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0 Preface

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1 Scope

The Kernel Modeling Language (KerML) is an application-independent modeling language with a well-grounded formal semantics for modeling existing or planned systems. The language includes general syntactic constructs for structuring models, such as relationships, annotations and namespaces; core semantic constructs that have semantics based on classification; and additional constructs for commonly needed modeling capabilities, such as associations and behaviors.

System models are expressed in KerML using a textual concrete syntax. This can be parsed to an abstract syntax representation, which is then given a semantic interpretation for the system being modeled. The semantics for the KerML core constructs is grounded in formal mathematical logic, providing a consistent basis for mathematical reasoning about KerML models. However, beyond this, the semantics of KerML constructs are specified by the relationship of user model elements to the KerML Semantic Library.

The Semantic Library models, also expressed in KerML, provide an ontological model of the meaning of KerML models. Indeed, all KerML models can be semantically expressed using solely core modeling constructs referencing the appropriate semantic concepts defined in the Semantic Library. KerML semantic constructs beyond the core are essentially just syntactic conveniences for reusing specific library concepts: structures for modeling objects, behaviors for modeling performances, associations for modeling links, etc.

Indeed, the full KerML language can be considered to be simply a syntactic extension of the core, which is semantically extended using library models. By intent, this approach can also be used to build on KerML to create more specific modeling languages. Application specific modeling languages can be built on KerML by extending the KerML abstract syntax, specializing its semantics, with concrete syntaxes similar to or entirely different from KerML’s.

To support this, the KerML Semantic Library also includes additional library models beyond those directly providing semantics for KerML syntactic constructs, capturing 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.

In this way, KerML can provide the kernel for a family of syntactically diverse but semantically integrated modeling languages.
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 8. 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 8) into an abstract syntax form, or may be represented only in an abstract syntax form (see also 8.2 and 8.3).

A *KerML modeling tool* is a software application 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 8.)

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 8.)

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 8 and Clause 9. 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) as specified in Clause 10.

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.
3 Normative References

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


https://www.omg.org/spec/ALF/1.1

[BLAKE] The BLAKE2 Cryptographic Hash and Message Authentication Code (MAC)
https://www.rfc-editor.org/rfc/rfc7693
BLAKE3

[fUML] Semantics of a Foundational Subset for Executable UML Models (fUML), Version 1.4
https://www.omg.org/spec/fUML/1.4

https://www.iso.org/standard/70907.html


https://www.iso.org/standard/50707.html

https://www.iso.org/standard/71616.html
(see also IECMA-404 The JSON data interchange syntax
https://www.ecma-international.org/publications-and-standards/standards/ecma-404/)

[MD] The MD2 Message-Digest Algorithm
The MD4 Message-Digest Algorithm
https://www.rfc-editor.org/rfc/rfc1320
The MD5 Message-Digest Algorithm
https://www.rfc-editor.org/rfc/rfc1321

[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

[SHS] FIPS Pub 180-4 Secure Hash Standard

[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)

https://www.itu.int/rec/T-REC-X.667-201210-I
(see also A Universally Unique IDentifier (UUID) URN Namespace

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

[ZIP] ZIP File Format Specification
https://pkware.cachefly.net/webdocs/casestudies/APPNOTE.TXT
4 Terms and Definitions

Various terms and definitions are specified throughout the body of this specification.
5 Symbols

A concrete syntax for KerML is specified in subclause 8.2 of this specification.
6 Introduction

6.1 Language Architecture

Developing systems generally involves creating a number of different specifications. For instance, a requirements specification gives the intended effects of a system, while a design specification determines how the system will bring about those effects. Many designs might be developed and evaluated against the same requirements. A test specification then describes test procedures that check whether requirements are met by real or virtual systems built and operated according to some design.

A model is a representation in some modeling language of all or part of any of the above kinds of system specification. The semantics of such models defines what it means for real or virtual things in a modeled system to conform to the specification given by the model. KerML is a foundational modeling language for expressing various kinds of system models with consistent semantics.

Syntactically, KerML is divided into three layers, with each layer building increasingly specific constructs on the previous layer. These layers are, from general to specific:

1. The Root Layer includes the most general syntactic constructs for structuring models, such as elements, relationships, annotations, and packaging.
2. The Core Layer includes the most general constructs that have semantics based on classification.
3. The Kernel Layer provides commonly needed modeling capabilities, such as associations and behavior.

The Core Layer grounds KerML semantics by interpreting it using mathematical logic. However, additional semantics are then specified through the relationship of Kernel abstract syntax constructs to model elements in the Kernel Semantic Library, which is written in KerML itself. Models expressed in KerML thus essentially reuse elements of the Semantic Library to give them semantics. The Semantic Library models give the basic conditions for the conformance of modeled things to the model, which are then augmented in the user model as appropriate.

Having a consistent specification of semantics helps people interpret models in the same way. In particular, because the Semantic Library models are expressed in the same language as user models, engineers and tool builders can inspect the library models to formally understand what real or virtual effects are actually being specified by their models for systems being modeled. More uniform model interpretation improves communication between everyone involved in modeling, including modelers and tool builders.

6.2 Document Organization

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

- **Clause 7** describes KerML from a user point of view, covering all the modeling constructs in the language. It is an informative reference for the normative language specification given in the following three subclauses.
- **Clause 8** specifies the normative metamodel for the KerML language. This includes the complete grammar for the concrete syntax, which is a textual notation (see 8.2), the abstract syntax, which is a MOF model (see 8.3), and formal semantics (see 8.4).
- **Clause 9** specifies the normative Kernel Model Libraries, each of which is a set of library models available to be used in all KerML user models. They include the Semantic Library, which is a set of KerML models used to provide Kernel-layer semantics to user models (see 9.2), the Data Type Library of standard data types (see 9.3) and the Function Library of functions on those data types (see 9.4).
- **Clause 10** specifies the format for standard file-based interchange of KerML models between tools.
Annex A provides basic (non-normative) guidance on incrementally instantiating models for execution, in a way that conforms to the formal semantics as (normatively) specified in the metamodel (see 8.4), as supported by the Semantic Model Library (see 9.2).

### 6.3 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, Jet Propulsion Laboratory
- 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
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- Bjorn Cole, Lockheed Martin Corporation
- Ivan Gomes, Twingeineer
- Hans Peter de Koning, DEKonsult
- Vince Molnár, Budapest University of Technology and Economics

Other contributors include:

- Manfred Koethe, 88solutions
- Karen Ryan, Siemens

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

- 88solutions Corporation
- Dassault Systèmes
- GiSE e.V.
- IBM
- INCOSE
- Intercax LLC
- Lockheed Martin Corporation
- MITRE
- Model Driven Solutions, Inc.
- PTC
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- Manas Bajaj, Intercax LLC (API and services development lead)
- Yves Bernard, Airbus (v1 to v2 transformation co-lead)
- Bjorn Cole, Lockheed Martin Corporation (metamodel development co-lead)
- Sanford Friedenthal, SAF Consulting (SST co-lead, requirements V&V lead)
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7 Language Description

(Informative)

7.1 Language Description Overview

This clause provides an informative description of KerML. Clause 8 gives the full definition of the KerML metamodel, which is the normative specification for implementing the language. In contrast, the description in this clause focuses on how the various constructs of the language are used, along with the Kernel Model Library (see Clause 9), to construct models. While non-normative, it is intended to be precise and consistent with the normative specification of the language.

The following subclauses present the language features in each of the Root, Core and Kernel Layers of KerML (as described in 6.1). Each layer is then further subdivided, following a parallel structure to the packaging of the metamodel (see 8.1). Each subclause within a layer includes references to the corresponding concrete syntax, abstract syntax and semantics subclauses from the normative metamodel specification. In this way, the clause can be used as a general reference for KerML as well as a guide for better understanding of the formal specification of the metamodel.

This clause contains many examples of the KerML textual notation. In order to distinguish this text from normal body text, the following stylistic conventions are used in this clause.

1. Textual notation appears in "code" font. This includes references to individual element names from both example models (such as Vehicle and wheels) and the Kernel Model Library (such as Performance and performances), as well as more extensive model snippets.
2. Keywords appear in **boldface**, both when referenced in-line in body text ("Features are declared using the feature keyword.") and when used within complete notation examples.
3. Longer samples of textual notation are written in separate paragraphs, indented relative to body paragraphs.

7.2 Root

7.2.1 Root Overview

The Root layer provides the most general syntactic capabilities of the language: elements and relationships between them, annotations of elements, and membership of elements in namespaces. These capabilities are the syntactic foundation for structuring models in KerML, but they do not actually represent anything about a modeled system, and so have no semantic specification. The Core and Kernel layers build on the foundation provided by Root to provide constructs with modeling semantics (see 7.3 and 7.4).

7.2.2 Elements and Relationships

7.2.2.1 Elements and Relationships Overview

Metamodel references:

- Concrete syntax, 8.2.3.1
- Abstract syntax, 8.3.2.1
- Semantics, none

Elements are the constituents of a model. Some elements represent relationships between other elements, known as the related elements 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 related element in a relationship and for there to be relationships between relationships.

One of the related elements of a relationship may be the owning related element of the relationship. If the owning related element of a relationship is deleted from a model, then the relationship is also deleted. Some of the related elements of a relationship (distinct from the owning related element, if any) may be owned related elements. If a relationship has owned related elements, then, if the relationship is deleted from a model, all its owned related elements are also deleted.

The owned relationships of an element are all those relationships for which the element is the owning related element. The owned elements of an element are all those elements that are owned related elements of the owned relationships of the element (notice the extra level of indirection through the owned relationships). The owning relationship of an element (if any) is the relationship for which the element is an owned related element (of which the element can have at most one). The owner of an element (if any) is the owning related element of the owning relationship of the element (again, notice the extra level of indirection through the owning relationship).

The deletion rules for relationships imply that, if an element is deleted from a model, then all its owned relationships are also deleted and, therefore, all its owned elements. 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 rooted in that element.

7.2.2.2 Elements

Every element has a unique identifier known as its element ID. The properties of an element can change over its lifetime, but its element ID does not change after the element is created. An element may also have additional identifiers, its alias IDs, which may be assigned for tool-specific purposes.

The KerML textual notation, however, does not have any provision for specifying element or alias IDs, since these are expected to be managed by the underlying modeling tooling. Instead, an element may also have a name and/or a short name, by which it can be referenced in the notation. While the language makes no formal distinction between names and short names, the intent is that the name of an element should be fully descriptive, particularly in the context of the definition of the element, while the short name, if given, should be an abbreviated name useful for referring to the element. (For further discussion of naming, see also 7.2.5).

In most cases, an element is declared using a keyword indicating the kind of element it is (e.g., classifier or feature). The declaration of an element may also specify a short name and/or name for it, in that order. The short name is distinguished by being surrounded by the delimiting characters < and >.

```
classifier <cl23> AClassifier;
feature aFeature;
```

Note that it is not required to specify either a short name 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 notation.

Names and short names have the same lexical structure, which has two variants.

1. A basic name is one that can be lexically distinguished in itself from other parts of the notation. The initial character of a basic name must be a lowercase letter, an uppercase letter or an underscore. The remaining characters of a basic name can be any character allowed as an initial character or any digit. However, a reserved keyword may not be used as a name, even though it has the form of a basic name (see 8.2.2.6 for the list of reserved words).

```
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 name consists of the characters within the single quotes – the single quotes are not included as part of the represented name. 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 within the name by using an escape sequence.

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

An escape sequence is a sequence of two text characters starting with a 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). Table 4 in subclause 8.2.2.3 shows the meaning of the allowed escape sequences.

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.

```java
namespace P {
    // This is the body of the namespace, declaring its owned members.
    classifier A;
    classifier B {
        // This is the body of the classifier, declaring its owned features.
        feature x;
        feature y;
    }
}
```

### 7.2.2.3 Relationships

The related elements 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 must have at least two related elements. A relationship with exactly two related elements is known as a binary relationship. A directed binary relationship is a binary relationship in which one related element is the source and one is the target. Most specialized kinds of relationship in KerML are directed binary relationships (the principal exceptions being dependencies, associations and connectors, see 7.2.3, 7.4.5, and 7.4.6).

Various kinds of relationships are declared with special notations showing their related elements. A relationship may also have a body that specifies owned related elements of the relationship, which may include any kind of element other than an annotating element (see 7.2.4). If an annotating element (i.e., a comment, textual representation or metadata feature) is included in the body of a relationship, then, rather than being directly an owned related element of the containing relationship, the annotating element is an owned related element of an annotation relationship owned by the containing relationship (see 7.2.3.2 for an example).

### 7.2.3 Dependencies
7.2.3.1 Dependencies Overview

Metamodel references:

- Concrete syntax, 8.2.3.2
- Abstract syntax, 8.3.2.2
- Semantics, none

A dependency is a kind of relationship between any number of client (source) and supplier (target) elements. It implies that a change to a supplier element may result in a change to a client element. Dependencies can be useful for representing relationships between elements in an abstract way. For example, a dependency can be used to represent that an upper layer of an architecture stack may depend on a lower layer of the stack.

7.2.3.2 Dependency Declaration

A dependency is declared using the keyword dependency, optionally followed by a short name and/or name (see 7.2.2). The client elements of the dependency are then given as a comma-separated list of qualified names following the keyword from, followed by a similar list of the supplier elements after the keyword to. If no short name or name is given for the dependency, then the keyword from may be omitted.

```
dependency Use
  from 'Application Layer' to 'Service Layer';

// 'Service Layer' is the client of this dependency, not its name.
dependency 'Service Layer'
  to 'Data Layer', 'External Interface Layer';
```

A dependency declaration may also optionally have a relationship body (see 7.2.2.3) containing any additional owned related elements (which act as suppliers) and annotating elements owned by the dependency via annotation relationships (see 7.2.4).

```
dependency 'Service Layer'
  to 'Data Layer', 'External Interface Layer'
  /* 'Service Layer' is the client of this dependency, not its name. */
```

7.2.4 Annotations

7.2.4.1 Annotations Overview

Metamodel references:

- Concrete syntax, 8.2.3.3
- Abstract syntax, 8.3.2.3
- Semantics, none

An annotation is a relationship between an annotated element and an annotating element that provides additional information about the element being annotated. Any kind of element may be annotated, but only certain kinds of elements may be annotating elements. Specific kinds of annotating elements include comments and textual representations (see 7.2.4.2 and 7.2.4.3). A further kind of annotating element for user-defined metadata is defined in the Kernel layer (see 7.4.13).

Each annotation relationship is between a single annotating element and a single annotated element, but an annotating element may have multiple annotation relationships with different annotated elements, and any element may have multiple annotations. The annotated element of an annotation can optionally be the owning related
element of the annotation, in which case the annotation is an owned annotation of the owning annotated element. If an annotating element is an owned member of a namespace (see 7.2.5) and is not involved in any annotation relationships, then its owning namespace is considered to be its annotated element without the need for an explicit annotation relationship.

### 7.2.4.2 Comments and Documentation

A **comment** is an annotating element with a textual **body** that in some way describes its annotated element. **Documentation** is a kind of comment that has the special status of documenting the annotated element, known in this case as the **documented element**. A documentation comment is always an owned element of its documented element.

The full declaration of a comment begins with the keyword `comment`, optionally followed by a short name and/or name (see 7.2.2.2). One or more annotated elements 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 also 8.2.2.2).

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

If the comment is an owned member of a namespace (see 7.2.5), then the explicit identification of annotated elements can be omitted, in which case the annotated element is implicitly the containing namespace. Further, in this case, if no short name 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. */
}
```

A **locale** can also be specified for a comment, using the keyword `locale` followed by the locale string, placed immediately before the comment body (whether or not the `comment` keyword is used). The locale identifies the language of the body text and, optionally, the region and/or encoding. The format is language[_territory][.codeset][@modifier] (conformant to [ISO15897]).

```
comment C_US_English locale "en_US"
   /* This is US English comment text */
```

A documentation comment is notated similarly to a regular comment, but using the keyword `doc` rather than `comment`. The documented element of a documentation comment is always the owning element of the documentation.

```
dependency X from A to B {
   doc X_Comment
      /* This is a documentation comment about X. */
      doc /* This is more documentation about X. */
}
namespace P {
   doc P_Comment /* This is a documentation comment about P. */
}
```

The actual **body** text of a comment does not include the initial /* and final */ characters. Further, the written text is processed to allow formatting using * characters to delimit consistent initial indentation of a comment lines. For example, the comment notation in:
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 tool may (but is not required to) display such text as rendered according to the markup. (See 8.2.3.3.2 for the complete rules for processing comment text.)

7.2.4.3 Textual Representations

A textual representation is an annotating element whose textual body represents its annotated element (known in this case as the represented element) in a given language. A textual representation is notated similarly to a documentation comment (see 7.2.4.2), but with the keyword rep instead of comment. As for documentation, a textual representation is always owned by its represented element. In particular, if the textual representation is an owned member of a namespace (see 7.2.5), the represented element is the containing Namespace. A textual representation declaration must also specify the language used for the textual body as a literal string (see 8.2.2.5) following the keyword language. If the textual representation has no short name or name, then the rep keyword can also be omitted.

class C {
    feature x: Real;
    inv x_constraint {
        rep inOCL 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 textual representation is processed as for regular comment text (see 7.2.4.2), and it is the result after such processing that is the textual representation body expected to conform to the named language.

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

The language name in a textual representation is case insensitive. The name can be of a natural language, but will often be for a machine-parsable language. In particular, there are recognized standard language names.

If the language is "kerml", then the body of the textual representation must be a legal representation of the represented element in the KerML textual notation. A tool can use such a textual representation to record the original KerML notation text from which an element is parsed. Other standard language names that can be used in a
textual representation include "ocl" and "alf", in which case the body of the textual representation must be written in the Object Constraint Language [OCL] or the Action Language for fUML [Alf], respectively.

However, for any other language than "kerml", the KerML specification does not define how the body text is to be semantically interpreted as part of the model being represented. An element with no other definition than a textual representation in a language other than KerML is essentially a semantically "opaque" element specified in the other language. Nevertheless, a conforming KerML tool may (but is not required to) interpret such an element consistently with the specification of the named language.

7.2.5 Namespaces

7.2.5.1 Namespaces Overview

Metamodel references:

- Concrete syntax, 8.2.3.4
- Abstract syntax, 8.3.2.4
- Semantics, none

A namespace is an element that contains other elements via membership relationships with those elements. The namespace is the source element and owner of the membership. The target of a membership can be any kind of element, known as the member element of the membership. If the membership is an owning membership, then the member element is known as an owned member element, which is the only owned related element of the membership.

A namespace may also import memberships from other namespaces. Further, a type, which is kind of namespace, may inherit memberships from other types that it specializes (see 7.3.2).

The members of a namespace are the member elements of all the memberships of the namespace (whether owned, imported or inherited). The owned members of a namespace are the owned member elements of all the owned memberships of the namespace that are owning memberships.

If an element is a member of a namespace, then any name for that element relative to the namespace is known as an unqualified name for that element in the namespace. If the containing namespace is not a root namespace (see 7.2.5.3), then the qualified name for the member element consists of a name for the containing namespace, known as the qualifier, followed by an unqualified name for the element. Since a namespace is an element that may itself be a member of another namespace, a qualifier may be a qualified name. Therefore, a qualified name of an element, in general, has the form of a list of unqualified names of namespaces, each relative to the previous one, followed by the unqualified name of the element in the final namespace.

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 (see 8.2.3.5).

Since namespaces and their members may have aliases (see 7.2.5.2), 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.
7.2.5.2 Namespace Declaration

A namespace that is not a root namespace (see 7.2.5.3), 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 short name and/or name (see 7.2.2.2). 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 be omitted and the declaration ended instead with a semicolon.

```xml
namespace '<1.1>' N1; // This is an empty namespace.
namespace '<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.
}
```

Declaring an element within the body of a namespace denotes that the element is an owned member of the namespace—that is, that there is an owning membership relationship between the namespace and the member element.

The visibility of the membership can be specified by placing one of the keywords public, protected or private before the public element declaration. If the membership is public (the default), then it is visible outside of the namespace. If it is private, then it is not visible. For namespaces other than types, protected visibility is equivalent to private. For types, protected visibility has a special meaning relating to member inheritance (see 7.3.2).

```xml
namespace N3 {
    public class C;
    private datatype D;
    feature f : C; // public by default
}
```

An alias for an element is a non-owning membership of the element in a namespace, which may or may not be the same namespace that owns the element. An alias name or short name is determined only relative to its membership in the namespace, and can therefore be different than the name or short name defined on the element itself. Note that the same element may be related to a namespace by multiple alias memberships, allowing the element to have multiple, different names relative to that namespace.

An alias is declared using the keyword alias followed by the alias short name and/or name, with a qualified name identifying the element given after the keyword for. The alias declaration may optionally include a body as described for relationships in 7.2.2.3. The visibility of the alias membership can be specified as for an owned member.

```xml
namespace N4 {
    class A;
    class B;
    alias <C> CCC for B {
        doc /* Documentation of the alias. */
    }
    private alias D for B;
}
```

A comment (see 7.2.4.2), including documentation, declared within a namespace body also becomes an owned member of the namespace. If no annotated elements are specified for the comment (with an about clause), then, by default, the comment is considered to be about the containing namespace.
With the ability to specify names, short names and aliases for elements, any element can potentially have several names relative to a namespace. However, the set of names provided for any one member of a namespace must be disjoint from the set of names provided for any other member of the namespace. That is, a namespace effectively provides a "space" of names, each one of which uniquely identifies a single member element of the namespace (though there may be multiple names that identify the same element). This is known as the distinguishibility of namespace memberships.

### 7.2.5.3 Root Namespaces

A root namespace is a namespace that has no owner. The owned members of a root namespace are known as top-level elements. Any element that is not a root namespace has an owner and, therefore, must be in the ownership tree of a top-level element of some root namespace.

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 is given simply by the list of representations of its top-level elements.

```kerml
class A;
feature c : C;

class C;
datatype D;
feature f : C;
package P;
```

Since the notation does not provide a means for naming a root namespace, the name of a top-level element is not qualified by the name of its containing root namespace. The name resolution rules consider all top-level elements to be directly and globally visible without qualification (see 8.2.3.5). Therefore, the fully qualified name of an element relative to a root namespace always begins with the name of a top-level element in the root namespace, without regard to the name (if any) of the root namespace.

### 7.2.5.4 Imports

A namespace may import visible memberships from other namespaces. The complete set of memberships of a namespace include all its owned memberships and all its imported memberships, and the member elements of imported memberships are included in the set of members of the namespace. Various kinds of namespaces may also define additional memberships to be included in the set of memberships of that kind of namespace (for instance, the memberships of a type also include its inherited members – see 7.3.2) and which of those are visible (e.g., public inherited memberships).

