Focus (in scene, out image);
step shoot : Shoot (in image, out picture);

```

If a Step has ownedGeneralizations (including all FeatureTypings, Subsettings and Redefinitions) whose general Type is a Behavior or Step, then the rules for the redefinition of the parameters of those Behaviors and Steps shall be the same as for the redefinition of the parameters of superclass Behaviors by a subclass Behavior (see [Clause](#)).

```

step focus : Focus
    (in scene, out image); // Parameters redefine parameters of Focus.

step refocus subsets focus; // Parameters are inherited.

```

Unlike the parameters declared in a Behavior, the parameters of a Step may have FeatureValues (see [7.4.10](#)).

A Step can also have a body, which may have Steps in it. The Step can inherit or override Steps from its Behavior types or any other Steps it subsets.

```

step takePictureWithAutoFocus : TakePicture {
  step redefines focus : AutoFocus;
}

```

7.4.6.3 Abstract Syntax

7.4.6.3.1 Overview

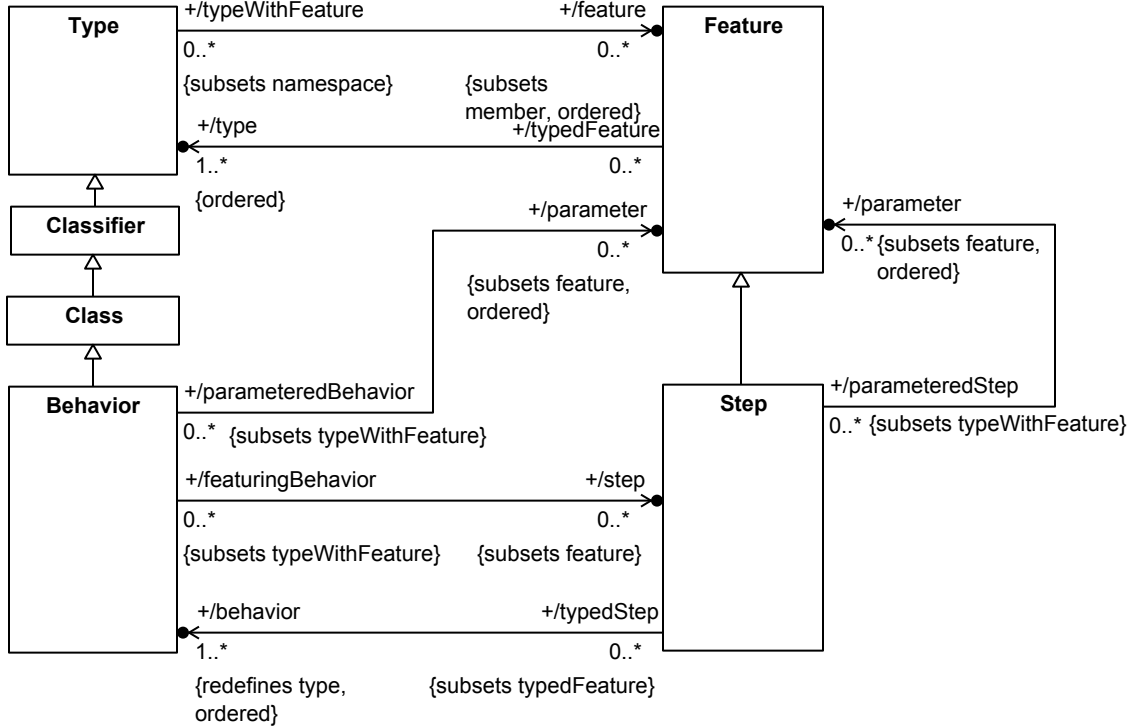


Figure 22. Behaviors

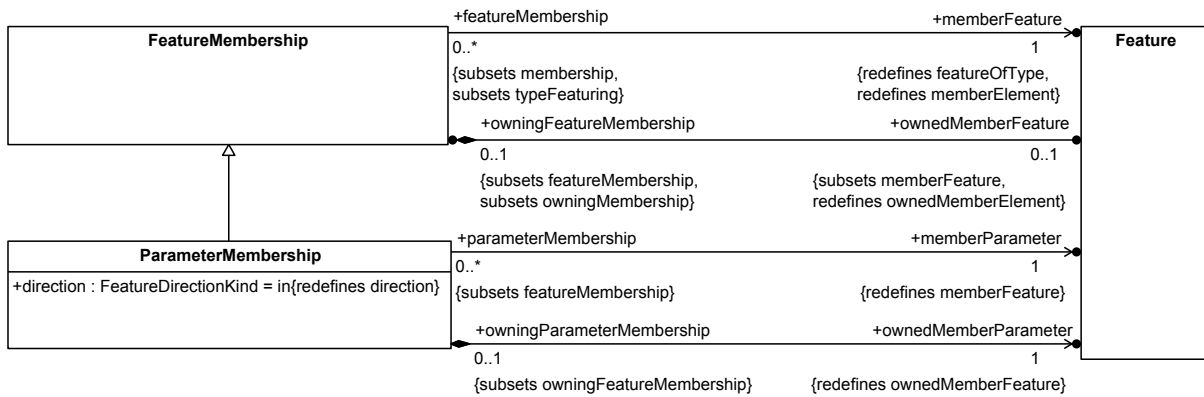


Figure 23. Parameter Memberships

7.4.6.3.2 Behavior

Description

A Behavior coordinates occurrences of other Behaviors, as well as changes in objects. Behaviors can be decomposed into Steps and be characterized by parameters.

General Classes

Class

Attributes

/parameter : Feature [0..*] {subsets feature, ordered}

The features of this Behavior that are owned by the Behavior via ParameterMemberships. A parameter always has a direction, indicating whether the values of the parameter are passed into and/or out of a performance of the Behavior.

/step : Step [0..*] {subsets feature}

The Steps that make up this Behavior.

Operations

No operations.

Constraints

behaviorClassifiesPerformance

[no documentation]

allSupertypes()->includes(Kernel Library::Performance)

7.4.6.3.3 Step

Description

A Step is a Feature that is typed by one or more Behaviors. Steps may be used by one Behavior to coordinate the performance of other Behaviors, supporting the steady refinement of behavioral descriptions. Steps can be ordered in time and can be connected using ItemFlows to specify things flowing between their parameters.

General Classes

Feature

Attributes

/behavior : Behavior [1..*] {redefines type, ordered}

The Behaviors that type this Step.

/parameter : Feature [0..*] {subsets feature, ordered}

The features of this Step whose owningFeatureMemberships are ParameterMemberships. Every parameter of a Step must either be inherited from a behavior of the Step or directly or indirectly redefine a parameter of a behavior of the Step.

Operations

No operations.

Constraints

No constraints.

7.4.6.3.4 ParameterMembership

Description

A ParameterMembership is a FeatureMembership that identifies its memberFeature as a parameter, which is always owned. The default direction for a ParameterMembership is in (unless it is a ReturnParameterMembership). A ParameterMembership must be owned by a Behavior or a Step.

General Classes

FeatureMembership

Attributes

direction : FeatureDirectionKind {redefines direction}

The default direction of a ParameterMembership is in.

memberParameter : Feature {redefines memberFeature}

The Feature that is identified as a parameter by this ParameterMembership, which must be the ownedMemberParameter.

ownedMemberParameter : Feature {redefines ownedMemberFeature}

The Feature that is identified as a parameter by this ParameterMembership, which is always owned by the ParameterMembership.

Operations

No operations.

Constraints

No constraints.

7.4.6.4 Semantics

Required Generalization to Model Library

1. Behaviors shall directly or indirectly specialize *Performances::Performance* (see [8.6.2.10](#)).
2. Steps shall directly or indirectly specialize *Performances::performances* (see [8.6.2.11](#)), which means they shall be typed by Behaviors.

Behavior Semantics

A Behavior of the form

```
behavior B ( in x, out y, inout z);
```

is semantically equivalent to

```
class B specializes Performances::Performance {  
    in feature x;  
    out feature y;  
    inout feature z;  
}
```

while a Behavior that explicitly specializes another Behavior:

```
behavior B1 specializes B (in x1, out y1);
```

is semantically equivalent to

```
class B1 specializes B {  
    in feature x1 redefines x;  
    out feature y1 redefines y;  
}
```

Step Semantics

A Step of the form

```
step s ( in u, out v, inout w);
```

is semantically equivalent to

```
feature s subsets Performances::performances {  
    in feature u;  
    out feature v;  
    inout feature w;  
}
```

while a Step that explicitly specializes Behaviors and/or Steps:

```
behavior b : B subsets s (in xx, out yy);
```

is semantically equivalent to

```
feature b : B subsets s {  
    in feature xx redefines B::x, s::u;  
    out feature yy redefines B::y, s::v;  
}
```

Note. Steps provide for (repeated) refinement of Behaviors by other Behaviors. The repetition ends with Steps typed by Behaviors from the Kernel Model Library for specifying changes in objects involved in the Behaviors.

Submission Note. The Kernel Model Library does not include primitive Behaviors that change objects yet. These will be included in the revised submission.

7.4.7 Functions

7.4.7.1 Functions Overview

Functions

Functions are Behaviors that designate a single output parameter as their result by a `ReturnParameterMembership`, a kind of `ParameterMembership` that requires `direction = out`. Functions can have other output parameters besides their result.

Functions classify *Evaluations* (see [8.6.2.3](#)), which are kinds of *Performances* expected to produce values for their result, but can also change involved *Objects* (including creation, destruction, and changes in feature values). Some Functions have no parameters with direction `out` or `inout` other than their result and do not change objects during their evaluation, such as the numerical functions in the Kernel Model Library (see [Clause 8](#)).

Expressions

Expressions are Steps typed only by a single Function (their function). They can be steps in any Behavior, including Functions, in which case such Expression can be designated as specifying the result of the Function by a `ResultExpressionMembership`. The result of this Expression shall be connected to the result of the featuring Function by a `BindingConnector` (see [7.4.5](#)).

Expressions can have their own (nested) parameters, to augment or redefine those of their functions, including the result. In particular, they can include another Expression to specify their result. In this case, the original Expression must have its own result, redefining those from its function or any other subsetted Expressions, which must be connected to the result of its result Expression by a `BindingConnector`.

Expressions are commonly organized into tree structures in which the input parameters of each Expression are connected by `BindingConnectors` to the result of each of its child Expressions (its arguments). KerML textual syntax includes traditional operator notation for constructing such Expression trees (see [7.4.8.2](#)).

Predicates

Predicates are Functions that whose result is typed by *Boolean* from the *ScalarValues* library (see [8.11](#)) and has a multiplicity of (exactly) 1. Predicates determine whether the values of their input parameters meet particular conditions at the time of evaluation, returning **true** if they do, and **false** otherwise. They classify *BooleanEvaluations*, which are required to have exactly one result of type *Boolean*.

Boolean Expressions and Invariants

BooleanExpressions are Expressions whose function is a Predicate. As such, a *BooleanExpression* must similarly have a result of type *Boolean*. Invariants are *BooleanExpressions* all of whose values (which are *BooleanEvaluations*) must result in **true**. *BooleanExpressions* might result in **true** or **false**, but Invariants must always result in **true**. (*BooleanExpressions* should not be confused with *LiteralBooleans*, which are also Expressions with a Boolean result, but are not typed by a Predicate and always evaluate to a constant value of **true** or **false**—see [7.4.8.3.4](#).)

7.4.7.2 Concrete Syntax

7.4.7.2.1 Functions

```
Function (m : Membership) : Function =
  ( isAbstract ?= 'abstract' )? 'function'
  FunctionDeclaration(this, m) FunctionBody(this)

FunctionDeclaration (f : Function, m : Membership) =
  ClassifierDeclaration(f, m) ParameterList(f) ReturnParameterPart(f)

ReturnParameterPart (t : Type) =
  t.ownedRelationship += ReturnParameterMember

ReturnParameterMember : ReturnParameterMembership =
  ownedMemberParameter = ParameterDeclaration(this)

FunctionBody (t : Type) =
  ';' | '{' TypeBodyElement(t)*
    ( t.ownedRelationship += ResultExpressionMember )? '}'

ResultExpressionMember : ResultExpressionMembership =
  ownedResultExpression = OwnedExpression
```

A Function is declared as a Behavior (see [7.4.6.2.1](#)), using the keyword **function**, with the addition of the declaration of a result parameter. The result parameter is declared like any other Behavior parameter, but after the parenthesized list of non-result parameters for the Function, rather than as part of it. If the Function has no parameters other than the result, then an empty set of parentheses () shall still be included before the declaration of the result parameter. No direction shall be given for a result parameter, since it always has direction out.

```
function Average (scores[1..*] : Rational) : Rational;
function Velocity
  (v_i : VelocityValue, a : AccelerationValue, dt : TimeValue )
  v_f : VelocityValue;
```

If no ownedSuperclassing is explicitly given for a Function, then it is implicitly given a default Superclassing to the Function *Evaluation* from the *Performances* library model (see [8.6](#)). If a Function has ownedSuperclassings that are Behaviors, then the rules for redefinition or inheritance of non-result parameters shall be the same as for a Behavior (see [7.4.6.2.1](#)). If some of the superclass Behaviors are Functions, then the result parameter of the subclass Function shall redefine the result parameters of the superclass Functions. If, in this case, the result parameter has no ownedRedefinitions, then it shall be implicitly given Redefinitions of the result parameter of each of the superclass Functions.

```
abstract function Dynamics
  (initialState : DynamicState, time : TimeValue) : DynamicState;
function VehicleDynamics specializes Dynamics
  // Each parameter redefines the corresponding superclass parameter
  (initialState : VehicleState, time : TimeValue) : VehicleState;
```

The body is like the body of a Behavior (see [7.4.6.2.1](#)), with the optional addition of the declaration of a result Expression at the end. A result Expression shall always be written using the Expression notation described in [7.4.8](#), *not* using the Expression declaration notation from [7.4.7.2.2](#).


```

function Average (scores[1..*] : Rational) : Rational {
    import RationalFunctions::Sum;
    import BaseFunctions::Length;

    Sum(scores) / Length(scores)
}

```

Note. A result Expression is written *without* a final semicolon.

The result of a Function can also be specified using an explicit binding, rather than a result Expression declaration.

```

function Velocity
    (v_i : VelocityValue, a : AccelerationValue, dt : TimeValue )
    v_f : VelocityValue {
    private feature v : VelocityValue = v_i + a * dt;
    binding v_f = v;
}

```

7.4.7.2.2 Expressions

```

Expression (m : Membership) : Expression =
    ( isAbstract ?= 'abstract' )? 'expr'
    ExpressionDeclaration(this, m) FunctionBody(this)

ExpressionDeclaration (e : Expression, m : Membership) =
    FeatureDeclaration(e, m)
    ( ValuePart(e) | StepParameterList(e) ReturnParameterPart(e) )?

```

An Expression can be declared as a Step (see [7.4.6.2.2](#)) using the keyword **expr** (see also [7.4.8.2](#) for more traditional Expression notation). If no ownedSubsetting or ownedRedefinition is explicitly given, then the Expression is implicitly given a default Subsetting to the Feature *evaluations* from the *Performances* library model (see [8.6](#)). Following the Feature declaration part, an Expression declaration can include *either* a FeatureValue (see [7.4.10](#)) *or* a parameter list and result parameter part, declared in the same way as for a Function (see [7.4.7.2.1](#)).

```

expr computation : Computedynamics (state, dt) result;
expr lastEval : Evaluation = computation;

```

If an Expression has ownedGeneralizations (including all FeatureTypings, Subsettings and Redefinitions) whose general Type is a Behavior (including a Function) or a Step (including an Expression), then the rules for the redefinition of the parameters of those Behaviors and Steps shall be the same as for the redefinition of the parameters of superclass Behaviors by a subclass Function (see [7.4.7.2.1](#)).

```

// Input parameters are inherited, result is redefined.
expr vehicleComputation subsets computation () : VehicleState;

```

As for a generic Step, the parameters declared in an Expression declaration may have FeatureValues (see [7.4.10](#)).

An Expression can also have a body which, like a Function body, can specify a result Expression.

```

    expr : Dynamics () result : VehicleState {
        vehicleComputation()
    }

```

7.4.7.2.3 Predicates

```

Predicate (m : Membership) : Predicate =
    ( isAbstract ?= 'abstract' )? 'predicate'
    PredicateDeclaration(this, m) FunctionBody(this)

PredicateDeclaration (p : Predicate, m : Membership) =
    ClassifierDeclaration(p, m)
    ( ParameterList(p) ReturnParameterPart(p)? )?

```

A Predicate is declared as a Function (see [7.4.7.2.1](#)), using the keyword **predicate**, except that declaring the result parameter is optional. If a result parameter is declared, then it must have type *Boolean* from the *ScalarValues* library model (see [8.11](#)) and multiplicity 1..1 (see [7.4.11](#)). If no result parameter is declared, then the Predicate is given an implicit one that meets the stated requirements.

```

predicate isAssembled (assembly : Assembly, subassemblies[*] : Assembly);

```

If no *ownedSuperclassing* is explicitly given for a Predicate, then it is implicitly given a default Superclassing to the Predicate *BooleanEvaluation* from the *Performances* library model (see [8.6](#)). If a Predicate has *ownedSuperclassings* that are Behaviors, then the rules for redefinition or inheritance of non-result parameters shall be the same as for a Function (see [7.4.7.2.1](#)).

The body of a Predicate is the same as a Function body (see [7.4.7.2.1](#)). If a result Expression is included, then it shall evaluate to a Boolean result.

```

predicate isFull (tank : FuelTank) {
    tank::fuelLevel == tank::maxFuelLevel
}

```

7.4.7.2.4 Boolean Expressions and Invariants

```

BooleanExpression (m : Membership) : BooleanExpression =
    ( isAbstract ?= 'abstract' )? 'bool'
    ExpressionDeclaration(this, m) FunctionBody(this)

Invariant (m : Membership) : Invariant =
    ( isAbstract ?= 'abstract' )? 'inv'
    ExpressionDeclaration(this, m) FunctionBody(this)

```

A BooleanExpression is declared as an Expression (see [7.4.7.2.2](#)), using the keyword **bool**, except that declaring the result parameter is optional. The requirements on and default for the result parameter of a BooleanExpression are the same as for a Predicate (see [7.4.7.2.3](#)). If no *ownedSubsetting* or *ownedRedefinition* is explicitly given, then the BooleanExpression is implicitly given a default Subsetting to the Feature *booleanEvaluations* from the *Performances* library model (see [8.6](#)). If a BooleanExpression has *ownedGeneralizations* (including all FeatureTypings, Subsettings and Redefinitions) whose general Type

is a Behavior or Step, then the rules for the redefinition of the parameters of those Behaviors and Steps shall be the same as for a regular Expression (see [7.4.7.2.2](#)).

```
// All input parameters are inherited.
bool assemblyChecks[*] : isAssembled;
```

A BooleanExpression can also have a body which, like a Predicate body, can specify a *Boolean* result Expression.

```
class FuelTank {
  feature fuelLevel : Real;
  feature readonly maxFuelLevel : Real;
  bool isFull { fuelLevel == maxFuelLevel }
}
```

An Invariant is declared exactly like any other BooleanExpression, except using the keyword **inv** instead of **bool**.