If the member name or member short name of any imported membership conflicts with the name of any owned member, or with the name of any visible membership from any other imported namespace, then the conflicting
membership is hidden and is not included in the set of imported memberships of the importing namespace. As a result of this rule and the distinguishability rule for owned members (see 7.2.5.2), the names of all owned and imported members will always be distinct from each other. Any specialized kind of namespace that adds further kinds of memberships (e.g., inherited memberships of types) always maintains the property that the names of all memberships of a namespace are distinct from each other.

The namespace that is the source of an import relationship, known as the importing namespace, also owns it. There are two types of import relationships. A membership import is a relationship between the importing namespace and a single membership, which becomes an imported membership of the importing namespace. A namespace import is a relationship between the importing namespace and an imported namespace, in which all visible memberships of the imported namespace become imported memberships of the importing namespace.

A membership import is denoted using the keyword import followed by a qualified name, which identifies the imported membership (be member name or member short name). The member element of the imported membership becomes an imported member of the importing namespace. Note that the imported membership may be for an alias of the imported member (see 7.2.5.2), in which case the element will be known by that name in the importing namespace.

```c
namespace N6 {  
import N4::A;  
import N4::C; // Imported with name "C".  
namespace M {   
import C; // "C" is re-imported from N4 into M.  
}  
}
```

A namespace import is also denoted using the keyword import followed by a qualified name, but with the qualified name suffixed by "::*". In this case, the qualified name identifies the imported namespace. All visible memberships of the imported namespace then become imported memberships of the importing namespace.

```c
namespace N7 {  
// Memberships A, B and C are all imported from N4.  
import N4::*;  
}
```

If the declaration of either a membership or namespace import is further suffixed by "::**", then the import is recursive. Such an import is equivalent to importing memberships as described above for either an imported membership or namespace, followed by further recursively importing from each imported member that is itself a namespace.

```c
namespace N8 {  
class A;  
class B;  
namespace M {   
class C;  
}  
}  
namespace N9 {  
import N8::*;  
// The above recursive import is equivalent to all  
// of the following taken together:  
// import N8;  
// import N8::*;  
// import N8::M::*;  
}  
namespace N10 {  
import N8::*::*;  
}
```
The visibility of an import can be specified by placing the keyword `public` or `private` before the import declaration. If the import is `public` (the default), then all the imported memberships become public for the importing namespace. If import is `private`, then the imported memberships become private relative to the importing namespace. An import declaration may optionally have a body, as described for relationships in 7.2.2.3.

```kerml
namespace N11 {
  public import N4::A {
    /* The imported membership is visible outside N11. */
  }

  private import N5::* {
    doc /* None of the imported memberships are visible */
    * outside of N11. */
  }
}
```

An import may also be declared with one or more filter conditions. Given as model-level evaluable Boolean expressions (see 7.4.9), listed after the imported membership or namespace specification, each surrounded by square brackets `[... ]`. Such a filtered import is equivalent to importing an implicit package that then both imports the given imported membership or namespace and has all the given filter conditions. The effect is such that, for a filtered import, memberships are imported if and only if they satisfy all the given filter conditions. (While filtered imports may be used in any namespace, packages and filter conditions are actually Kernel-layer concepts, because expressions are only defined in that layer. See 7.4.14.)

```kerml
namespace N12 {
  import Annotations::*;
  // Only import elements of NA that are annotated as Approved.
  import NA::*[@Approved];
}
```

## 7.3 Core
### 7.3.1 Core Overview

The Core layer builds on the Root layer to add the minimum constructs for modeling systems as designed, built and operated. **Semantics** is about how models are interpreted as giving conditions on how things should be (i.e., as a specification of a modeled system) or as a reflection of how things are (i.e, as a description of a modeled system). KerML semantics are based on **classification**: a model has elements that classify things in the modeled system.

A **type** is the most general kind of model element that classifies things (see 8.2.4.1.1). **Classifiers** are types that classify things, such as cars, people and processes being carried out, as well as how they are related by **features** (see 7.3.3). **Features** are also types, classifying relations between things (see 8.2.4.3.1). In addition to simple relations between two things, KerML allows features to classify longer chains of relations. For example, cars owned by people who live in a particular city might be required to be registered. These cars are identified by a chain of two relations, first the ownership of the car, then the residence of the owner.

KerML also supports taxonomies of classifications using **specialization** relationships between types. All the things classified by a specialized type are also classified by the general types it is related to via specialization relationships.
This means that all the things classified by a specialized type have all the features of its general types, referred to as *inheriting* features from general to specific types. KerML includes several special kinds of specialization, including *subclassification* between classifiers, *subsetting* and *redefinition* between features, and *feature typing* between a feature and another type.

### 7.3.2 Types

#### 7.3.2.1 Types Overview

**Metamodel references:**

- Concrete syntax, 8.2.4.1
- Abstract syntax, 8.3.3.1
- Semantics, 8.4.3.2

*Types* classify things in a modeled system. The set of things classified by a type is the *extent* of the type, each member of which is an *instance* of the type. Everything being modeled is an instance of the type *Anything* from the *Base* library model (see 9.2.2).

A type gives conditions for what things must be in or not in its extent (*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. These conditions apply to all procedures that determine the extents of types, including logical solving, inference, and execution.

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. (Note that necessary conditions are usually stated as what must be true of all instances in the extent, even though they really only determine what is not.) Alternatively, *Car* could require all four wheeled things to be in its extent (sufficient condition).

Types are namespaces, enabling them to have members via membership relationships to other elements identified as their members (see 7.2.5). These include *inherited* memberships, which are certain memberships from the general types of their *owned specializations* (see 7.3.2.3). The member names of all inherited memberships must be distinct from each other and from the member names of all owned memberships. A membership that would otherwise be imported is hidden by an inherited membership with the same member name, similarly to how it would be hidden by a conflicting owned membership (see 7.2.5).

**Note.** Name conflicts due to inherited memberships can be resolved by redefining them to give non-conflicting member names (see 7.3.4).

#### 7.3.2.2 Type Declaration

A type is declared using the keyword *type*, optionally followed by a short name and/or name. In addition, a type declaration defines either one or more *owned specializations* for the type (see 7.3.2.3) or a *conjugator* for the type (see 7.3.2.4). This may optionally be followed by the definition of one or more *owned disjoinings* (see 7.3.2.5).

```plaintext
type A specializes Base::Anything disjoint from B;
type C conjugates A;
```

A type is specified as *abstract* by placing the keyword *abstract* before the keyword *type*. A type that is not abstract is called a *concrete* type. Declaring a type to be abstract means that all instances of the type must also be instances of at least one concrete type that directly or indirectly specializes the abstract type.
abstract type A specializes Base::Anything;
type A1 specializes A;
type A2 specializes A;

The multiplicity constrains the number of instances in the extent of a type (the cardinality of the extent). A multiplicity is a feature whose values are natural numbers (extended with infinity, see 9.3.2.1) that are the only ones allowed for the cardinality of its featuring type (each multiplicity is the feature of exactly one Type). A type can have at most one feature that is its multiplicity. Cardinality for classifiers is the number of things it classifies. For features that are not end features (see below), cardinality is the number of values of the feature for a specific instance of its featuring types.

Note. The semantics of multiplicity is different for features that are identified as end features. End Features are used primarily in the definition of associations and connectors, and the semantics of end features is discussed in conjunction with them (see 7.4.5 and 7.4.6, respectively).

The multiplicity of a type can be specified as a range after any identification of the Type, between square brackets [...]. (See 7.4.12 for a complete description of multiplicity ranges, including declaring named multiplicity features.)

// 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 7.2.5.2). However, for types, protected members, indicated using the keyword protected instead of public or private, have special visibility rules for inheritance (see 7.3.2.3). A feature declared as an owned member of a type is automatically considered to be an owned feature of the type, related by a feature membership, unless its declaration is preceded by the keyword member, in which case it is related by regular membership (see 7.3.2.6 for details).

type Super specializes Base::Anything {
    private namespace N {
        type Sub specializes Super;
    }
    protected feature f : N::Sub;
    member feature f1 : Super featured by N::Sub;
}

The conditions that a type places on its instances (e.g., what feature it has) are always considered necessary. They can be indicated as sufficient by placing the keyword all after the keyword type. In this case, the type places additional sufficiency conditions on its instances corresponding to all the necessary conditions. 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. (See also the discussion in 7.3.2.1.)

type all Car specializes MaterialThing {
}

7.3.2.3 Specialization

Specializations are relationships between types, identified as specific and general, indicating that all instances of the specific type are instances of the general one (that is, 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 one, referred to syntactically as inheriting features from general to specific types. A type may participate in multiple specialization relationships, both as specific and general types.

A specialization relationship is declared using the keyword specialization, optionally followed by a short name and/or a name. The qualified name of the specific type, or a feature chain (see 7.3.4.6) if the specific type is such a
feature, is then given after the keyword `subtype`, followed by the qualified name of the general type, or a feature chain if the general type is such a feature, after the keyword `specializes`. The symbol `:> ` can be used interchangeably with the keyword `specializes`. A specialization declaration can also optionally have a relationship body (see §7.2.3) for, e.g., nested annotations.

```
specialization Gen subtype A specializes B;
specialization subtype x => Base::things {
  doc /* This specialization is unnamed. */
}
```

If no `shortName` or `name` is given, then the keyword `specialization` may be omitted.

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

The `directsupertypes` of a type are all the general types in specializations for which the type is the specific type, and the `direct subtypes` of a type are all the specific types in specializations for which the type is the general type. `Indirect supertypes` include, recursively, the supertypes of the direct supertypes of a type, and similarly for `indirect subtypes`.

Specialization relationships can form cycles, which means all types in the cycle have the same instances (same extent). However, since all types are required to specialize the base type `Anything` (directly or indirectly), no cycle of valid types can be entirely closed, unless it includes the type `Anything`.

The `owned specializations` of a type are those specializations that are owned relationships of the type (see §7.2.2), for which the type is the `specific` type. An owned specialization of a type is defined as part of the declaration of the type, rather than in a separate declaration, by including the qualified name or feature chain of the general type in a list after the keyword `specializes` (or the symbol `:> `).

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

A type `inherits` all visible and protected memberships of the general types of its owned specializations. `Protected` memberships are all owned and inherited memberships of the general type whose visibility is declared as `protected` (see also §7.3.2.2 on `protected` visibility; for imported memberships, protected visibility is equivalent to `private`). This means protected memberships are memberships that are only visible to their owning type and to (direct or indirect) specializations of it.

```
type A specializes Base::Anything {
  feature f; // Public by default.
  protected feature g;
  private feature h;
}
type B specializes A {
  // B inherits feature memberships for
  // f and g, but not h.
}
```

### 7.3.2.4 Conjugation

`Conjugation` is a relationship between types, identified as the `original` type and the `conjugated` type, indicating the conjugated type inherits visible and protected memberships from the original type, except the direction of input and output features is reversed (see §7.3.4.1 on features with direction). Features with direction `in` relative to the original type are treated as having direction `out` relative to the conjugated type, and vice versa for direction `out` treated as `in`. Features with no direction or direction `inout` in the original type are inherited without change.
A conjugation relationship is declared using the keyword `conjugation`, followed by a short name and/or a name. The qualified name of the conjugated type, or a feature chain (see 7.3.4.6) if the conjugated type is such a feature, is then given after the keyword `conjugate`, followed by the qualified name of the original type, or a feature chain if the original type is such a feature, after the keyword `conjugates`. The symbol ~ can be used interchangeably with the keyword `conjugates`. A conjugation declaration can also optionally have a relationship body (see 7.2.2.3) for, e.g., nested annotations.

```plaintext
type Original specializes Base::Anything {
    in feature Input;
}
type Conjugate1 specializes Base::Anything;
type Conjugate2 specializes Base::Anything;
conjugation c1 conjugate Conjugate1 conjugates Original;
conjugation c2 conjugate Conjugate2 ~ Original {
    doc /* This conjugation is equivalent to c1. */
}
```

If no short name or name is given, then the keyword `conjugation` may be omitted.

```plaintext
conjugate Conjugate1 conjugates Original;
congugate Conjugate2 ~ Original;
```

An owned conjugation is an owned relationship of a type (7.2.2) that is a conjugation relationship, for which the type is the conjugated type. An owned conjugation for a type is defined as part of the declaration of the type, rather than in a separate declaration, by including the qualified name or feature chain of the original type after the keyword `conjugates` (or the symbol ~).

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

A type can be the conjugated type of at most one conjugation relationship, and a conjugated type cannot be the specific type in any specialization relationship.

### 7.3.2.5 Disjoining

Types related by disjoining do not share instances (instances cannot be in more than one of the extents; the extents are disjoint). For example, a classifier for mammals is disjoint from a classifier for minerals, and a feature for people's parents is disjoint from a feature for their children.

A disjoining relationship is declared using the keyword `disjoining`, optionally followed by a short name and/or a name. The qualified name of the first type, or a feature chain (see 7.3.4.6) if the type is such a feature, is then given after the keyword `disjoint`, followed by the qualified name of the second type, or a feature chain, if the the type is such a feature, after the keyword `from`. A disjoining declaration can also optionally have a relationship body (see 7.2.2.3) for, e.g., nested annotations.

```plaintext
disjoining Disj disjoint A from B;
disjoining disjoint Mammal from Mineral;
disjoining disjoint Person::parents from Person::children {
    doc /* No Person can have a parent as a child. */
}
```

If no short name or name is given, then the keyword `disjoining` may be omitted.

```plaintext
disjoint A from B;
disjoint Mammal from Mineral;
disjoint Person::parents from Person::children;
```
An owned disjoining of a type is an owned relationship of the type (see 7.2.2) that is a disjoining relationship. An owned disjoining is defined as part of the declaration of the type, rather than in a separate declaration, by including the qualified name or feature chain of the disjoining type in a list after the keyword disjoint from, placed after any owned specializations.

```plaintext
type C specializes Anything disjoint from A, B;
type Mammal :> Animal disjoint from Mineral;
```

### 7.3.2.6 Feature Membership

A feature membership is a relationship between a type and a feature that is both a kind of owning membership and a kind of type featuring (see 7.3.4.8). Features related to a type via feature membership are identified as owned features of the type. The owning type is one of the feature's featuring types, meaning that the feature specifies a relation between the owning type and the type of the feature.

A feature that is declared within the body of a type is normally an owned feature of that type, so it automatically has that type as a featuring type (because feature membership is a kind of type featuring). This also applies to the bodies of classifiers (see 7.3.3) and features (see 7.3.4), since they are kinds of types. A feature may also be aliased in a type like any other Element (see 7.2.5), in which case it is related to the aliasing type by a regular membership relationship, not a feature membership, and, so, does not become one of the owned features of the type.

```plaintext
feature person[*] : Person;
classifier Person {
    // This declares an owned feature using a feature membership.
    feature age[1] : ScalarValues::Integer;

    // This is not a feature membership.
    alias personAlias for person;
}
```

However, if a feature declaration in the body of type is preceded by the keyword member, then the feature is owned by the containing type via a membership relationship, not a feature membership. In this case, the feature is not an owned feature of the containing type, and it does not automatically have the containing type as a featuring type, though it may have featuring types declared in its featured by list (see 7.3.4.1 on declaring the owned typings of a feature).

```plaintext
classifier A;
classifier B {
    // Feature f has B as its featuring type.
    feature f;

    // Feature g has A as its featuring type, not B.
    member feature g featured by A;
}
```

### 7.3.2.7 Unioning, Intersecting, and Differencing

Unioning, intersecting, and differencing are relationships between an owning type and a set of other types.

1. **Unioning** specifies that the owning type classifies everything that is classified by any of the unioned types.
2. **Intersecting** specifies that the owning type classifies everything that is classified by all of the intersecting types.
3. **Differencing** specifies that the owning type classifies everything that is classified by the first of the differenced types but not by any of the remaining types.
Since these relationships are always owned by the source type, they are defined as part of the declaration of that type, using the keywords \texttt{unions}, \texttt{intersects}, and \texttt{differences}, respectively, followed by a list of qualified names (or feature chains, if appropriate, see 7.3.4.6) of the related types. These relationship clauses are placed after any owned specializations (see 7.3.2.3) but may otherwise appear in any order with each other and with any disjoining clause (see 7.3.2.5).

\begin{verbatim}
classifier Adult;
classifier Child;

classifier Person unions Adult, Child {
  feature dependents : Child[*];
  feature offspring : Person[*];
  feature grownOffspring : Adult[*] :> offspring;
  feature dependentOffspring : Child[*] :> dependents, offspring
    differences offspring, grownOffspring
    intersects dependents, offspring;
}
\end{verbatim}

Multiple relationships of each kind can be specified using multiple clauses in a single declaration. In the case of differencing, any additional \texttt{differences} clauses after the first one mean that the owning type does \textit{not} classify anything classified by any of the related types. It is not allowable, though, for a type to have just one of any of these relationships over all.

\begin{verbatim}
  // This is valid.
  classifier Person unions Adult unions Child;

  // This is NOT valid.
  classifier Person unions Adult;
\end{verbatim}

### 7.3.3 Classifiers

#### 7.3.3.1 Classifiers Overview

Metamodel references:

- Concrete syntax, 8.2.4.2
- Abstract syntax, 8.3.3.2
- Semantics, 8.4.3.3

Classifiers are types that classify things in the modeled system, as distinct from features, which model the relations between them (see 7.3.4). Subclassification is a kind of specialization that specifically relates classifiers.

#### 7.3.3.2 Classifier Declaration

The notation for a classifier is the same as the generic notation for a type (see 7.3.2.2), except using the keyword \texttt{classifier} rather than \texttt{type}. However, any general types referenced in a \texttt{specializes} list must be Classifiers, and the specializations defined are specifically subclassifications (see 7.3.3.3). A classifier is also not required to have any owned subclassifications explicitly specified. If no explicit subclassification is given for a classifier, and the classifier is not conjugated, then the classifier is given a default subclassification to the most general base classifier \texttt{Anything} from the Base library model (see 9.2.2).

\begin{verbatim}
classifier Person { // Default superclassifier is Base::Anything.
  feature age : ScalarValues::Integer;
}
classifier Child specializes Person;
\end{verbatim}
The declaration of a classifier may also specify that the classifier is a conjugated type (see §7.3.2.4), in which case the original type must also be a classifier.

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

### 7.3.3.3 Subclassification

A subclassification relationship is declared using the keyword `specialization`, optionally followed by a short name and/or a name. The qualified name of the `subclassifier` is then given after the keyword `subclassifier`, followed by the qualified name of the `superclassifier` after the keyword `specializes`. The symbol `:>` can be used interchangeably with the keyword `specializes`. A subclassification declaration can also optionally have a relationship body (see §7.2.2.3) for, e.g., nested annotations.

```plaintext
specialization Super subclassifier A specializes B;
specialization subclassifier B :> A {
  /* This subclassification is unnamed. */
}
```

If no short name or name is given, then the keyword `specialization` may be omitted.

```plaintext
subclassifier C specializes A;
specializes
 subclassifier C specializes B;
```

An owned subclassification 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 superclassifier in a list after the keyword `specializes` (or the symbol `:>`).

```plaintext
classifier C specializes A, B;
```

### 7.3.4 Features

#### 7.3.4.1 Features Overview

`Features` are types that classify how things in a modeled system are related, including by chains of relations. Relations between things can also 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 `featuring types` (the `domain`) with instances in the intersection of the extents of its `featured types` (the `co-domain`). Instances in the domain of a feature are said to "have values" that are instances of the co-domain. The domain of features with no explicit `featuring types` is the type `Anything` from the `Base library model` (see §9.2.2).

Type `featuring` is a relationship between a feature and a type that identifies the type as a `featuring type` of the feature. `Feature membership` is both a kind of owning membership and a kind of type `featuring`, by which a type owns a feature and becomes a featuring type of that feature (see §7.3.2.6).
There are also several forms of specialization that apply specifically to features.

- **Feature typing** is a relationship between a feature and a type that identifies the type as a featured type of the feature.
- **Subsetting** is a relationship between a specific feature (the subsetting feature) and a more general feature (the subsetted feature), where the specific feature may further constrain the featuring types, featured types and multiplicity of the general feature.
- **Redefinition** is a kind of subsetting in which the specific feature (the redefining feature) also replaces an otherwise inherited general feature (the redefined feature) in the context of the owning type of the specific feature.

### 7.3.4.2 Feature Declaration

The notation for a feature is similar to the generic notation for a type (see 7.3.2.2), except using the keyword `feature` rather than `type`. Further, a feature can have any of three kinds of specialization, each identified by a specific keyword or equivalent symbol:

- **typed by** or `:` – Specifies FeatureTyping (see 7.3.4.3).
- **subsets** or `:> `– Specifies Subsetting (see 7.3.4.4).
- **redefines** or `:>>` – Specifies Redefinition (see 7.3.4.5).

In general, clauses for the different kinds of Specialization 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 library model (see 9.2.2). This is true even if a feature typing 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 conjugated type (see 7.3.2.4), in which case the original type must also be a feature. In this case, the feature must not have any owned specializations.

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

As for any type, the multiplicity of a feature can be given in square brackets `[...]` after any identification of the feature (see also 7.3.2.2). However, the multiplicity for a feature can also be placed after one of the specialization clauses in the feature declaration, but, in all cases, only one multiplicity may be specified. In particular, this allows a notation style for multiplicity consistent with that used in previous modeling languages (such as UML). It is also useful when redefining a Feature without giving an explicit name (see 7.3.4.5).

```
feature redefines children[0];
```
In addition to, or instead of, an explicit multiplicity, a feature declaration can include either or both of the following keywords (in either order). The properties flagged by these keywords are only meaningful if the feature has a multiplicity upper bound greater than one.

- **nonunique** – If a feature is *non-unique*, then, for any domain instance, the same co-domain instance may appear more than once as a value of the feature. The default is that the feature is *unique*.
- **ordered** – If a feature is *ordered*, then for any domain instance, the values of the feature can be placed in order, indexed from 1 to the number of values. The default is that the feature is *unordered*.

```plaintext
feature sensorReadings : ScalarValues::Real [*] nonunique ordered;
```

There are four other kinds of relationships that can be declared as owned relationships of a feature, each indicated by a specific keyword:

- **disjoint from** – Specifies disjoining (see 7.3.2.5).
- **chains** – Specifies feature chaining (see 7.3.4.6).
- **inverse of** – Specifies feature inverting (see 7.3.4.7).
- **featured by** – Specifies type featuring (see 7.3.4.7).