```
class FuelTank {
  feature fuelLevel : Real;
  feature readonly maxFuelLevel : Real;
  inv { fuelLevel >= 0 & fuelLevel <= maxFuelLevel }
}
```

7.4.7.3 Abstract Syntax

7.4.7.3.1 Overview

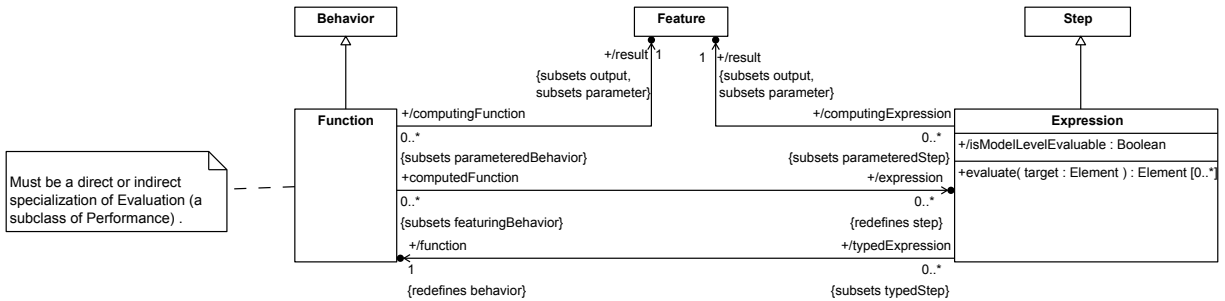


Figure 24. Functions

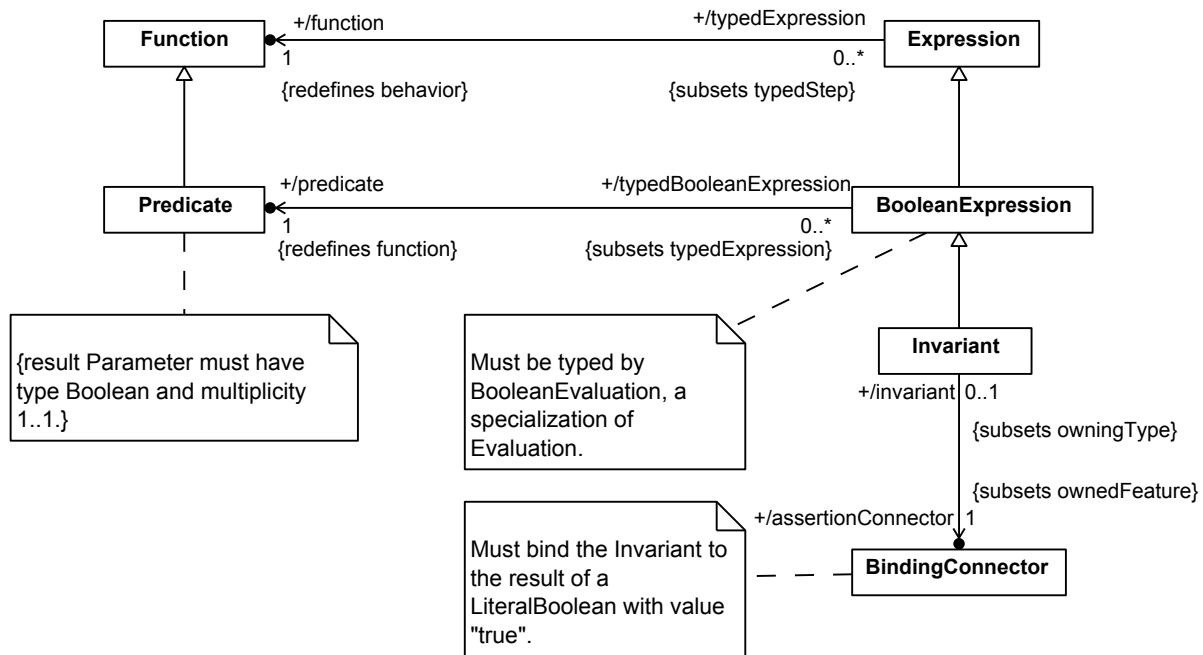


Figure 25. Predicates

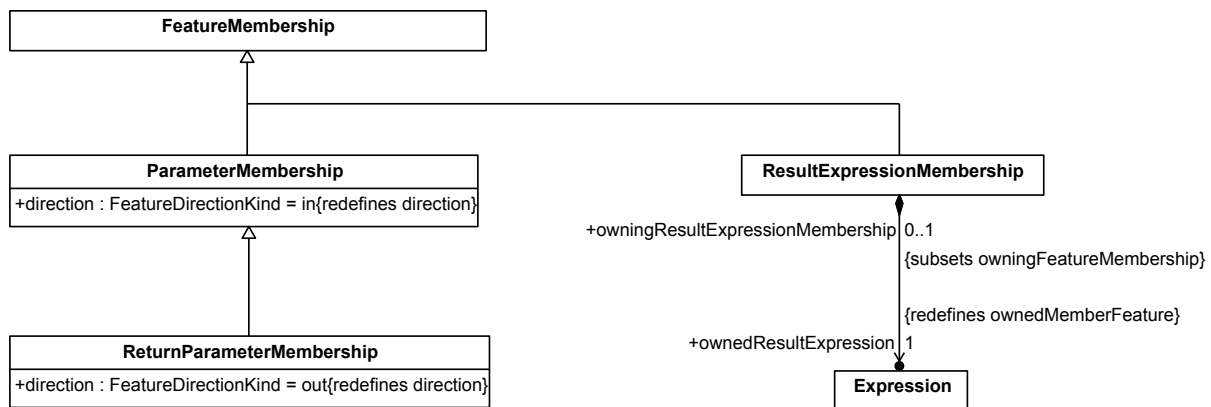


Figure 26. Function Memberships

7.4.7.3.2 BooleanExpression

Description

An **BooleanExpression** is a Boolean-valued **Expression** whose type is a **Predicate**. It represents a logical condition resulting from the evaluation of the **Predicate**.

A **BooleanExpression** must subset, directly or indirectly, the **Expression** *booleanEvaluations* from the Base model library, which is typed by the base **Predicate** *BooleanEvaluation*. As a result, a **BooleanExpression** must always be typed by **BooleanEvaluation** or a subclass of **BooleanEvaluation**.

General Classes

Expression

Attributes

/predicate : Predicate {redefines function}

The Predicate that types the Expression.

Operations

No operations.

Constraints

No constraints.

7.4.7.3.3 Expression

Description

An Expression is a Step that is typed by a Function. An Expression that also has a Function as its `featuringType` is a computational step within that Function. An Expression always has a single `result` parameter, which redefines the `result` parameter of its defining function. This allows Expressions to be interconnected in tree structures, in which inputs to each Expression in the tree are determined as the results of other Expressions in the tree.

General Classes

Step

Attributes

/function : Function {redefines behavior}

The Function that types this Expression.

/isModelLevelEvaluable : Boolean

Whether this Expression meets the constraints necessary to be evaluated at *model level*, that is, using metadata within the model.

/result : Feature {subsets parameter, output}

The single parameter of this Expression whose `owningFeatureMembership` is a `ReturnFeatureMembership`. The result of an Expression must either be inherited from its `function` or (directly or indirectly) redefine the `result` parameter of its `function`.

Operations

evaluate(target : Element) : Element [0..*]

If this Expression `isModelLevelEvaluable`, then evaluate it using the `target` as the context Element for resolving Feature names and testing classification. The result is a collection of Elements, each of which must be a `LiteralExpression` or an `AnnotatingFeature`.

pre: `isModelLevelEvaluable`

Constraints

No constraints.

7.4.7.3.4 Function

Description

A Function is a Behavior that has an output parameter specifically identified as its `result`. It represents the performance of a calculation that produces the values of its `result` parameter. This calculation may be decomposed into Expressions that are the `steps` of the Function.

General Classes

Behavior

Attributes

`/expression : Expression [0..*] {redefines step}`

The Expressions that are steps in the calculation of the `result` of this Function.

`/result : Feature {subsets parameter, output}`

The distinguished `result` parameter of the Function, derived as the `parameter` related to the Function by a `ReturnParameterMembership`.

Operations

No operations.

Constraints

No constraints.

7.4.7.3.5 Invariant

Description

An Invariant is a `BooleanExpression` that is asserted to be true. This assertion is made by the Invariant having a `BindingConnector` as an `ownedFeature` that binds the `result` of the Invariant to the `result` of a `LiteralBoolean` with value *true*.

General Classes

`BooleanExpression`

Attributes

`/assertionConnector : BindingConnector {subsets ownedFeature}`

An `ownedFeature` of the Invariant that is a `BindingConnector` between the `result` of the Invariant and the `result` of a `LiteralBoolean` with value *true*.

Operations

No operations.

Constraints

No constraints.

7.4.7.3.6 Predicate

Description

A Predicate is a Behavior whose `result` Parameter has type *Boolean* and multiplicity 1..1.

General Classes

Function

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.4.7.3.7 ResultExpressionMembership

Description

A ResultExpressionMembership is a FeatureMembership that indicates that the `ownedResultExpression` provides the result values for the Function or Expression that owns it. The owning Function or Expression must contain a BindingConnector between the `result` parameter of the `ownedResultExpression` and the `result` parameter of the Function or Expression.

General Classes

FeatureMembership

Attributes

`ownedResultExpression` : Expression {redefines ownedMemberFeature}

The Expression that provides the result for the owner of the ResultExpressionMembership.

Operations

No operations.

Constraints

No constraints.

7.4.7.3.8 ReturnParameterMembership

Description

A ReturnParameterMembership is a ParameterMembership that indicates that the `memberParameter` is the `result` parameter of a Function or Expression. The `direction` for a ReturnParameterMembership must be `out`.

General Classes

ParameterMembership

Attributes

`direction` : FeatureDirectionKind {redefines `direction`}

The `direction` of a ReturnParameterMembership must be `out`.

Operations

No operations.

Constraints

No constraints.

7.4.7.4 Semantics

Required Generalizations to Model Library

1. Functions shall directly or indirectly specialize *Performances::Evaluation* (see [8.6.2.3](#)).
2. Predicates shall directly or indirectly specialize *Performances::BooleanEvaluation* (see [8.6.2.1](#)).
3. Expressions shall directly or indirectly specialize *Performances::evaluations* (see [8.6.2.4](#)), which means they shall be directly or indirectly typed by *Performances::Evaluation*.
4. BooleanExpressions (including Invariants) shall directly or indirectly specialize *Performances::booleanEvaluations* (see [8.6.2.2](#)), which means they shall be directly or indirectly typed by *Performances::BooleanEvaluation*.

Function Semantics

A Function of the form

```
function F (a, b) result {  
    resultExpr  
}
```

is semantically equivalent to

```
class F specializes Performances::Evaluation {  
    in a;  
    in b;  
    out result redefines Performances::Evaluation::result  
        = resultExpr;  
}
```

where the binding to *resultExpr* is interpreted as a FeatureValue (see [7.4.10](#)).

Expression Semantics

An Expression of the form

```
expr e : F (a, b) result {  
    resultExpr  
}
```

is semantically equivalent to

```
feature e : F subsets Performances::evaluations {  
    in a redefines F::a;  
    in b redefines F::b;  
    out result redefines F::result  
        = resultExpr;  
}
```

Predicate Semantics

A Predicate is simply a Function with a Boolean result (see [7.4.7.1](#)) and, otherwise, has no additional semantics.

Boolean Expression and Invariant Semantics

An Invariant of the form

```
inv i ( ... ) result {  
    resultExpr  
}
```

is semantically equivalent to

```
feature i subsets Performances::booleanEvaluations {  
    ...  
    out result redefines Performances::booleanEvaluations::result  
        = resultExpr;  
    private alwaysTrue = true;  
    binding result = alwaysTrue;  
}
```

7.4.8 Expressions

7.4.8.1 Expressions Overview

Expressions are commonly organized into tree structures to specify compound computations (see [7.4.7](#)). KerML includes extensive textual syntax for constructing Expression trees, including traditional operator notations (see [7.4.8.2](#)) for Functions in the Kernel Model Library (see [Clause 8](#)). These concrete syntax notations map entirely to an abstract syntax involving just a few specialized Expressions (see [7.4.8.3](#)):

- The non-leaf nodes of an Expression tree are InvocationExpressions, a kind of Expression that specifies its inputs (owned arguments) as other Expressions, one for each of the input parameters of its function.
- The edges of the tree are BindingConnectors between the input parameters of an InvocationExpression (redefining those of its function) and the results of its argument Expressions.

- The leaf nodes are these kinds of Expressions:
 - FeatureReferenceExpressions whose `results` are values of a referenced Feature that is not part of the Expression tree, by subsetting the referenced Feature.
 - LiteralExpressions that `result` in the literal value of one of the primitive DataTypes from the *ScalarValues* model library (see [8.11](#)).
 - NullExpressions that `result` in an empty set of values, as required by the `result` multiplicity being 0.

Release Note. Additional operators not currently covered in this Expression syntax include explicit casting, dynamic de-referencing ("dot" expressions) and assignment.

Model-Level Evaluable Expressions

A *model-level evaluable* Expression is an Expression that is restricted such that it can be evaluated using metadata within a model itself. Model-level evaluable Expressions are used to give values to the `metadataFeatures` of an `AnnotatingFeature` (see [7.4.12](#)) and as element filtering conditions (see [7.4.13](#)).

All NullExpressions, LiteralExpressions and FeatureReferenceExpressions are model-level evaluable. An InvocationExpression is model-level evaluable if it meets the following conditions:

1. All its `argument` Expressions are model-level evaluable.
2. It has a single `function` that is a library Function listed as being model-level evaluable in [Table 7](#) or [Table 9](#).

In all other cases, an Expression shall be considered to be *not* model-level evaluable.

Release note. The Functions allowed in model-level evaluable expressions may be expanded in future releases.

7.4.8.2 Concrete Syntax

7.4.8.2.1 Operator Expressions

```

OwnedExpressionMember : FeatureMembership =
    ownedFeatureMember = OwnedExpression

OwnedExpression : Expression =
    ConditionalExpression
    | BinaryOperatorExpression
    | UnaryOperatorExpression
    | ClassificationExpression
    | ExtentExpression
    | SequenceExpression

ConditionalExpression : InvocationExpression =
    ownedRelationship += OwnedExpressionMember
    ownedRelationship += [['?']]
    ownedRelationship += OwnedExpressionMember ':'
    ownedRelationship += OwnedExpressionMember

BinaryOperatorExpression : InvocationExpression =
    ownedRelationship += OwnedExpressionMember
    ownedRelationship += [[BinaryOperator]]
    ownedRelationship += OwnedExpressionMember

BinaryOperator =
    '??' | '|' | '&&' | '|' | '^' | '&' | '==' | '!='
    | '<' | '>' | '<=' | '>=' | '+' | '-' | '*' | '/' | '%' | '**'

UnaryOperatorExpression : InvocationExpression =
    ownedTyping += [[UnaryOperator]]
    ownedRelationship += OwnedExpressionMember

UnaryOperator =
    '+' | '-' | '!' | '~'

ClassificationExpression =
    ( ownedFeatureMembership += OwnedExpressionMember )?
    ownedTyping += [[ClassificationOperator]]
    ownedRelationship += TypeReferenceMember

ClassificationOperator =
    'istype' | 'hastype' | '@'

ExtentExpression : InvocationExpression =
    ownedRelationship += ['all']
    ownedRelationship += TypeReferenceMember

TypeReferenceMember : FeatureMembership =
    ownedMemberFeature = TypeReference

TypeReference : Feature =
    ownedRelationship += OwnedFeatureTyping

```

Operator expressions provided a shorthand notation for InvocationExpressions that invoke a library Function represented as an *operator symbol*. [Table 7](#) shows the mapping from operator symbols to the Functions they represent from the Kernel Model Library (see [Clause 8](#)). An operator expression generally contains subexpressions called its *operands* that generally correspond to the `argument` Expressions of the InvocationExpression, except in the case of operators representing *control Functions*, in which case the evaluation of certain operands is as determined by the Function (see [7.4.8.4](#) for details).

Note. In the above productions for operator expressions, the special notation `[['operator']]` is used to indicate that the given `operator` symbol shall be parsed and then resolved to the appropriate library function as given in [Table 7](#) (see also [7.1.3](#), [Table 4](#)).

Operator expressions include the following:

- *Conditional expression.* The *conditional test* operator `?` is a ternary operator that evaluates to the value of its second operand, depending on whether the result of its first operand is true or false. Note that only one of the second or third operand is actually evaluated.

```
x >= 0 ? x : -x
```

- *Binary operator expression.* A *binary operator* is one that has two operands. In general, both operands become arguments of the InvocationExpression, with their results being passed to the invocation of the Function represented by the operator. However, the null-coalescing (`??`), logical and (`&&`) and logical or (`||`) operators all correspond the control Functions (see [8.26](#)) in which their second operand is only evaluated depending on a certain condition of the value of their first operand (whether it is null, true or false, respectively).

```
x + y
list[i] ?? default
i > 0 && sensor[i] != null
```

- *Unary operator expressions.* A *unary operator* is one that has a single operand. The result of evaluating this operand is passed to the invocation of the Function represented by the operator.

```
-x
!isOutOfRange(sensor)
```

- *Classification expression.* The *classification operators* **`istype`** and **`hastype`** are syntactically similar to binary operators, but, instead of an Expression as their second operand, they take a Type name. These operators test whether the value of their first operand is classified by the named Type (either including or not including subtypes, respectively). The symbol `@` may be used as a synonym for **`istype`**.

```
sensor istype ThermalSensor
sensor @ ThermalSensor
person hastype Administrator
```

The classification operators may also be used without a first operand, in which case the first operand is implicitly `Anything::self` (see [8.2.2.1](#)). This is useful, in particular, when used as a test within an element filter condition Expression (see [7.4.13.2](#)).

```
istype ThermalSensor
@ThermalSensor
hastype Administrator
```

- *Extent expression.* The *extent operator* **all** is syntactically similar to a unary operator, but, instead of an Expression as its operand, it takes a type name. An extent expression evaluates to a sequence of all instances of the named Type.

all Sensor

Though not directly expressed in the syntactic productions given above, in any operator expression containing nested operator expressions, the nested expressions shall be implicitly grouped according to the *precedence* of the operators involved, as given in [Table 8](#). Operator expressions with higher precedence operators shall be grouped more tightly than those with lower precedence operators. For example, the operator expression

$-x + y * z$

is considered equivalent to

$((-x) + (y * z))$

Table 7. Operator Mapping

Operator	Library Function	Description	Model-Level Evaluable?
all	BaseFunctions::'all'	Type Extent	No
istype	BaseFunctions::'istype'	Is directly or indirectly instance of type	Yes
hastype	BaseFunctions::'hastype'	Is directly instance of type	Yes
@	BaseFunctions::'@'	Same as 'istype'	Yes
==	BaseFunctions::'=='	Equality	Yes
!=	BaseFunctions::'!='	Inequality	Yes
	ScalarFunctions::' '	Logical "inclusive or"	Yes
^	ScalarFunctions::'^'	Logical "exclusive or"	Yes
&	ScalarFunctions::'&'	Logical "and"	Yes
<	ScalarFunctions::'<'	Less than	Yes
>	ScalarFunctions::'>'	Greater than	Yes
<=	ScalarFunctions::'<='	Less than or equal to	Yes
>=	ScalarFunctions::'>='	Greater than or equal to	Yes
+	ScalarFunctions::'+'	Addition	Yes
-	ScalarFunctions::'-'	Subtraction	Yes
*	ScalarFunctions::'*'	Multiplication	Yes
/	ScalarFunctions::'/'	Division	Yes
%	ScalarFunctions::'%'	Remainder	Yes
**	ScalarFunctions::'**'	Exponentiation	Yes
??	ControlFunctions::'??'	Null coalescing	Yes

Operator	Library Function	Description	Model-Level Evaluable?
	ControlFunctions::' '	Conditional "or"	Yes
&&	ControlFunctions::'&&'	Conditional "and"	Yes
?	ControlFunctions::'??'	Conditional test (ternary)	Yes

Table 8. Operator Precedence (highest to lowest)

Unary
all
+ - ! ~
Binary
@ [
**
* / %
+ -
< > <= >=
istype hastype @
== !=
&
^
&&
??
Ternary
?

7.4.8.2.2 Sequence Expressions


```

SequenceExpression : Expression
    SequenceIndexExpression
    | SequenceOperationExpression
    | SequenceConstructionExpression
    | BaseExpression

SequenceIndexExpression : InvocationExpression =
    ownedRelationship += SequenceExpressionMember
    ownedRelationship += [['[]']
    ownedRelationship += OwnedExpressionMember ']'

SequenceOperationExpression : InvocationExpression
    ownedRelationship += SequenceExpressionMember
    '->' ownedRelationship += [[NAME]]
    ( ownedRelationship += BodyExpressionMember )+

SequenceExpressionMember : FeatureMembership =
    ownedMemberFeature = SequenceExpression

BodyExpressionMember : FeatureMembership =
    ownedMemberFeature = BodyExpression

BodyExpression : Expression =
    ownedRelationship += BodyParameterMember
    ( ownedRelationship += BodyParameterMember ) *
    '(' ownedRelationship += OwnedExpressionMember ')'
    | ownedRelationship += OwnedFeatureTyping

BodyParameterMember : ParameterMembership =
    memberName = Name ownedMemberFeature = BodyParameter

BodyParameter : Feature =
    ( TypedBy(this) MultiplicityPart(this)? |
      MultiplicityPart(this) TypedBy(this)? )?

SequenceConstructionExpression : Expression =
    '{' SequenceListExpression | SequenceRangeExpression '}'

SequenceListExpression : Expression =
    OwnedExpression | SequenceElementList

SequenceElementList : InvocationExpression =
    ownedRelationship += OwnedExpressionMember
    ownedRelationship += [[',']]
    ownedRelationship += SequenceListMember

SequenceListMember : FeatureMembership
    ownedFeatureMember = SequenceListExpression

SequenceRangeExpression : InvocationExpression =
    ownedRelationship += OwnedExpressionMember

```

```
ownedRelationship += [['..']]
ownedRelationship += OwnedExpressionMember
```

Sequence expressions provide a shorthand notation for InvocationExpressions that invoke library Functions that operate on sequences of values. [Table 9](#) shows the mapping from operator symbols and keywords used in sequence expressions to the Functions they represent from the Kernel Model Library (see [Clause 8](#)).

Note. In the above productions for operator expressions, the special notation `['operator']` or `[NAME]` is used to indicate that the given operator symbol or NAME shall be parsed and then resolved to the appropriate library function as given in [Table 9](#) (see also [7.1.3](#), [Table 4](#)).

Sequence expressions include the following:

- *Sequence index expression.* The first operand of a sequence index expression is expected to evaluate to a sequence of values, and the second operand is expected to evaluate to an index into that sequence. Default indexing is from 1 using *Natural* numbers. However, the functionality of the indexing Function `[` from the *BaseFunctions* library model (see [8.13](#)) may be specialized for domain-specific types.

```
sensors[activeSensorIndex]
```

- *Sequence operation expression.* A sequence operation expression invokes a control Function that takes a sequence as its single argument. The second operand of a sequence operation expression is a parameterized Expression or the name of a Function, which can be invoked multiple times as necessary, depending on the functionality of the sequence operation Functions (see [8.26](#) for further description of these Functions).

```
sensors -> select s (s::isActive)
members -> reject member (!inGoodStanding(member))
factors -> reduce RealFunctions::'*'
```

- *Sequence construction expression.* A sequence construction expression is used to construct a sequence of values, either by giving a list of Expressions that evaluate to the values in the sequence (in order) or by giving two Expressions that evaluate to the upper and lower bounds (inclusive) of a range of values to be included in the sequence.