The clauses for these relationships must appear after any specialization or conjugation part, but can otherwise appear in any order.

```plaintext
feature cousins : Person[*] chains parents.siblings.children featured by Person;
feature children : Person[*] featured by Person inverse of parents;
```

There are a number of additional properties of a feature that can be flagged by adding specific keywords to its declaration. If present, these are always specified in the following order, before the keyword `feature`:

1. **in**, **out**, **inout** – Specifies the *direction* of a feature, which determines what is allowed to change its values on instances of its domain:
   - **in** – Things "outside" the instance. These features identify things input to an instance.
   - **out** – The instance itself or things "inside" it. These features identify things output by an instance.
   - **inout** – Both things "outside" and "inside" the instance. These features identify things that are both input to and output by an instance.
2. **abstract** – Specifies that the feature is *abstract* (see 7.3.2.2 on abstract types in general).
3. **composite** or **portion** – Specifies that the feature is either a *composite* or *portion* feature (specifying both is not allowed).
   - Values of a composite feature, on each instance of the feature's domain, cannot exist after the featuring instance ceases to exist. This only applies to values at the time the instance goes out of existence, not to other things in the co-domain that might have been values before that.
   - Portion features are composite features where the values cannot exist without the whole, because they are the "same thing" as the whole. (For example, the portion of a person's life when they are a child cannot be added or removed from that person's life.)
4. **readonly** – Specifies that the feature is *read only*. Values of read only features on each instance of their domain are the same during the entire existence of that instance.
5. **derived** – Specifies that the feature is *derived*. Such a feature is typically expected to have a bound feature value expression that completely determines its value at all times (see 7.4.11 on feature values, which is a kernel concept).
6. **end** – Specifies that the feature is an *end feature*. Any kind of type can have end features, but they are mostly used in associations (see 7.4.5) and connectors (see 7.4.6), and they are further described in those contexts.
(Note that the semantics of composite, portion, and readonly require a model of things existing in time, which is provided in the Kernel layer, see 7.4.3).

```kernml
classifier Fuel {
    portion feature fuelPortion : Fuel;
}

classifier Tank {
    in feature fuelFlow : Fuel;
    composite feature fuel : Fuel;
}

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

### 7.3.4.3 Feature Typing

A feature typing relationship is declared using the keyword specialization, optionally followed by a short name and/or a name. The qualified name of the typed feature is then given after the keyword typing, followed by the qualified name of the type, or a feature chain (see 7.3.4.6), after the keyword typed by. The symbol : can be used interchangeably with the keyword typed by. A feature typing declaration can also optionally have a relationship body (see 7.2.2.3) for, e.g., nested annotations.

```kernml
specialization t1 typing customer typed by Person;
specialization t2 typing employer : Organization {
    doc /* An employer is an Organization. */
}
```

If no short name or name is given, then the keyword specialization may be omitted.

```kernml
typing customer typed by Person;
typing employer : Organization;
```

An owned feature typing is a feature typing that is an owned relationship of its type feature. An owned feature typing is defined as part of the declaration of the typed feature, rather than in a separate declaration, by including the qualified name or feature chain for the type in a list after the keyword typed by (or the symbol :).

```kernml
feature foodItem typed by Food, InventoryItem;
```

### 7.3.4.4 Subsetting

Subsetting is a kind of specialization between two features. This means that the values of the subsetting feature are also values of the subsetted feature on each instance (separately) of the domain of the subsetting feature.

A subsetting relationship is declared using the keyword specialization, optionally followed by a short name and/or a name. The qualified name of the subsetting feature, or a feature chain (see 7.3.4.6), is then given after the keyword subset, followed by the qualified name of the subsetted feature, or a feature chain, after the keyword subsets. The symbol :> can be used interchangeably with the keyword subsets. A subsetting declaration can also optionally have a relationship body (see 7.2.2.3) for, e.g., nested annotations.

```kernml
specialization Sub subset parent subsets person;
specialization subset mother subsets parent {
    doc /* All mothers are parents. */
}
```
If no short name or name is given, then the keyword `specialization` may be omitted.

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

An *owned subsetting* is a subsetting that is an owned relationship of the subsetting feature. An owned subsetting is defined as part of the declaration of the subsetting feature, rather than in a separate declaration, by including the qualified name or feature chain of the subsetted feature in a list after the keyword `subsets` (or the symbol `:>`).

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

A subsetting feature can restrict aspects of the subsetted feature, otherwise it will, by default, have the same properties as the subsetted feature. In particular, a subsetting feature can constrain its featured types to be specializations of those of the subsetted feature and add additional feature types. A subsetting feature can also restrict the multiplicity of its subsetted feature to allow cardinalities that are smaller than those of the subsetted feature (e.g., by specifying smaller lower and/or upper bounds).

```
classifier Wheel;
classifier DriveWheel specializes Wheel;
feature anyWheels[*] : Wheel;

classifier Automobile {
    // Restricts multiplicity
    composite feature wheels[4] subsets anyWheels;
    // Restricts multiplicity and type.
    composite feature driveWheels[2] : DriveWheel subsets wheels;
}
```

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

```
classifier Automobile {
    composite feature wheels[4] ordered subsets anyWheels;
    // driveWheels must be ordered because wheels is ordered.
    composite feature driveWheels[2] ordered : DriveWheel subsets wheels;
}
```

If a subsetted feature is unique, then the subsetting feature must not be specified as non-unique. If the subsetted feature is non-unique, then the subsetting feature 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 subsets accessibleURLs; // Cannot be nonunique.
}
```

### 7.3.4.5 Redefinition

Redefinition is a kind of subsetting that requires the values of the redefining feature and the redefined feature to be the same on each instance (separately) of the domain of the redefining feature. This means any restrictions on the values of the redefining feature relative to the redefined feature, such as typing or multiplicity, also apply to the values of the redefined feature, and vice versa.

A redefinition relationship is declared using the keyword `specialization`, optionally followed by a short name and/or a name. The qualified name of the redefining feature, or a feature chain (see 7.3.4.6), is then given after the keyword `redefinition`, followed by the qualified name of the redefined feature, or a feature chain, after the
keyword **redefines**. The symbol :>> can be used interchangeably with the keyword **redefines**. A redefinition declaration can also optionally have a relationship body (see 7.2.2.3) for, e.g., nested annotations.

```plaintext
specialization Redef redefinition LegalRecord::guardian redefines parent;
specialization redefinition Vehicle::vin redefines RegisteredAsset::identifier {
    doc /* A "vin" is a Vehicle Identification Number. */
}
```

If no short name or name is given, then the keyword **specialization** may be omitted.

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

A feature can only be redefined once for any featuring type. A feature without any feature types is considered to be implicitly featured by the most general base type Anything (see 7.3.4.1). It is therefore allowable to redefine such a feature by a redefining feature that does have some other featuring type. It is, however, illegal for one such feature to redefine another, because that would correspond to a semantically inconsistent redefinition of one feature of Anything by another.

The restrictions on the specification of the multiplicity, ordering and uniqueness of a subsetting feature (see 7.3.4.4) also apply to a redefining feature. In addition, the multiplicity of a redefining feature must only allow cardinalities that are consistent with the multiplicity of the redefined feature (e.g., it cannot have a multiplicity lower bound that is less than that of the redefined feature).

An **owned redefinition** is a redefinition that is an owned relationship of its redefining feature. An owned redefinition of a feature is defined as part of the declaration of the feature, rather than in a separate declaration, by including the qualified name or feature chain of the redefined feature in a list after the keyword **redefines** (or the symbol :>>).

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

If a redefining feature is declared as an owned feature of a type (see 7.3.2.6), then each of the redefined features of its owned redefinitions must be features that would otherwise be inherited from supertypes of its owning type. When redefined, however, these otherwise inheritable features are not inherited and are, instead, replaced by the redefining feature. This enables the redefining feature to have the same name as a redefined feature, if desired. (Note, however, that even though a redefined feature is not in the namespace of the owning type of the redefining feature, the redefined feature still has values on instances of that type, particularly when they are considered as instances of the supertype that owns the redefined feature. The values will be the same as for the redefining feature, as described above.)

In general, the resolution of a qualified name begins with the namespace in which the name appears and proceeds outwards from there to containing namespaces (see 8.2.3.5). However, the resolution of the qualified names of redefined features of owned redefinitions follow special rules. In particular, the local namespace of the owning type of the redefining feature is not included in the name resolution of the redefined features, with resolution beginning instead with the direct supertypes of the owning type. Since redefined features 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. The special rules for redefined features, however, allow such a reference, because the name resolution begins with the namespaces of the supertypes of the owning type, one of which must contain the redefined feature.

```plaintext
classifier RegisteredAsset {
    feature identifier : Identifier;
}
classifier Vehicle : RegisteredAsset { // Owning type.
    // Legal even though "identifier" is not inherited.
    feature vin redefines identifier;
}
```
If neither a name nor a short name is given in the declaration of a feature with an owned redefinition, then the feature is implicitly given the same name and short name as the first redefined feature (which may itself have implicit names, if the redefined feature is itself a redefining feature). These implicit names are used in name resolution, just as explicitly declared names would be. This is useful when declaring a feature that that redefines another feature in order to constrain it, while maintaining the same naming.

```classifier WheeledVehicle {
    // The declared name is "wheels".
    composite feature wheels[1..*] : Wheel;
}
classifier MotorizedVehicle specializes WheeledVehicle {
    // The effective name is "wheels", the same name as
    // WheeledVehicle::wheels, which is being redefined.
    composite feature redefines wheels[2..4];
}
classifier Automobile specializes MotorizedVehicle {
    // The effective name is "wheels", the same (effective) name
    // as "MotorizedVehicle::wheels", which is being redefined.
}
```

### 7.3.4.6 Feature Chaining

*Feature chaining* is an owned relationship between the owning *chained feature* and a *chaining feature*. If a feature has any chaining features, then it must have at least two. The list of chaining features of a chained feature is called its *feature chain*.

The meaning of a chained feature depends on its feature chain. The values of a chained feature are the same as the values of the last feature in the chain. These can be found by starting with the values of the first feature (for each instance of the chained feature's domain), then on each of those, finding the values of the second feature in the chain, and so on, to values of the last feature. If a chained feature is ordered, any ordering of values earlier in the chain are imposed on values found later in the chain. If a chained feature is non-unique, duplicate values found in the last feature of the chain (which might be due to multiple values of the earlier features) are preserved in the chained feature, otherwise the last feature can have no duplicates.

A feature chain is notated as a sequence of two or more qualified names separated by dot (.) symbols. Each qualified name in a feature chain must resolve to a feature. The first qualified name in a feature chain is resolved in the local namespace as usual (see 8.2.3.5). Subsequent qualified names are then resolved using the previously resolved feature as the context namespace (but considering only visible memberships). This notation specifies a list of chaining features, as given by the resolution of the qualified names in the chain, in order.

The feature chain notation can be placed after the keyword *chains* in the declaration of the Feature, appearing after any specialization or conjugation part, but before any disjoining or type featuring part (see also 7.3.4.2).

```feature cousins chains parents.siblings.children;
```

The featuring types of the chaining feature are implicitly considered to include the featuring types of the first chaining feature. Similarly, the featured types of the chaining feature are implicitly considered to include the featured types of the last chaining feature.

The feature chain notation may also be used to specify a related element in the declaration of any of the following relationships:

1. Specialization (see 7.3.2.3)
2. Conjugation (see 7.3.2.4)
3. Unioning, intersecting and differencing (see 7.3.2.7)
4. Disjoining (see 7.3.2.5)
5. Subsetting (see 7.3.4.4)
6. Redefinition (see 7.3.4.5)
7. Feature inverting (see 7.3.4.7)
8. Connector (see 7.4.6, in the Kernel layer)

In this case, the related element specified using the feature chain notation becomes an owned related feature of the relationship with the feature chain as notated.

```
feature uncles subsets parents.siblings;
feature cousins redefines parents.siblings.children;
connector vehicle.wheelAssembly.wheels to vehicle.road;
```

Note. A similar dot notation is also used for the related Kernel-layer concept of a feature chain expression (see 7.4.9.3). However, it is always syntactically unambiguous as to whether the notation should be parsed as a plain feature chain or as a feature chain expression.

### 7.3.4.7 Feature Inverting

Feature inverting is a relationship between two features whose interpretations as relations are the inverse of each other. For example, a feature identifying each person's parents is the inverse of a feature identifying each person's children. A person identified as a parent of another will identify that other as one of their children.

A feature inverting relationship is declared using the keyword `inverting`, optionally followed by a short name and/or a name. The qualified name of the first feature, or a feature chain (see 7.3.4.6), is then given after the keyword `inverse`, followed by the qualified name of the second feature, or a feature chain, after the keyword `of`. A feature inverting declaration can also optionally have a relationship body (see 7.2.2.3) for, e.g., nested annotations.

```
inverting parent_child inverse Person::parent of Person::child {
    doc /* A Person is the parent of their children. */
}
```

If no short name or name is given, then the keyword `inverting` may be omitted.

```
inverse Person::parents of Person::children;
```

An owned feature inverting is a feature inverting that is an owned relationship of its first feature. An owned feature inverting is defined as part of the declaration of the inverted feature, rather than in a separate declaration, by giving the qualified name or feature chain of the other feature after the keyword `inverse of`.

```
classifier Person {
    feature children : Person[*];
    feature parents : Person[*] inverse of children;
}
```

Note that only a single feature identification is allowed after `inverse of`. While it is possible to declare multiple feature inverting relationships for a single feature, this is generally not useful.

Inverse features can be arbitrarily nested. However, while it is allowable to use feature chains in the declaration of a feature inverting relationship, note that a feature chain is a separate feature from any of the features it chains. In order to indicate that two declared features are inverses, one should use qualified names rather than feature chains.

```
classifier A {
    feature b1: B {
        feature c1: C;
    }
```
7.3.4.8 Type Featuring

Type featuring is a relationship between a feature and a type, identifying the type as a featuring type of the feature (see also 7.3.4.1). Feature membership is a kind of type featuring that also makes the feature an owned member of the featuring type (see 7.3.2.6).

A type featuring relationship is declared using the keyword `featuring`, optionally followed by a short name and/or a name, and the keyword `of`. The qualified name of the featured feature is then given, followed by the qualified name of the featuring type after the keyword `featured by`. A type featuring declaration can also optionally have a relationship body (see 7.2.2.3) for, e.g., nested annotations.

```plaintext
featuring engine_by_Vehicle of engine featured by Vehicle;
featuring power featured by engine {
  doc /* The engine of a Vehicle has power. */
}
```

An owned type featuring is a type featuring that is an owned relationship of the featured feature. An owned type featuring is defined as part of the declaration of the feature, rather than in a separate declaration, by including the qualified name of the featuring type in a list after the keyword `featured by`.

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

Note that the domain of a feature is given by the intersection of its featuring types. That is, in the above example, an instance in the domain of `engine` must be both a `Vehicle` and a `PoweredComponent`.

7.4 Kernel

7.4.1 Kernel Overview

The Kernel layer completes KerML. It extends the Core layer to add modeling capabilities beyond basic classification. These include specialized classifiers for things that have the semantics of data values (data types) from others that have an independent existence over time and space (classes), and for reified relationships between things (associations).

Classes have instances that exist or happen in time and space. They are divided into those for structure and behavior. Structures typically limit how things and relations between them might change over time, while behaviors specify changes within those limits. Structures and behaviors do not overlap, but structures can be involved in, perform, and own behaviors. Behaviors can coordinate other behaviors via steps (usages of behaviors). Functions are behaviors that yield a single result, which can be used to form trees of expressions. Interactions combine behaviors and associations. Some associations are also structures.

The Kernel layer adds semantics beyond the Core primarily by specifying how model elements use the Kernel model library (see Clause 9), rather than be specified mathematically as in the Core. The Kernel textual syntax introduces keywords that translate to patterns of using Core abstract syntax and library models, acting as syntactic "markers" for modeling patterns tying Kernel to the Core. In the simplest case, this involves introducing implicit specializations of model library types. For example, classes must directly or indirectly subclassify the library class
Occurrence, while behaviors must directly or indirectly subclassify the library class Performance. 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 to redefine the source and target ends of BinaryLink.

This is also how other modeling languages can be built on KerML. Domain-specific metamodels and libraries can also reuse Kernel metamodel and libraries, inheriting the patterns of library reuse above, as well as the mathematical semantics they inherit from Core. This enables domain-specific modelers to use terms and syntax familiar to them and still benefit from automated assistance based on mathematically-defined semantics.

7.4.2 Data Types

Metamodel references:

- Concrete syntax, 8.2.5.1
- Abstract syntax, 8.3.4.1
- Semantics, 8.4.4.2

Data types are classifiers that classify data values (see 9.2.2.2.2). Certain primitive data types have have specified extents of values, such as the numerical and other types from the ScalarValues library model (see 9.3.2). Other data types have features whose values can distinguish one instance of the data type from another. But, otherwise, different data values are not distinguishable.

This means that data types cannot also be classes or associations, or share instances with them. It also means that data types classify things that do not exist in time or space, because they require changing relations to other things. The feature values of a data value cannot change over time, because different feature values would inherently identify a different data value.

A data type is declared as a classifier (see 7.3.3), using the keyword datatype. If no owned superclasiing is explicitly given for the data type, then it is implicitly given a default superclasiing to the data type DataValue from the Base library model (see 9.2.2).

If any of the types of a feature are data types, then none of its types can be classes or associations, because classes and associations are disjoint from data types (see 8.4.4.2). If a feature has data types as its types, and no owned subsetting or owned redefinition 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 9.2.2).

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

7.4.3 Classes

Metamodel references:

- Concrete syntax, 8.2.5.2
- Abstract syntax, 8.3.4.2
- Semantics, 8.4.4.3

Classes are classifiers that classify occurrences, which exist in time and space (see 9.2.4). Relations between an occurrence and other things can change over time and space, while the occurrence still maintains an independent identity.
A class is declared as a classifier (see 7.3.3), using the keyword class. If no owned superclassing is explicitly given for the class, then it is implicitly given a default superclassing to the class Occurrence from the Occurrences model library (see 9.2.4).

If any of the types of a feature are classes, then none of its types can be data types, because data types are disjoint from classes (see 8.4.4.3). If a feature has class types, and no owned subsetting or owned redefinition is explicitly given in the feature declaration, then the feature is implicitly given a default subsetting to the feature occurrences from the Occurrences library model (see 9.2.4), unless at least one of the types is an association structure, in which case the default subsetting is as described in 7.4.5.

```java
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 default.
}
```

### 7.4.4 Structures

Metamodel references:

- Concrete syntax, 8.2.5.3
- Abstract syntax, 8.3.4.3
- Semantics, 8.4.4.4

Structures are classes that classify objects, which are kinds of occurrences. Structures typically limit how their instances and relations between them can change over time, as opposed to Behaviors, which indicate how objects and their relations change. Structures and behaviors do not overlap, but structures can own behaviors, and the objects they classify can be involved in and perform behaviors.

A structure is declared as a classifier (see 7.3.3), using the keyword struct. If no owned superclassing is explicitly given for the structure, then it is implicitly given a default superclassing to the structure Object from the Objects library model (see 9.2.5).

If any of the types of a feature are structures, then all of them must be. If a feature has structure types, and no owned subsetting or owned redefinition is explicitly given in the feature declaration, then the feature is implicitly given a default subsetting to the feature objects from the Objects library model (see 9.2.5), unless at least one of the types is an association structure, in which case the default subsetting shall be as specified in 7.4.5.

```java
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.
}
```

### 7.4.5 Associations

Metamodel references:

- Concrete syntax, 8.2.5.4
- Abstract syntax, 8.3.4.4
• Semantics, 8.4.4.5

**Associations** are classifiers that classify *links* between things (see 9.2.3.1) At least two owned features of an association must be end features (see 7.3.4.2), its *association ends*, which identify the things being linked by (at the "ends" of) each link (exactly one thing per end, which might be the same thing). Associations with exactly two association ends are called *binary associations*. Associations can also have features that are not end features, which characterize each instance of the association separately from the things it links.

An association is declared as a classifier (see 7.3.3), using the keyword `assoc`. If no owned superclassing 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 9.2.3).

An association is also a relationship between the types of its association ends, which might be the same type, and are identified by its *related types*. Links are between instances of an association's related types. For binary associations, the two related types are identified as the *source type* and the *target type*, which might be the same. For associations with more than two association ends ("n-ary"), the first related type is the source type and all the remaining related types are target types.

The semantics of multiplicity is different for end features from that for non-end features (as described in 7.3.4.2). The end features of an association determine the *participants* in the links that are instances of the association and, as such, effectively have multiplicity of "1" relative to the association. But, if an association end has a multiplicity specified other than 1..1, then this is interpreted as follows: For each association end, the multiplicity, ordering and uniqueness constraints specified for that end apply to each set of instance of the association that have the same (single) values for each of the other ends. For a binary association, this corresponds to the multiplicity resulting from "navigating" across the association given a value at one end of the association to the other end of the association. (See also 8.4.4.5 on association semantics.)

If an association has a single superclassifier that is an association, it may inherit association ends from this superclassifier association. However, if it declares any owned association ends, then each of these must redefine an association end of the superclassifier association, in order, up to the number of association ends of the superclassifier. If no redefinition is given explicitly for an owned association end, then it is considered to implicitly redefine the association end at the same position, in order, of the superclassifier Association (including implicit defaults), if any.

```plaintext
assoc Ownership { // Specializes Links::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.
}
```

If an association has more than one superclassifier that is an association, then the association *must* declare a number of owned association ends at least equal to the maximum number of association ends of any of its superclassifier associations. Each of these owned association ends must then redefine the corresponding association end (if any) at the same position, in order, of each of the superclassifier associations.

**Association structures** are both associations and structures (see 7.4.4 on structures), classifying *link objects*, which are both links and objects (see 9.2.5.1 on objects). As objects, link objects can be created and destroyed, and their non-end features can change over time. However, the values of the end features of a link object are fixed and cannot change over its lifetime (that is, they are effectively *read only*, see also 7.3.4.2).
An association structure is declared like a regular association, but using the keyword `assoc struct`. An association structure must directly or indirectly specialize the base associations structure `LinkObject`. If this is not the case due to the explicit owned superclassifications in its declaration, then it is implicitly given a default superclassing to either the association structure `BinaryLinkObject` (if it is a binary association structure) or the association structure `LinkObject` (otherwise), both of which are from the `Objects` library model (see 9.2.5). The same rules on association ends described above for associations also apply to association structures. An association structure may specialize an association that is not an association structure, but all subclassifications of an association structure must be association structures.

```cpp
// Also implicitly specializations Objects::BinaryLinkObject.
assoc struct ExtendedOwnership specializes Ownership {
    // End features are inherited from Ownership.
    // The values of the feature "revaluations" may change over time.
    feature revaluations[*] ordered : MonetaryValue;
}
```

If a feature has one or more association types, then its owned end features follow the same rules for redefinition of the association ends of its association types as described above for the redefinition of the association ends of superclassifications associations by a subclassifier association. If a feature declaration has no explicit owned subsettings or owned redefinitions, and any of its types are binary associations, then the feature is implicitly given a default subsetting to the feature `binaryLinks` from the `Links` library model (see 9.2.3) or to the feature `binaryLinkObjects` from the `Objects` library model (see 9.2.5), if any of the associations are association structures. 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` library model (see 9.2.3) or to the feature `linkObjects` from the `Objects` library model (see 9.2.5), if any of the associations are association structures.