```
{ fuselage, wing1, wing2, tail }
{ 1 .. size(sensors) }
```

Table 9. Sequence Operator Mapping

Operator	Library Function	Description	Model-level Evaluable?
<code>[</code>	<code>BaseFunctions:: '['</code>	Sequence indexing	Yes
<code>,</code>	<code>BaseFunctions:: ','</code>	Sequence construction	Yes
<code>collect</code>	<code>ControlFunctions::collect</code>	Sequence collection	No
<code>select</code>	<code>ControlFunctions::select</code>	Sequence selection	No
<code>reject</code>	<code>ControlFunctions::reject</code>	Sequence rejection	No
<code>reduce</code>	<code>ControlFunctions::reduce</code>	Sequence reduction	No
<code>forAll</code>	<code>ControlFunctions::forAll</code>	Sequence universal test	No

Operator	Library Function	Description	Model-level Evaluable?
exists	ControlFunctions::exists	Sequence existential test	No
..	ScalarFunctions::'..'	Range construction	No

7.4.8.2.3 Base Expressions

```

BaseExpression : Expression =
    NullExpression
  | LiteralExpression
  | FeatureReferenceExpression
  | InvocationExpression
  | '(' OwnedExpression ')'

NullExpression : NullExpression =
    'null' | '{' '}'

FeatureReferenceExpression : FeatureReferenceExpression =
    ownedRelationship += FeatureReferenceMember

FeatureReferenceMember : ReturnParameterMembership =
    ownedMemberParameter = FeatureReference

FeatureReference : Feature =
    ownedRelationship += Subset

InvocationExpression : InvocationExpression =
    ownedRelationship += OwnedFeatureTyping '(' ArgumentList(this)? ')'

ArgumentList (e : InvocationExpression) =
    PositionalArgumentList(e) | NamedArgumentList(e)

PositionalArgumentList (e : InvocationExpression) =
    e.ownedRelationship += OwnedExpressionMember
    ( ',' e.ownedRelationship += OwnedExpressionMember )*

NamedArgumentList (e : InvocationExpression) =
    e.ownedRelationship += NamedExpressionMember
    ( ',' e.ownedRelationship += NamedExpressionMember )*

NamedExpressionMember : FeatureMembership =
    memberName = NAME '=>' ownedMemberFeature = OwnedExpression

```

The *base expressions* include representations for InvocationExpressions, FeatureReferenceExpressions, NullExpressions and LiteralExpressions. Parenthesizing any Expression represented in the concrete syntax of [7.4.8.2](#) also makes it syntactically a base expression, though it is otherwise equivalent to the contained Expression.

Any InvocationExpression can be directly represented by giving the qualified name for the Function to be invoked followed by a list of argument Expressions, surrounded by parentheses (). The parentheses must be included, even if the argument list is empty.

```
IntegerFunctions::'+'(i, j)
isInGoodStanding(member)
Computation()
```

If the qualified name given for an InvocationExpression resolves to an Expression instead of a Function, then the invocation is taken to be for the function of the named Expression, as specialized by that Expression.

```
function UnaryFunction(x : Anything): Anything;
function apply(expr fn : UnaryFunction, value : Anything): Anything {
    fn(value) // Invokes UnaryFunction as specified by parameter fn.
}
```

A FeatureReferenceExpression is represented simply by the qualified name of the Feature being referenced.

```
member
spacecraft::mainAssembly::sensors
sensor::isActive
```

Note that the referenced Feature may be an Expression. The notation for a reference to an Expression is distinguished from the notation for an invocation by not having following parentheses.

```
expr addOne : UnaryFunction(x : Anything): Integer {
    x is type Integer? x + 1: 0
}
feature two = apply(addOne, 1); // "addOne" is a reference to expr addOne
```

A NullExpression is notated by the keyword **null**. A NullExpression always evaluates to a result of "no values", which is equivalent to the empty sequence {}.

LiteralExpressions are described in [7.4.8.2.4](#).

7.4.8.2.4 Literal Expressions

```
LiteralExpression : LiteralExpression =  
    LiteralBoolean  
    | LiteralString  
    | LiteralInteger  
    | LiteralReal  
    | LiteralUnbounded  
  
LiteralBoolean : LiteralBoolean =  
    value = BooleanValue  
  
BooleanValue : Boolean =  
    'true' | 'false'  
  
LiteralString : LiteralString  
    value = STRING_VALUE  
  
LiteralInteger : LiteralInteger =  
    value = DECIMAL_VALUE  
  
LiteralReal : LiteralReal =  
    value = RealValue  
  
RealValue : Real =  
    DECIMAL_VALUE? '.' ( DECIMAL_VALUE | EXPONENTIAL_VALUE )  
    | EXPONENTIAL_VALUE  
  
LiteralUnbounded : LiteralUnbounded =  
    '*'
```

A `LiteralExpression` is represented by giving a lexical literal for the `value` of the `LiteralExpression`.

- A `LiteralBoolean` is represented by either of the keyword **true** or **false**.
- A `LiteralString` is represented by a lexical string value as specified in [7.1.2.6](#).
- A `LiteralInteger` is represented by a lexical decimal value as specified in [7.1.2.5](#). Note that notation is only provided for non-negative integers (i.e., natural numbers). Negative integers can be represented by applying the unary negation operator `-` (see [7.4.8.2.1](#)) to an unsigned decimal literal.
- A `LiteralReal` is represented with a syntax constructed from lexical decimal values and exponential values (see [7.1.2.5](#)). The full real number notation allows for a literal with a decimal point, with or without an exponential part, as well as an exponential value without a decimal point.

```
3.14  
.5  
2.5E-10  
1E+3
```

- A `LiteralUnbounded` is represented by the symbol `*`.

7.4.8.3 Abstract Syntax

7.4.8.3.1 Overview

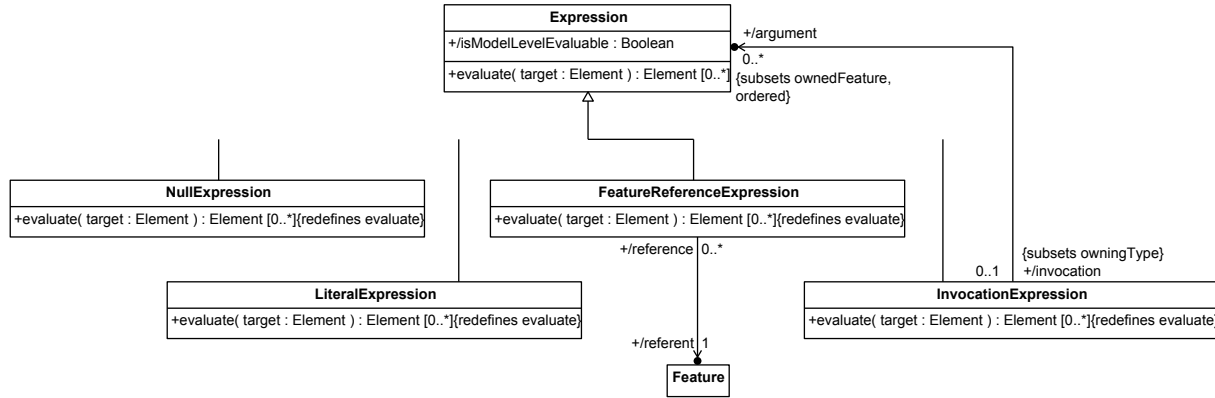


Figure 27. Expressions

Release Note. The concrete syntax and (model-level) semantics of MetadataExpressions will be fully described in the next release.

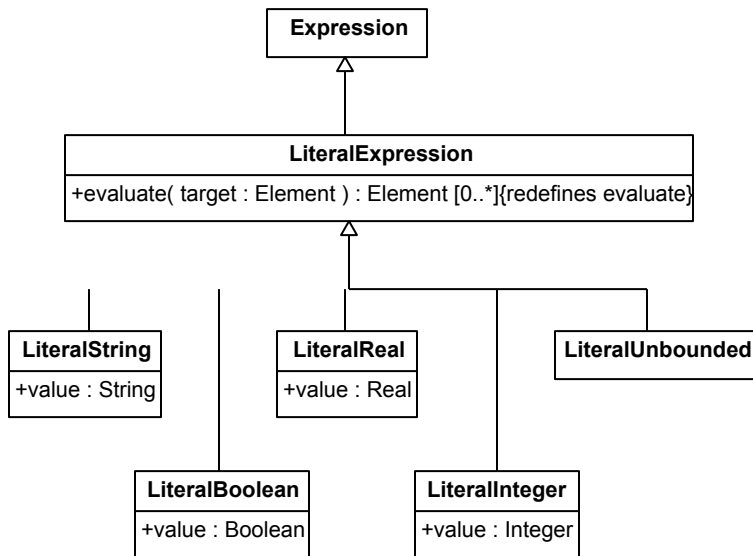


Figure 28. Literal Expressions

7.4.8.3.2 FeatureReferenceExpression

Description

A FeatureReferenceExpression is an Expression whose result is bound a referent Feature. The only members allowed for a FeatureReferenceExpression are the referent, the result and the BindingConnector between them.

General Classes

Expression

Attributes

/referent : Feature

The Feature that is referenced by this FeatureReferenceExpression.

Operations

evaluate(target : Element) : Element [0..*]

If the target Element is a Type that has a feature that redefines the referent, then return the result of evaluating the Expression given by the FeatureValue of that feature. Otherwise, if the referent has no featuringTypes, return the referent. Otherwise return an empty sequence.

```
body: if not target.oclIsKindOf(Type) then Sequence{}  
else  
    let feature: Sequence(Feature) =  
        target.oclAsType(Type).feature->select(f |  
            f.ownedRedefinition.redefinedFeature->  
                includes(referent)) in  
    if feature->notEmpty() then  
        feature.valuation.value.evaluate(target)  
    else if referent.featureingType->isEmpty()  
        then referent  
    else Sequence{}  
    endif endif  
endif
```

Constraints

featureReferenceExpressionIsModelLevelEvaluable

A FeatureReferenceExpression is always model-level evaluable (though it may produce no value on some targets).

7.4.8.3.3 InvocationExpression

Description

An InvocationExpression is an Expression each of whose input parameters are bound to the result of an owned argument Expression. Each input parameter may be bound to the result of at most one argument.

General Classes

Expression

Attributes

/argument : Expression [0..*] {subsets ownedFeature, ordered}

An Expression owned by the InvocationExpression whose result is bound to an input parameter of the InvocationExpression.

Operations

evaluate(target : Element) : Element [0..*]

Apply the Function that is the `type` of this `InvocationExpression` to the argument values resulting from evaluating each of the `argument` Expressions on the given `target`. If the application is not possible, then return an empty sequence.

Constraints

`invocationExpressionIsModelLevelEvaluable`

An `InvocationExpression` is model-level evaluable if all its `argument` Expressions are model-level evaluable and it has a single `type` that is a model-level evaluable primitive Function from the Kernel model library.

7.4.8.3.4 LiteralBoolean

Description

An Expression that provides a *Boolean* value as a result. A `LiteralBoolean` must have an owned `result` parameter whose type is *Boolean*.

General Classes

`LiteralExpression`

Attributes

`value` : *Boolean*

The *Boolean* value that is the result of evaluating this Expression.

Operations

No operations.

Constraints

No constraints.

7.4.8.3.5 LiteralExpression

Description

An Expression that provides a basic value as a result. A `LiteralExpression` must directly or indirectly specialize the Function *LiteralEvaluation* from the *Base* model library, which has no parameters other than its result, which is a single *DataValue*.

General Classes

`Expression`

Attributes

No attributes.

Operations

`evaluate(target : Element) : Element [0..*]`

The model-level value of a LiteralExpression is itself.

body: Sequence{self}

Constraints

literalExpressionIsModelLevelEvaluable

A LiteralExpression is always model-level evaluable.

isModelLevelEvaluable = true

7.4.8.3.6 LiteralInteger

Description

An Expression that provides an Integer value as a result. A LiteralInteger must have an owned `result` parameter whose type is *Integer*.

General Classes

LiteralExpression

Attributes

value : Integer

The Integer value that is the result of evaluating this Expression.

Operations

No operations.

Constraints

No constraints.

7.4.8.3.7 LiteralReal

Description

An Expression that provides a Real value as a result. A LiteralInteger must have an owned `result` parameter whose type is *Real*.

General Classes

LiteralExpression

Attributes

value : Real

The Real value that is the result of evaluating this Expression.

Operations

No operations.

Constraints

No constraints.

7.4.8.3.8 LiteralString

Description

An Expression that provides a String value as a result. A LiteralString must have an owned `result` parameter whose type is *String*.

General Classes

LiteralExpression

Attributes

value : String

The String value that is the result of evaluating this Expression.

Operations

No operations.

Constraints

No constraints.

7.4.8.3.9 LiteralUnbounded

Description

An Expression that provides the unbounded ("*") value of the DataType *UnlimitedNatural*. A LiteralUnbounded must have an owned `result` parameter whose type is *UnlimitedNatural*.

General Classes

LiteralExpression

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.4.8.3.10 NullExpression

Description

An Expression that results in a null value. A NullExpression must be typed by a *NullEvaluation* that results in an empty value.

General Classes

Expression

Attributes

No attributes.

Operations

evaluate(target : Element) : Element [0..*]

The model-level value of a NullExpression is an empty sequence.

body: Sequence{ }

Constraints

nullExpressionIsModelLevelEvaluable

A NullExpression is always model-level evaluable.

isModelLevelEvaluable = true

7.4.8.4 Semantics

Required Generalizations to Model Library

1. LiteralExpressions shall directly or indirectly specialize *Performances::literalEvaluations* (see [8.6](#)), which means their function is *Performances::LiteralEvaluations* or a specialization of it.
2. NullExpressions shall directly or indirectly specialize *Performances::nullEvaluations* (see [8.6](#)), which means their function is *Performances::NullEvaluations* or a specialization of it.

Also see Required Generalizations for Expressions in [7.4.7.4](#).

Invocation Expression Semantics

Given a function of the form

```
function F(a, b, ...) result;
```

an InvocationExpression of the form

```
F(expr_1, expr_2, ...)
```

is semantically equivalent to $e :: \text{result}$, where the Expression e is

```

expr e : F (a, b, ...) result {
  expr e_1 ( ) result {
    ...
  }
  expr e_2 ( ) result {
    ...
  }
  ...
  binding a = e_1::result;
  binding b = e_2::result;
  ...
}

```

and each e_n is the equivalent of $expr_n$ according to this subclause.

With the exception of operators that map to control Functions (see below), the concrete syntax operator Expression notation (see [7.4.8.2.1](#)) is simply special surface syntax for InvocationExpressions of standard library Functions. For example, a unary operator Expression such as

`! expr`

is equivalent to the InvocationExpression

`ScalarFunctions::'!' (expr)`

and a binary operator Expression such as

`expr_1 + expr_2`

is equivalent to the InvocationExpression

`ScalarFunctions::'+' (expr_1, expr_2)`

where the InvocationExpressions are then semantically interpreted as above.

The + and – operators are the only operators that have both unary and binary usages. However, the corresponding library functions have optional 0..1 multiplicity on their second parameters, so it is acceptable to simply not provide an input for the second argument when mapping the unary usages of these operators.

Submission Note. Functions in the library Packages *BaseFunctions* and *ScalarFunctions* are extensively specialized in other library Packages to constrain their parameter types (e.g., the Package *RealFunctions* constrains parameter types to be *Real*, etc.). The semantics of Function specialization and dynamic dispatch based on parameter types will be addressed in the revised submission.

Control Function Invocation Semantics

Some Functions in the *ControlFunctions* library model have owned Expressions. InvocationExpressions apply to these Functions as usual, but they also include owned Expressions that redefine each of the owned Expressions of the Function being invoked. This is reflected in special rules in the synthesis of abstract syntax from concrete syntax for such invocations (see [7.4.8.2](#)).

The ternary condition test operator ? has one parameter and two owned Expressions. Therefore, a conditional test Expression (see [7.4.8.2.1](#)) of the form

expr_1 ? *expr_2* : *expr_3*

is semantically equivalent to the result of

```
expr : ControlFunctions::'?' (test) result {
  composite expr e_1 ( ) result {
    ...
  }
  composite expr e_2 redefines thenValue ( ) result {
    ...
  }
  composite expr e_3 redefines elseValue ( ) result {
    ...
  }
  bind test = e_1::result;
}
```

The binary conditional logical operators && and || have one parameter and one owned Expression. Therefore, a conditional logical Expression (see [7.4.8.2.1](#)) of the form

expr_1 && *expr_2*

is semantically equivalent to the result of

```
expr : ControlFunctions::'&&' (firstValue) result {
  composite expr e_1 ( ) result {
    ...
  }
  composite expr e_2 redefines secondValue ( ) result {
    ...
  }
  bind firstValue = e_1::result;
}
```

Finally, the sequence operations collect, select, reject, reduce, forAll and exists have one parameter and one owned Expression. Therefore, a sequence operation expression (see [7.4.8.2.2](#)) such as

expr_1 -> select x (*expr_2*)

is semantically equivalent to

```
expr : ControlFunctions::select (collection) result {
  composite expr e_1 ( ) result {
    ...
  }
  composite expr redefines selector (x) result {
    expr_2
  }
  bind collection = e_1::result;
}
```

Feature Reference Expression Semantics

A FeatureReferenceExpression for a Feature *f* is semantically equivalent the Expression

```
expr () result {
  binding result = f;
}
```

where the types of the `result` parameter are considered to be implicitly the same as those of `f`.

Literal Expression Semantics

With the exception of `LiteralUnbounded`, each kind of `LiteralExpression` has a `value` meta-property of a different primitive Type, which determines the `result` of the Expression. `LiteralUnbounded` does not have a `value` property, because its `result` is always the "unbounded" value `*` from the standard DataType *UnlimitedNatural*.

Submission Note. The semantics of literals will be more formally addressed in the revised submission.

Null Expression Semantics

Invocations of `NullExpressions` do not produce any `result` values (see rules above and [7.4.8.1](#)).

Model-Level Evaluable Expression Semantics

As defined in [7.4.7.2.2](#), a model-level evaluable Expression is an Expression that can be evaluated using metadata available within a model itself. This means that the evaluation rules for such an expression can be defined entirely within the abstract syntax. If an Expression is model-level evaluable, then using `evaluate` operation on it gives the model-level evaluation of the Expression as an ordered list of Elements.

A model-level evaluable Expression is evaluated on a given *target* object (see [7.4.12.4](#) and [7.4.13.4](#) for the targets used in the case of `metadataValues` and `filterConditions`, respectively), according to the following rules.

1. A `NullExpression` evaluates to the empty list.
2. A `LiteralExpression` evaluates to itself.
3. An `FeatureReferenceExpression` evaluates to one of the following.
 - If the target Element has an `AnnotatingFeature` (see [7.4.12](#)) with a `metadataFeature` that redefines the `referent`, then the `FeatureReferenceExpression` evaluates to the result of evaluating the corresponding `metadataValue` expression on the same target Element.
 - Otherwise, if the `referent` is a Feature with no `FeaturingTypes` or with *Anything* as a `FeaturingType`, then the `FeatureReferenceExpression` evaluates to the `referent`.
 - Otherwise, the `FeatureReferenceExpression` evaluates to the empty list.
4. An `InvocationExpression` evaluates to an application of its `function` to argument values corresponding by the results of evaluating each of the `argument` Expressions of the `InvocationExpression`, with the correspondence as given below.

Every Element in the list resulting from a model-level evaluation of an Expression according to the above rules will be either a `LiteralExpression` or a Feature of *Anything*. If each of these Elements is further evaluated according to its regular instance-level semantics, then the resulting list of instances will correspond to the result that would be obtained by evaluating the original Expression using its regular semantics on the referenced metadata of the target Element.

Release Note. It is expected that, in a future release, the semantics of model-level evaluation will be more formally defined as Expression evaluation on a reflective KerML abstract syntax model of the KerML.

7.4.9 Interactions

7.4.9.1 Interactions Overview

Interactions

Interactions are Behaviors that are also Associations (see [7.4.6](#) and [7.4.4](#), respectively), whose instances are *Performances* and also *Links* between *Occurrences* (see [8.6](#), [8.4](#), and [8.5](#)). They are used to specify how participants affect each other and collaborate.

Transfers are a kind of Interaction between two participants, as defined in the Kernel Model Library (see [8.7](#)). They specify when things (*items*) are provided by one *Occurrence* (via one of its Feature) and accepted by another (also via a Feature).

Item Flows

ItemFlows are Steps that are also binary Connectors (see [7.4.6](#) and [7.4.5](#), respectively) typed only by *Transfer* (see [8.7](#)), or a specialization of it. An ItemFlow specifies a transfer of *items* between the *Occurrences* identified by its first connectorEnd (*transferSource*) and its second (*transferTarget*) .

SuccessionItemFlows are ItemFlows that are also Successions (see [7.4.5](#)), requiring time ordering between their *transferSource*, the transfer *Occurrence*, and their *transferTarget*. That is, the transfer happens in the time between the end of its source *Occurrence* and the start of its target *Occurrence*.

7.4.9.2 Concrete Syntax

7.4.9.2.1 Interactions

```
Interaction (m : Membership) : Interaction =  
  ( isAbstract ?= 'abstract' )? 'interaction'  
  BehaviorDeclaration(this, m)  TypeBody(m)
```

An Interaction is declared as a Behavior (see [7.4.6.2.1](#)), using the keyword **interaction**. If no *ownedSuperclassings* is explicitly given for the Interaction, then it is implicitly given default Superclassings to *both* the Behavior *Performance* from the *Performances* library model (see [8.6](#)) and the Association *BinaryLink* or the Class *Link* from the *Objects* library model (see [8.5](#)), depending on whether it is a binary Association or not.

As a kind of Behavior, if the Interaction has *ownedSuperclassings* whose superclasses are Behaviors, then the rules related to their parameters are the same as for any subclass Behavior (see [7.4.6.2.1](#)). As a kind of Association, the body of an Interaction must declare at least two *associationEnds*. If the Interaction has *ownedSuperclassings* whose superclasses are Associations, the rules related to their *associationEnds* are the same as for any subclass Association (see [7.4.4.2](#)).