### 7.4.6 Connectors

#### 7.4.6.1 Connectors Overview

**Metamodel references:**

- *Concrete syntax*, 8.2.5.5
- *Abstract syntax*, 8.3.4.5
- *Semantics*, 8.4.4.6

Connectors are features that are typed by associations (see 7.4.5), having values that are links (see 9.2.3.1). Like an association, a connector has end features, known as its connector ends. Each connector end redefines an association end from each of the associations that type the connector and subsets a feature that becomes a related feature of the connector. Connectors typed by binary associations are called binary connectors.

A connector is also a relationship between its related features. For binary connectors, the two related features are identified as the *source feature* and the *target feature*, which might be the same. For connectors with more that two connector ends ("n-ary"), the first related feature is the source feature and all the remaining related features are target features.

Connectors can be thought of as "instance-specific" associations, because their values (which are links) are each limited to linking things identified via related features on the same instance of the connector's domain (or by things identified by that instance, recursively, see below). For example, an association could be used to model an engine driving wheels, and to type a connector in the car model. This connector specifies an engine driving wheels only in the same car, not in another car, as would be allowed with just the association.

Specifically, the values (links) of a connector are restricted to those that link things

1. classified by the types of its association ends, regardless of the domain of the connector
For example, if the wheels in a car are taken to be part of its drive train, rather than part of the car directly, then the engine in each car will drive wheels identified by that car's drive train, rather than a feature of the car directly. This requires that each related feature of a connector have some featuring type of the connector as a direct or indirect featuring type (where a feature with no featuring type is treated as if the classifier Anything was its featuring type). In particular, this condition is satisfied if a connector has an owned type that either also directly owns the related features of the connector or from which the related features can be reached by chaining (see 7.3.4.6). Otherwise, explicit owned type featurings (see 7.3.4.8) should be used to ensure that the connector has a sufficiently general domain.

**Binding connectors** are binary connectors that require their source and target features to have the same values on each instance of their domain. They are typed by the library association SelfLink (which only links things in the modeled universe to themselves, see 9.2.3.1) and have end multiplicities of exactly 1. This requires a SelfLink to exist between each value of the source feature and exactly one value of the target feature, and vice-versa.

To be meaningful, the declared co-domains of the related features of a binding connector must at least overlap. Since the interpretations of data types are disjoint from those of classes, this means that a feature typed by data types can only be bound to another feature typed by data types. In the determination of the equivalence of such features, indistinguishable data values are considered equivalent. The binding of features typed by classes to another feature typed by classes, on the other hand indicates that the same occurrences play the roles represented by each of the related features.

**Successions** are binary connectors requiring their source and target features to identify Occurrences that are ordered in time. They are typed by the library association HappensBefore (see 9.2.4.1), which links occurrences that happen completely separately in time, with the connector's source feature being the earlier occurrence and the target feature being the later occurrence.

### 7.4.6.2 Connector Declaration

A connector is declared as a feature (see 7.3.4.2) using the keyword `connector`. If no owned subsetting or owned redefinition is explicitly given for a connector, and none of its types are association structures, then the connector is implicitly given a default subsetting to the feature binaryLinks from the Links library model (see 9.2.3), if it is a binary connector, or to the feature links from the Links library model, otherwise. If at least one of the types of a connector is an association structure, then the default subsetting is instead to the feature binaryLinkObjects from the Objects library model (see 9.2.5), if it is a binary connector, or to the feature linkObjects from the Objects library model, otherwise.

In addition, a connector declaration includes connector end features that reference the features related by the connector. The connector ends may either be owned by the connector or inherited from the associations that type it or other connectors that it subsets (see also the description of association ends in 7.4.5). Each owned end of a connector redefines the end at the corresponding position (if any) of each of the associations or connectors it specializes. A connector with more than two ends can also have more ends than any of its supertypes. However, a connector that specializes a binary association or connector must itself be binary, with exactly two ends.

The related feature referenced by a connector end is specified using the keyword `references` or the equivalent symbol `::>`. The number of connector ends is the same as the number of related features (including duplicates).

```plaintext
// Specializes Objects::BinaryLinkObject by default.
assoc struct Mounting {
    end feature mountingAxle[1] : Axle;
}
```
struct WheelAssembly {
    composite feature axle[1] : Axle;

    // Subsets Objects::binaryLinkObjects by default.
    connector mount[2] : Mounting {
        end feature mountingAxle references axle;
        end feature mountedWheel references wheels;
    }
}

The **references** notation indicates that connector end features have *reference subsetting* relationships to the features related by the connector. Reference subsetting has the same semantics as regular subsetting (see 7.3.4.4) but is used to syntactically differentiate one of the owned subsettings of a feature. While reference subsetting is used primarily for connector ends in KerML, it can actually be specified as an owned subsetting in the declaration of any kind of feature, using the **references** or **::>** symbol. A feature is allowed to have at most one owned subsetting that is a reference subsetting.

```plaintext
struct WheelAssembly {
    composite feature axle[1] : Axle {
    }
    connector mount[2] : Mounting {
        end mountingAxle references axle;
        end mountedWheel references wheels subsets mountingAxle.mountedWheels;
    }
}
```

Instead of explicitly declaring connector ends in the body of the connector, they can be listed between parentheses, after the regular feature declaration part and before the body of the connector (if any). In this case, the end declarations are limited to be of the form \( e \ references f \) or \( e \ ::> f \), where \( e \) is the name of an association end and \( f \) is the qualified name of a related feature.

```plaintext
struct WheelAssembly {
    composite feature axle[1] : Axle;
    connector mount[2] : Mounting (axle, wheels);
}
```

The association end names can also be omitted, in which case the connector ends are matched in order to corresponding association ends.

```plaintext
struct WheelAssembly {
    composite feature axle[1] : Axle;
    connector mount[2] : Mounting (axle, wheels);
}
```

By default, the connector ends of a connector are declared in the same order as the association ends of the types of the connector. However, if the connector has a single type, then the related features can be given in any order, with each related feature paired with an association end of the type using a notation of the form \( e \ references f \) or \( e \ ::> f \).
where $e$ is the name of an association end and $f$ is the qualified name of a related feature. In this case, the name of each association end must appear exactly once in the list of connector end declarations.

A special notation can be used for a binary connector, in which the source related feature is referenced after the keyword `from`, and the target related feature is referenced after the keyword `to`.

```plaintext
struct WheelAssembly {
    composite feature axle[1] : Axle;
    connector mount : Mounting from axle to wheels;
}
```

If a binary connector declaration includes only the related features part, then the keyword `from` can be omitted.

```plaintext
struct WheelAssembly {
    composite feature axle[1] : Axle;
    // Subsets Links::binaryLinks by default.
    connector axle to wheels;
}
```

If a binary connector has a single type, then the names of the association ends of the type can also be used in the declaration of the connector ends in the special notation for binary connectors. However, since the connector ends are always declared in order from source to target in this notation, the association end names given must match those from the type in the order they are declared for that type.

```plaintext
struct WheelAssembly {
    composite feature axle[1] : Axle;
    connector mount[2] : Mounting
        from mountingAxle ::> axle
        to mountedWheel ::> wheels;
}
```

In any of the above notations, a multiplicity can be specified for a connector end, after the qualified name of the related feature for that end. In this case, the given multiplicity redefines the multiplicity that would otherwise be inherited from the association end corresponding to the connector end.

```plaintext
struct WheelAssembly {
    // Connects each one of the halfAxles to a different one of the wheels.
    connector mount : Mounting from halfAxles[1] to wheels[1];
}
```

Note that, if a connector is an owned feature of a type (as above), the context consistency condition for the related features of the connector (see 7.4.6.1) requires that these features also be directly or indirectly nested within the owning type. The feature chain dot notation (see 7.3.4.6) should be used when connecting so-called "deeply nested" features.

While the resolution of a feature chain is similar to a qualified name, the feature path contextualizes the resolution of the final feature. Thus, for example, while the qualified name `axle::halfAxles` statically resolves to `Axle::halfAxles`, in the Feature chain `axle.halfAxles`, `halfAxles` is understood to be specifically the feature as nested in `axle`. 
7.4.6.3 Binding Connector Declaration

A binding connector is declared as a feature (see 7.3.4.2) using the keyword binding. In addition, a binding connector declaration gives, after the keyword of, the qualified names of the two related features that are bound by the binding connector, separated by the symbol =, after the regular feature declaration part and before the body of the binding connector (if any). If no owned subsetting or owned redefinition is explicitly given, then the binding connector is implicitly given a default subsetting to the feature selfLinks from the Links library model (see 9.2.3). Note that, due to this default subsetting, if no type is explicitly given for a binding connector, then it will implicitly have the type SelfLink (the type of selfLinks).

```
struct Vehicle {
    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 binding connector declaration includes only the related features part, then the keyword of can be omitted.

```
struct Vehicle {
    composite feature fuelTank {
        out feature fuelFlowOut : Fuel;
    }

    composite feature engine {
        in feature fuelFlowIn : Fuel;
    }

    binding fuelTank.fuelFlowOut = engine.fuelFlowIn;
}
```

The connector ends of a binding connector always have multiplicity 1..1.

(See also 7.4.11 on the use of binding connectors with feature values.)
7.4.6.4 Succession Declaration

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 feature after the keyword `first` and the qualified name of the target feature after the keyword `then`. If no owned subsetting or owned redefinition is explicitly given, then the succession is implicitly given a default subsetting to the feature `happensBeforeLinks` from the `Occurrences` library model (see 9.2.4). 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 `happensBeforeLinks`).

```plaintext
behavior TakePicture {
  composite step focus : Focus;
  composite step shoot : Shoot;
  succession controlFlow first focus then shoot;
}
```

If a succession declaration includes only the related features part, then the keyword `first` can be omitted.

```plaintext
behavior TakePicture {
  composite step focus : Focus;
  composite step shoot : Shoot;
  succession focus then shoot;
}
```

As for connector ends on regular connectors, constraining multiplicities can also be defined for the connector ends of successions.

```plaintext
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];
}
```

7.4.7 Behaviors

7.4.7.1 Behaviors Overview

Metamodel references:

- Concrete syntax, 8.2.5.6
- Abstract syntax, 8.3.4.6
- Semantics, 8.4.4.7

Behaviors are classes that classify performances, which are kinds of occurrences that can be spread out in disconnected portions of space and time (see 9.2.6). The performance of behaviors can cause effects on other things, including their existence and relations, some of which might be accepted as input to or provided as output from the behavior.

Behaviors can have steps, which are features typed by behaviors, allowing the containing behavior to coordinate the performance of other behaviors. Steps can be ordered in time using succession connectors (see 7.4.6.4). They can also be connected by item flows to model things flowing between the output of one step and the input of another. Steps can also nest other steps to augment or redefine steps inherited from their behavior types.
7.4.7.2 Behavior Declaration

A behavior is declared as a classifier (see 7.3.3), using the keyword `behavior`. If no owned superclasiing is explicitly given for the behavior, then it is implicitly given a default superclasiing to the behavior `Performance` from the `Performances` library model (see 9.2.6).

Features declared in the body of a behavior with a non-null direction (see 7.3.4.2) are considered to be the owned parameters of the behavior. Features with direction `in` are input parameters, those with direction `out` are output parameters, and those with direction `inout` are both input and output parameters.

```
// Specializes Performances::Performance by default.
behavior TakePicture {
    in scene : Scene;
    out picture : Picture;
}
```

Parameters are ordered in the lexical order they are declared in the body of a behavior. They may appear at any location within the body.

If a behavior has owned subclassifications whose superclasiifiers are behaviors, then each of the owned parameters of the subclassifier behavior must, in order, redefine the parameter at the same position of each of the superclasiifier 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 {
    in c1 redefines a1, b1;
    out c2 redefines a2, b2;
}
```

If there is a single superclasiifier behavior, then the subclassifier behavior can declare fewer owned parameters than the superclasiifier behavior, inheriting any additional parameters from the superclasiifier (which are considered to be ordered after any owned parameters). If there is more than one superclasiifier behavior, then every parameter from every superclasiifier must be redefined by an owned parameter of the subclassifier. If every superclasiifier parameter is redefined, then the subclassifier behavior may also declare additional parameters, ordered after the redefining parameters. If no redefinitions are given explicitly for a parameter, then the parameter is implicitly given owned redefinitions of superclasiifier 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 b1; out b2; inout b3; } // Redefinitions are implicit.
behavior C1 :> A1, B1 { in c1; out c2; inout c3; }
```

Steps (see 7.4.7.3) 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 superclasiifier Behavior.

```
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;
    composite step shoot : Shoot;
}
```
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;
    succession focus then shoot;
    composite flow focus.image to shoot.image;
    composite step shoot : Shoot;
    binding picture = shoot.picture;
}
```

### 7.4.7.3 Step Declaration

A step is declared as a feature (see 7.3.4.2) using the keyword `step`. If no owned subsetting or owned redefinition is explicitly given, then the step is implicitly given a default subsetting to the feature `performances` from the `Performances` library model (see 9.2.6).

As for a behavior, directed features declared in the body of a step are considered to be parameters of the step (see 7.4.7.2). If a step has owned specializations (including all feature typings, subsettings, and redefinitions), whose general type is a behavior or a step, then the rules for the redefinition of parameters of the behaviors and steps are the same as for the redefinition of the parameters of superclassifier behaviors by a subclassifier behavior (see 7.4.7.2).

```
step focus : Focus {
    // Parameters redefine parameters of Focus.
    in scene;
    out image;
}
```

// Parameters are inherited.
step refocus subsets focus;

A step can also have a body, which may have steps in it. A step can inherit or redefine steps from its behavior types or any other steps it subsets.

```
step takePictureWithAutoFocus : TakePicture {
    in feature unfocusedScene redefines scene;
    step redefines focus : AutoFocus;
    out feature focusedPicture redefines picture;
}
```

### 7.4.8 Functions

#### 7.4.8.1 Functions Overview

Metamodel references:

- Concrete syntax, 8.2.5.7
- Abstract syntax, 8.3.4.7
- Semantics, 8.4.4.8
Functions are behaviors (see 7.4.7) with one out parameter designated as the result parameter. Functions classify evaluations (see 9.2.6.2.3), which are kinds of performances that produce results as values of the result parameter. Like all behaviors, functions can change things, often referred to as "side effects". A pure function is one that has no side effects and always produces the same results given the same input values, similarly to a function in the mathematical sense. The numerical functions in the Kernel Function Library (see 9.4), for example, are pure functions.

Expressions are steps (see 7.4.7) typed by only a single function, which means that their values are evaluations. An expression whose value is an evaluation with results is said to evaluate to those results. They can be steps in any behavior, but a function, in particular, can designate one of its expression steps as the result expression that gives the value of its result parameter. Expressions can have their own nested parameters, to augment or redefine those of their functions, including the result parameter. They can also own other expressions and designate a result expression, similarly to a function. (See also 7.4.9 for more on expressions).

Predicates are functions whose result is a single Boolean value (that is, true or false). A predicate determines whether the values of its input parameters meet particular conditions at the time of its evaluation, resulting in true if they do, and false otherwise. Predicates classify boolean evaluations, which are specialized evaluations giving a Boolean result (see 9.2.6.2.1).

Boolean expressions are expressions whose function is a predicate and, so, evaluate to a Boolean result. A boolean expression might, in general, evaluate to true at some times and false at other times. An invariant, though, is a boolean expression that must always evaluate to either true at all times or false at all times. By default, an invariant is asserted to always evaluate to true, while a negated invariant is asserted to always evaluate to false.

7.4.8.2 Function Declaration

A function is declared as a behavior (see 7.4.7.2), using the keyword function. If no owned superclassing is explicitly given for a function, then it is implicitly given a default subclassification to the function Evaluation from the Performances library model (see 9.2.6). As for a behavior, any feature declared in the body of a function with an explicit direction is considered to be a parameter of the function. In addition, the result parameter of a function may be declared in its body by beginning the declaration with the keyword return (instead of a direction keyword).

```plaintext
// Specializes Performances::Evaluation by default.
function Velocity {
    in v_i : VelocityValue;
    in a : AccelerationValue;
    in dt : TimeValue;
    return v_f : VelocityValue;
}
```

If a function has owned subclassifications that are behaviors, then the rules for redefinition or inheritance of non-result parameters are the same as for a behavior (see 7.4.7.2). If some of the superclassifier behaviors are functions, then the result parameter of the subclassifier function must redefine the result parameters of the superclassifier functions. If, in this case, the result parameter of the subclassifier function has no owned redefinitions, then it is implicitly given redefinitions of the result parameter of each of the superclassifier functions.

```plaintext
abstract function Dynamics {
    in initialState : DynamicState;
    in time : TimeValue;
    return : DynamicState;
}

function VehicleDynamics specializes Dynamics {
    // Each parameter redefines the corresponding superclassifier parameter
    in initialState : VehicleState;
    in time : TimeValue;
}
```
The body of a function is like the body of a behavior (see 7.4.7.2), with the optional addition of the declaration of a result expression at the end. A result expression is always written using the Expression notation described in 7.4.9, not using the Expression declaration notation from 7.4.8.3. The result of the result expression is implicitly bound to the result parameter of the containing function.

```plaintext
function Average {
    in scores[1..*] : Rational;
    return : Rational;
    sum(scores) / size(scores)
}
```

Note. A result expression is written without a final semicolon.

The result of a function can also be explicitly bound, either using a binding connector (see 7.4.6.3) or a feature value on the result parameter declaration (see 7.4.11). In this case, the body of the function should not include a result expression.

```plaintext
function Average {
    in scores[1..*] : Rational;
    return : Rational = sum(scores) / size(scores);
}
```

7.4.8.3 Expression Declaration

An expression can be declared as a step (see 7.4.7.3) using the keyword `expr` (see also 7.4.9 for more traditional expression notation). If no owned subsetting or owned redefinition is explicitly given, then the expression is implicitly given a default subsetting to the feature `evaluations` from the `Performances` library model (see 9.2.6).

As for a step, directed features declared in the body of an expression are considered to be parameters of the expression (see 7.4.7.3). If an expression has owned specializations (including all feature typings, 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 are the same as for the redefinition of the parameters of superclassifier behaviors by a subclassifier function (see 7.4.8.2).

```plaintext
expr computation : ComputeDynamics {
    // Parameters redefined parameters of ComputeDynamics.
    in state;
    in dt;
    return result;
}
expr vehicleComputation subsets computation {
    // Input parameters are inherited, result is redefined.
    return : VehicleState;
}
```

Like a function body, an expression body can also specify a result expression.

```plaintext
expr : VehicleDynamics {
    in initialState;
    in time;
    return result;
}
```
vehicleComputation(initialState, time)
}

Or the result can be explicitly bound.

expr : Dynamics {
    in initialState;
    in time;
    return result : VehicleState = vehicleComputation(initialState, time);
}

7.4.8.4 Predicate Declaration

A predicate is declared as a function (see 7.4.8), using the keyword `predicate`. If no owned subclassification is explicitly given for a predicate, then it is implicitly given a default subclassification to the predicate `BooleanEvaluation` from the `Performances` library model (see 9.2.6). If a predicate has owned subclassifications that are behaviors, then the rules for redefinition or inheritance of non-result parameters are the same as for a function (see 7.4.8.2). Since a predicate must always return a Boolean result, it is not necessary to explicitly declare a result parameter for it. However, if a result parameter is declared, then it must have type `Boolean` from the `ScalarValues` library model (see 9.3.2) and multiplicity 1..1 (see 7.4.12).

predicate isAssembled {
    in assembly : Assembly;
    in subassemblies[*] : Assembly;
}

The body of a predicate is the same as a function body (see 7.4.8). If a result expression is included, then it must have a Boolean result.

predicate isFull {
    in tank : FuelTank;
    tank.fuelLevel == tank.maxFuelLevel
}

7.4.8.5 Boolean Expression and Invariant Declaration

A boolean expression is declared as an expression (see 7.4.8.3), using the keyword `bool`. If no owned subsetting or owned redefinition is explicitly given, then the boolean expression is implicitly given a default subsetting to the feature `booleanEvaluations` from the `Performances` library model (see 9.2.6).

As for an expression, directed features declared in the body of a boolean expression are considered to be parameters of the boolean expression (see 7.4.8.3). If a boolean expression has owned specializations (including all feature typings, 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 are the same as for a regular expression declaration (see 7.4.8.3). The requirements on, and default for, the result parameter of a boolean expression are the same as for a predicate (see 7.4.8.4).

// All input parameters are inherited.
bool assemblyChecks[*] : isAssembled;

Like a predicate body (see 7.4.8.4), a boolean expression body can specify a Boolean result expression.

class FuelTank {
    feature fuelLevel : Real;
    feature readonly maxFuelLevel : Real;
}
bool isFull { fuelLevel == maxFuelLevel }
}

An invariant is declared like any other boolean expression, except using the keyword \texttt{inv} instead of \texttt{bool}, and, additionally, this keyword may be optionally followed by one of the keywords \texttt{true} or \texttt{false}, to indicate whether the invariant is asserted to be true or false (i.e., is negated). The default is \texttt{true}.

class FuelTank {
  feature fuelLevel : Real;
  feature readonly maxFuelLevel : Real;
  // The invariant is asserted true by default.
  inv { fuelLevel >= 0 & fuelLevel <= maxFuelLevel }
  // The invariant is explicitly asserted false, that is, it is negated.
  inv false { fuelLevel > maxFuelLevel }
}

7.4.9 Expressions

7.4.9.1 Expressions Overview

Metamodel references:

- Concrete syntax, 8.2.5.8
- Abstract syntax, 8.3.4.8
- Semantics, 8.4.4.9

As described in 7.4.8, expressions are steps typed by functions, and 7.4.8.3 covers the general notation for declaring an expression as a step. However, expressions are commonly organized into tree structures, with expressions as the nodes, and the input parameters of each expression bound to the result of each of its child expressions. KerML includes extensive textual notation for constructing expression trees, including traditional operator notations for functions in the Kernel Model Library (see Clause 9).

These expression notations map entirely to an abstract syntax involving just a few specialized kinds of expressions:

- The non-leaf nodes of an expression tree are \textit{invocation expressions}, a kind of expression that specifies its input values as the results of other expressions (its \textit{argument} expressions), one for each of the input parameters of its \textit{invoked} function.
- The edges of the tree are binding connectors between the input parameters of an invocation expression (redefining those of its \textit{function}) and the results of its argument expressions.
- The leaf nodes are these kinds of expressions:
  - \textit{Feature reference expressions} evaluate to values of a referenced feature that is not part of the expression tree.
  - \textit{Literal expressions} evaluate to the literal value of one of the primitive data types from the \texttt{ScalarValues} model library (see 9.3.2).
  - \textit{Null expressions} evaluate to the empty set.