```
interaction Authorization {  
  end feature client[*] : Computer;  
  end feature server[*] : Computer;  
  composite step login;  
  composite step authorize;  
  composite succession login then authorize;  
}
```

7.4.9.2.2 Item Flows

```
ItemFlow (m : Membership) : ItemFlow =
  ( isAbstract ?= 'abstract' )? 'stream'
  ItemFlowDeclaration(this, m) TypeBody(this)

SuccessionItemFlow (m : Membership) : SuccessionItemFlow =
  ( isAbstract ?= 'abstract' )? 'flow'
  ItemFlowDeclaration(this, m) TypeBody(this)

ItemFlowDeclaration (i : ItemFlow, m : Membership) :
  ( FeatureDeclaration(i, m)
    ( 'of' i.ownedRelationship += ItemFeatureMember
      | i.ownedRelationship += EmptyItemFeatureMember )
    'from'
    | ( isSufficient ?= 'all' )?
      i.ownedRelationship += EmptyItemFeatureMember
    )
    i.ownedRelationship += ItemFlowEndMember 'to'
    i.ownedRelationship += ItemFlowEndMember

ItemFlowFeatureMember : FeatureMembership =
  ( memberName = NAME ':' )? ownedMemberFeature = ItemFeature

ItemFeature : Feature =
  ownedTyping += OwnedFeatureTyping
  ( ownedRelationship += MultiplicityMember )?
  | ownedRelationship += MultiplicityMember
  ( ownedTyping += OwnedFeatureTyping )?

EmptyItemFeatureMember : FeatureMembership =
  ownedMemberFeature = EmptyItemFeature

EmptyItemFeature : Feature =
  {}

ItemFlowEndMember : FeatureMembership =
  ownedMemberFeature = ItemFlowEnd

ItemFlowEnd : Feature =
  ownedRelationship += ItemFlowFeatureMember

ItemFlowFeatureMember : FeatureMembership =
  ownedMemberFeature = ItemFlowFeature

ItemFlowFeature : Feature =
  ownedRelationship += Redefinition
```

An ItemFlow declaration is syntactically similar to a binary Connector declaration (see [7.4.5.2.1](#)), using the keyword **stream**, or **flow** for a SuccessionItemFlow. However, rather than specifying the `relatedFeatures` for the ItemFlow, the declaration gives the `sourceOutput` Feature for the Transfer after the keyword **from** and the

targetInput Feature for the Transfer after the keyword **to**. The relatedFeatures are then determined as the owning Features of the Features given in the ItemFlow declaration. It is these relatedFeatures that are constrained to have a common context with the ItemFlow (see [7.4.5.2.1](#)) on the common context rule for Connectors), not the Features actually given in the declaration.

```
class Vehicle {
  composite feature fuelTank {
    out feature fuelOut : Fuel;
  }
  composite feature engine {
    in feature fuelIn : Fuel;
  }
  // The ItemFlow actually connects the fuelTank to the engine.
  // The transfer moves Fuel from fuelOut to fuelIn.
  stream fuelFlow from fuelTank::fuelOut to engine::fuelIn;
}
```

An ItemFlow declaration can also include an explicit declaration of the type and/or multiplicity of the items that are flowing, after the keyword **of**. This asserts that any items transferred by the ItemFlow have the declared Type. In the absence of an item declaration, any values may flow across the ItemFlow, consistent with the types of the sourceOutput and targetInput Features.

```
stream of flowingFuel : Fuel from fuelTank::fuelOut to engine::fuelIn;
```

If no Feature declaration or item declaration details are included in an ItemFlow declaration, then the keyword **from** may also be omitted.

```
stream fuelTank::fuelOut to engine::fuelIn;
```

Note. ItemFlows are also commonly used to move data from the output parameters of one step to the input parameters of another step.

```
behavior TakePicture {
  composite step focus : Focus (out image : Image);
  composite step shoot : Shoot (in image : Image);
  // The use of a SuccessionItemFlow means that focus must complete before
  // the image is transferred, after which shoot can begin.
  flow focus::image to shoot::image;
}
```

If no ownedSubsetting or ownedRedefinition is explicitly given, then the ItemFlow is implicitly given a default Subsetting to the ItemFlow *transfers* from the *Transfers* model library (see [8.7](#)), or to the SuccessItemFlow *flows*, if a SuccessionItemFlow is being declared. If an Expression has ownedGeneralizations (including all FeatureTypings, Subsettings and Redefinitions) whose general Type is a Behavior or a Step, then the rules for the redefinition of the parameters of those Behaviors and Steps shall be the same as for the redefinition of the parameters of superclass Behaviors by a subclass Step (see [7.4.6.2.2](#)).

7.4.9.3 Abstract Syntax

7.4.9.3.1 Overview

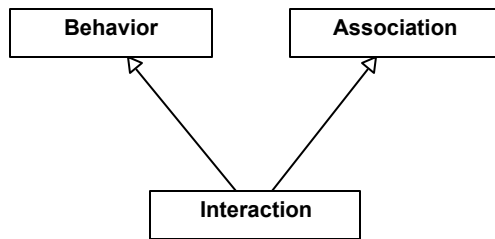


Figure 29. Interactions

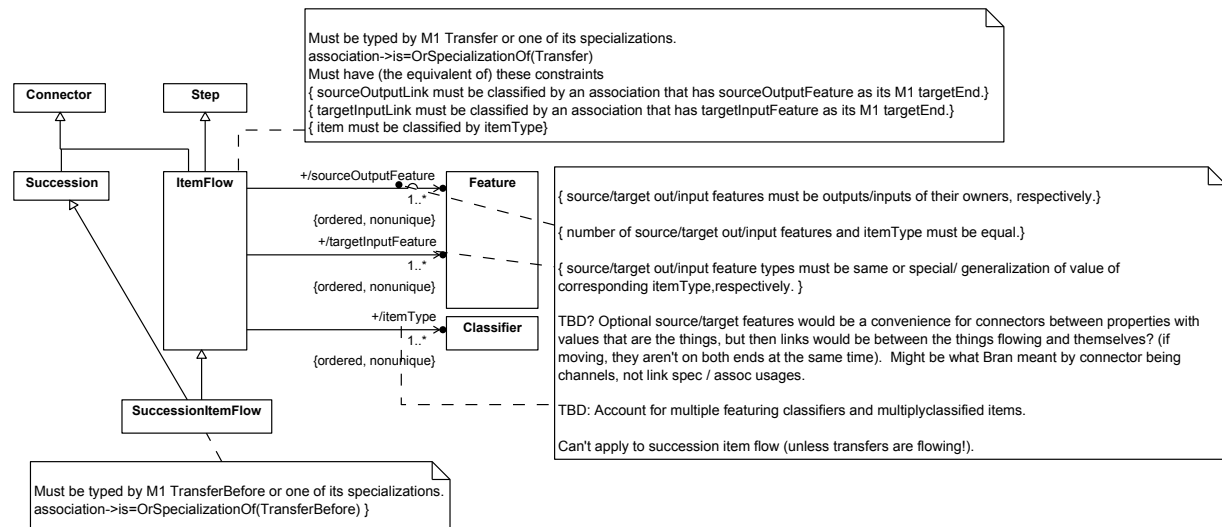


Figure 30. Item Flows

7.4.9.3.2 ItemFlow

Description

An ItemFlow is a Step that represents the transfer of objects or values from one Feature to another. ItemFlows can take non-zero time to complete.

General Classes

Connector
Step

Attributes

/itemFeature : ItemFeature [1..*] {subsets ownedFeature}

The Feature representing the Item in transit between the source and the target during the transfer. (IMPL)

/itemFlowEnd : ItemFlowEnd [2..*] {redefines connectorEnd}

A connectorEnd of this ItemFlow. (IMPL)

/itemFlowFeature : ItemFlowFeature [2..*]

The `sourceOutputFeatures` and `targetInputFeatures` of this `ItemFlow`. (IMPL).

`/itemType : Classifier [1..*] {ordered, nonunique}`

The Type of the item transferred.

`/sourceOutputFeature : Feature [1..*] {ordered, nonunique}`

The Feature that originates the `ItemFlow`.

`/targetInputFeature : Feature [1..*] {ordered, nonunique}`

The Feature that receives the `ItemFlow`.

Operations

No operations.

Constraints

No constraints.

7.4.9.3.3 Interaction

Description

An Interaction is a Behavior that is also an Association, providing a context for multiple objects that have behaviors that impact one another.

General Classes

Behavior
Association

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.4.9.3.4 SuccessionItemFlow

Description

A `SuccessionItemFlow` is an `ItemFlow` that also provides temporal ordering. It classifies *Transfers* that cannot start until the source *Occurrence* has completed and that must complete before the target *Occurrence* can start.

General Classes

Succession
ItemFlow

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.4.9.4 Semantics

Required Generalizations to Model Library

1. Interactions directly or indirectly specialize *Link::Link* (see [8.3.2.3](#)), or *Links::BinaryLink* (see [8.3.2.1](#)) for Interactions with exactly two participants.
2. Interactions shall directly or indirectly specialize *Performances::Performance* (see [8.6.2.10](#)).
3. ItemFlows shall directly or indirectly specialize *Transfers::transfers* (see [8.7.2.2](#)), which means they shall be directly or indirectly typed by *Transfers::Transfer* (see [8.7.2.1](#)).
4. The *connectorEnds* of ItemFlows shall
 - a. Redefine *transferSource* and *transferTarget* of *Transfers::Transfer* (see [8.7.2.1](#)).
 - b. Nest Features that redefine *transferSource::sourceOutput* and *transferTarget::targetInput*, respectively.
 - c. Subset the Features given in the ItemFlow.
5. ItemFlows that specify the kind of item flowing shall add an *ownedFeature* that directly or indirectly redefines *Transfer::item*.
6. SuccessionItemFlows directly or indirectly specialize *Transfers::flows* (see [8.7.2.4](#)), which means they shall be directly or indirectly typed by *Transfers::TransferBefore* (see [8.7.2.3](#)).

Interaction Semantics

An Interaction of the form

```
interaction I (in x, out y, inout z) {  
    end feature e1;  
    end feature e2;  
}
```

is semantically equivalent to the Core model

```
classifier I specializes Link::BinaryLink, Performances::Performance {  
    end feature e1 redefines Link::BinaryLink::source {  
        feature e2 = I::e2(e1);  
    }  
    end feature e2 redefines Link::BinaryLink::target {  
        feature e1 = I::e2(e2);  
    }  
    in feature x;  
    out feature y;
```

```

    inout feature z;
}

```

Item Flow Semantics

An ItemFlow of the form

```

stream of item : T from f1::f1_out to f2::f2_in;

```

is semantically equivalent to the core model

```

feature subsets Transfer::transfers {
  end feature redefines transferSource subsets f1 {
    feature redefines sourceOutput subsets f1::f1_out;
  }
  end feature redefines transferTarget subsets f2 {
    feature redefines targetInput subsets f2::f2_in;
  }
}

```

7.4.10 Feature Values

7.4.10.1 Feature Values Overview

FeatureValues are FeatureMemberships that require a Feature to identify (have values that are) the result of evaluating a nested Expression (value). Features that have a FeatureValue (at most one) shall also have a nested BindingConnector (valueConnector) between the Feature and result of the value Expression.

7.4.10.2 Concrete Syntax

```

ValuePart (f : Feature) =
    '=' f.ownedRelationship += FeatureValue

FeatureValue : FeatureValue =
    value = OwnedExpression

```

A Feature value is declared using the symbol = followed by a representation of the value Expression using the concrete syntax from [7.4.8.2](#). This notation is appended to the declaration of the Feature that is the featureWithValue for the FeatureValue. A FeatureValue can be included with the following kinds of Feature declaration:

- Feature (see [7.3.4.2.1](#))
- Step (see [7.4.6.2.2](#))
- Expression (see [7.4.7.2.2](#))
- BooleanExpression and Invariant (see [7.4.7.2.4](#))

```

feature monthsInYear : Natural = 12;
class TestRecord {
  feature scores[1..*] : Integer;
  derived feature averageScore[1] : Integer = sum(scores)/size(scores);
}

```

Note. Despite the similarity of the notation to use in some previous modeling languages, a `FeatureValue` in KerML is *not* a "default value" or an "initial value". Instead, the semantics of binding mean that a `FeatureValue` asserts that a `Feature` is *equivalent* to the result of the value `Expression` (see [7.4.5.4](#) on the semantics of `BindingConnectors`). To highlight this, a feature of a `Type` with a `FeatureValue` can be flagged as **derived** (though this is not required, nor is it required that the value of a **derived** `Feature` be computed using a `FeatureValue`).

Submission Note. Allowing the specification of default and initial values is planned to be addressed in the revised submission.

A `FeatureValue` can also be used in the declaration of a parameter of in a `Step` or `Expression` declaration (see [7.4.6.2.2](#) and [7.4.7.2.2](#)).

```
behavior ProvidePower(in cmd : Command, out wheelTorque : Torque) {
  composite step generate : GenerateTorque(
    in cmd = ProvidePower::cmd,
    out generatedTorque);
  composite step apply : ApplyTorque(
    in generatedTorque = generate::generatedTorque,
    out appliedTorque = ProvidePower::wheelTorque);
}
```

7.4.10.3 Abstract Syntax

7.4.10.3.1 Overview

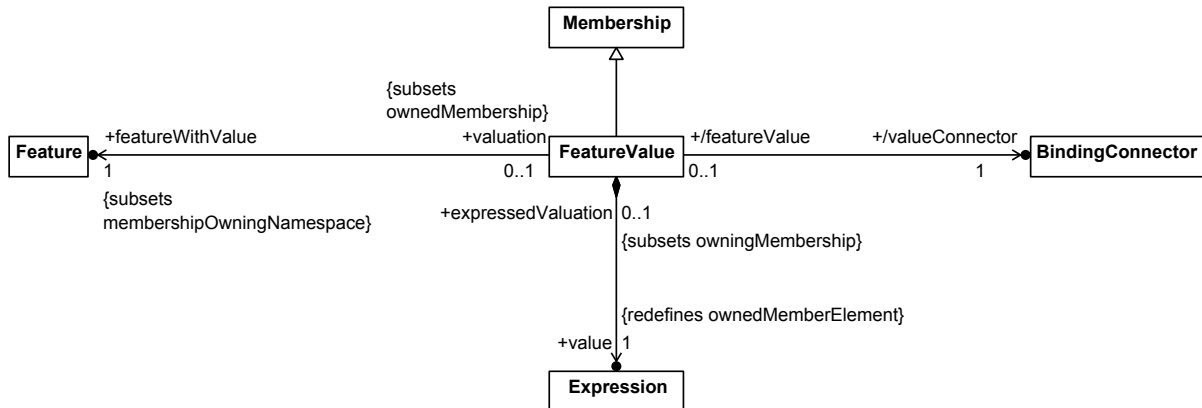


Figure 31. Feature Values

7.4.10.3.2 FeatureValue

Description

A `FeatureValue` is a `Membership` that identifies a particular member `Expression` that provides the value of the `Feature` that owns the `FeatureValue`. A `FeatureValue` requires that there be a `BindingConnector` between the `Feature` and the `result` of the `Expression`, enforcing the intended semantics. A `Feature` can have at most one `FeatureValue`.

General Classes

`Membership`

Attributes

`featureWithValue : Feature {subsets membershipOwningNamespace}`

The Feature to be provided a value.

`value : Expression {redefines ownedMemberElement}`

The Expression that provides the value of the `FeatureWithValue` as its result.

`/valueConnector : BindingConnector`

The `BindingConnector` that binds the result of the `value` Expression to the `FeatureWithValue`.

Operations

No operations.

Constraints

`featureValueBindingConnector`

The `valueConnector` must be an ownedMember of the `featureWithValue` whose `relatedElements` are the `featureWithValue` and the result of the `value` Expression and whose `featuringTypes` are the same as those of the `featureWithValue`.

```
valueConnector.owningNamespace = featureWithValue and
valueConnector.relatedFeature->includes(featureWithValue) and
valueConnector.relatedFeature->includes(value.result) and
valueConnector.featuringType = featureWithValue.featuringType
```

`featureValueExpressionDomain`

The `value` Expression must have the same `featuringTypes` as the `featureWithValue`.

```
value.featuringType = featureWithValue.featuringType
```

7.4.10.4 Semantics

A Feature of the form

```
feature f = expr;
```

is semantically equivalent to

```
feature f {
  expr e () result { ... }
  binding f = e::result;
}
```

where `e` is the interpretation of `expr` as described in [7.4.8.4](#).

7.4.11 Multiplicities

7.4.11.1 Multiplicities Overview

Core defines Multiplicity as a Feature for specifying cardinalities (number of instances) of a Type by enumerating all numbers the cardinality might be (see [7.3.2.3.7](#)). Kernel specializes this to MultiplicityRanges for specifying cardinalities by two natural numbers (a range). A MultiplicityRange has `lowerBound` and `upperBound` Expressions that are evaluated to determine the lowest and highest cardinalities. The `lowerBound` Expression result shall be typed by *Natural*, while the `upperBound` Expression shall result result shall be typed by *UnlimitedNatural* (both from the *ScalarValues* library model, see [8.11](#)). An `upperBound` value of `*` means that the cardinality includes all numbers greater than or equal to the `lowerBound` value (unbounded).

Submission Note. More kinds of Multiplicities (such as multiple ranges like `[2..4, 6..8]`) will be considered for the revised submission.

7.4.11.2 Concrete Syntax

```
Multiplicity : MultiplicityRange =  
  '[' ( ownedRelationship += MultiplicityExpressionMember '..' )?  
    ownedRelationship += MultiplicityExpressionMember ']'  
  
MultiplicityExpressionMember : Membership =  
  ownedMemberElement = Expression
```

A MultiplicityRange is written in the form `[lowerBound.. upperBound]`, where `lowerBound` and `upperBound` are Expressions represented in the notation described in [7.4.8](#). LiteralExpressions can be used to in a MultiplicityRange with fixed lower and/or upper bounds. If only a single Expression is given, then the result of the Expression is used as both the lower and upper bound of the range, unless the result is the *UnlimitedNatural* unbounded value `*`, in which the lower bound is taken to be 0.

```
class Automobile {  
  composite feature wheels : Wheel[4]; // Equivalent to [4..4]  
  feature driveWheels[2..4] subsets wheels;  
}  
feature autoCollection : Automobile[*]; // Equivalent to [0..*]
```

7.4.11.3 Abstract Syntax

7.4.11.3.1 Overview

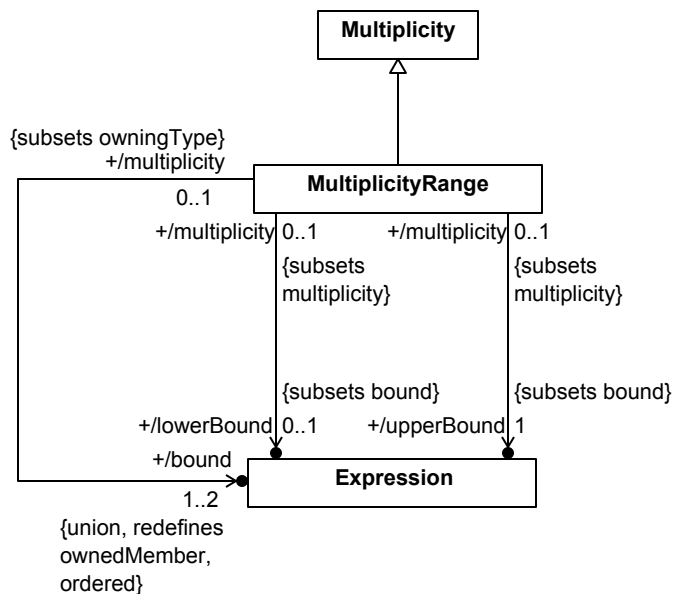


Figure 32. Multiplicities

7.4.11.3.2 MultiplicityRange

Description

A `MultiplicityRange` is a `Multiplicity` whose value is defined to be the (inclusive) range of natural numbers given by the result of a `lowerBound` Expression and the result of an `upperBound` Expression. The result of the `lowerBound` Expression shall be of type *Natural*, while the result of the `upperBound` Expression shall be of type *UnlimitedNatural*. If the result of the `upperBound` Expression is the unbounded value `*`, then the specified range includes all natural numbers greater than or equal to the `lowerBound` value.

General Classes

`Multiplicity`

Attributes

`/bound` : Expression [1..2] {redefines ownedMember, ordered, union}

The bound Expressions of the `MultiplicityRange`. These shall be the only `ownedMembers` of the `MultiplicityRange`.

`/lowerBound` : Expression [0..1] {subsets bound}

The Expression whose result provides the lower bound of `MultiplicityRange`. If no `lowerBound` Expression is given, then the lower bound shall have the same value as the upper bound, unless the upper bound is unbounded (`*`), in which case the lower bound shall be 0.

`/upperBound` : Expression {subsets bound}

The Expression whose result is the upper bound of the `MultiplicityRange`.

Operations

No operations.

Constraints

`multiplicityRangeExpressionDomain`

The bounds of a `MultiplicityRange` shall have the same `featuringTypes` as the `MultiplicityRange`.

```
bound->forAll(b | b.featuringType = self.featuringType)
```

7.4.11.4 Semantics

Required Generalizations to Model Library

1. `MultiplicityRanges` shall directly subset `Base::naturals` (see [8.2](#)), which means they shall be directly or indirectly typed by `ScalarValues::Natural`.

Multiplicity Range Semantics

A `MultiplicityRange` of the form

```
[expr_1.. expr_2]
```

represents a range of data values of the DataType *Natural* (see [8.11.2.4](#)) that are greater than or equal to the result of the Expression *expr_1* and less than or equal to the result of the Expression *expr_2*. Essentially, this is

```
all Natural -> select n (expr_1 <= n & n <= expr_2)
```

where, if *expr_2* evaluates to the unbounded value `*`, all *Natural* data values are less than it.

A `MultiplicityRange` having only a single expression:

```
[expr]
```

is interpreted in one of the following ways:

- If *expr* evaluates to `*`, then the values of the `MultiplicityRange` are the entire extent of *Natural*.
- Otherwise, the values of the `MultiplicityRange` are all *Natural* data values less than or equal to the result of *expr*.

```
all Natural -> select n (n <= expr)
```

Note. A conforming tool is not expected to compute the entire set of *Natural* numbers that are values of a `MultiplicityRange`. It is sufficient to check that the values of a Type have a cardinality that is within the range specified by `MultiplicityRange`.

7.4.12 Metadata

7.4.12.1 Metadata Overview

Metadata is additional information on Elements of a model that does not have any instance-level semantics (in the sense described in [7.3.1.1](#)). In general, metadata is specified in `AnnotatingElements` (including `Comments` and `TextualRepresentations`) attached to `annotatedElements` using `Annotation Relationships` (see [7.2.3](#)). An `AnnotatingFeature` is a kind of `AnnotatingElement` that allows for the definition of structured metadata with

modeler-specified attributes. This may be used, for example, to add tool-specific information to a model that can be relevant to the function various kinds of tooling that may use or process a model, or domain-specific information relevant to a certain project or organization.

An `AnnotatingFeature` is syntactically a `Feature` (see [7.3.4](#)) that is typed by a single `DataType` (see [7.4.2](#)), with implicit multiplicity `1..1`. If the `DataType` has no features, then the `AnnotatingFeature` simply acts as a user-defined syntactic tag on the `annotatedElement`. If the `DataType` has features, then the `AnnotatingFeature` must have nested features that redefine each of the features of its type, binding them to the results of model-level evaluable Expressions (see [7.4.8](#)), which provide the values of the specified attributive metadata for the `annotatedElement`.

7.4.12.2 Concrete Syntax

```
AnnotatingFeature (m : Membership, e : Element) : AnnotatingFeature =
  ( '@' | 'metadata' ) AnnotatingFeatureDeclaration(this, m)
  ( 'about' annotation += Annotation
    ownedRelationship += Annotation
    ( ',' annotation += Annotation
      { ownedRelationship += Annotation } ) *
  | annotation += ElementAnnotation(e)
    { ownedRelationship += Annotation }
  )

AnnotatingFeatureDeclaration (a : AnnotatingFeature, m : Membership) =
  ( Identification(this, m) ( ':' | 'typed' 'by' ) )?
  a.ownedRelationship += ownedFeatureTyping

AnnotatingFeatureBody (a : AnnotatingFeature) =
  ';' | '{' ( a.ownedRelationship += MetadataFeatureMember ) * '}'

MetadataFeatureMember : FeatureMembership =
  ownedMemberFeature = MetadataFeature

MetadataFeature : MetadataFeature =
  'feature'? ( ';>' | 'redefines'? ownedRelationship += OwnedRedefinition
  '=' metadataFeatureValue = MetadataFeatureValue ';'

MetadataFeatureValue : MetadataFeatureValue =
  metadataValue = OwnedExpression
```

An `AnnotatingFeature` is declared using the keyword **metadata** (or the symbol `@`), optionally followed by a `nameId` and/or `name`, followed by the keyword **typed by** (or the symbol `:`) and the qualified name of exactly one `DataType` (see [7.4.2](#)). If no `nameId` or `name` is given, then the keyword **typed by** (or the symbol `:`) may also be omitted. One or more `annotatedElements` are then identified for the `AnnotatingFeature` after the keyword **about**, indicating that the `AnnotatingFeature` has `Annotation Relationships` to each of the identified `Elements`.

```
datatype SecurityRelated;
```

```
metadata securityDesignAnnotation : SecurityRelated about SecurityDesign;
```

If the specified `DataType` has `features`, then a body must be given for the `AnnotatingFeature` that declares `MetadataFeatures` that redefine each of the features of the `DataType` and binds them to the result of `MetadataExpressions` (see [7.4.7.3.3](#)). The `MetadataFeatures` of an `AnnotatingFeature` must always have the same names as the names of the typing `DataType`, so the shorthand prefix redefines notation (see [7.3.4.2.5](#)) is always used.

```
datatype ApprovalAnnotation {
    feature approved : Boolean;
    feature approver : String;
}

metadata ApprovalAnnotation about Design {
    feature redefines approved = true;
    feature redefines approver = "John Smith";
}
```

The keyword **feature** and/or **redefines** (or the equivalent symbol `:>>`) may be omitted in the declaration of a `MetadataFeature`.

```
metadata ApprovalAnnotation about Design {
    approved = true;
    approver = "John Smith";
}
```

If the `AnnotatingFeature` is an `ownedMember` of a `Namespace` (see [7.2.4](#)), then the explicit identification of `annotatedElements` can be omitted, in which case the `annotatedElement` shall be implicitly the containing `Namespace`.

```
class Design {
    // This AnnotatingFeature is implicitly about the class Design.
    @ApprovalAnnotation {
        approved = true;
        approver = "John Smith";
    }
}
```

7.4.12.3 Abstract Syntax

7.4.12.3.1 Overview

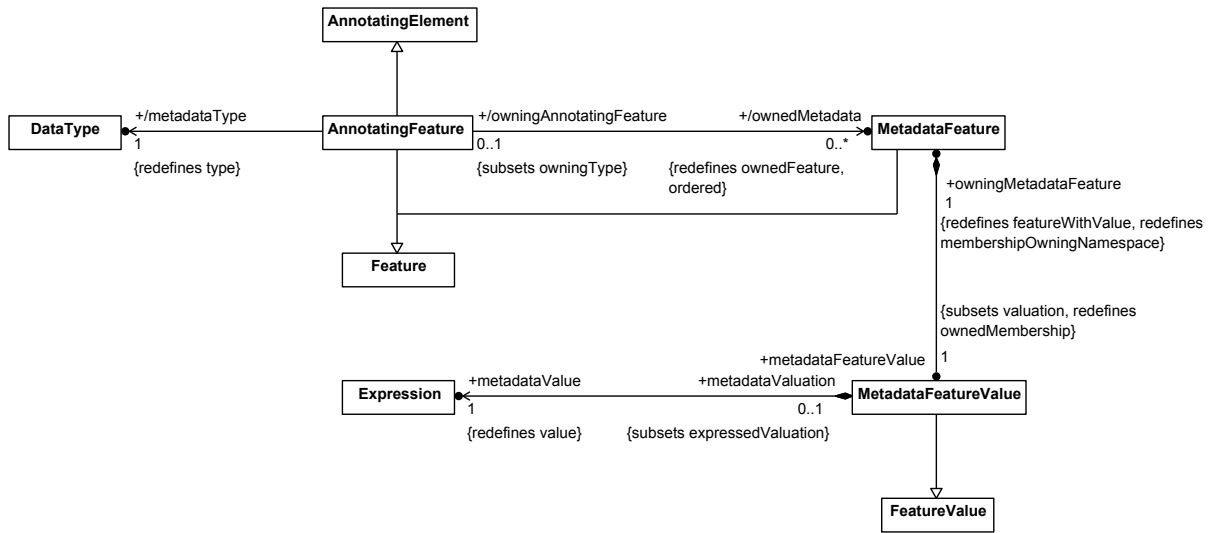


Figure 33. Metadata Annotation

7.4.12.3.2 AnnotatingFeature

Description

An **AnnotatingFeature** is a **Feature** that is used to annotate another **Element** with metadata. The **AnnotatingFeature** is typed by a **DataType** and binds metadata values to all the `features` of that **DataType**.

General Classes

AnnotatingElement
Feature

Attributes

`/metadataType` : **DataType** {redefines type}

The `type` of this **AnnotatingFeature**, which must be a **DataType**.

`/ownedMetadata` : **MetadataFeature** [0..*] {redefines ownedFeature, ordered}

The `ownedFeatures` of this **AnnotatingFeature**, each of which must redefine a `feature` of the `metadataType`.

Operations

No operations.

Constraints

No constraints.

7.4.12.3.3 MetadataFeature

Description

General Classes

Abstract Syntax Description

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.4.12.3.4 MetadataFeatureValue

Description

General Classes

Abstract Syntax Description

Attributes

No attributes.

Operations

No operations.

Constraints

No constraints.

7.4.12.4 Semantics

As noted in [7.4.12.1](#), while `AnnotatingFeatures` are `Features`, they are defined only within a model and do not strictly have instance-level semantics in the sense specified in the Core (see [7.3.4](#)). However, at a meta-level, an `AnnotatingFeature` can be treated as if the metaclasses of its `annotatedElements` where its `featuringTypes`. In this case, the `AnnotatingFeature` defines a map from its `annotatedElements`, as instances of their metaclasses, to a single instance of its `metadataType`.

Further, a model-level evaluable `Expression` is simply an `Expression` that can be evaluated using metadata available within a model itself (see [7.4.7.2.2](#)). If a model-level evaluable `Expression` is evaluated on such metadata according to the regular semantics of `Expressions`, then the result will be the same as the static evaluation of the `Expression` within the model. Therefore, if an `AnnotatingFeature` is instantiated as above, the binding of its features to the results of evaluating the model-level evaluable `Expressions` given as `metadataValues` can be interpreted according to the regular semantics of `FeatureValues` (see [7.4.10](#)) and `BindingConnectors` (see [7.4.5](#)).

When a `metadataValue` Expression is model-level evaluated (as described in [7.4.8.4](#)), its target is the `AnnotatingFeature` that owns the associated `metadataFeature`. This means that the `metadataValue` Expression for one `metadataFeature` may reference other `metadataFeatures` of the `AnnotatingFeature`, as well as `Features` with no `featuringTypes` or *Anything* as a `featuringType`.

7.4.13 Packages

7.4.13.1 Packages Overview

A `Package` is a `Namespace` used to group `Elements`, without any instance-level semantics (as opposed to `Types`, which are `Namespaces` with classification semantics—see [7.3.2](#)). It may also have one or more `filterConditions` used to filter its `importedMemberships`. A `filterCondition` is a Boolean-valued, model-level evaluable Expression (see [7.4.8](#)) related to the `Package` by an `ElementFilterMembership`. Each `filterCondition` of a `Package` shall result in true when model-level evaluated (see [7.4.8.4](#)) for any imported member of the `Package` as described in [7.4.13.4](#).

7.4.13.2 Concrete Syntax

```
Package (m : Membership) : Package =
    PackageDeclaration(this, m) PackageBody(m)

PackageDeclaration (p : Package, m : Membership) =
    'package' Identification(p, m)

PackageBody (m: Membership) : Package =
    ';'
    | '{' ( NamespaceBodyElement(m)
          | ownedRelationship += ElementFilterMember ) *
    '}'

ElementFilterMember : ElementFilterMembership =
    ( ownedRelationship += PrefixDocumentation ) *
    ( visibility = BasicVisibilityIndicator ) ?
    'filter' condition = OwnedExpression ';'

```

A `Package` is notated like a generic `Namespace`, but using the keyword **package** instead of **namespace**.

```
package AddressBooks {
    datatype Entry {
        feature name: String;
        feature address: String;
    }
    struct AddressBook {
        composite feature entries[*]: Entry;
    }
}
```

In addition, a `Package` body may contain one or more members that give `filterConditions` for the `Package`. These are notated using the keyword **filter** followed by a Boolean-valued, model-level evaluable Expression.

```

package Annotations {
  datatype ApprovalAnnotation {
    feature approved : Boolean;
    feature approver : String;
    feature level : Natural;
  }
  ...
}

package DesignModel {
  import Annotations::*;
  struct System {
    @ApprovalAnnotation {
      approved = true;
      approver = "John Smith";
      level = 2;
    }
  }
  ...
}

package UpperLevelApprovals {
  // This package imports all direct or indirect members
  // of the DesignModel package that have been approved
  // at a level greater than 1.
  import DesignModel::*;
  filter @Annotations::ApprovalAnnotation &&
    Annotations::ApprovalAnnotation::approved &&
    Annotations::ApprovalAnnotation::level > 1;
}

```

Note that a `filterCondition` in a `Package` will filter *all* imports of that `Package`. That is why full qualification is used for `Annotations::ApprovalAnnotation` above, since an imported elements of the *Annotations* `Package` would be filtered out by the very `filterCondition` in which the elements are intended to be used. This may be avoided by combining one or more `filterConditions` with a specific import, using the filtered Import notation defined in [7.2.4.2.2](#).

```

package UpperLevelApprovals {
  // Recursively import all annotation data types and all
  // features of those types.
  import Annotations::*;

  // The filter condition for this import applies only to
  // elements imported from the DesignModel package.
  import DesignModel::*[@ApprovalAnnotation && approved && level > 1];
}

```

7.4.13.3 Abstract Syntax

7.4.13.3.1 Overview

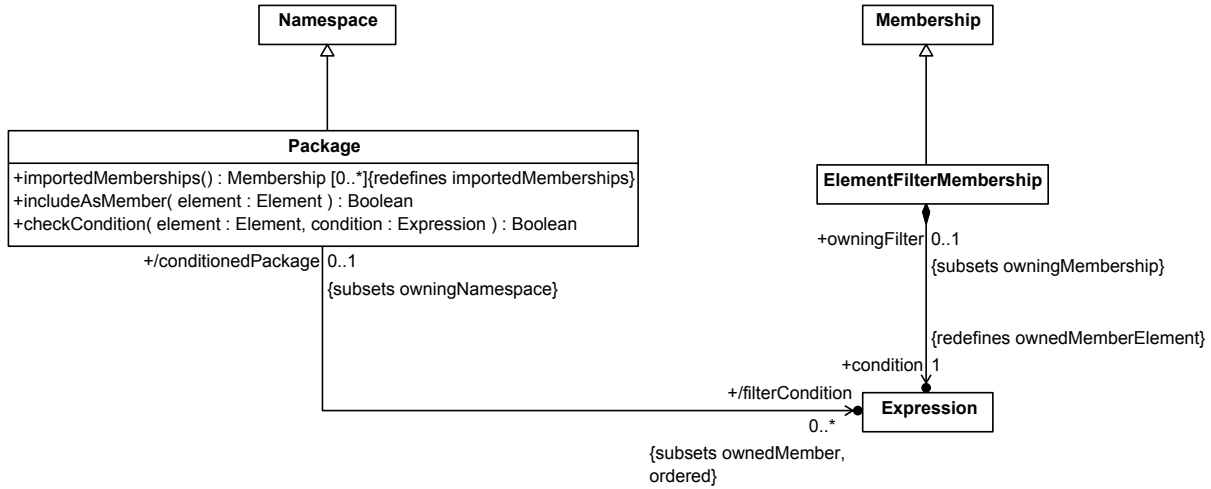


Figure 34. Packages

7.4.13.3.2 ElementFilterMembership

Description

ElementFilterMembership is a Membership between a Namespace and a model-level evaluable Boolean Expression, asserting that imported members of the Namespace should be filtered using the condition Expression. A general Namespace does not define any specific filtering behavior, but such behavior may be defined for various specialized kinds of Namespaces.

General Classes

Membership

Attributes

condition : Expression {redefines ownedMemberElement}

The model-level evaluable Boolean Expression used to filter the members of the membershipOwningNamespace of this ElementFilterMembership.

Operations

No operations.

Constraints

elementFilterIsBoolean

The result Feature of the condition Expression must have *ScalarValues::Boolean* as a type.

elementFilterIsModelLevelEvaluable

The condition Expression must be model-level evaluable.

`condition.isModelLevelEvaluable`

7.4.13.3 Package

Description

A Package is a Namespace used to group Elements, without any instance-level semantics. It may have one or more model-level evaluable `filterCondition` Expressions used to filter its `importedMemberships`. Any imported member must meet all of the `filterConditions`.

General Classes

Namespace

Attributes

`/filterCondition : Expression [0..*] {subsets ownedMember, ordered}`

The model-level evaluable Boolean Expressions used to filter the members of this Package, derived as those `ownedMembers` of the Package that are owned via `ElementFilterMembership`.

Operations

`checkCondition(element : Element, condition : Expression) : Boolean`

Model-level evaluate the given `condition` Expression with the given `element` as its target. If the result is a `LiteralBoolean`, return its value. Otherwise return *false*.

```
body: let results: Sequence(Element) = condition.evaluate(element) in
    result->size() = 1 and
    results->at(1).oclIsKindOf(LiteralBoolean) and
    results->at(1).oclAsType(LiteralBoolean).value
```

`importedMemberships() : Membership [0..*]`

Exclude Elements that do not meet all the `filterConditions`.

```
body: self.oclAsType(Namespace).importedMemberships()->
    select(m | self.includeAsMember(m.memberElement))
```

`includeAsMember(element : Element) : Boolean`

Determine whether the given `element` meets all the `filterConditions`.