An expression can also be the referent of a feature reference expression in an expression tree, as above. This enables the evaluation of the referent expression to be taken as the value of the argument of an invocation, rather than passing the value of the \textit{result} of the evaluation. As a shorthand for doing this, the concrete syntax for an expression body (as described in 7.4.8.3) can be used as a leaf node in the expression syntax tree.

A \textit{model-level evaluable} expression is an expression that refers to metadata, which is data about model elements, rather than the things being modeled. Model-level evaluable expressions can give values to the features of metadata (see 7.4.13) and be used as element filtering conditions in packages (see 7.4.14). The expressiveness of model-level evaluable expressions is restricted to support this:
• All null expressions, literal expressions and feature reference expressions are model-level evaluable.
• An invocation expression is model-level evaluable if and only if it meets the following conditions:

1. All its argument expressions are model-level evaluable.
2. It invokes a function that is listed as being model-level evaluable in Table 5 (in 8.2.5.8.1) or Table 7 (in 8.2.5.8.2).

7.4.9.2 Operator Expressions

Operator expression notation provides a shorthand for invocation expressions that invoke a library function represented as an operator symbol. (Table 5 in 8.2.5.8.1 shows the mapping from operator symbols to the functions they represent from the Kernel Model Library.) An operator expression contains subexpressions called its operands that generally correspond to the argument expressions of the invocation expression, except in the case of operators representing control functions, in which case the evaluation of certain operands is as determined by the function.

Operator expressions include the following:

• **Conditional expressions.** The conditional test operator if is followed by three operands, with the symbol ? after the first operand and the keyword else after the second operand. A conditional expression evaluates to the value of its second or third 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.

```plaintext
if x >= 0? x else -x
```

• **Binary operator expressions.** A binary operator is one that has two operands. The binary operators include numerical operators (+, -, *, /, %, ^, **), logical operators (&&, ||, xor), comparison operators (==, !=, <, >, <=,>=,===, !==), and the range construction operator (..). In general, both operands become arguments of the invocation expression, with their results being passed to the invocation of the function represented by the operator. However, the null-coalescing (?), conditional and (and), conditional or (or) and implication (implies) operators all correspond to control functions 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, false, or true, respectively).

```plaintext
x + y
list#(i) ?? default
i > 0 and sensor#(i) != null
sensor == null or sensor.reading > 0
```

The operators == and != apply to operands that have single values, testing whether they are equal or unequal, respectively. They also evaluate to true or false, respectively, if their operands are both null (no values). The operators === and !== apply specifically to values that are occurrences (see 9.2.4). They test whether two occurrences are portions (in space and/or time) of the same life occurrence. Informally, these operators test whether or not two occurrences have the same "identity". For data values (values that are not occurrences), === and !== are the same as == and !=.

```plaintext
currentPortion == tripPortion // True for same trip portions
currentPortion === tripPortion // True for any two portions of same trip
```

• **Unary operator expressions.** A unary operator is one that has a single operand. The result of evaluating the operand is passed to the invocation of the Function represented by the operator. The unary operators include the numerical operators + and − and the logical operator not.

```plaintext
-x
not isOutOfRange(sensor)
not completed
```
• **Classification expressions.** The *classification operators* are syntactically similar to binary operators, but, instead of an expression as their second operand, they take a type name. The classification operators `istype` and `hastype` test whether all of the values of their first operand is classified by the named type (either including or not including subtypes, respectively). The `@` operator is similar to `istype`, but tests whether at least one of the values of its first operand is classified by the named type. Note that this means that `istype` and `hastype` evaluate to true on a `null` (empty list) value, while `@` evaluates to false.

```
sensors istype ThermalSensor // Are all sensors ThermalSensors?
sensors @ ThermalSensor // Is any sensor a ThermalSensor?
person hastype Administrator
```

The classification operator `as`, known as the *cast operator*, performs an `istype` test of whether each of the values of its first operand is classified by the named type, and then it selects only those values that pass the test to include in its result. The result values of such a cast expression (if any) are always guaranteed to be instances of the named type.

```
sensors as ThermalSensor
person as Administrator
```

The classification operators may also be used without a first operand, in which case the first operand is implicitly `Anything::self` (see 9.2.2.2.1). This is useful, in particular, when used as a test within an element filter condition expression (see 7.4.14).

```
istype ThermalSensor
@ThermalSensor
hastype Administrator
as Supervisor
```

• **Metaclassification expressions.** The metaclassification operators `@@` and `meta` take the qualified name of any kind of element as their first operand and a metaclass (see 7.4.13) as their second operand. They are shorthands for classification expressions with the operators `@` and `as`, respectively, and a metadata access expression (see 7.4.9.4) as their first operand. As such, `@` tests whether any metadata associated with an element are classified by the given metaclass, while `meta` filters the metadata associated with an element and evaluates to those that are classified by the given metaclass.

```
// Shorthand for designModel.metadata @ ApprovalAnnotation
designModel @@ ApprovalAnnotation

// Shorthand for sensors.metadata as KerML::Feature
sensors meta KerML::Feature

// Evaluates to the string "sensors".
(sensors meta KerML::Feature).name
```

• **Extent expressions.** 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
```

In an operator expression containing nested operator expressions, the nested expressions are implicitly grouped according to the *precedence* of the operators involved, as given in Table 6 (in 8.2.5.8.1). Operator expressions with higher precedence operators are grouped more tightly than those with lower precedence operators. In addition, all binary operators other than exponentiation group to the left. The exponentiation operators (`^` and `**`) group to the right. For example, the operator expression

```
-w + x * y * z + a ^ b ^ c
```
is considered equivalent to

\[
( -w) + ( (x * y) * z ) + ( a ^ (b ^ c) )
\]

7.4.9.3 Primary Expressions

Primary expression notation provides additional shorthands for certain kinds of invocation expressions. For those cases in which the invoked function is represented by an operator symbol, the symbol is mapped to the appropriate library function as given in Table 7 (in 8.2.5.8.2).

Primary expressions include the following:

- **Index expression.** An index expression specifies the invocation of the indexing function '#' from the BaseFunctions library model (see 9.4.2). The default behavior for this function is given by the specialization SequenceFunctions::'#', for which the first operand 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. Note that parentheses are required around the second operand.

  \[
  \text{sensors#(activeSensorIndex)}
  \]

  However, the behavior of the '#' operator is specialized for the OrderedCollection (see 9.3.3.2.7) and Array (see 9.3.3.2.1) data types from the Collections library model. In this case, the first operand must be a single value of one of these data types. For an Array, the second operand is a sequence of indexes whose size is the rank of the Array (i.e., the number of dimensions of the Array).

  \[
  \text{detectorArray#(n, m)}
  \]

- **Sequence expression.** A sequence expression consists of a list of one or more expressions separated by comma (,) symbols, optionally terminated by a final comma, all surrounded by parentheses (...). Such an expression specifies sequential invocations of the sequence concatenation function ',' from the BaseFunctions library model (see 9.4.2). The default behavior for this Function is given by the specialization SequenceFunctions::',', which concatenates the sequence of values resulting from evaluating its two arguments. With this behavior, a sequence expression concatenates, in order, the results of evaluating all the listed expressions.

  \[
  \text{(temperatureSensor, windSensor, precipitationSensor)}
  \]

  \[
  ( 1, 3, 5, 7, 11, 13, )
  \]

  A sequence expression with a single constituent expression simply evaluates to the value of the contained expression, as would be expected for a parenthesized expression. The empty sequence () is not actually a sequence expression, but, rather, an alternative notation for a null expression (see 7.4.9.4).

  \[
  (\text{highValue + lowValue}) / 2
  \]

  Sequences of values are not themselves values. Therefore, sequences are “flat”, with no element of a sequence itself being a sequence. For example, \((1, 2, 3, 4), (1, 2, 3, 4)\) and \((1, 2, 3, 4)\) all evaluate to the same sequence of values as \((1, 2, 3, 4)\). To model nested collection values, use the data types from the Collections library model (see 9.3.3).

- **Feature chain expression.** A feature chain expression consists of a primary expression and a feature qualified name or a feature chain (7.3.4.6), separated by a dot (.) symbol. The referenced feature is evaluated in the context of each of the result values of the primary expression, in order. The resulting feature values are then collected into a sequence in order of evaluation. The qualified name for the referent feature is resolved using the result parameter of the primary expression as the context namespace (see 8.2.3.5), but considering only visible memberships.
The primary expression is "getPlatform(id)".
The feature chain is "sensors.isActive".
Results in a sequence of Boolean values,
one for each platform sensor.
getPlatform(id).sensors.isActive

To avoid ambiguity, the primary expression of a feature chain expression cannot be itself a feature chain expression. To read a list of features sequentially, rather than in a single evaluation, delimit nested feature chain expressions using parentheses

getPlatform(id).sensors.isActive

Collect expression. A collect expression consists of a primary expression and an expression body (see 7.4.9.4) separated by a dot (.) symbol. The expression body must have a single input parameter. The expression body is evaluated on each of the result values from the primary expression, in order, and each of the results are collected into a sequence in order of evaluation (that is, a collect expression is a shorthand for invoking the ControlFunctions::collect function).

sensors.{in s: Sensor; s.reading} // results in a sequence of readings of each of the sensors

Select expression. A select expression consists of a primary expression and an expression body (see 7.4.9.4) separated by a dot-question-mark (? symbol. The expression body must have a single input parameter and a Boolean result. The expression body is evaluated on each of the result values from the primary expression, in order, and those for which the expression body evaluates to true are selected for inclusion in the result of the select expression (that is, a select expression is a shorthand for invoking the ControlFunctions::select function).

sensors.?{in s: Sensor; s.isActive} // results in the subsequence of sensors that are active

Function operation expression. A function operation expression is a special syntax for an invocation expression in which the first argument is given before the arrow (->) symbol, which is followed by the name of the function to be invoked and an argument list for any remaining arguments (see 7.4.9.4). This is useful for chaining invocations in an effective data flow.

sensors -> selectSensorsOver(limit) -> computeCriticalValue()

If the invoked function has exactly two input parameters, and the second input parameter is an expression, then an expression body (see 7.4.9.4) can be used as the argument for the second argument without surrounding parentheses. The argument expression body should declare parameters consistent with those on the parameter expression (if any). This is particularly useful when invoking functions from the ControlFunctions library model (see 9.4.17).

sensors -> select {in s: Sensor; s::isActive}
members -> reject {in member: Member; not member->isInGoodStanding()}
factors -> reduce {in x: Real; in y: Real; x * y}

If the argument expression is simply the direct invocation of another function, then the argument expression may be specified using simply the name of the invoked function.

factors -> reduce RealFunctions::*
7.4.9.4 Base Expressions

**Base expression** notation includes representations for literal expressions, null expressions, invocation expressions, feature reference expressions (including using expression bodies as base expressions).

- **Literal expressions** are described in 7.4.9.5.
- A **null expression** is notated by the keyword `null`. A null expression always evaluates to a result of "no values", which is equivalent to the empty sequence `()`.
- An **invocation expression** 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 `()` and separated by commas. The parentheses must be included, even if the argument list is empty.

```
IntegerFunctions::'+'(i, j)
isInGoodStanding(member#(n))
AddMember(org, member)
```

The arguments are matched to the input parameters of the given function in order. Alternatively, the arguments may be matched to parameters by name, using the form `paramName = argExpression`, in which case they may be given in any order. Note that, if the named argument notation is used, it must be used for all arguments.

```
AddMember(newMember = member, organization = org)
```

If the qualified name given for an invocation expression resolves to an expression instead of a function, then the invocation expression is considered to subset the named expression, meaning that, effectively, the invocation is taken to be for the function of the named expression, as specialized by that expression.

```
function UnaryFunction { in x : Anything; return: Anything; }
function apply {
    in expr fn : UnaryFunction;
    in value : Anything;

    // Invokes UnaryFunction as specified by parameter fn.
    return : Anything = fn(value);
}
```

It is also possible to specify an expression to be invoked using a feature chain (see 7.3.4.6).

```
class Stats {
    feature vales[1..*] : Real;
    expr avg { sum(values)/size(values) }
}
feature myStats : States {
    redefines feature values = (1.0, 2.0, 3.0);
}
feature myAvg = myStats.avg();
```

- A **construction expression** is an invocation expression in which the invocation target is a classifier that is not a function. In this case, the result of the construction expression is a new instance of the target classifier, with the results of the argument expressions bound to the public features of the type, in order or by name.

```
class Member {
    feature firstName : String;
    feature lastName : String;
    feature memberNumber : Integer;
    feature sponsor : Member[0..1];
}
```
```java
feature thisMember = Member("Jane", "Doe", 1234, null);
feature nextMember = Member(
    firstName = "John", lastName = "Doe", sponsor = thisMember,
    memberNumber = thisMember.memberNumber + 1);
```

- A feature reference expression is represented simply by the qualified name of the feature being referenced.

```java
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.

```java
expr
addOne : UnaryFunction {
    if x istype Integer? (x as Integer) + 1 else 0
}
feature
two = apply(addOne, 1); // "addOne" is a reference to expr addOne
```

Rather than declaring a named expression in order to pass it as an argument, an expression body may be used directly as a base expression. In this case, any parameters must be declared as features with direction within the expression body (see 7.4.8.3). Such body expressions are particularly useful when used for the second argument of a function operation expression (see 7.4.9.3).

```java
feature
two =
    apply({
        in x;
        if x istype Integer? (x as Integer) + 1 else 0}, 1);
feature
incrementedValues =
    values -> collect {in x: Number; x + 1};
```

- A metadata access expression is represented by suffixing the qualified name of any kind of element with the notation .metadata. This is a reflective expression that evaluates to the sequence of metadata features associated with the named element in the model itself, as instances of their respective metaclasses (see 7.4.13 on metadata and metaclasses). In addition, the last value in the sequence is an instance of the metaclass for the named element from the KerML reflective abstract syntax model (see 9.2.17), representing its instantiation as a model element.

```java
metaclass
SecurityAnnotation;
class
SecureSystem {
    metadata
        SecurityAnnotation;
}
```

// Two values: an instance of SecurityAnnotation
// and an instance of type KerML::Class.
```java
feature
sysMetadata = SecureSystem.metadata;
```

### 7.4.9.5 Literal Expressions

A literal expression is represented by giving a lexical literal for the value of the expression.

- A literal Boolean is represented by either of the keywords `true` or `false`.
- A literal string is represented by a lexical string value surrounded by double quotes "…" as specified in 8.2.2.5.

"This is a string literal."
• A literal integer is represented by a lexical decimal value as specified in 8.2.2.4. 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 7.4.9.2) to an unsigned decimal literal.

0
1234

• A literal rational is represented with a syntax constructed from lexical decimal values and exponential values (see 8.2.2.4). The full rational 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 literal infinity is represented by the symbol *.

7.4.10 Interactions

7.4.10.1 Interactions Overview

Metamodel references:

• Concrete syntax, 8.2.5.9
• Abstract syntax, 8.3.4.9
• Semantics, 8.4.4.10

Interactions are behaviors that are also associations (see 7.4.7 and 7.4.5, respectively), classifying performances that are also links between occurrences (see 9.2.3 through 9.2.6). They specify how the linked participants affect each other and collaborate.

Transfers are interactions between two participants that carry items from one occurrence to another, with items optionally identified by output and input features of the source and target occurrence, respectively (see 9.2.7).

Item flows are steps that are also binary connectors (see 7.4.7 and 7.4.6, respectively), with values that are transfers. An item flow optionally ensures that items are transferred from an output feature of the connected source feature to an input feature of the target feature. Succession item flows are item flows that are also successions (see 7.4.6). They identify transfers that happen after their source (that is, after the end of the occurrence where the items come from) and before their target (that is, before the start of the occurrence where the items go to).

7.4.10.2 Interaction Declaration

An interaction is declared as a behavior (see 7.4.7), using the keyword interaction. If no owned subclassification is explicitly given for the interaction, then it is implicitly given default subclassifications to both the behavior Performance from the Performances library model (see 9.2.6) and the association BinaryLink or the association Link from the Links library model (see 9.2.3), depending on whether it is a binary interaction or not.

As a kind of behavior, if the interaction has owned subclassifications whose superclasses are behaviors, then the rules related to their parameters are the same as for any subclassifier behavior (see 7.4.7). As a kind of association, the body of an interaction must declare at least two association ends. If the interaction has owned subclassifications whose superclasses are associations, the rules related to their association ends are the same as for any association that is a subclassifier (see 7.4.5).

interaction Authorization {
  end feature client[*] : Computer;}
end feature server[*] : Computer;
composite step login;
composite step authorize;
composite succession login then authorize;
}

7.4.10.3 Item Flow Declaration

An item flow declaration is syntactically similar to a binary connector declaration (see 7.4.6), using the keyword `flow`, or `succession flow` for a succession item flow. If no owned subsetting or owned redefinition is explicitly given, then the item flow is implicitly given a default subsetting to the item flow `transfers` from the Transfers model library (see 9.2.7), or to the succession item flow `transfersBefore`, if a succession item flow is being declared. If an item flow has owned specializations (including all feature typings, 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 are the same as for the redefinition of the parameters of general behavior or step by a specializing step (see 7.4.7.3).

Unlike a regular binary connector declaration, though, an item flow declaration does not directly specify the related features for the item flow. Instead, the declaration gives the `source output` feature for the transfer after the keyword `from` and the `target input Feature` for the transfer after the keyword `to`. The related features are then determined as the owning features of the features given in the item flow declaration. It is these related features that are constrained to have a common context with the item flow (see 7.4.6), not the features actually given in the declaration.

```plaintext
struct Vehicle {
  composite feature fuelTank[1] {
  }
  composite feature engine {
    in feature fuelIn[1] : Fuel;
  }
  // The item flow actually connects the fuelTank to the engine.
  // The transfer moves Fuel from fuelOut to fuelIn.
  flow fuelFlow from fuelTank::fuelOut to engine::fuelIn;
}
```

The source output and target input features of an item flow can also be specified using feature chains (see 7.3.4.6). In this case, the related features are determined as the features identified by the chains, excluding the last feature. This is particularly useful when the desired related features are inherited features.

```plaintext
struct Vehicle {
  composite feature fuelTank[1] {
  }
  composite feature engine[1] {
    in feature fuelIn[1] : Fuel;
  }
}

feature vehicle : Vehicle {
  // The item flow actually connects the inherited fuelTank
  // feature to the inherited engine feature.
  flow fuelFlow from fuelTank.fuelOut to engine.fuelIn;
}
```

An item flow 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 item flow have the declared type. In the
absence of an item declaration, any values may flow across the item flow, consistent with the types of the source output and target input features.

    flow of flowingFuel : Fuel from fuelTank.fuelOut to engine.fuelIn;

If no feature declaration or item declaration details are included in an item flow declaration, then the keyword from may also be omitted.

    flow fuelTank.fuelOut to engine.fuelIn;

Item flows 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[1] : Image; }
        composite step shoot : Shoot { in image[1] : Image; }
        // The use of a succession item flow means that focus must complete before
        // the image is transferred, after which shoot can begin.
        succession flow focus.image to shoot.image;
    }

7.4.11 Feature Values

Metamodel references:

• Concrete syntax, 8.2.5.10
• Abstract syntax, 8.3.4.10
• Semantics, 8.4.4.11

A feature value is a membership relationship (see 7.2.5) between an owning feature and a value expression, whose result provides values for the feature. The feature value relationship is specified as either bound or initial, and as either fixed or a default. A feature can have at most one feature value relationship.

A fixed, bound feature value relationship is declared using the symbol = followed by a representation of the value expression using the concrete syntax described in 7.4.9. This notation is appended to the declaration of the owning feature of the feature value.

    feature monthsInYear : Natural = 12;
    struct TestRecord {
        feature scores[1..*] : Integer;
        derived feature averageScore[1] : Rational = sum(scores)/size(scores);
    }

Features that have a feature value relationship of this form implicitly have a nested binding connector (see 7.4.6) between the feature and the result of the value expression, with the binding connector having the same featuring types as the declared feature (i.e., TestRecord, in the example above).

Note. The semantics of binding mean that such a feature value asserts that a feature is equivalent to the result of the value expression. To highlight this, a feature with such a feature value 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 feature value – see also 7.3.4.2).

A fixed, initial feature value relationship is declared as above but using the symbol := instead of =.

    feature count[1] : Natural := 0;
In this case, the feature also has an implicit nested binding connector, but the featuring types of the binding connector are the starting snapshots of the featuring types of the declared feature. That is, the result of the value expression gives the initial values of the declared feature but, unlike in the case of a bound value, these initial values may subsequently change.

A default feature value relationship is declared similarly to the above, but with the keyword default preceding the symbol = or :=, depending on whether it is bound or initial. However, for a default, bound feature value, the symbol = may be elided.

```plaintext
struct Vehicle {
    feature mass[1] : Real default 1500.0;
}
struct TestWithCutoff :> TestRecord {
    feature cutoff[1] : Rational default = 0.75 * averageScore;
}
```

For a default feature value relationship, no binding connector is added to the feature declaration, but the default will apply when an instance of the featuring type is constructed, if no other explicit values are given for the feature.

A feature value relationship can be included with the following kinds of feature declaration:

- Feature (see 7.3.4.2)
- Step (see 7.4.7.3)
- Expression (see 7.4.8.3)
- Boolean expression and invariant (see 7.4.8.5)

```plaintext
behavior ProvidePower {
    in cmd[1] : Command;
    out wheelTorque[1] : Torque;
    composite step generate : GenerateTorque {
        in cmd = ProvidePower::cmd;
        out generatedTorque;
    }
    composite step apply : ApplyTorque {
        in generatedTorque = generate.generatedTorque;
        out appliedTorque = ProvidePower::wheelTorque;
    }
}
```

### 7.4.12 Multiplicities

**Metamodel references:**

- Concrete syntax, 8.2.5.11
- Abstract syntax, 8.3.4.11
- Semantics, 8.4.4.12

Multiplicity is defined in the Core layer as a feature for specifying cardinalities (number of instances) of a type by enumerating all numbers the cardinality might be (see 7.3.2.2). The Kernel layer provides a specific way to do this by specifying a range of cardinalities. A multiplicity range has lower bound and upper bound expressions that are evaluated to determine the lowest and highest cardinalities, with both expression evaluating to natural numbers (that is, of type Natural from the ScalarValues library model, see 9.3.2). An upper bound value of * (infinity) means that the cardinality includes all numbers greater than or equal to the lower bound value.
A multiplicity range is written in the form [lowerBound..upperBound], where each of lowerBound and upperBound is either a literal expression or a feature reference expression represented in the notation described in 7.4.9. Literal expressions can be used to specify a multiplicity range with fixed lower and/or upper bounds. If the result of the lowerBound expression is *, then the meaning of the multiplicity range is not defined.

A multiplicity range can also be written without the lower bound (or ..). In this case, the result of the single expression is used as both the lower and upper bound of the range, unless the result is the infinite value *, in which case the lower bound is taken to be 0.

Multiplicity ranges can be used in the declaration of types, particularly features (see 7.3.4.2).

```plaintext
struct Automobile {
    feature n : Positive[1];
    composite feature wheels : Wheel[n]; // Equivalent to [n..n] for n < *
    feature driveWheels[2..n] subsets wheels;
}

feature autoCollection : Automobile[*]; // Equivalent to [0..*]
```

It is also possible to declared a multiplicity feature using the keyword multiplicity, optionally followed by a short name and/or name, and including either a multiplicity range or a subsetting of another multiplicity. A multiplicity declaration is a kind of feature declaration, and it can optionally include a body as in a generic feature declaration (see 7.3.4.2).

```plaintext
multiplicity zeroOrMore [0..*];
multiplicity m subsets zeroOrMore;
```

If a multiplicity feature is declared in the body of a type, then this becomes the multiplicity of the type. A type can have at most one multiplicity, whether this is given in the declaration or the body of the type.

```plaintext
feature driveWheels subsets wheels {
    multiplicity [2..n];
}

feature autoCollection {
    multiplicity subsets zeroOrMore;
}
```

### 7.4.13 Metadata

**Metamodel references:**

- Concrete syntax, 8.2.5.12
- Abstract syntax, 8.3.4.12
- Semantics, 8.4.4.13

**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). In general, metadata is specified in annotating elements (including comments and textual representations) attached to annotated elements (see 7.2.4). A metadata feature is a kind of annotating element that allows for the definition of structured metadata with modeler-specified features. This may be used, for example, to add tool-specific information to a model that can be relevant to the function of various kinds of tooling that may use or process a model, or domain-specific information relevant to a certain project or organization.

A metadata feature is syntactically a feature (see 7.3.4) that is typed by a single metaclass, which is a kind of structure (see 7.4.4), with implicit multiplicity 1..1. If the metaclass has no features, then the metadata feature simply acts as a user-defined syntactic tag on the annotated element. If the metaclass has features, then the metadata feature must have nested features that redefine each of the features of its type, binding them to the results of model-
A metadata feature is declared using the keyword `metadata` (or the symbol `@`), optionally followed by a short name and/or name, followed by the keyword `typed by` (or the symbol `:`) and the qualified name of exactly one metaclass. If no short name or name is given, then the keyword `typed by` (or the symbol `:`) may also be omitted. One or more annotated elements are then identified for the metadata feature after the keyword `about`, indicating that the metadata feature has annotation relationships to each of the identified elements (see 7.2.4).

```plaintext
metadata securityDesignAnnotation : SecurityRelated about SecurityDesign;
```

Any owned feature of a metadata feature must be a redefinition of a feature of the typing metaclass, with a feature value binding it to the result of a model-level evaluable expressions (see 7.4.9). The owned features of a metadata feature must always have the same names as the names of the typing metaclass, so the shorthand prefix redefines notation (see 7.3.4.5) is always used.

```plaintext
metadata ApprovalAnnotation about Design {
    feature redefines approved = true;
    feature redefines approver = "John Smith";
}
```

The keywords `feature` and/or `redefines` (or the equivalent symbol `:>>`) may be omitted in the declaration of a metadata feature.

```plaintext
metadata ApprovalAnnotation about Design {
    approved = true;
    approver = "John Smith";
}
```

If the metadata feature is an owned member of a namespace (see 7.2.5), then the explicit identification of annotated elements (following the `about` keyword) can be omitted, in which case the annotated element is implicitly the containing namespace (see 7.2.4).

```plaintext
class Design {
    // This metadata feature is implicitly about the class Design.
    @ApprovalAnnotation {
        approved = true;
        approver = "John Smith";
    }
}
```

If a metadata feature has one or more concrete features that directly or indirectly subset `Metaobject::annotatedElement`, then, for each annotated element of the metadata feature, there must be at least one such feature for which the metaclass of the annotated element conforms to all the types of the feature (which must all be specializations of the reflective metaclass `KerML::Element`, see 9.2.17).
```plaintext
metaclass Command {
    // A metadata feature of this metaclass may annotate
    // a behavior or a step.
    subsets annotatedElement : KerML::Behavior;
    subsets annotatedElement : KerML::Step;
}

behavior Save specializes UserAction {
    @Command; // This is valid.
    redefine step doAction {
        @Command; // This is valid.
    }
}

struct Options {
    @Command; // This is INVALID.
}
```

If the metaclass of a metadata feature is a direct or indirect specialization of `Metaobjects::SemanticMetadata` (see 9.2.16.2.3), then the annotated elements must all be types and the feature `SemanticMetadata::baseType` must be bound to a value of type `KerML::Type` (see 9.2.17). Each type annotated by such semantic metadata has an implicit specialization added to a type determined from the `baseType` value as follows:

- If the annotated type is neither a classifier nor a feature, then the annotated type implicitly specializes the `baseType`.
- If the annotated type is a classifier and the `baseType` is a classifier, then annotated classifier implicitly subclassifies the `baseType`.
- If the annotated type is a classifier and the `baseType` is a feature, then the annotated classifier implicitly subclassifies each type of the `baseType`.
- If the annotated type is a feature and the `baseType` is a feature, then the annotated feature shall implicitly subset the `baseType`.
- In all other cases, no implicit specialization is added.

When evaluated in a model-level evaluable expression, the meta-cast operator `meta` (see 7.4.9.2) may be used to cast a feature referenced as its first operand to the actual reflective metaclass value for this feature, which may then be bound to the `baseType` feature of `SemanticMetadata`.

```plaintext
behavior UserAction;
step userActions : UserAction[*] nonunique;

metaclass Command specializes SemanticMetadata {
    // The cast operation "userAction meta KerML::Feature" has
    // type KerML::Feature, which conforms to the type Type of
    // baseType. Since userActions is a step, the expression
    // evaluates at model level to a value of type KerML::Step.
    redefines baseType = userActions meta KerML::Feature;
}

// Save implicitly subclassifies UserAction (which is the
// type of userActions).
behavior Save {
    @Command;
}

// previousAction implicitly subsets userActions.
step previousAction[1] {
    @Command;
}
```
User-Defined Keywords

A user-defined keyword is a (possibly qualified) metaclass name or short name preceded by the symbol `#`. The user-defined keyword is placed immediately before the language-defined (reserved) keyword for the declaration and specifies a metadata feature annotation of the declared element. Note that this notation can only be used for metadata features that do not have nested features. If the named metaclass is a kind of `SemanticMetadata`, then the implicit specialization rules given above for semantic metadata apply.

```plaintext
// It is often convenient to use a lower-case initial name or
// short name for semantic metadata intended to be used as a keyword.

metaclass <command> CommandMetadata :> SemanticMetadata {
    redefines baseType = userActions meta KerML::Feature;
}

#command behavior Save;
#command step previousAction[1];
```

It is also possible to include more than one user defined-keyword in a declaration.

```plaintext
#SecurityRelated #command def Save;
```

### 7.4.14 Packages

Metamodel references:

- Concrete syntax, 8.2.5.13
- Abstract syntax, 8.3.4.13
- Semantics, 8.4.4.14

Packages are namespaces used to group elements, without any instance-level semantics (as opposed to types, which are namespaces with classification semantics, see 7.3.2). A package is notated like a generic namespace (see 7.2.5.2), but using the keyword `package` instead of `namespace`.

```plaintext
package AddressBooks {
    datatype Entry {
        feature name[1]: String;
        feature address[1]: String;
    }
    struct AddressBook {
        composite feature entries[*]: Entry;
    }
}
```

A package may also have one or more filter conditions for selecting a subset of its imported memberships. A filter condition is a Boolean-valued, model-level evaluable expression (see 7.4.9) that must evaluate to true for any imported member of the package. These are notated using the keyword `filter` followed by the filter condition expression.

```plaintext
package Annotations {
    metaclass ApprovalAnnotation {
        feature approved[1] : Boolean;
        feature approver[1] : String;
        feature level[1] : 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 and
    Annotations::ApprovalAnnotation::approved and
    Annotations::ApprovalAnnotation::level > 1;
}

A filter condition can operate on metadata on elements (see 7.4.13), such as checking for a metadata feature of a particular type or accessing the values of the features of a metadata feature. For the purposes of filter condition expressions, every element is also considered to have an implicit metadata feature that is typed by a metaclass from the reflective library model of the KerML abstract syntax (see 9.2.17). This enables filter conditions to test for the abstract syntax metaclass of an element and to access the values of abstract syntax meta-attributes.

Note that a filter condition in a package will filter all imports of that Package. That is why full qualification is used for Annotations::ApprovalAnnotation in the example above, since imported elements of the Annotations package would be filtered out by the very filter condition in which the elements are intended to be used. This may be avoided by combining one or more filter conditions with a specific import, using the filtered import notation described in 7.2.5.4).

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 and approved and level > 1];
}

The KerML library package contains a complete model of the KerML abstract syntax represented in KerML itself. When a filter condition is evaluated on an element, abstract syntax metadata for the element can be tested as if the element had an implicit metadata feature typed by the type from the KerML package corresponding to the metaclass of the element.

package PackageApprovals {
  import Annotations::*;
  import KerML::*;

  import DesignModel::*[@Structure and
    Structure::ownedFeature != null and
    @ApprovalAnnotation and
In general, a library package is a package that is expected to be commonly available and reused across many user models. A package can be explicitly identified as a library package using the keyword `library`. This allows tooling to identify any element contained directly in a library package as being a library element from that specific library package.