```
body: let metadataAnnotations: Sequence(AnnotatingElement) =
    element.ownedAnnotation.annotatingElement->
        select(oclIsKindOf(AnnotatingFeature)) in
    self.filterCondition->forall(cond |
        metadataAnnotations->exists(elem |
            self.checkCondition(elem, cond)))
```

Constraints

No constraints.

7.4.13.4 Semantics

Packages do not have any instance-level semantics.

The `filterConditions` of a `Package` are model-level evaluable `Expressions` that are evaluated as described in [7.4.8.4](#). All `filterConditions` are checked against every `Membership` that would otherwise be imported into the `Package` if it had no `filterCondition`. A `Membership` shall be imported into the `Package` if and only if every `filterCondition` evaluates to true either with no target `Element`, or with any `AnnotatingFeature` of the `memberElement` of the `Membership` as the target `Element`.

Implementation Note. As of 2020-01, an `AnnotatingFeature` must be owned by the imported `Element` in order to be accessed when evaluating a `filterCondition`.

8 Model Library

8.1 Model Library Overview

The Kernel Model Library is a collection of KerML models that are part of the semantics of the metamodel (see [Clause 7](#)). They are reused when constructing KerML user models (instantiating the metamodel), as specified by constraints and semantics of metaelements, such as Types being required to specialize Anything from the library and Behaviors specializing Performances. The library can be specialized for particular applications, such as systems.

The major areas covered in the Model Library are:

1. The *Base* library model (see [8.2](#)) provides the base of the Generalization hierarchy for all KerML Types, including the most general Classifier *Anything* and the most general Feature *things*. It also contains the base DataType *DataValue* and its corresponding base Feature *dataValues*.
2. The *Occurrences* library model (see [8.4](#)) models *Occurrences* and the temporal Associations between them. The *Objects* library model (see [8.5](#)) then specializes *Occurrences* to provide a model of *Objects* and *Links*, giving semantics to Classes and Associations, respectively. And the *Performances* library model (see [8.6](#)) specializes *Occurrences* to provide a model of *Performances* and *Evaluations*, giving semantics to Behaviors and Expressions, respectively. Temporal associations can therefore be used to specify the order in which Performances are carried out during other Performances, or when Objects exist in relation to each other, or combinations involving Performances and Objects. The *Transfers* library model (see [8.7](#)) models the asynchronous of items between *Occurrences*, giving semantics to Item Flows.
3. The *Control Performances*, *State Performances* and *TransitionPerformances* library models (see [8.8](#), [8.9](#) and [8.10](#)) provide semantic models for the coordination of a number of *Performances* that, together, collaborate to carry out some overall combined *Performance*. KerML does not provide any special syntax corresponding to these library models (e.g., KerML does not have any "control node" or "state machine" syntax), though various Behaviors define in the library models can be used as the `types` of Steps in order to coordinate the *Performance* of an overall containing Behavior. It is expected that other languages built on KerML and using these library models can add syntax as needed by their applications.
4. The *ScalarValues* and *NonScalarValues* model libraries (see [8.11](#) and [8.12](#)) provide a set of primitive and collection DataTypes that can be used in KerML user models. Additional library models (see [8.13](#) through [8.26](#)) then provide Functions that can be used to operate both on the standard DataTypes and more generally. The KerML operator and sequence expression notations map to invocations of certain of these library Functions. It is expected that other languages built on KerML will provide additional domain models as needed by their applications, which may include specializations of the library Functions for domain-specific DataTypes. In this way, the same KerML concrete syntax for Expressions notation can continue to be used, extended with domain-specific semantics.

Note. Since KerML does not provide any normative graphical notation, the diagrams in this clause should be considered informative overviews of the library models they depict. The normative representation of all library models is using the textual concrete syntax, as provided in machine-readable files associated with this specification document.

Submission Note. The documentation provided in this clause is currently incomplete. Full documentation, as appropriate, will be provided in the revised submission.

8.2 Base

8.2.1 Base Overview

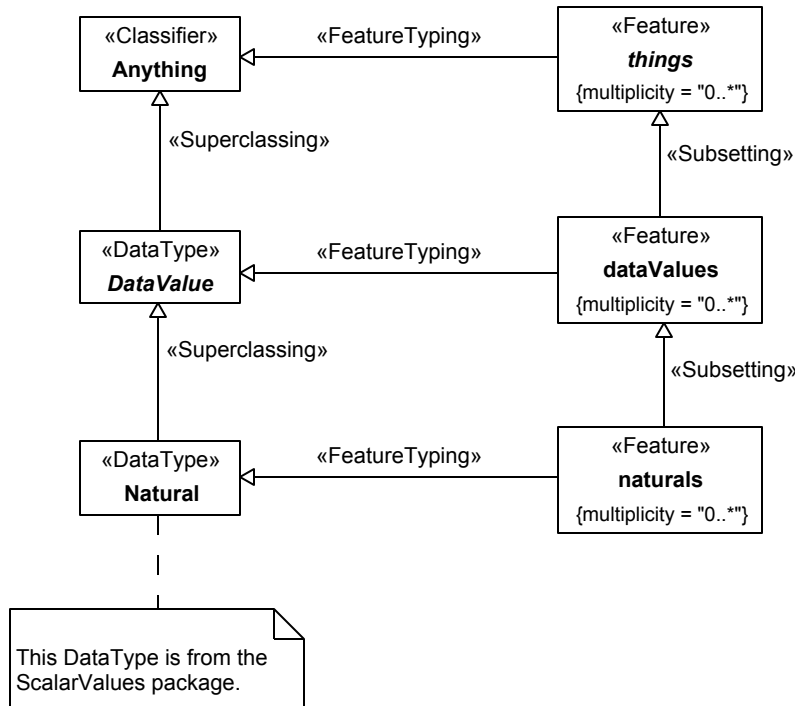


Figure 35. Base Types

8.2.2 Elements

8.2.2.1 Anything <Classifier>

Description

Anything is the most general Classifier (M1 instance of M2 Classifier). All other M1 elements (in libraries or user models) specialize it (directly or indirectly). Anything is the type for things, the most general Feature. Since FeatureTyping is a kind of Generalization, this means that Anything is also a generalization of things.

General Classes

No general classes.

Attributes

No attributes.

Constraints

No constraints.

8.2.2.2 DataValue <DataType>

Description

DataValue is Anything that can only be distinguished by how they are related to other things (via Features). It is the most general Datatype (M1 instance of M2 Datatype). All other M1 Datatypes (in libraries or user models) specialize it (directly or indirectly).

General Classes

Anything

Attributes

No attributes.

Constraints

No constraints.

8.2.2.3 dataValues <Feature>

Description

`dataValues` is a specialization of `things` restricted to type `DataValue`. All other Features typed by `DataValue` or its specializations (in libraries or user models) specialize it (directly or indirectly).

General Classes

`DataValue`
`things`

Attributes

No attributes.

Constraints

No constraints.

8.2.2.4 naturals <Feature>

Description

General Classes

`Natural`
`dataValues`

Attributes

No attributes.

Constraints

No constraints.

8.2.2.5 things <Feature>

Description

`things` is the most general Feature (M1 instance of M2 Feature). All other Features (in libraries or user models) specialize it (subset or redefine, directly or indirectly). It is typed by `Anything`.

General Classes

Anything

Attributes

No attributes.

Constraints

No constraints.

8.3 Links

8.3.1 Links Overview

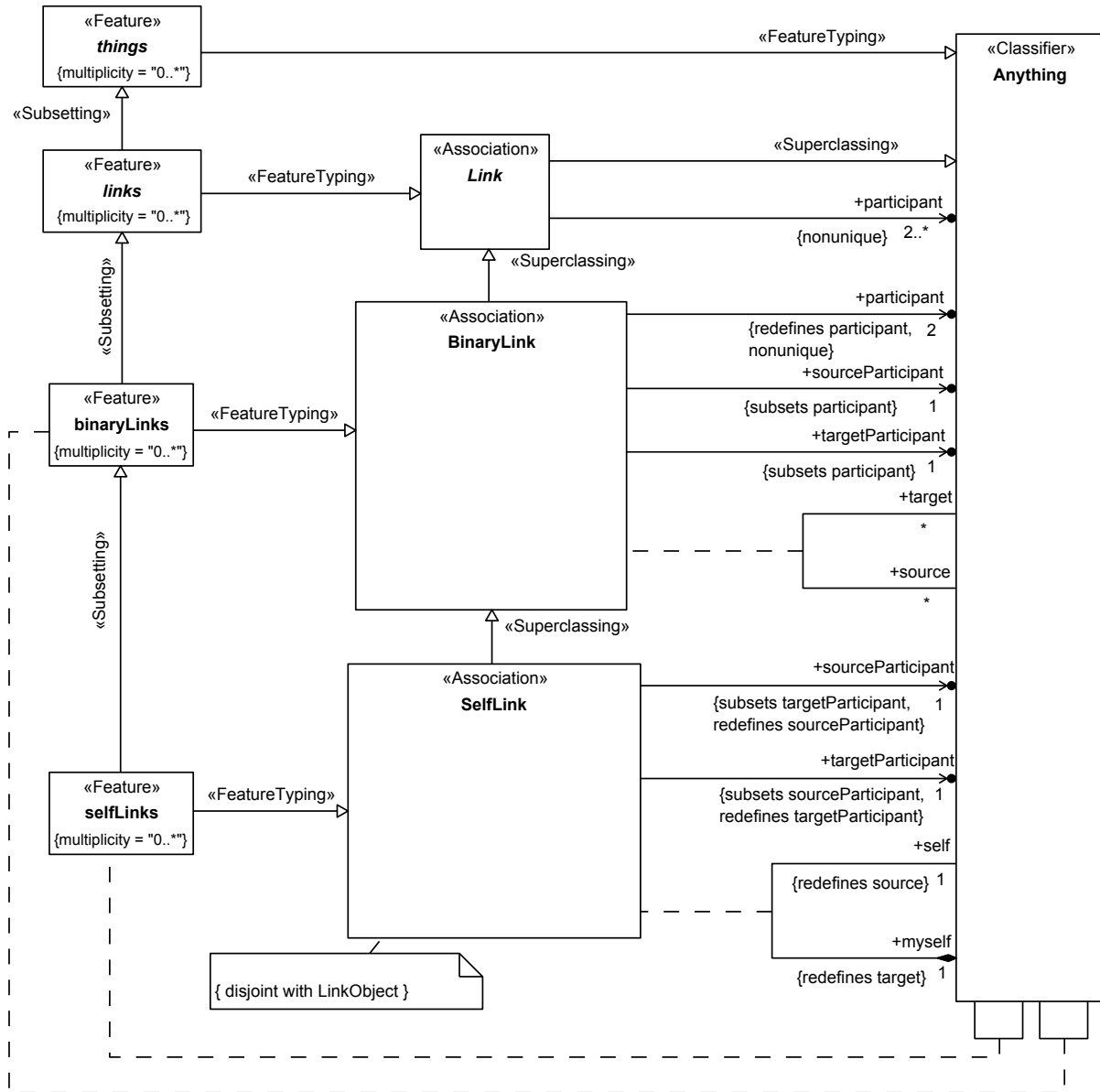


Figure 36. Links

8.3.2 Elements

8.3.2.1 BinaryLink <Association>

Description

BinaryLink is a Link with exactly two participant Features ("binary" Association). All other binary associations (in libraries or user models) specialize it (directly or indirectly).

General Classes

Link

Attributes

participant : Anything {redefines participant, nonunique}

The participants of this BinaryLink, which are restricted to be exactly two.

source : Anything [0..*]

The end Feature of this BinaryLink corresponding to the sourceParticipant.

sourceParticipant : Anything {subsets participant}

The participant that is the source of this BinaryLink.

target : Anything [0..*]

The end Feature of this BinaryLink corresponding to the targetParticipant.

targetParticipant : Anything {subsets participant}

The participant that is the target of this BinaryLink.

Constraints

No constraints.

8.3.2.2 binaryLinks <Feature>

Description

binaryLinks is a specialization of links restricted to type BinaryLink. All other Features typed by BinaryLink or its specializations (in libraries or user models) specialize it (directly or indirectly).

General Classes

links

BinaryLink

Attributes

[no name] : Anything

[no name] : Anything

Constraints

No constraints.

8.3.2.3 Link <Association>

Description

Link is the most general Association (M1 instance of M2 Association). All other Associations (in libraries or user models) specialize it (directly or indirectly). Specializations of Link are domains of Features subsetting

Link::participants, exactly as many as associationEnds of the Association classifying it, each with multiplicity 1. Values of Link::participants on specialized Links must be a value of at least one of its subsetting Features.

General Classes

Anything

Attributes

participant : Anything [2..*] {nonunique}

The participants that are associated by this Link.

Constraints

No constraints.

8.3.2.4 links <Feature>

Description

links is a specialization of things restricted to type Link. It is the most general feature typed by Link. All other Features typed by Link or its specializations (in libraries or user models) specialize it (directly or indirectly).

General Classes

Link
things

Attributes

No attributes.

Constraints

No constraints.

8.3.2.5 SelfLink <Association>

Description

SelfLink is a BinaryLink where the sourceParticipant and targetParticipant are the same. All other BinaryLinks where this is the case specialize it (directly or indirectly).

General Classes

BinaryLink

Attributes

myself : Anything {redefines target}

The inverse end to self, corresponding to the targetParticipant of the SelfLink.

self : Anything {redefines source}

The source end of the SelfLink, named to indicate that a SelfLink always relates a thing to itself.

sourceParticipant : Anything {subsets targetParticipant, redefines sourceParticipant}

The source participant of this SelfLink, which must be the same as the target participant.

targetParticipant : Anything {subsets sourceParticipant, redefines targetParticipant}

The target participant of this SelfLink, which must be the same as the source participant.

Constraints

No constraints.

8.3.2.6 selfLinks <Feature>

Description

selfLinks is a specialization of binaryLinks restricted to type SelfLink. It is the most general BindingConnector. All other BindingConnectors (in libraries or user models) specialize it (directly or indirectly).

General Classes

SelfLink
binaryLinks

Attributes

[no name] : Anything

[no name] : Anything

Constraints

No constraints.

8.4 Occurrences

8.4.1 Occurrences Overview

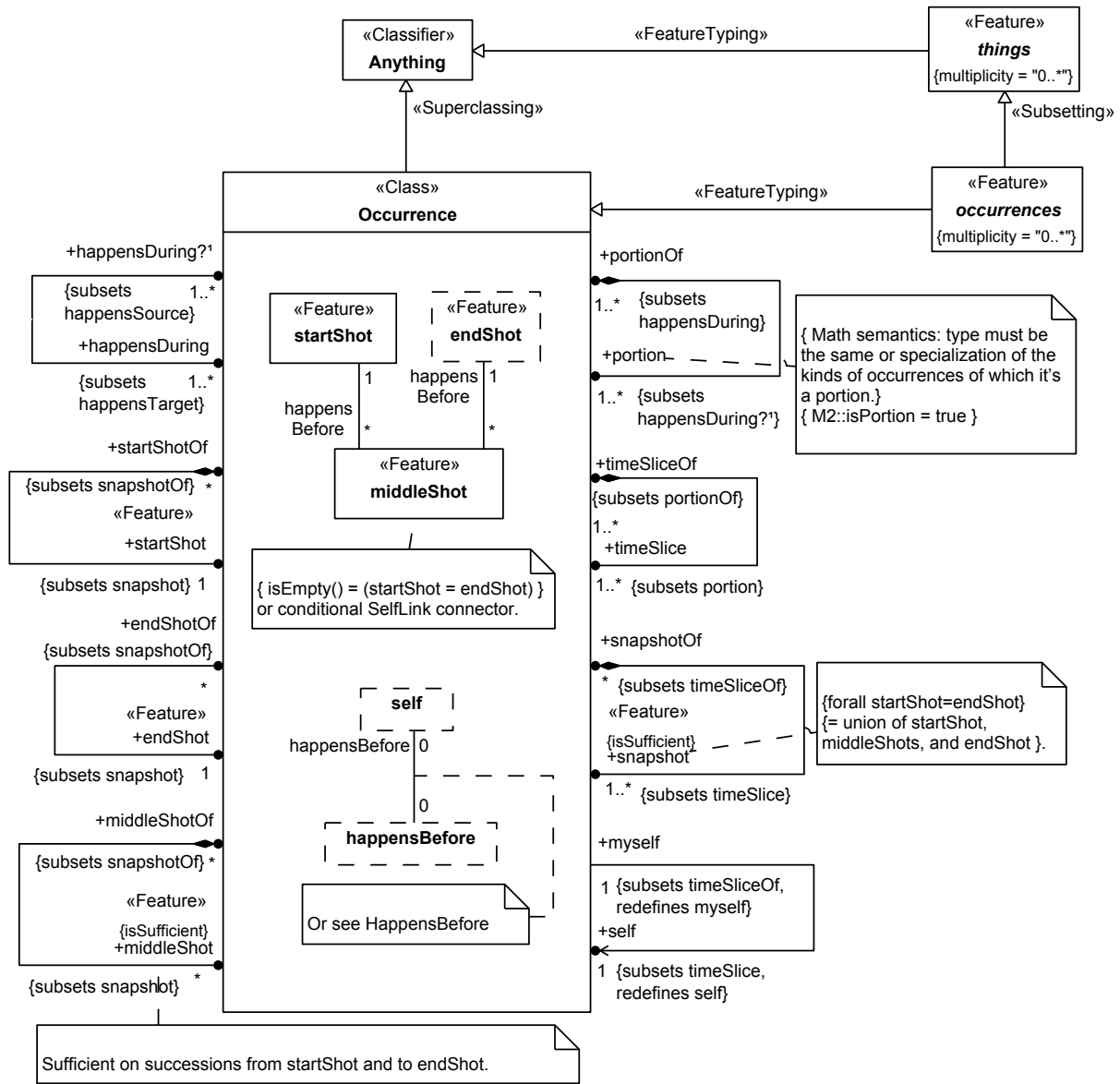


Figure 37. Occurrences

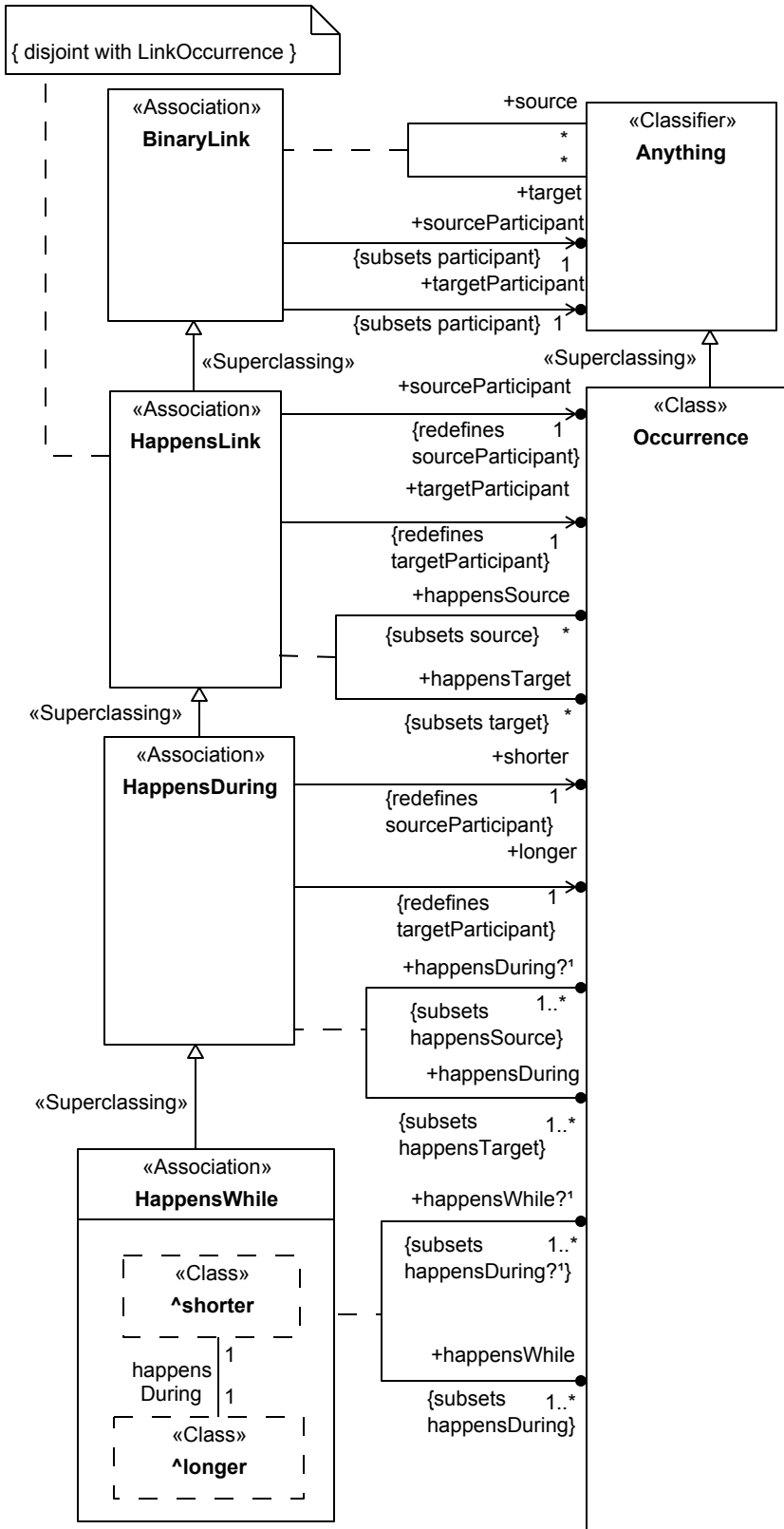


Figure 38. Happenings During

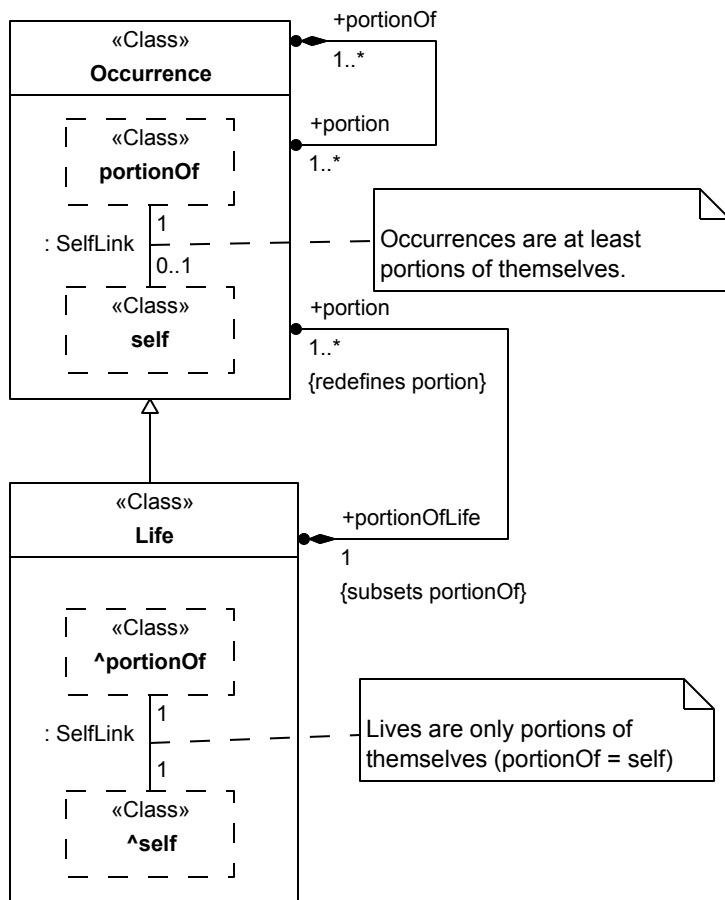


Figure 40. Lives

8.4.2 Elements

8.4.2.1 HappensBefore <Association>

Description

HappensBefore links an *earlier* Occurrence to a *later* one. The Occurrences do not overlap in time; none of their *snapshots* happen at the same time. This means no Occurrence HappensBefore itself.

General Classes

HappensLink

Attributes

earlier : Occurrence {redefines sourceParticipant}

The earlier Occurrence in this HappensBefore relationship.

later : Occurrence {redefines targetParticipant}

The later Occurrence in this HappensBefore relationship.

Constraints

No constraints.

8.4.2.2 HappensDuring <Association>

Description

HappensDuring links a `shorter` Occurrence to a `longer` one. The `shorter` Occurrence completely overlaps the `longer` one in time; all `snapshots` of the `shorter` Occurrence happen at the same time as some `snapshot` of the `longer` one. This means every Occurrence HappensDuring itself.

General Classes

HappensLink

Attributes

`longer` : Occurrence {redefines `targetParticipant`}

The longer of the two participants in this HappensDuring Link.

`shorter` : Occurrence {redefines `sourceParticipant`}

The shorter of the two participants in this HappensDuring Link.

Constraints

No constraints.

8.4.2.3 HappensWhile <Association>

Description

HappensWhile is a HappensDuring and its inverse. This means the linked Occurrences completely overlap each other in time (they happen at the same time); all `snapshots` of each Occurrence happen at the same time as one of the `snapshots` of other. This means every Occurrence HappensWhile itself.

General Classes

HappensDuring

Attributes

No attributes.

Constraints

No constraints.

8.4.2.4 Life <Classifier>

Description

Life is the class of Occurrences that are "maximal portions". That is, they are only portions of themselves.

General Classes

Occurrence

Attributes

portion : Occurrence [1..*] {redefines portion}

Occurrences that are portions of this Life, including at least this Life.

Constraints

No constraints.

8.4.2.5 Occurrence <Classifier>

Description

An Occurrence is Anything that happens over time and space (the four physical dimensions). Occurrences can be portions of another Occurrence within time and space, including slices in time, leading to snapshots that take zero time.

General Classes

Anything

Attributes

endShot : Occurrence {subsets snapshot}

The snapshot representing the end of this Occurrence in time.

endShotOf : Occurrence [0..*] {subsets snapshotOf}

Occurrences of which this Occurrence is the end snapshot.

happensAfter : Occurrence [0..*] {subsets happensSource}

Inverse of happensBefore (Occurrences that end when this one starts or earlier).

happensBefore : Occurrence [0..*] {subsets happensTarget}

Occurrences that start no earlier than this Occurrence ends.

happensDuring : Occurrence [1..*] {subsets happensTarget}

Occurrences that start when this one does or earlier and end when this one does or later (including this one).

happensDuring?¹ : Occurrence [1..*] {subsets happensSource}

Occurrences that start earlier and end later than this Occurrence.

happensSource : Occurrence [0..*] {subsets source}

happensTarget : Occurrence [0..*] {subsets target}

happensWhile : Occurrence [1..*] {subsets happensDuring}

Occurrences that start and end at the same time as this one.

happensWhile?¹ : Occurrence [1..*] {subsets happensDuring?¹}

Inverse of happensWhile (Occurrences that start and end at the same time as this one).

incomingTransfer : Transfer [0..*]

incomingTransferToSelf : Transfer [0..*] {subsets incomingTransfer}

Transfers for which this Occurrence is the `targetParticipant`.

middleShot : Occurrence [0..*] {subsets snapshot}

middleShotOf : Occurrence [0..*] {subsets snapshotOf}

outgoingTransfer : Transfer [0..*]

outgoingTransferFromSelf : Transfer [0..*] {subsets outgoingTransfer}

Transfers for which this Occurrence is the `sourceParticipant`.

portion : Occurrence [1..*] {subsets happensDuring?¹}

Occurrences that happen within the time and space of this one (including this one) and that are considered the same thing occurring, see `Life`.

portionOf : Occurrence [1..*] {subsets happensDuring}

Occurrences of which this Occurrence is a portion, including at least this Occurrence.

portionOfLife : Life {subsets portionOf}

The Life of which this Occurrence is a portion.

self : Occurrence {subsets timeSlice, redefines self}

This Occurrence related to itself (via an instance of `SelfLink`).

snapshot : Occurrence [1..*] {subsets timeSlice}

Time slices of this Occurrence that happen at a single instant of time (i.e., have no duration).

snapshotOf : Occurrence [0..*] {subsets timeSliceOf}

Occurrences of which this Occurrence is a snapshot, including at least this Occurrence.

startShot : Occurrence {subsets snapshot}

The snapshot representing the start of this Occurrence in time.

startShotOf : Occurrence [0..*] {subsets snapshotOf}

Occurrences of which this Occurrence is the end snapshot.

`timeSlice : Occurrence [1..*] {subsets portion}`

portions of this Occurrence over some slice of time, including at least this Occurrence.

`timeSliceOf : Occurrence [1..*] {subsets portionOf}`

Occurrences of which this Occurrence is a time slice, including at least this Occurrence.

`transferBeforeTarget : Occurrence [0..*] {redefines transferTarget, happensBefore}`

Occurrences whose input is the target of a TransferBefore of items from this Occurrence.

`transferTarget : Occurrence [0..*] {subsets target}`

Occurrences whose input is the target of a Transfer of items from this Occurrence.

Constraints

No constraints.

8.4.2.6 occurrences <Classifier>

Description

`occurrences` is a specialization of `things` restricted to type `Occurrence`. It is the most general feature typed by `Occurrence`. All other Features typed by `Occurrence` or its specializations (in libraries or user models) specialize it (directly or indirectly).

General Classes

`things`
`Occurrence`

Attributes

No attributes.

Constraints

No constraints.

8.4.2.7 successions <Feature>

Description

`successions` is a specialization of `binaryLinks` restricted to type `HappensBefore`. It is the most general Succession (M1 instance of M2 Succession). All other Successions (in libraries or user models) specialize it (directly or indirectly).

General Classes

`HappensBefore`

binaryLinks

Attributes

[no name] : Occurrence

[no name] : Occurrence

Constraints

No constraints.

8.5 Objects

8.5.1 Objects Overview

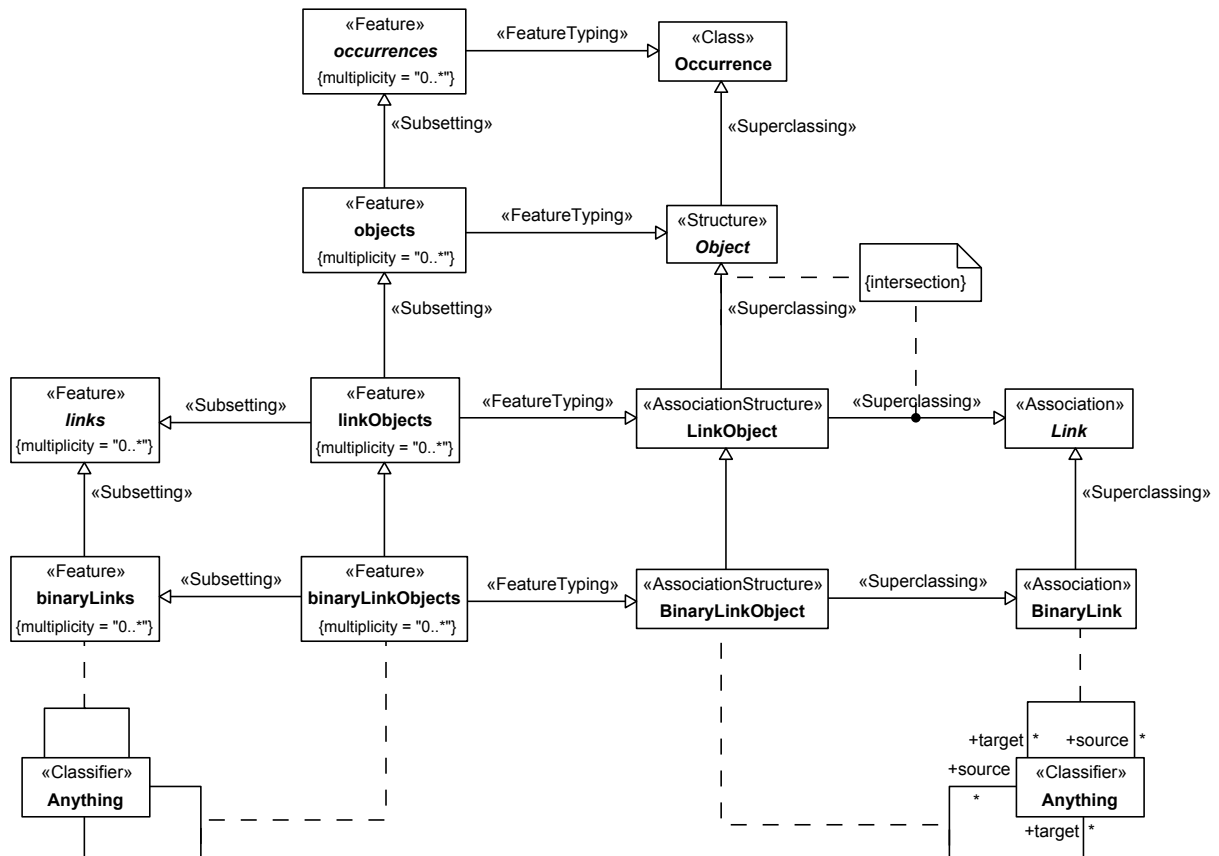


Figure 41. Objects

8.5.2 Elements

8.5.2.1 binaryLinkObjects <Feature>

Description

General Classes

linkObjects
BinaryLinkObject
binaryLinks

Attributes

[no name] : Anything

[no name] : Anything

Constraints

No constraints.

8.5.2.2 BinaryLinkObject <AssociationStructure>

Description

General Classes

LinkObject
BinaryLink

Attributes

source : Anything [0..*]

target : Anything [0..*]

Constraints

No constraints.

8.5.2.3 LinkObject <AssociationStructure>

Description

LinkObject is the most general AssociationStructure (M1 instance of M2 AssociationStructure). All other AssociationStructures (in libraries or user models) specialize it (directly or indirectly).

General Classes

Object
Link

Attributes

No attributes.

Constraints

No constraints.

8.5.2.4 linkObjects <Feature>

Description

`linkObjects` is a specialization of `links` and `objects` restricted to type `LinkObject`. It is the most general feature typed by `LinkObject`. All other Features typed by `LinkObject` or its specializations (in libraries or user models) specialize it (directly or indirectly).

General Classes

`LinkObject`
`links`
`objects`

Attributes

No attributes.

Constraints

No constraints.

8.5.2.5 Object <Structure>

Description

An Object is an Occurrence that is not a Performance. It is most general Structure (M1 instance of M2 Structure). All other Structures (in libraries or user models) specialize it (directly or indirectly).

General Classes

`Occurrence`

Attributes

`enactedPerformance` : `Performance` [0..*] {subsets happensDuring?¹}

Performances that are enacted by this object.

`involvedIn` : `Performance` [0..*]

Performances in which this Object is involved.

Constraints

No constraints.

8.5.2.6 objects <Feature>

Description

`objects` is a specialization of `occurrences` restricted to type `Object`. It is the most general feature typed by `Object`. All other Features typed by `Object` or its specializations (in libraries or user models) specialize it (directly or indirectly).

General Classes

occurrences
Object

Attributes

No attributes.

Constraints

No constraints.

8.6 Performances

The Performances library provides elements to classify dynamic spans of time. Performances are the library base elements for to constrain the changes of objects over time. These support descriptions to generic or specific objects and also of objects alone or in interaction.

Evaluations are library base elements to constrain changes over time that result in the determination of specific values. They specialize into library elements for different kinds of expected results, such as `LiteralEvaluation` or `BooleanEvaluation`.

Specialized Link library elements are provided to indicate whether an object is intended to performing the given behavior or simply involved in it. The `Performs` relationship indicates that instances of `Performance` are "inside" their linked `Object` instances, indicating that the universe of affected states is expected to be those of the object. `Performance` instances linked by `Involves` instances to `Object` instances may describe object state evolution or reference dynamics outside those objects.

8.6.1 Performances Overview

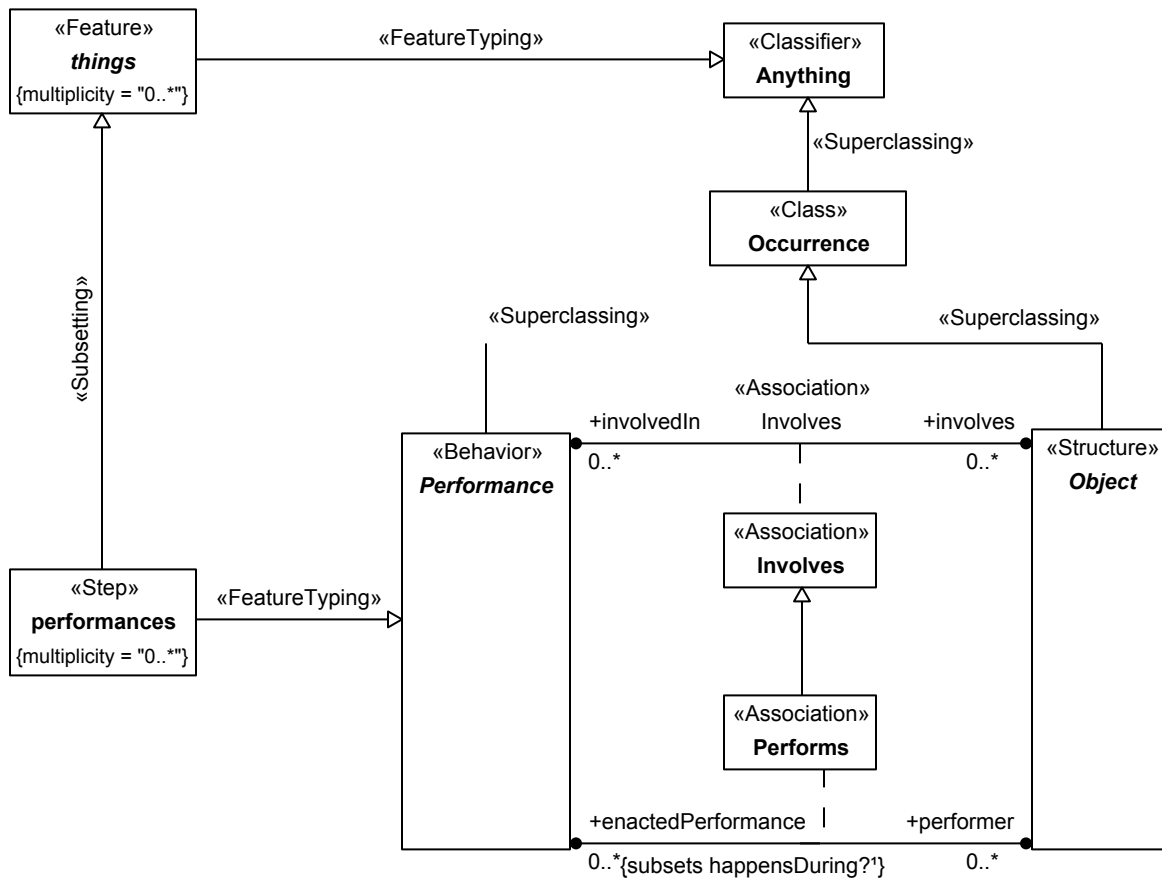


Figure 42. Performances

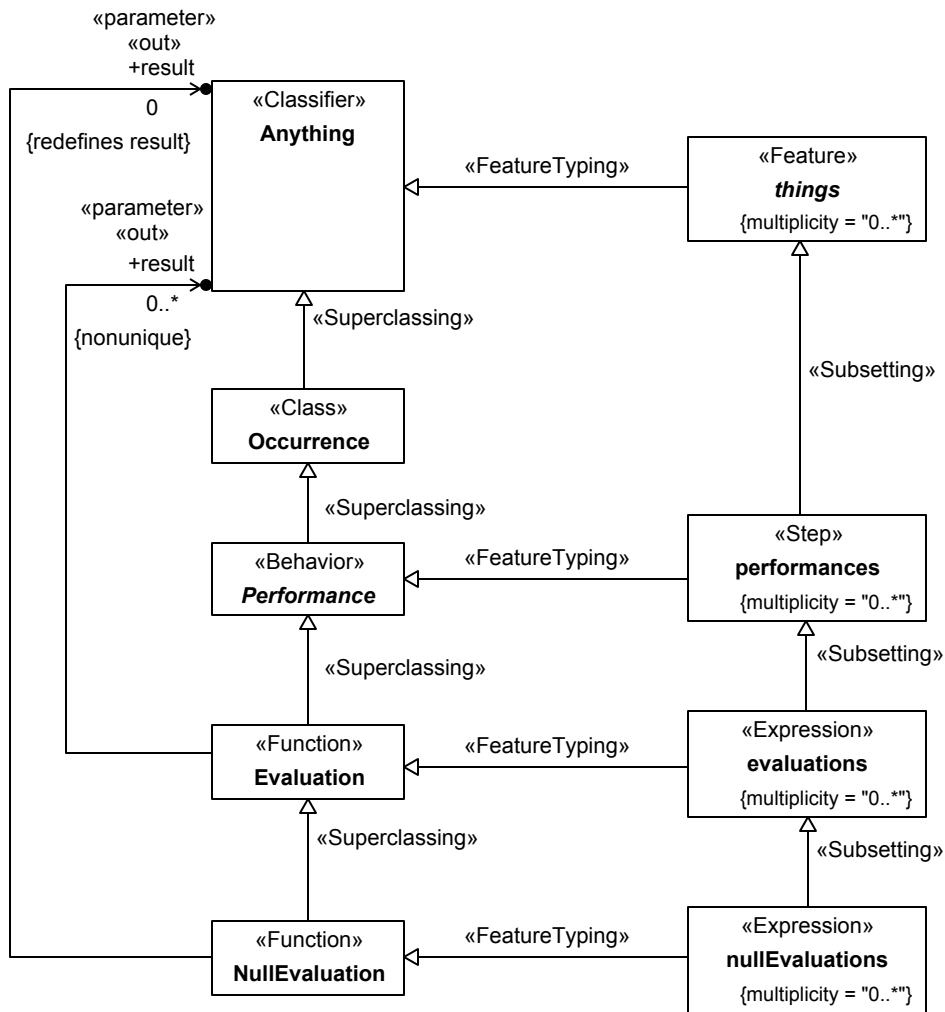


Figure 43. Evaluations

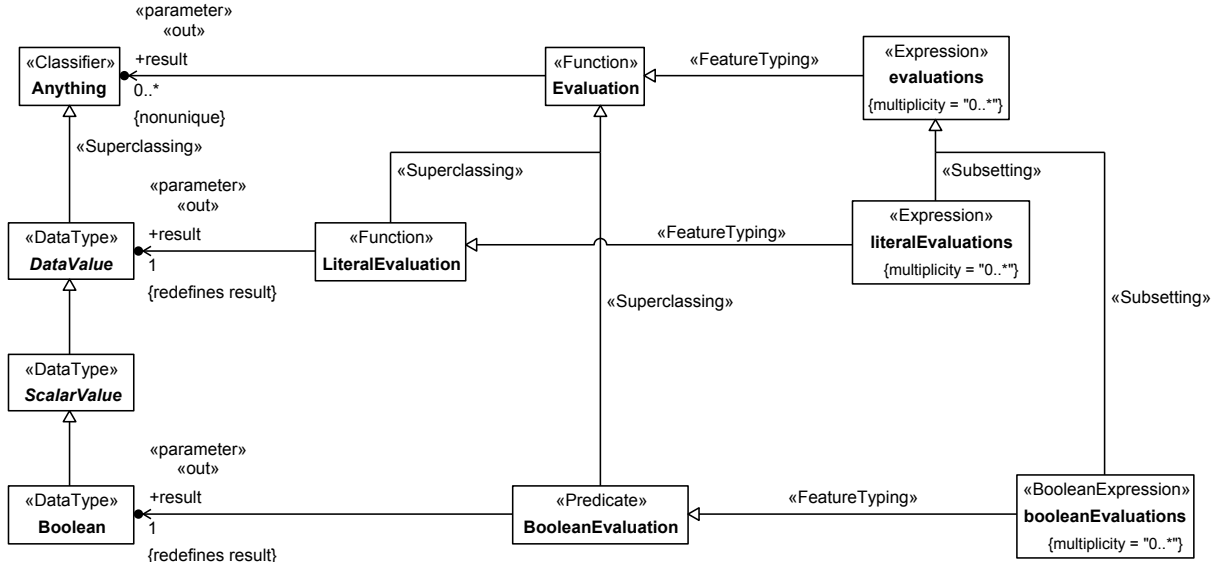


Figure 44. Literal and Boolean Evaluations

8.6.2 Elements

8.6.2.1 BooleanEvaluation <Predicate>

Description

BooleanEvaluation is a specialization of Evaluation that is the most general predicate that may be evaluated to produce a Boolean truth value.

General Classes

Evaluation

Attributes

result : Boolean {redefines result}

The Boolean result of this BooleanExpression.

Constraints

No constraints.

8.6.2.2 booleanEvaluations <BooleanExpression>

Description

booleanEvaluations is a specialization of evaluations restricted to type BooleanEvaluation.

General Classes

BooleanEvaluation

evaluations

Attributes

No attributes.

Constraints

No constraints.

8.6.2.3 Evaluation <Function>**Description**

An Evaluation is a Performance that ends with the production of a result.

General Classes

Performance

Attributes

result : Anything [0..*] {nonunique}

The `result` is the outcome of the Evaluation.

Constraints

No constraints.

8.6.2.4 evaluations <Feature>**Description**

`evaluations` is a specialization of `performances` for Evaluations of functions.

General Classes

performances

Evaluation

Attributes

No attributes.

Constraints

No constraints.

8.6.2.5 Involves <Association>**Description**

Involves classifies relationships between Performances and Objects.

General Classes

No general classes.

Attributes

No attributes.

Constraints

No constraints.

8.6.2.6 LiteralEvaluation <Function>

Description

LiteralEvaluation is a specialization of Evaluation for the case of LiteralExpressions.

General Classes

Evaluation

Attributes

result : DataValue {redefines result}

The result of this LiteralEvaluation, which is always a single DataValue.

Constraints

No constraints.

8.6.2.7 literalEvaluations <Expression>

Description

literalEvaluations is a specialization of evaluations restricted to type LiteralEvaluation.

General Classes

LiteralEvaluation
evaluations

Attributes

No attributes.

Constraints

No constraints.

8.6.2.8 NullEvaluation <Function>

Description

NullEvaluation is a specialization of Evaluation for the case of null expressions.

General Classes

Evaluation

Attributes

result : Anything {redefines result}

The result of this NullEvaluation, which always must be empty (i.e., "null").

Constraints

No constraints.

8.6.2.9 nullEvaluations <Expression>

Description

`evaluations` is a specialization of `performances` for Evaluations of functions.

General Classes

NullEvaluation
evaluations

Attributes

No attributes.

Constraints

No constraints.

8.6.2.10 Performance <Behavior>

Description

A Performance is an Occurrence that applies constraints to how Objects interact or change over its life.

General Classes

Occurrence

Attributes