```kerml
library package AddressBooks {
  ...
}
```

The standard library packages in the Kernel Model Libraries (see Clause 9) are further identified using the keyword `standard`. However, only library packages from the Kernel Model Libraries, or from other recognized standard model libraries, should be identified as standard library packages.
8 Metamodel

8.1 Metamodel Overview

This clause presents the normative specification of the metamodel for KerML, which includes the KerML concrete syntax, abstract syntax and semantics (though the complete semantics depends on the model library specified in Clause 9).

1. **Concrete syntax** specifies how the language appears to modelers. Modelers construct and review models using a textual notation that conforms to the concrete syntax specification (see 8.2).

2. **Abstract syntax** specifies linguistic terms and relations between them (as opposed to library model terms), which may be expressed in the concrete syntax (see 8.3). The abstract syntax omits aspects of the concrete syntax, such as delimiters and formatting, that are do not affect what modelers are trying to expression. A concrete syntax representation of a model can be parsed into an abstract syntax representation, or an abstract syntax representation can be serialized into the concrete syntax notation. The mapping between the concrete and abstract syntax is given as part of the grammar specification for the concrete syntax (see 8.2.1 on the conventions for this).

3. **Semantics** specifies the interpretation of models as representations of or specifications for modeled systems (see 8.4). The semantics for a core subset of the abstract syntax are specified using mathematical logic. Semantics for the rest of KerML are specified by mapping complicated abstract syntax constructs into equivalent models using the core subset, and, in particular, introducing implied relationships to required elements from the KerML model library (see 8.4.1 on this approach).

As described in 6.1, KerML is divided into Root, Core and Kernel Layers, which cut across each of the above facets. The subclauses on Concrete Syntax (8.2) and Abstract Syntax (8.3) are each further subdivided into subclauses on the three layers, and then, within each layer, into subclauses following the package structure of the abstract syntax. Subclause 8.4 on Semantics only covers the Core and Kernel Layers, because Root Layer constructs do not have model-level semantics.

Throughout this clause, the names of elements from the KerML abstract syntax model appear in a "code" font. Further:

1. Names of metaclasses appear exactly as in the abstract syntax, including capitalization, except possibly with added pluralization. When used as English common nouns, e.g., "an Element", "multiple FeatureTypings", they refer to instances of the metaclass. E.g., "Elements can own other Elements" refers to instances of the metaclass Element that reside in models. This can be modified with the term "metaclass" as necessary to refer to the metaclass itself instead of its instances, e.g., "The Element metaclass is contained in the Elements package."

2. Names of properties of metaclasses, when used as English common nouns, e.g., “an ownedRelatedElement”, “multiple featuringTypes”, refer to values of the properties. This can be modified using the term "metaproperty" as necessary to refer to the metaproperty itself instead of its values, e.g., "The ownedRelatedElement metaproperty is contained in the Elements package."

Similar stylistic conventions apply to text about KerML models, except that an "italic code" front is used.

1. Convention 1 above applies to KerML Types (e.g., Performance), using "type" (or a more specialized term) instead of "metaclass" (e.g., "the Performance behavior").

2. Convention 2 above applies to KerML Features (e.g, performances), using "feature" (or a more specialized term) instead of "metaproperty" (e.g., "the performances step").

8.2 Concrete Syntax
8.2.1 Concrete Syntax Overview

The concrete syntax for KerML is a textual notation that can be used to express or construct an abstract syntax representation of a model. The lexical structure of the KerML textual notation defines how the string of characters in a text is divided into a set of lexical elements. Such lexical elements can be categorized as whitespace, notes, or tokens. Only tokens are significant for the mapping of the notation to the abstract syntax. The syntactic structure of the KerML textual notation defines how lexical tokens are grouped and mapped to an abstract syntax representation of a model.

Both the lexical and syntactic structures are specified as grammars consisting of productions for lexical elements or non-terminal syntactic elements (see Table 1). The body of a production is specified using an Extended Backus Naur Form (EBNF) notation (see Table 2). The syntactic grammar includes further notations to describe how the concrete syntax maps to the abstract syntax element being synthesized (see Table 3).

Subclause 8.2.2 presents the lexical grammar for KerML. Subclauses 8.2.3, 8.2.4, and 8.2.5 then each present the portion of the syntactic grammar for KerML covering the Root, Core and Kernel Layers of KerML (see 6.1). Each of these subclauses is further divided into subclauses corresponding to each of the packages from the abstract syntax model (see 8.3). The starting production for the syntactic grammar is RootNamespace (see 8.2.3.4.1).

<table>
<thead>
<tr>
<th>LEXICAL_ELEMENT = ...</th>
<th>Define a production for the LEXICAL_ELEMENT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NonterminalElement : AbstractSyntaxElement = ...</td>
<td>Define a production for the NonterminalElement that synthesizes the AbstractSyntaxElement. If the NonterminalElement has the same name as the AbstractSyntaxElement, then &quot;&quot;: AbstractSyntaxElement&quot; may be omitted.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lexical element</th>
<th>LEXICAL_ELEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal element</td>
<td>'terminal'</td>
</tr>
<tr>
<td>Non-terminal element</td>
<td>NonterminalElement</td>
</tr>
<tr>
<td>Sequential elements</td>
<td>Element1 Element2</td>
</tr>
<tr>
<td>Alternative elements</td>
<td>Element1</td>
</tr>
<tr>
<td>Optional elements (zero or one)</td>
<td>Element ?</td>
</tr>
<tr>
<td>Repeated elements (zero or more)</td>
<td>Element *</td>
</tr>
<tr>
<td>Repeated elements (one or more)</td>
<td>Element +</td>
</tr>
<tr>
<td>Grouping</td>
<td>( Elements ... )</td>
</tr>
</tbody>
</table>

<p>| Property assignment | p = Element | Assign the result of parsing the concrete syntax Element to abstract syntax property p. |</p>
<table>
<thead>
<tr>
<th><strong>List property construction</strong></th>
<th>p += Element</th>
<th>Add the result of parsing the concrete syntax Element to the abstract syntax list property p.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boolean property assignment</strong></td>
<td>p ?= Element</td>
<td>If the concrete syntax Element is parsed, then set the abstract Boolean property p to true.</td>
</tr>
<tr>
<td><strong>Non-parsing assignment</strong></td>
<td>{ p = value } { p += value }</td>
<td>Assign (or add) the given value to the abstract syntax property p, without parsing any input. The value may be a literal or a reference to another abstract syntax property. The symbol &quot;this&quot; refers to the element being synthesized.</td>
</tr>
<tr>
<td><strong>Name resolution</strong></td>
<td>[QualifiedName]</td>
<td>Parse a QualifiedName, then resolve that name to an Element reference (see 8.2.3.5) for use as a value in an assignment as above.</td>
</tr>
</tbody>
</table>

### 8.2.2 Lexical Structure

#### 8.2.2.1 Line Terminators and White Space

- **LINE_TERMINATOR** = implementation defined character sequence
- **LINE_TEXT** = character sequence excluding LINE_TERMINATORS
- **WHITE_SPACE** = space | tab | form_feed | LINE_TERMINATOR

**Notes**

1. Notation text is 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.

2. Any characters in text line that are not a part of the line terminator are referred to as line text.

3. 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 8.2.2).
8.2.2.2 Notes and Comments

SINGLE_LINE_NOTE =
    '//' LINE_TEXT

MULTILINE_NOTE =
    '/*' COMMENT_TEXT '*/'

REGULAR_COMMENT =
    '//' COMMENT_TEXT '*'

COMMENT_TEXT =
    ( COMMENT_LINE_TEXT | LINE_TERMINATOR )*

COMMENT_LINE_TEXT =
    LINE_TEXT excluding the sequence '*/'

8.2.2.3 Names

NAME =
    BASIC_NAME | UNRESTRICTED_NAME

BASIC_NAME =
    BASIC_INITIAL_CHARACTER BASIC_NAME_CHARACTER*

UNRESTRICTED_NAME =
    single_quote ( NAME_CHARACTER | ESCAPE_SEQUENCE )* single_quote
    (see Note 1)

BASIC_INITIAL_CHARACTER =
    ALPHABETIC_CHARACTER | '_'

BASIC_NAME_CHARACTER =
    BASIC_INITIAL_CHARACTER | DECIMAL_DIGIT

ALPHABETIC_CHARACTER =
    any character 'a' through 'z' or 'A' through 'Z'

DECIMAL_DIGIT =
    any character '0' through '9'

NAME_CHARACTER =
    any printable character other than backslash or single_quote

ESCAPE_SEQUENCE =
    see Note 2

Notes

1. The single_quote character is '. The name represented by an UNRESTRICTED_NAME shall consist of the characters within the single quotes, with escape characters resolved as described below. The surrounding single quote characters are not part of the represented name.

2. An ESCAPE_SEQUENCE is a sequence of two text characters starting with a backslash that 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 also 8.2.2.1). Table 4 shows the meaning of the allowed escape sequences. The ESCAPE_SEQUENCES in an UNRESTRICTED_NAME shall be replaced by the characters specified as their meanings in the actual represented name.
### Table 4. Escape Sequences

<table>
<thead>
<tr>
<th>Escape Sequence</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>\</td>
<td>Single Quote</td>
</tr>
<tr>
<td>&quot;&quot;</td>
<td>Double Quote</td>
</tr>
<tr>
<td>\b</td>
<td>Backspace</td>
</tr>
<tr>
<td>\f</td>
<td>Form Feed</td>
</tr>
<tr>
<td>\t</td>
<td>Tab</td>
</tr>
<tr>
<td>\n</td>
<td>Line Terminator</td>
</tr>
<tr>
<td>\</td>
<td>Backslash</td>
</tr>
</tbody>
</table>

#### 8.2.2.4 Numeric Values

DECIMAL_VALUE =

\[\text{DECIMALancel digit}^+\]

EXPONENTIAL_VALUE =

\[\text{DECIMAL-value e} ('e' | 'E') ('+\text{ or }'-'|) ? \text{DECIMAL-value}\]

**Notes**

1. A DECIMAL_VALUE may specify a natural literal, or it may be part of the specification of a real literal (see 8.2.5.8.4). Note that a DECIMAL_VALUE does not include a sign, because negating a literal is an operator in the KerML expression syntax.
2. An EXPONENTIAL_VALUE may be used in the specification of a real literal (see 8.2.5.8.4). 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.

#### 8.2.2.5 String Value

STRING_VALUE =

\["\text{string-character} | \text{ESCAPE_SEQUENC}^+ "\]

STRING_CHARACTER =

any printable character other than backslash or ""

**Notes**

1. ESCAPE_SEQUENCE is specified in 8.2.2.3.

#### 8.2.2.6 Reserved Words

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

about abstract alias all and as assoc behavior binding bool by chains class classifier comment composite conjugate conjugates conjugation connector datatype default dependency derived differences disjoining disjoint doc else end expr false feature featured featuring filter first flow for from function hastype if
Tooling for the KerML textual notation should generally highlight keywords relative to other text, for example by using boldface and/or distinctive coloring. However, while keywords are shown in boldface in this specification, the specification does not require any specific highlighting (or any highlighting at all), and KerML textual notation documents are expected to be interchanged as plain text (see also Clause 10 on Model Interchange).

8.2.2.7 Symbols

The symbols shown below are non-name tokens composed entirely of characters that are not alphanumeric. In some cases these symbols have no meaning themselves, but are used to allow unambiguous separation between other tokens that do have meaning. In other cases, they are distinguished notations in the KerML sublanguage (see 8.2.5.8) that map to particular library Functions or symbolic shorthand for meaningful relationships.

( ) { } [ ] ; , ~ @ # % & ^ | * ** + - / -> . . . : :: > >> ::> < <= = := == === != !== > >= ? ?? .?

Some symbols are made of 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 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 keywords in the concrete syntax have an equivalent symbolic representation. For convenience, the concrete syntax grammar uses the following special lexical terminals, which match either the symbol or the corresponding keyword.

TYPED_BY    = '::' | 'typed' 'by'
SPECIALIZES = '::>' | 'specializes'
SUBSETS     = '::>' | 'subsets'
REFERENCES  = '::>' | 'references'
REDEFINES   = '::>' | 'redefines'
CONJUGATES  = '~'   | 'conjugates'

8.2.3 Root Concrete Syntax

8.2.3.1 Elements and Relationships Concrete Syntax

Identification : Element =
{ '<' declaredShortName = NAME '>' }?
{ declaredName = NAME }?

RelationshipBody : Relationship =
';' | '{' RelationshipOwnedElement* '}'

RelationshipOwnedElement : Relationship =
ownedRelatedElement += OwnedRelatedElement
| ownedRelationship += OwnedAnnotation

OwnedRelatedElement : Element =
NonFeatureElement | FeatureElement
8.2.3.2 Dependencies Concrete Syntax

Dependency =
  ( ownedRelationship += PrefixMetadataAnnotation )* 
  'dependency' ( Identification? 'from')? 
  client += [QualifiedName] ( ',' client += [QualifiedName] )* 'to' 
  supplier += [QualifiedName] ( ',' supplier += [QualifiedName] )* 
  RelationshipBody

Notes
1. PrefixMetadataAnnotation is defined in the Kernel layer (see 8.2.5.12).

8.2.3.3 Annotations Concrete Syntax

8.2.3.3.1 Annotations

Annotation =
  annotatedElement = [QualifiedName]

OwnedAnnotation : Annotation =
  annotatingElement = AnnotatingElement
  { ownedRelatedElement += annotatingElement }

AnnotatingElement =
  Comment
  | Documentation
  | TextualRepresentation
  | MetadataFeature

Notes
1. MetadataFeature is defined in the Kernel layer (see 8.2.5.12).

8.2.3.3.2 Comments and Documentation

Comment =
  ( 'comment' Identification 
    ( 'about' annotation += Annotation 
      { ownedRelationship += annotation } 
      ( ',' annotation += Annotation 
        { ownedRelationship += annotation } )* 
    )? 
  )?
  ( 'locale' locale = STRING_VALUE )?
  body = REGULAR_COMMENT

Documentation =
  'doc' Identification
  ( 'locale' locale = STRING_VALUE )?
  body = REGULAR_COMMENT

Notes
1. The text of a lexical REGULAR_COMMENT or PREFIX_COMMENT shall be processed as follows before it is included as the body of a Comment or Documentation:
   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.

2. 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.

8.2.3.3.3 Textual Representation

TextualRepresentation =
   ( 'rep' Identification )?
   'language' language = STRING_VALUE
   body = REGULAR_COMMENT

Notes

1. The lexical text of a REGULAR_COMMENT shall be processed as specified in 8.2.3.3.2 for Comments before being included as the body of a TextualRepresentation.

2. See also 8.3.2.3.6 on the standard language names recognized for a TextualRepresentation.

8.2.3.4 Namespaces Concrete Syntax

8.2.3.4.1 Namespaces

RootNamespace : Namespace =
   NamespaceBodyElement*
(See Note 1)

Namespace =
   ( ownedRelationship += PrefixMetadataMember )*  
   NamespaceDeclaration NamespaceBody
(See Note 2)

NamespaceDeclaration : Namespace =
   'namespace' Identification

NamespaceBody : Namespace =
   '://' | '{' NamespaceBodyElement* '}'

NamespaceBodyElement : Namespace =
   ownedRelationship += NamespaceMember
   | ownedRelationship += AliasMember
   | ownedRelationship += Import

MemberPrefix : Membership =
   ( visibility = VisibilityIndicator )?
VisibilityIndicator : VisibilityKind = 'public' | 'private' | 'protected'

NamespaceMember : OwningMembership =
   NonFeatureMember
   | NamespaceFeatureMember

NonFeatureMember : OwningMembership =
   MemberPrefix
   ownedRelatedElement += MemberElement

NamespaceFeatureMember : OwningMembership =
   MemberPrefix
   ownedRelatedElement += FeatureElement

AliasMember : Membership =
   MemberPrefix
   'alias' ( '<' memberShortName = NAME '>' )?
   ( memberName = NAME )?
   'for' memberElement = [QualifiedName]
   RelationshipBody

QualifiedName =
   ( NAME '::' )* NAME

(See Note 3)

Notes

1. A root Namespace is a Namespace that has no owningNamespace (see 8.3.2.4). Every Element other than a root Namespace must be contained, directly or indirectly, within some root Namespace. Therefore, every valid KerML concrete syntax text can be parsed starting from the RootNamespace production.

2. PrefixMetadataMember is defined in the Kernel layer (see 8.2.5.12).

3. 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. The segment names of the qualified name other than the last identify a sequence of nested Namespaces that provide the context for resolving the final segment name (see 8.2.3.5). The notation [QualifiedName] is used in concrete syntax grammar productions to indicate the result of resolving text parsed as a QualifiedName (see also 8.2.1).

8.2.3.4.2 Imports

Import =
   ( visibility = VisibilityIndicator )?
   'import' ( isImportAll ?= 'all' )?
   ImportDeclaration RelationshipBody

ImportDeclaration : Import
   MembershipImport | NamespaceImport

MembershipImport =
   importedMembership = [QualifiedName]
   ( '::' isRecursive ?= '***' )?
(see Note 1)
NamespaceImport =
    importedNamespace = [QualifiedName] '::' '*'
    ('::' isRecursive ?= '***')?
    | importedNamespace = FilterPackage
    { ownedRelatedElement += importedNamespace }

FilterPackage : Package =
    ownedRelationship += ImportDeclaration
    { ownedRelationship += FilterPackageMember }+

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

Notes

1. The importedMembership of a MembershipImport is the single case in which the Element required from the resolution [QualifiedName] is the actual Membership identified by the QualifiedName, not the memberElement of that Membership (see 8.2.3.5).

8.2.3.4.3 Namespace Elements

MemberElement : Element =
    AnnotatingElement | NonFeatureElement

NonFeatureElement : Element =
    Dependency
    | Namespace
    | Type
    | Classifier
    | DataType
    | Class
    | Structure
    | Metaclass
    | Association
    | AssociationStructure
    | Interaction
    | Behavior
    | Function
    | Predicate
    | Multiplicity
    | Package
    | LibraryPackage
    | Specialization
    | Conjugation
    | Subclassification
    | Disjoining
    | FeatureInverting
    | FeatureTyping
    | Subsetting
    | Redefinition
    | TypeFeaturing

FeatureElement : Feature =
    Feature
    | Step
    | Expression
    | BooleanExpression
8.2.3.5 Name Resolution

8.2.3.5.1 Name Resolution Overview

A qualified name consists of a sequence of one or more segment names (see 8.2.3.4.1). Each segment name is a simple name, that is, it is a lexical NAME token (see 8.2.2.3). The qualification part of a qualified name with more than one segment name is itself a qualified name, consisting of all the segment names of the original qualified name except for the last. For example the qualified name A::B::C consists of the segment names A, B and C, and its qualification part is A::B.

Name resolution is a process for determining the Element that is identified by a qualified name. The result of the process is actually a Membership relationship identified by the qualified name. However, in all cases but one, the required Element to be inserted into the abstract syntax is the memberElement of that Membership, in which case the metaclass of the memberElement must conform to the expected metaclass in the context of the name resolution. The one exception is the resolution of the qualified name for the importedMembership of a MembershipImport (see 8.2.3.4.2), in which case the required Element is the identified Membership itself.

The basic name resolution process consists of the following two steps. The terms "local Namespace", "visible resolution" and "full resolution" used below are defined in 8.2.3.5.2, 8.2.3.5.3, and 8.2.3.5.4.

1. If the qualified name has only one segment name, then the resolution of the qualified name is the full resolution of that segment name relative to the local Namespace for the qualified name – unless the local Namespace is a root Namespace, in which case the global Namespace is used instead.

2. Otherwise, resolve the qualification part of the qualified name relative to the local Namespace of the original qualified name. This must resolve to a Namespace, and the resolution of the original qualified name is then the visible resolution of its last segment name relative to this Namespace.

If either of the above steps fails, or if the resulting Element does not have the proper type for its context, then the qualified name has no resolution, and the parsing of the text containing it fails with a name resolution error.

Note. The invoking the Namespace::resolve, as defined in the abstract syntax (see 8.3.2.4.5), carries out the above basic resolution process with the target Namespace considered as the local Namespace for the given qualified name.

The basic name resolution process is used directly to resolve a qualified name in all cases except when the qualified name specifies the redefinedFeature of a Redefinition with an owningFeature that has an owningType. In this case, the basic name resolution processes is repeated with the general Type of each ownedSpecialization of the owningType considered in turn as the local Namespace, until a resolution is found. If no resolution is found for any of these, then the overall resolution fails.

Note. When implementing the name resolution process as specified here, some additional points need to be considered.

- The descriptions given in 8.2.3.5.2, 8.2.3.5.3, and 8.2.3.5.4 presume that the derived membership, importedMembership and (for a Type) inheritedMembership properties of a Namespace have been fully computed, including memberships resulting from implied Relationships (see 8.4.2). However, when parsing a complete KerML concrete syntax text, the values of these properties may themselves be
based on other Relationships (e.g., alias Memberships, Imports and Specializations) whose
target references are given by qualified names that must be resolved. Name resolution must therefore
proceed incrementally during a parse, avoiding infinite loops caused by attempting to resolve again names
that are already pending resolution. Note, however, that it is possible to at least locally resolve a name to a
Membership in a Namespace without immediately resolving the memberElement of that Membership.

- Circularity is allowed for Imports and Specializations. Therefore, when traversing the graph of
these Relationships, an implementation must avoid re-processing a Namespace that has already been
visited.

8.2.3.5.2 Local and Global Namespaces

Every Namespace other than a root Namespace (see 8.2.3.4.1) is nested in a containing Namespace called its
owningNamespace (see 8.3.2.4).

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 Namespaces that are available to
the first Namespace, which shall include at least all the root Namespaces from the KerML Model Libraries (see Clause
9). If a tool imports a model interchange project (see 10.3), then the available Namespaces shall also include all the
root Namespaces from any used project of the imported project. A conforming tool can also provide means for
making additional Namespaces available to a root Namespace, such as by creating a new root Namespace or
adding an additional used project.

A qualified name is always used to identify an Element that is a target Element of some context
Relationship. The local Namespace for resolving the qualified name is then determined depending on the kind
of context Relationship, as given in the following.

Import (see 8.3.2.4.2)

- The local Namespace is the importOwningNamespace.

Membership (see 8.3.2.4.3)

- If the membershipOwningNamespace is a FeatureReferenceExpression (see 8.3.4.8.4), then the
local Namespace is the non-invocation Namespace for the membershipOwningNamespace, which is
defined to be the nearest containing Namespace that is none of the following:
  - FeatureReferenceExpression
  - InvocationExpression
  - ownedFeature of an InvocationExpression
- If the membershipOwningNamespace is a FeatureChainExpression see 8.3.4.8.3, then the local
Namespace is the result parameter of the argument Expression of the FeatureChainExpression.
- Otherwise, the local Namespace is the membershipOwningNamespace.

Specialization (see 8.3.3.1.8)

- If the Specialization is a ReferenceSubsetting (see 8.3.3.3.9), and its referencingFeature is
an end Feature whose owningType is a Connector, then the local Namespace is the
owningNamespace of the Connector.
- If the Specialization is a FeatureTyping (see 8.3.3.3.6), and its owningFeature is an
InvocationExpression, then the local Namespace is the non-invocation Namespace for the
owningFeature (determined as for a FeatureReferenceExpression under Membership above).
- Otherwise, if the owningType is not null, then the local Namespace is the owningNamespace of the
owningType.
- Otherwise, the local Namespace is the owningNamespace of the Specialization.
Conjugation (see 8.3.3.1.2)

• If the owningType is not null, the local Namespace is the owningNamespace of the owningType.
• Otherwise, the local Namespace is the owningNamespace of the Conjugation.

FeatureChaining (see 8.3.3.3.4)

• If the FeatureChaining is the first ownedFeatureChaining of its featureChained, then the local Namespace is determined as if the owningRelationship of the featureChained (which will be a Membership, Subsetting or Conjugation) was the context Relationship (see above).
• Otherwise, the local Namespace is the chainingFeature of the previous FeatureChaining in the ownedFeatureChaining list.

8.2.3.5.3 Local and Visible Resolution

A Namespace defines a mapping from names to its memberships, known as the local resolution of those names. Each membership of a Namespace is the local resolution for its memberShortName and memberName (if non-null). Note that this includes owned, imported and (if the Namespace is a Type) inherited Memberships.

Note. If the Namespace is well formed, then there can be at most one Membership that is the local resolution of any given name.

The visible resolution of a name is similar to its local resolution, but the memberships considered are restricted to those that are visible outside the Namespace. The visible Memberships of a Namespace shall comprise the following:

• All ownedMemberships of the Namespace with visibility = public.
• All importedMemberships of the Namespace that are derived from Import Relationships with visibility = public.
• If the Namespace is a Type, then all inheritedMemberships of the Type with visibility = public.

8.2.3.5.4 Full Resolution

The full resolution of a simple name relative to a Namespace considers Memberships not only in that Namespace, but also in directly or indirectly containing Namespaces, all the way out to the global Namespace. Full resolution relative to a Namespace other than the global Namespace proceeds as follows:

1. If the name has a local resolution relative to a Namespace (see 8.2.3.5.3), then that is also its full resolution relative to that Namespace.
2. Otherwise:
   • If the Namespace is not a root Namespace, then the full resolution of the name relative to the original Namespace is determined as its full resolution relative to the owningNamespace of the original Namespace.
   • If the Namespace is a root Namespace, then the full resolution of the name resolution relative to the original Namespace is its resolution in the global Namespace.

The resolution of a simple name in the global Namespace is the Membership in the global Namespace (as defined in 8.2.3.5.2) whose (non-null) shortMemberName or memberName is equal to the simple name.

Note. It is possible that there will be more than one Membership in the global Namespace that resolves a given simple name. In this case, one of these Memberships is chosen for the resolution of the name, but which one is chosen is not otherwise determined by this specification.
8.2.4 Core Concrete Syntax

8.2.4.1 Types Concrete Syntax

8.2.4.1.1 Types

Type =
    TypePrefix 'type'
    TypeDeclaration TypeBody

TypePrefix : Type =
    ( isAbstract ?= 'abstract' )?
    ( ownedRelationship += PrefixMetadataMember )*  

TypeDeclaration : Type =