involves : Object [0..*]

Objects that are involved in this Performance.

performer : Object [0..*]

Objects that enact this performance.

Constraints

No constraints.

8.6.2.11 performances <Feature>

Description

`performances` is the most general feature for Performances of behaviors.

General Classes

Performance
things

Attributes

No attributes.

Constraints

No constraints.

8.6.2.12 Performs <Association>

Description

`Performs` is a specialization of `Involves` that asserts that the `performer` enacts the behavior carried out by the `enactedPerformance`.

General Classes

Involves

Attributes

No attributes.

Constraints

No constraints.

8.7 Transfers

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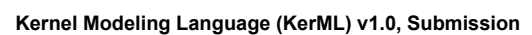


Figure 45. Transfers

8.7.2.1 Transfer <Interaction>

Description

General Classes

Performance
BinaryLink

Attributes

isInstant : Boolean

isMove : Boolean

isPush : Boolean

item : Anything [1..*]

self : Transfer {redefines self}

sourceOutputLink : BinaryLinkObject [1..*]

sourceParticipant : Occurrence {redefines sourceParticipant}

sourceSendShot : Occurrence

targetInputLink : BinaryLinkObject [1..*]

targetParticipant : Occurrence {redefines targetParticipant}

targetReceiveShot : Occurrence

transferSource : Occurrence [0..*] {subsets source}

Constraints

No constraints.

8.7.2.2 transfers <Feature>

Description

General Classes

Transfer

Attributes

[no name] : Occurrence

[no name] : Occurrence

Constraints

No constraints.

8.7.2.3 TransferBefore <Interaction>

Description

General Classes

Transfer
HappensBefore

Attributes

sourceParticipant : Occurrence {redefines earlier, sourceParticipant}

targetParticipant : Occurrence {redefines later, targetParticipant}

transferBeforeSource : Occurrence [0..*] {redefines happensAfter, transferSource}

Constraints

No constraints.

8.7.2.4 transfersBefore <Feature>

Description

General Classes

TransferBefore
transfers

Attributes

[no name] : Occurrence

[no name] : Occurrence

Constraints

No constraints.

8.8 Control Performances

8.8.1 Control Performances Overview

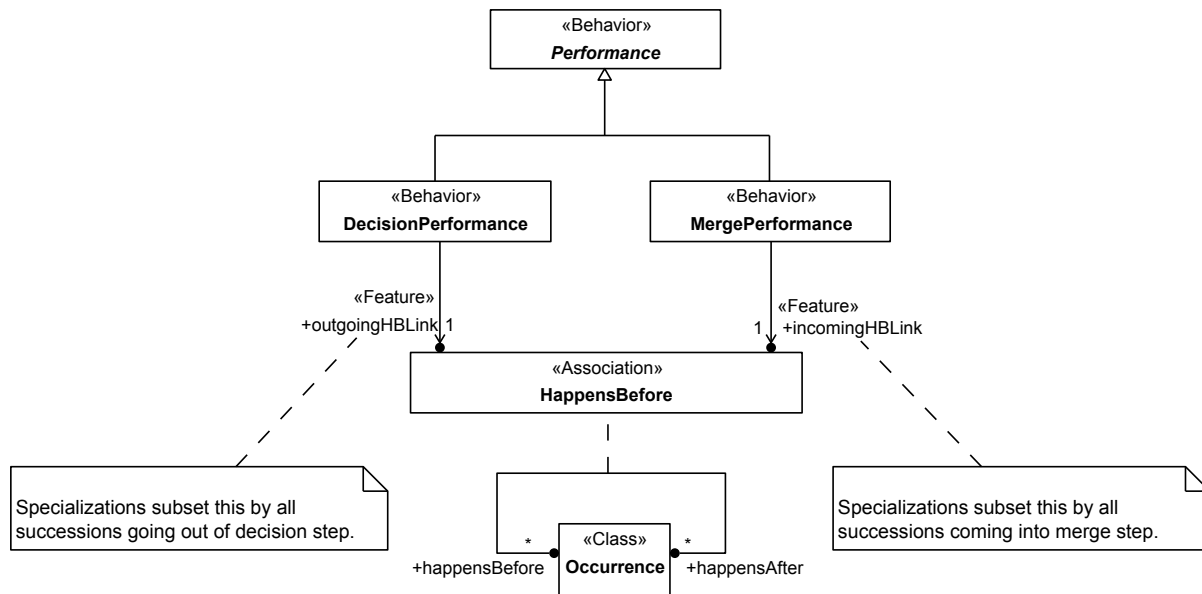


Figure 48. Control Performances

8.8.2 Elements

8.8.2.1 DecisionPerformance <Behavior>

Description

General Classes

Performance

Attributes

outgoingHBLink : HappensBefore

Constraints

No constraints.

8.8.2.2 MergePerformance <Behavior>

Description

General Classes

Performance

Attributes

incomingHBLink : HappensBefore

Constraints

8.9.1 State Performances Overview



8.9.2.1 StatePerformance <Behavior>

Description

General Classes

Model Library Element Description

Attributes

No attributes.

Constraints

No constraints.

8.10 Transition Performances

8.10.1 Transition Performances Overview

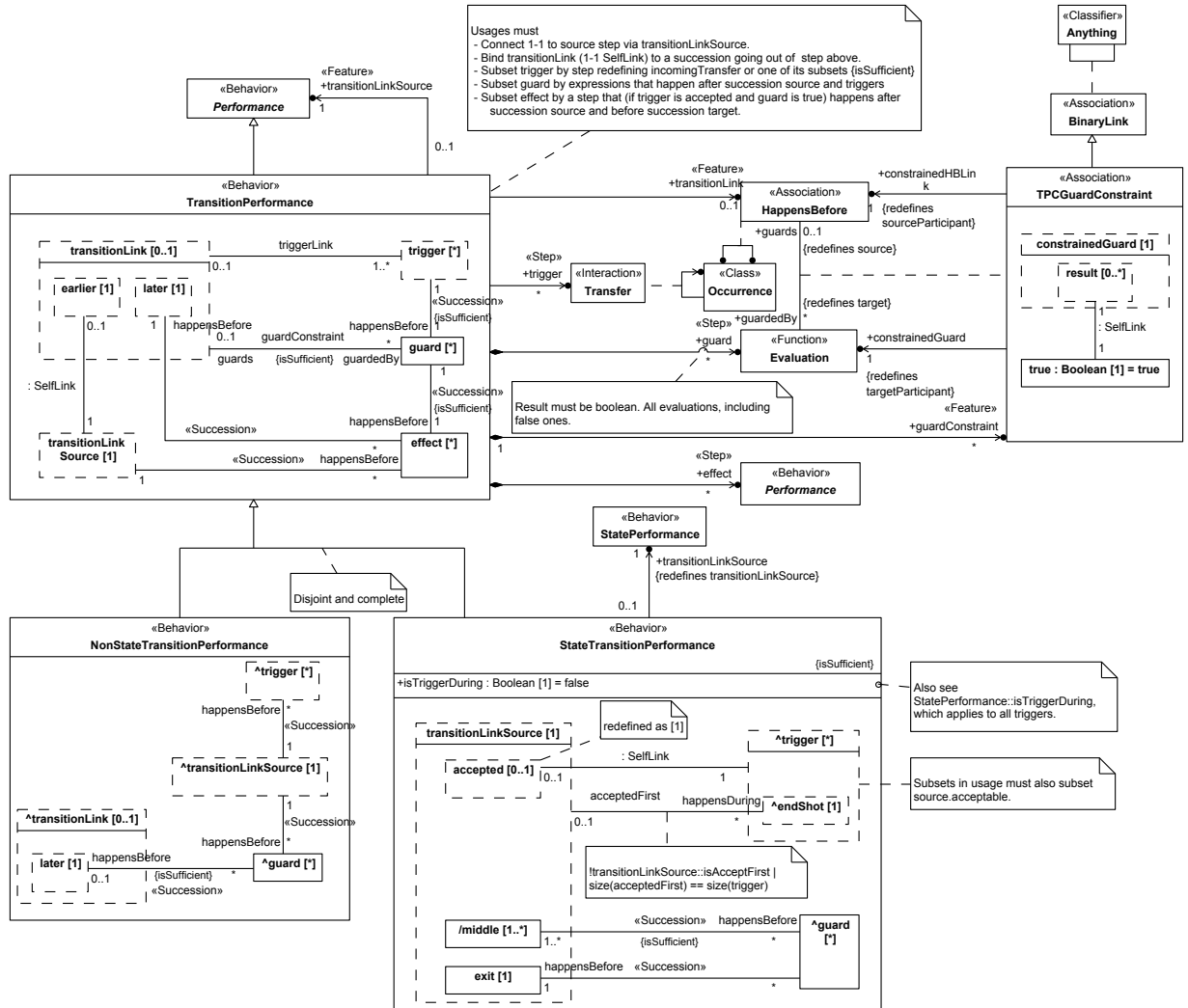


Figure 50. Transition Performances

8.10.2 Elements

8.10.2.1 TransitionPerformance <Behavior>

Description

General Classes

Model Library Element Description

Attributes

No attributes.

Constraints

No constraints.

8.10.2.2 NonStateTransitionPerformance <>

Description

General Classes

TransitionPerformance

Attributes

No attributes.

Constraints

No constraints.

8.10.2.3 StateTransitionPerformance <Behavior>

Description

General Classes

TransitionPerformance

Attributes

isTriggerDuring : Boolean

transitionLinkSource : StatePerformance {redefines transitionLinkSource}

Constraints

No constraints.

8.10.2.4 TPCGuardConstraint <Association>

Description

General Classes

BinaryLink

Attributes

constrainedGuard : Evaluation {redefines targetParticipant}

constrainedHBLink : HappensBefore {redefines sourceParticipant}

guardedBy : Evaluation [0..*] {redefines target}

guards : HappensBefore [0..1] {redefines source}

true : Boolean

Constraints

No constraints.

8.11 Scalar Values

8.11.1 Scalar Values Overview

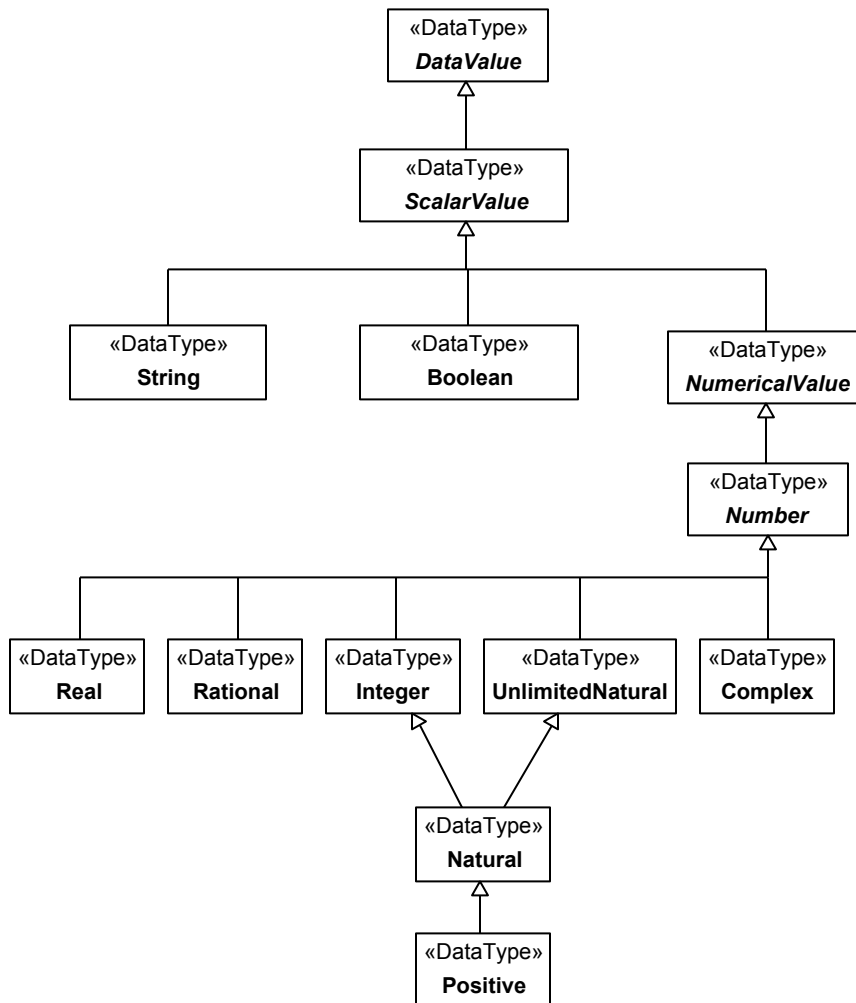


Figure 51. Scalar Values

8.11.2 Elements

8.11.2.1 Boolean <DataType>

Description

General Classes

ScalarValue

Attributes

No attributes.

Constraints

No constraints.

8.11.2.2 Complex <DataType>

Description

General Classes

Number

Attributes

No attributes.

Constraints

No constraints.

8.11.2.3 Integer <DataType>

Description

General Classes

Number

Attributes

No attributes.

Constraints

No constraints.

8.11.2.4 Natural <DataType>

Description

General Classes

DataValue
Integer
UnlimitedNatural

Attributes

No attributes.

Constraints

No constraints.

8.11.2.5 Number <DataType>

Description

General Classes

NumericalValue

Attributes

No attributes.

Constraints

No constraints.

8.11.2.6 NumericalValue <DataType>

Description

General Classes

ScalarValue

Attributes

No attributes.

Constraints

No constraints.

8.11.2.7 Positive <DataType>

8.11.2.8 Rational <DataType>

Description

General Classes

Number

Attributes

No attributes.

Constraints

No constraints.

8.11.2.9 Real <DataType>

Description

General Classes

Number

Attributes

No attributes.

Constraints

No constraints.

8.11.2.10 ScalarValue <DataType>

Description

General Classes

DataValue

Attributes

No attributes.

Constraints

No constraints.

8.11.2.11 String <DataType>

Description

General Classes

ScalarValue

Attributes

No attributes.

Constraints

No constraints.

8.11.2.12 UnlimitedNatural <DataType>

Description

General Classes

Number

Attributes

No attributes.

Constraints

No constraints.

8.12 Collections

8.12.1 Collections Overview

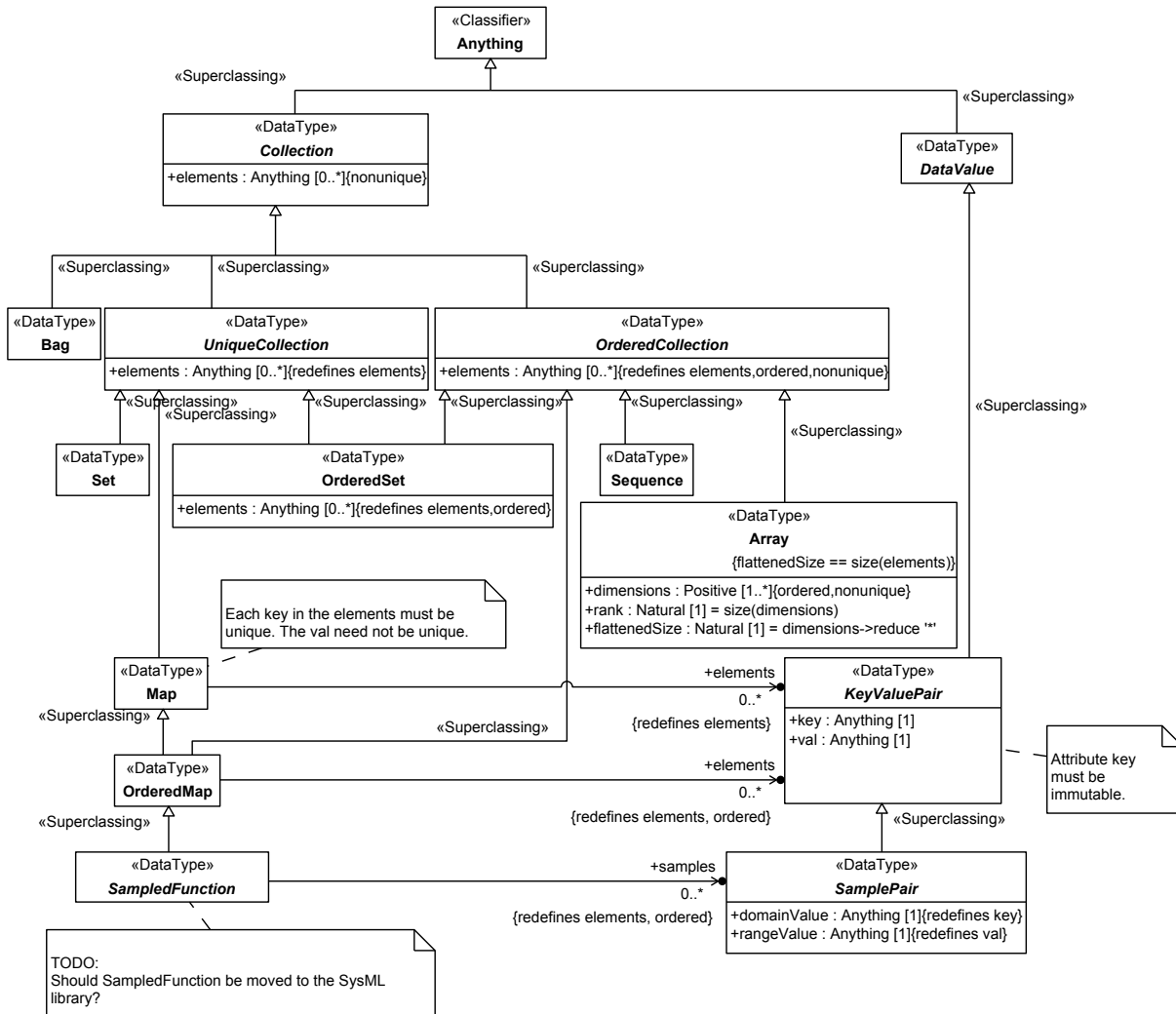


Figure 52. Collections

8.12.2 Elements

8.12.2.1 Array <DataType>

Description

An Array is a fixed size, multi-dimensional Collection of which the `elements` are nonunique and ordered. Its `dimensions` specify how many dimensions the array has, and how many elements there are in each dimension. The `rank` is equal to the number of `dimensions`. The `flattenedSize` is equal to the total number of `elements` in the array.

The `elements` of an Array can be assessed by a tuple of indices. The number of indices is equal to `rank`. The packing of the `elements`, i.e. the flattened representation, follows the C programming language convention, namely the last index varies fastest.

Note: This Array can also represent the generalized concept of a mathematical matrix of any rank, i.e. not limited to rank two.

General Classes

OrderedCollection

Attributes

dimensions : Positive [1..*] {ordered, nonunique}

flattenedSize : Natural

rank : Natural

Constraints

sizeConstraint

[no documentation]

flattenedSize == size(elements)

8.12.2.2 Bag <DataType>

Description

A Bag is a variable size Collection of which the `elements` are unordered and nonunique.

General Classes

Collection

Attributes

No attributes.

Constraints

No constraints.

8.12.2.3 Collection <DataType>

Description

A Collection is an abstract `DataType` that represents a collection of elements of a given type.

A Collection is either mutable or immutable, or mutability is unspecified.

TODO: Decide on whether to add Mutability, and if so, how.

General Classes

Anything

Attributes

elements : Anything [0..*] {nonunique}

Constraints

No constraints.

8.12.2.4 OrderedSet <DataType>

Description

An OrderedSet is a variable size Collection of which the elements are unique and ordered.

General Classes

OrderedCollection
UniqueCollection

Attributes

elements : Anything [0..*] {redefines elements, ordered}

Constraints

No constraints.

8.12.2.5 SampledFunction <DataType>

Description

A SampledFunction is a representation of a discretely sampled mathematical function, that has SamplePairs as samples. The sequence of domainValue/code> of the samples form the domain of the function, and the sequence of rangeValue form the range of the function.

A SampledFunction can be used for many engineering purposes. For example, it can represent a time series observation, where the domain consists of time instants expressed on a given timescale and the range consists of observed quantity values. It can also capture a physical property of a substance that depends on temperature or pressure or both.

.

A SampledFunction with numerical domain and range types (in a specialization of SamplePair) can be used as input to an interpolation algorithm in order to obtain range values for domain values that fall in-between the discretely sampled domain values.

General Classes

OrderedMap

Attributes

samples : SamplePair [0..*] {redefines elements, ordered}

Constraints

No constraints.

8.12.2.6 Sequence <DataType>

Description

A Sequence is a variable size Collection of which the `elements` are nonunique and ordered.

General Classes

OrderedCollection

Attributes

No attributes.

Constraints

No constraints.

8.12.2.7 Set <DataType>

Description

A Set is a variable size Collection of which the `elements` are unique and unordered.

General Classes

UniqueCollection

Attributes

No attributes.

Constraints

No constraints.

8.13 Base Functions

8.13.1 Base Functions Overview

8.13.2 Elements

8.14 Data Functions

8.14.1 Data Functions Overview

8.14.2 Elements

8.15 Scalar Functions

8.15.1 Scalar Functions Overview

8.15.2 Elements

8.16 Boolean Functions

8.16.1 Boolean Functions Overview

8.16.2 Elements

8.17 String Functions

8.17.1 String Functions Overview

8.17.2 Elements

8.18 Numerical Functions

8.18.1 Numerical Functions Overview

8.18.2 Elements

8.19 Natural Functions

8.19.1 Natural Functions Overview

8.19.2 Elements

8.20 Integer Functions

8.20.1 Integer Functions Overview

8.20.2 Elements

8.21 UnlimitedNatural Functions

8.21.1 UnlimitedNatural Functions Overview

8.21.2 Elements

8.22 Rational Functions

8.22.1 Rational Functions Overview

8.22.2 Elements

8.23 Real Functions

8.23.1 Real Functions Overview

8.23.2 Elements

8.24 Complex Functions

8.24.1 Complex Functions Overview

8.24.2 Elements

8.25 Collection Functions

8.25.1 Collection Functions Overview

8.25.2 Elements

8.26 Control Functions

8.26.1 Control Functions Overview

8.26.2 Elements

9 Model Interchange

KerML models may be interchanged between conformant KerML modeling tools (see [Clause 2](#)) using text files in any of the following formats:

1. Textual notation, using the textual concrete syntax defined in this specification. Note that in certain limited cases, models conformant with the KerML syntax, but prepared by a means other than using the KerML textual concrete syntax, may not be fully serializable into the standard textual notation. In this case, a tool may either not export such model at all using the textual notation, or export the model as closely as possible, informing the user of any changes from the original model.
2. JSON, using a format consistent with the JSON schema based on the KerML abstract syntax, consistent with the REST/HTTP platform-specific binding of the Element Navigation Service of the Systems Modeling API and Services specification [SysAPI].
3. XML, using the XML Metadata Interchange [XMI] format based on the MOF-conformant abstract syntax metamodel for KerML.

Every conformant KerML modeling tool shall provide the ability to import and/or export (as appropriate) models in at least one of the first two formats.

Submission Note. Model interchange will be addressed more fully in the revised submission. Issues to be addressed include interchanging tool-generated metadata (such as Element identifiers) in the textual notation and full documentation of the JSON format.

A Annex: Conformance Test Suite

Submission Note. The conformance test suite will be provided in the revised submission.