    ( isSufficient ?= 'all' )? Identification
    ( ownedRelationship += OwnedMultiplicity )?
    ( SpecializationPart | ConjugationPart )+ TypeRelationshipPart*

SpecializationPart : Type =
    SPECIALIZES ownedRelationship += OwnedSpecialization
    ( ',' ownedRelationship += OwnedSpecialization )*  

ConjugationPart : Type =
    CONJUGATES ownedRelationship += OwnedConjugation

TypeRelationshipPart : Type =
    DisjoiningPart
    | UnioningPart
    | IntersectingPart
    | DifferencingPart

DisjoiningPart : Type =
    'disjoint' 'from' ownedRelationship += OwnedDisjoining
    ( ',' ownedRelationship += OwnedDisjoining )* 

UnioningPart : Type =
    'unions' ownedRelationship += Unioning
    ( ',' ownedRelationship += Unioning )* 

IntersectingPart : Type =
    'intersects' ownedRelationship += Intersecting
    ( ',' ownedRelationship += Intersecting )* 

DifferencingPart : Type =
    'differences' ownedRelationship += Differencing
    ( ',' ownedRelationship += Differencing )* 

TypeBody : Type =
    ';' | '{' TypeBodyElement* '}'

TypeBodyElement : Type =
    ownedRelationship += NonFeatureMember
    | ownedRelationship += FeatureMember
    | ownedRelationship += AliasMember
    | ownedRelationship += Import
8.2.4.1.2 Specialization

Specialization =
  ( 'specialization' Identification )?
  'subtype' SpecificType
  SPECIALIZES GeneralType
  RelationshipBody

OwnedSpecialization : Specialization =
  GeneralType

SpecificType : Specialization :
  specific = [QualifiedName]
  | specific += OwnedFeatureChain
  { ownedRelatedElement += specific }

GeneralType : Specialization =
  general = [QualifiedName]
  | general += OwnedFeatureChain
  { ownedRelatedElement += general }

8.2.4.1.3 Conjugation

Conjugation =
  ( 'conjugation' Identification )?
  'conjugate'
  { conjugatedType = [QualifiedName]
    | conjugatedType = FeatureChain
    { ownedRelatedElement += conjugatedType }
  }
  CONJUGATES
  { originalType = [QualifiedName]
    | originalType = FeatureChain
    { ownedRelatedElement += originalType }
  }

OwnedConjugation : Conjugation =
  originalType = [QualifiedName]
  | originalType = FeatureChain
  { ownedRelatedElement += originalType }

8.2.4.1.4 Disjoining

Disjoining =
  ( 'disjoining' Identification )?
  'disjoint'
  { typeDisjoined = [QualifiedName]
    | typeDisjoined = FeatureChain
    { ownedRelatedElement += typeDisjoined }
  }
  'from'
  { disjoiningType = [QualifiedName]
    | disjoiningType = FeatureChain
    { ownedRelatedElement += disjoiningType }
  }

OwnedDisjoining : Disjoining =
  disjoiningType = [QualifiedName]
8.2.4.1.5 Unioning, Intersecting and Differencing

Unioning =
  unioningType = [QualifiedName]
  | ownedRelatedElement += OwnedFeatureChain

Intersecting =
  intersectingType = [QualifiedName]
  | ownedRelatedElement += OwnedFeatureChain

Differencing =
  differencingType = [QualifiedName]
  | ownedRelatedElement += OwnedFeatureChain

8.2.4.1.6 Feature Membership

FeatureMember : OwningMembership =
  TypeFeatureMember
  | OwnedFeatureMember

TypeFeatureMember : OwningMembership =
  MemberPrefix 'member' ownedRelatedElement += FeatureElement

OwnedFeatureMember : FeatureMembership =
  MemberPrefix ownedRelatedElement += FeatureElement

8.2.4.2 Classifiers Concrete Syntax

8.2.4.2.1 Classifiers

Classifier =
  TypePrefix 'classifier'
  ClassifierDeclaration TypeBody

ClassifierDeclaration : Classifier =
  ( isSufficient ?= 'all' )? Identification
  ( ownedRelationship += OwnedMultiplicity )?
  ( SuperclassingPart | ConjugationPart )?
  TypeRelationshipPart*

SuperclassingPart : Classifier =
  SPECIALIZES ownedRelationship += OwnedSubclassification
  ( ',' ownedRelationship += OwnedSubclassification )*

8.2.4.2.2 Subclassification

Subclassification =
  ( 'specialization' Identification )?
  'subclassifier' subclassifier = [QualifiedName]
  SPECIALIZES superclassifier = [QualifiedName]
  RelationshipBody

OwnedSubclassification : Subclassification =
  superclassifier = [QualifiedName]

8.2.4.3 Features Concrete Syntax
8.2.4.3.1 Features

Feature =
  FeaturePrefix
  ( 'feature'? FeatureDeclaration
   | 'feature'
   | ownedRelationship += PrefixMetadataMember
  )
  ValuePart? TypeBody
(See Note 1)

FeaturePrefix : Feature =
  ( direction = FeatureDirection )?
  ( isAbstract ?= 'abstract' )?
  ( isComposite ?= 'composite' | isPortion ?= 'portion' )?
  ( isReadOnly ?= 'readonly' )?
  ( isDerived ?= 'derived' )?
  ( isEnd ?= 'end' )?
  ( ownedRelationship += PrefixMetadataMember )* (See Note 1)

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

FeatureDeclaration : Feature =
  ( isSufficient ?= 'all' )?
  ( FeatureIdentification
   ( FeatureSpecializationPart | ConjugationPart )?
   | FeatureSpecializationPart
   | ConjugationPart
  )
  FeatureRelationshipPart*

FeatureIdentification : Feature =
  '<' shortName = NAME '>' ( name = NAME )?
  | name = NAME

FeatureRelationshipPart : Feature =
  TypeRelationshipPart
  | ChainingPart
  | InvertingPart
  | TypeFeaturingPart

ChainingPart : Feature =
  'chains'
  ( ownedRelationship += OwnedFeatureChaining
  | FeatureChain )

InvertingPart : Feature =
  'inverse' 'of' ownedRelationship += OwnedFeatureInverting

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

FeatureSpecializationPart : Feature =
  FeatureSpecialization+ MultiplicityPart? FeatureSpecialization*
  | MultiplicityPart FeatureSpecialization*
MultiplicityPart : Feature =
    ownedRelationship += OwnedMultiplicity
    | ( ownedRelationship += OwnedMultiplicity )?
    | ( isOrdered ?= 'ordered' ( {isUnique = false} 'nonunique' )? 
    | {isUnique = false} 'nonunique' ( isOrdered ?= 'ordered' )? )

FeatureSpecialization : Feature =
    Typings | Subsettings | References | Redefinitions

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

TypedBy : Feature =
    TYPED_BY ownedRelationship += OwnedFeatureTyping

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

Subsets : Feature =
    SUBSETS ownedRelationship += OwnedSubsetting

References : Feature =
    REFERENCES ownedRelationship += OwnedReferenceSubsetting

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

Redefines : Feature =
    REDEFINES ownedRelationship += OwnedRedefinition

Notes

1. PrefixMetadataMember is defined in the Kernel layer (see 8.3.4.12).

8.2.4.3.2 Feature Typing

FeatureTyping =
    ( 'specialization' Identification )?
    'typing' typedFeature = [QualifiedName]
    TYPED_BY GeneralType
    RelationshipBody

OwnedFeatureTyping : FeatureTyping =
    GeneralType

8.2.4.3.3 Subsetting

Subsetting =
    ( 'specialization' Identification )?
    'subset' SpecificType
    SUBSETS GeneralType
    RelationshipBody

OwnedSubsetting : Subsetting =
    GeneralType

OwnedReferenceSubsetting : ReferenceSubsetting =
    GeneralType
8.2.4.3.4 Redefinition

Redefinition =
    ( 'specialization' Identification )?
    'redefinition' SpecificType
    REDEFINED GeneralType
    RelationshipBody

OwnedRedefinition : Redefinition =
    GeneralType

8.2.4.3.5 Feature Chaining

OwnedFeatureChain : Feature =
    FeatureChain

FeatureChain : Feature =
    ownedRelationship += OwnedFeatureChaining
    ( '.' ownedRelationship += OwnedFeatureChaining )+

OwnedFeatureChaining : FeatureChaining =
    chainingFeature = [QualifiedName]

8.2.4.3.6 Feature Inverting

FeatureInverting =
    ( 'inverting' Identification? )?
    'inverse'
    ( featureInverted = [QualifiedName]
      | featureInverted = OwnedFeatureChain
      { ownedRelatedElement += featureInverted } )
    'of'
    ( invertingFeature = [QualifiedName]
      | ownedRelatedElement += OwnedFeatureChain
      { ownedRelatedElement += invertingFeature } )

RelationshipBody

OwnedFeatureInverting : FeatureInverting =
    invertingFeature = [QualifiedName]
    | invertingFeature = OwnedFeatureChain
    { ownedRelatedElement += invertingFeature }

8.2.4.3.7 Type Featuring

TypeFeaturing =
    'featuring' ( Identification 'of' )?
    featureOfType = [QualifiedName]
    'by' featuringType = [QualifiedName]
    RelationshipBody

OwnedTypeFeaturing : TypeFeaturing =
    featuringType = [QualifiedName]

8.2.5 Kernel Concrete Syntax
8.2.5.1 Data Types Concrete Syntax

DataType =
  TypePrefix 'datatype'
  ClassifierDeclaration TypeBody

8.2.5.2 Classes Concrete Syntax

Class =
  TypePrefix 'class'
  ClassifierDeclaration TypeBody

8.2.5.3 Structures Concrete Syntax

Structure =
  TypePrefix 'struct'
  ClassifierDeclaration TypeBody

8.2.5.4 Associations Concrete Syntax

Association =
  TypePrefix 'assoc'
  ClassifierDeclaration TypeBody

AssociationStructure =
  TypePrefix 'assoc' 'struct'
  ClassifierDeclaration TypeBody

8.2.5.5 Connectors Concrete Syntax

8.2.5.5.1 Connectors

Connector =
  FeaturePrefix 'connector'
  ( FeatureDeclaration? ValuePart?
    | ConnectorDeclaration
  )
  TypeBody

ConnectorDeclaration : Connector =
  BinaryConnectorDeclaration | NaryConnectorDeclaration

BinaryConnectorDeclaration : Connector =
  ( FeatureDeclaration? 'from' | isSufficient ?= 'all' 'from'? )?
  ownedRelationship += ConnectorEndMember 'to'
  ownedRelationship += ConnectorEndMember

NaryConnectorDeclaration : Connector =
  FeatureDeclaration?
  '(' ownedRelationship += ConnectorEndMember ','
    ownedRelationship += ConnectorEndMember
    ( ',' ownedRelationship += ConnectorEndMember )'
    ')'?

ConnectorEndMember : EndFeatureMembership =
  ownedRelatedElement += ConnectorEnd

ConnectorEnd : Feature =
  ( declaredName = NAME REFERENCES )?
ownedRelationship += OwnedReferenceSubsetting
( ownedRelationship += OwnedMultiplicity )?

8.2.5.5.2 Binding Connectors

BindingConnector =
  FeaturePrefix 'binding'
  BindingConnectorDeclaration TypeBody

BindingConnectorDeclaration : BindingConnector =
  FeatureDeclaration
  ( 'of' ownedRelationship += ConnectorEndMember
    '=' ownedRelationship += ConnectorEndMember )?
  | ( isSufficient ?= 'all' )?
  ( 'of'? ownedRelationship += ConnectorEndMember
    '=' ownedRelationship += ConnectorEndMember )?

8.2.5.5.3 Successions

Succession =
  FeaturePrefix 'succession'
  SuccessionDeclaration TypeBody

SuccessionDeclaration : Succession =
  FeatureDeclaration
  ( 'first' ownedRelationship += ConnectorEndMember
    'then' ownedRelationship += ConnectorEndMember )?
  | ( s.isSufficient ?= 'all' )?
  ( 'first'? ownedRelationship += ConnectorEndMember
    'then' ownedRelationship += ConnectorEndMember )?

8.2.5.6 Behaviors Concrete Syntax

8.2.5.6.1 Behaviors

Behavior =
  TypePrefix 'behavior'
  ClassifierDeclaration TypeBody

8.2.5.6.2 Steps

Step =
  FeaturePrefix
    'step' FeatureDeclaration ValuePart?
    TypeBody

8.2.5.7 Functions Concrete Syntax

8.2.5.7.1 Functions

Function =
  TypePrefix 'function'
  ClassifierDeclaration FunctionBody

FunctionBody : Type =
  ';' | '{' FunctionBodyPart '}'

FunctionBodyPart : Type =
  ( TypeBodyElement
    | ownedRelationship += ReturnFeatureMember

8.2.5.7.2 Expressions

Expression =
  FeaturePrefix
  'expr' FeatureDeclaration ValuePart?
  FunctionBody

8.2.5.7.3 Predicates

Predicate =
  TypePrefix 'predicate'
  ClassifierDeclaration FunctionBody

8.2.5.7.4 Boolean Expressions and Invariants

BooleanExpression =
  FeaturePrefix
  'bool' FeatureDeclaration ValuePart?
  FunctionBody

Invariant =
  FeaturePrefix
  'inv' ( 'true' | isNegated ?= 'false' )?
  FeatureDeclaration ValuePart?
  FunctionBody

8.2.5.8 Expressions Concrete Syntax

8.2.5.8.1 Operator Expressions

OwnedExpressionReferenceMember : FeatureMembership =
  ownedRelationship += OwnedExpressionReference

OwnedExpressionReference : FeatureReferenceExpression =
  ownedRelationship += OwnedExpressionMember

OwnedExpressionMember : FeatureMembership =
  ownedFeatureMember = OwnedExpression

OwnedExpression : Expression =
  ConditionalExpression
  | ConditionalBinaryOperatorExpression
  | BinaryOperatorExpression
  | UnaryOperatorExpression
  | ClassificationExpression
  | MetaclassificationExpression
  | ExtentExpression
  | PrimaryExpression
ConditionalExpression : OperatorExpression =
    operator = 'if'
    ownedRelationship += ArgumentMember '?'
    ownedRelationship += ArgumentExpressionMember 'else'
    ownedRelationship += ArgumentExpressionMember

ConditionalBinaryOperatorExpression : OperatorExpression =
    ownedRelationship += ArgumentMember
    operator = ConditionalBinaryOperator
    ownedRelationship += ArgumentExpressionMember

ConditionalBinaryOperator =
    '?' | 'or' | 'and' | 'implies'

BinaryOperatorExpression : OperatorExpression =
    ownedRelationship += ArgumentMember
    operator = BinaryOperator
    ownedRelationship += ArgumentMember

BinaryOperator =
    '|' | '&' | 'xor' | '..'
    | '==' | '!=' | '===' | '!=='
    | '<' | '>' | '<=' | '>='
    | '+' | '-' | '*' | '/'
    | '%'

UnaryOperatorExpression : OperatorExpression =
    operator = UnaryOperator
    ownedRelationship += ArgumentMember

UnaryOperator =
    '+' | '-' | '~' | 'not'

ClassificationExpression : OperatorExpression =
    ( ownedRelationship += ArgumentMember )?
    ( operator = ClassificationTestOperator
    ownedRelationship += TypeReferenceMember
    | operator = CastOperator
    ownedRelationship += TypeResultMember
    )

ClassificationTestOperator =
    'istype' | 'hastype' | '@'

CastOperator =
    'as'

MetaclassificationExpression : OperatorExpression =
    ownedRelationship += MetadataArgumentMember
    ( operator = MetaClassificationTestOperator
    ownedRelationship += TypeReferenceMember
    | operator = MetaCastOperator
    ownedRelationship += TypeResultMember
    )

ArgumentMember : ParameterMembership =
    ownedMemberParameter = Argument

Argument : Feature =
    ownedRelationship += ArgumentValue
ArgumentValue : FeatureValue =
    value = OwnedExpression

ArgumentExpressionMember : FeatureMembership =
    ownedRelatedElement += ArgumentExpression

ArgumentExpression : Feature =
    ownedRelationship += ArgumentExpressionValue

ArgumentExpressionValue : FeatureValue =
    value = OwnedExpressionReference

MetadataArgumentMember : ParameterMembership =
    ownedRelatedElement += MetadataArgument

MetadataArgument : Feature =
    ownedRelationship += MetadataValue

MetadataValue : FeatureValue =
    value = MetadataReference

MetadataReference : MetadataAccessExpression =
    referencedElement = [QualifiedName]

MetaclassificationTestOperator =
    '@@'

MetaCastOperator =
    'meta'

ExtentExpression : OperatorExpression =
    operator = 'all'
    ownedRelationship += TypeReferenceMember

TypeReferenceMember : FeatureMembership =
    ownedMemberFeature = TypeReference

TypeResultMember : ResultParameterMembership =
    ownedMemberFeature = TypeReference

TypeReference : Feature =
    ownedRelationship += ReferenceTyping

ReferenceTyping : FeatureTyping =
    type = [QualifiedName]

Notes

1. OperatorExpressions provide a shorthand notation for InvocationExpressions that invoke a library Function represented as an operator symbol. Table 5 shows the mapping from operator symbols to the Functions they represent from the Kernel Model Library (see Clause 9). An OperatorExpression contains subexpressions called its operands that generally correspond to the argument Expressions of the OperatorExpression, except in the case of operators representing control Functions, in which case the evaluation of certain operands is as determined by the Function (see 8.4.4.9 for details).

2. Though not directly expressed in the syntactic productions given above, in any OperatorExpression containing nested OperatorExpressions, the nested OperatorExpressions shall be implicitly
grouped according to the *precedence* of the operators involved, as given in *Table 6*. Operator Expressions with higher precedence operators shall be grouped more tightly than those with lower precedence operators. Further, all Binary Operators other than exponentiation are left-associative (i.e., they group to the left), while the exponentiation operators (^ and **) are right-associative (i.e., they group to the right).

3. The unary operator symbol ~ maps to the library Function `DataFunctions::'~'`, as shown in *Table 5*. This abstract Function may be given a concrete definition in a domain-specific Function library, but no default definition is provided in the Kernel Functions Library. If no domain-specific definition is available, a tool should give a warning if this operator is used.

### Table 5. Operator Mapping

<table>
<thead>
<tr>
<th>Operator</th>
<th>Library Function</th>
<th>Description</th>
<th>Model-Level Evaluable?</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>BaseFunctions::'all'</td>
<td>Type extent</td>
<td>No</td>
</tr>
<tr>
<td>istype</td>
<td>BaseFunctions::'istype'</td>
<td>All argument values are directly or indirectly instances of a type</td>
<td>Yes</td>
</tr>
<tr>
<td>hasType</td>
<td>BaseFunctions::'hasType'</td>
<td>All argument values are directly instances of a type</td>
<td>Yes</td>
</tr>
<tr>
<td>@</td>
<td>BaseFunctions::'@'</td>
<td>Any argument value is directly or indirectly an instance of a type</td>
<td>Yes</td>
</tr>
<tr>
<td>@@</td>
<td>BaseFunctions::'@@'</td>
<td>Any argument value is directly or indirectly an instance of a metaclass</td>
<td>Yes</td>
</tr>
<tr>
<td>as</td>
<td>BaseFunctions::as</td>
<td>Select instances of type (cast)</td>
<td>Yes</td>
</tr>
<tr>
<td>meta</td>
<td>BaseFunctions::meta</td>
<td>Select instances of a metaclass (metacast)</td>
<td>Yes</td>
</tr>
<tr>
<td>==</td>
<td>BaseFunctions::'=='</td>
<td>Equality</td>
<td>Yes</td>
</tr>
<tr>
<td>!=</td>
<td>BaseFunctions::'!='</td>
<td>Inequality</td>
<td>Yes</td>
</tr>
<tr>
<td>===</td>
<td>BaseFunctions::'==='</td>
<td>Same (equality for data values, same lives for occurrences)</td>
<td>Yes</td>
</tr>
<tr>
<td>!==</td>
<td>BaseFunctions::'!=='</td>
<td>Not same</td>
<td>Yes</td>
</tr>
<tr>
<td>xor</td>
<td>DataFunctions::'xor'</td>
<td>Logical &quot;exclusive or&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>not</td>
<td>DataFunctions::'not'</td>
<td>Logical &quot;not&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>~</td>
<td>DataFunctions::'~'</td>
<td>Undefined</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DataFunctions::'</td>
<td>'</td>
</tr>
<tr>
<td>&amp;</td>
<td>DataFunctions::'&amp;'</td>
<td>Logical &quot;and&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>&lt;</td>
<td>DataFunctions::'&lt;'</td>
<td>Less than</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt;</td>
<td>DataFunctions::'&gt;'</td>
<td>Greater than</td>
<td>Yes</td>
</tr>
<tr>
<td>&lt;=</td>
<td>DataFunctions::'&lt;='</td>
<td>Less than or equal to</td>
<td>Yes</td>
</tr>
<tr>
<td>Operator</td>
<td>Library Function</td>
<td>Description</td>
<td>Model-Level Evaluable?</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------</td>
<td>--------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>&gt;=</td>
<td>DataFunctions::'='</td>
<td>Greater than or equal to</td>
<td>Yes</td>
</tr>
<tr>
<td>+</td>
<td>DataFunctions::'+'</td>
<td>Addition</td>
<td>Yes</td>
</tr>
<tr>
<td>-</td>
<td>DataFunctions::'-'</td>
<td>Subtraction</td>
<td>Yes</td>
</tr>
<tr>
<td>*</td>
<td>DataFunctions::'*'</td>
<td>Multiplication</td>
<td>Yes</td>
</tr>
<tr>
<td>/</td>
<td>DataFunctions::'/'</td>
<td>Division</td>
<td>Yes</td>
</tr>
<tr>
<td>%</td>
<td>DataFunctions::'%'</td>
<td>Remainder</td>
<td>Yes</td>
</tr>
<tr>
<td>^ **</td>
<td>DataFunctions::'^'</td>
<td>Exponentiation</td>
<td>Yes</td>
</tr>
<tr>
<td>..</td>
<td>DataFunctions::'..'</td>
<td>Range construction</td>
<td>Yes</td>
</tr>
<tr>
<td>??</td>
<td>ControlFunctions::'??'</td>
<td>Null coalescing</td>
<td>Yes</td>
</tr>
<tr>
<td>if</td>
<td>ControlFunctions::'if'</td>
<td>Conditional test (ternary)</td>
<td>Yes</td>
</tr>
<tr>
<td>or</td>
<td>ControlFunctions::'or'</td>
<td>Conditional &quot;or&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>and</td>
<td>ControlFunctions::'and'</td>
<td>Conditional &quot;and&quot;</td>
<td>Yes</td>
</tr>
<tr>
<td>implies</td>
<td>ControlFunctions::'implies'</td>
<td>Conditional &quot;implication&quot;</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 6. Operator Precedence (highest to lowest)

<table>
<thead>
<tr>
<th>Operator</th>
<th>Library Function</th>
<th>Description</th>
<th>Model-Level Evaluable?</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ - ~</td>
<td></td>
<td>not</td>
<td></td>
</tr>
<tr>
<td>^ **</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* / %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>..</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; &gt; &lt;= &gt;=</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>istype hastype @ @ as meta</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>== !== !== = !=</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp;</td>
<td></td>
<td>and</td>
<td></td>
</tr>
<tr>
<td>xor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 8.2.5.8.2 Primary Expressions

**PrimaryExpression** : Expression =  
  FeatureChainExpression  
  | NonFeatureChainPrimaryExpression

**PrimaryArgumentValue** : FeatureValue =  
  value = PrimaryExpression

**PrimaryArgument** : Feature =  
  ownedRelationship += PrimaryArgumentValue

**PrimaryArgumentMember** : ParameterMembership =  
  ownedMemberParameter = PrimaryArgument

**NonFeatureChainPrimaryExpression** : Expression =  
  BracketExpression  
  | IndexExpression  
  | SequenceExpression  
  | SelectExpression  
  | CollectExpression  
  | FunctionOperationExpression  
  | BaseExpression

**NonFeatureChainPrimaryArgumentValue** : FeatureValue =  
  value = NonFeatureChainPrimaryExpression

**NonFeatureChainPrimaryArgument** : Feature =  
  ownedRelationship += NonFeatureChainPrimaryArgumentValue

**NonFeatureChainPrimaryArgumentMember** : ParameterMembership =  
  ownedMemberParameter = PrimaryArgument

**BracketExpression** : OperatorExpression =  
  ownedRelationship += PrimaryArgumentMember  
  operator = '['  
  ownedRelationship += SequenceExpressionListMember ']

**IndexExpression** : OperatorExpression =  
  ownedRelationship += PrimaryArgumentMember  
  operator = '#'  
  '(' ownedRelationship += SequenceExpressionListMember ')' 

**SequenceExpression** : Expression =  
  '(' SequenceExpressionList ')

---

**Kernel Modeling Language (KerML) v1.0 Beta 1**
SequenceExpressionList : Expression =
  OwnedExpression ',',? | SequenceOperatorExpression

SequenceOperatorExpression : OperatorExpression =
  ownedRelationship += OwnedExpressionMember
  operator = ','
  ownedRelationship += SequenceExpressionListMember

SequenceExpressionListMember : FeatureMembership =
  ownedMemberFeature = SequenceExpressionList

FeatureChainExpression : FeatureChainExpression =
  ownedRelationship += NonFeatureChainPrimaryArgumentMember '.'
  ownedRelationship += FeatureChainMember

CollectExpression : CollectExpression =
  ownedRelationship += PrimaryArgumentMember '.'
  ownedRelationship += BodyExpressionMember

SelectExpression : SelectExpression =
  ownedRelationship += PrimaryArgumentMember '.?'
  ownedRelationship += BodyExpressionMember

FunctionOperationExpression : InvocationExpression =
  ownedRelationship += PrimaryArgumentMember '->'
  ownedRelationship += ReferenceTyping
  ( ownedRelationship += BodyArgumentMember
   | ownedRelationship += FunctionReferenceArgumentMember
   | ArgumentList )

BodyArgumentMember : ParameterMembership =
  ownedMemberParameter = BodyArgument

BodyArgument : Feature =
  ownedRelationship += BodyArgumentValue

BodyArgumentValue : FeatureValue =
  value = BodyExpression

FunctionReferenceArgumentMember : ParameterMembership =
  ownedMemberParameter = FunctionReferenceArgument

FunctionReferenceArgument : Feature =
  ownedRelationship += FunctionReferenceArgumentValue

FunctionReferenceArgumentValue : FeatureValue =
  value = FunctionReferenceExpression

FunctionReferenceExpression : FeatureReferenceExpression =
  ownedRelationship += FunctionReferenceMember

FunctionReferenceMember : FeatureMembership =
  ownedMemberFeature = FunctionReference

FunctionReference : Expression =
  ownedRelationship += ReferenceTyping

FeatureChainMember : Membership =
  FeatureReferenceMember
  | OwnedFeatureChainMember
Notes

1. Primary expressions provide additional shorthand notations for certain kinds of InvocationExpressions. For those cases in which the InvocationExpression is an OperatorExpression, its operator shall be resolved to the appropriate library function as given in Table 7. Note also that, for a CollectionExpression or SelectExpression, the abstract syntax constrains the operator to be collect and select, respectively, separately from the . and .? symbols used in their concrete syntax notation (see 8.3.4.8.2 and 8.3.4.8.15).

2. The grammar allows a bracket syntax [...] that parses to an invocation of the library Function BaseFunctions::'[', as shown in Table 7. This notation is available for use with domain-specific library models that give a concrete definition to the abstract base ']' Function, but no default definition is provided in the Kernel Functions Library. If no domain-specific definition is available, a tool should give a warning if this operator is used.

Table 7. Primary Expression Operator Mapping

<table>
<thead>
<tr>
<th>Operator</th>
<th>Library Function</th>
<th>Description</th>
<th>Model-level Evaluable?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[</td>
<td>BaseFunctions::'['</td>
<td>Undefined</td>
<td>No</td>
</tr>
<tr>
<td>#</td>
<td>BaseFunctions::'#'</td>
<td>Indexing</td>
<td>Yes</td>
</tr>
<tr>
<td>,</td>
<td>BaseFunctions::','</td>
<td>Sequence construction</td>
<td>Yes</td>
</tr>
<tr>
<td>.</td>
<td>ControlFunctions::'.'</td>
<td>Feature chaining</td>
<td>Yes</td>
</tr>
<tr>
<td>collect</td>
<td>ControlFunctions::collect</td>
<td>Sequence collection</td>
<td>Yes</td>
</tr>
<tr>
<td>select</td>
<td>ControlFunctions::select</td>
<td>Sequence selection</td>
<td>Yes</td>
</tr>
</tbody>
</table>

8.2.5.8.3 Base Expressions

BaseExpression : Expression =
    NullExpression
    | LiteralExpression
    | FeatureReferenceExpression
    | MetadataAccessExpression
    | InvocationExpression
    | BodyExpression

NullExpression : NullExpression =
    'null' | '()' 

FeatureReferenceExpression : FeatureReferenceExpression =
    ownedRelationship += FeatureReferenceMember

FeatureReferenceMember : Membership =
    memberElement = FeatureReference

FeatureReference : Feature =
    [QualifiedName]

MetadataAccessExpression =
    referenceElement = [QualifiedName] '.' 'metadata'
InvocationExpression : InvocationExpression =
    ownedRelationship += ( OwnedFeatureTyping | OwnedSubsetting )
ArgumentList
(See Note 1)

ArgumentList : InvocationExpression =
    '(' ( PositionalArgumentList | NamedArgumentList )? ')'  

PositionalArgumentList : InvocationExpression =
    e.ownedRelationship += ArgumentMember
    ( ',' e.ownedRelationship += ArgumentMember )*

NamedArgumentList : InvocationExpression =
    ownedRelationship += NamedArgumentMember
    ( ',' ownedRelationship += NamedArgumentMember )*

NamedArgumentMember : FeatureMembership =
    ownedMemberFeature = NamedArgument

NamedArgument : Feature =
    ownedRelationship += ParameterRedefinition '='
    ownedRelationship += ArgumentValue

ParameterRedefinition : Redefinition =
    redefinedFeature = [QualifiedName]

BodyExpression : FeatureReferenceExpression =
    ownedRelationship += ExpressionBodyMember

ExpressionBodyMember : FeatureMembership =
    ownedMemberFeature = ExpressionBody

ExpressionBody : Expression =
    '{' FunctionBodyPart '}'

Notes

1. The first ownedRelationship of an InvocationExpression should be parsed as a FeatureTyping if the target Type is a Classifier and as a Subsetting if the target Type is a Feature.

8.2.5.8.4 Literal Expressions

LiteralExpression =
    LiteralBoolean |
    LiteralString |
    LiteralInteger |
    LiteralReal |
    LiteralInfinity

LiteralBoolean =
    value = BooleanValue

BooleanValue : Boolean =
    'true' | 'false'

LiteralString =
    value = STRING_VALUE

LiteralInteger =
value = DECIMAL_VALUE

LiteralReal =
value = RealValue

RealValue : Real =
    DECIMAL_VALUE? '.' ( DECIMAL_VALUE | EXPONENTIAL_VALUE )
    | EXPONENTIAL_VALUE

LiteralInfinity =
    '*'

8.2.5.9 Interactions Concrete Syntax

8.2.5.9.1 Interactions

Interaction =
    TypePrefix 'interaction'
    ClassifierDeclaration TypeBody

8.2.5.9.2 Item Flows

ItemFlow =
    FeaturePrefix 'flow'
    ItemFlowDeclaration TypeBody

SuccessionItemFlow =
    FeaturePrefix 'succession' 'flow'
    ItemFlowDeclaration TypeBody

ItemFlowDeclaration : ItemFlow =
    ( FeatureDeclaration ValuePart?
    ( 'of' ownedRelationship += ItemFeatureMember )?
    ( 'from' ownedRelationship += ItemFlowEndMember
    'to' ownedRelationship += ItemFlowEndMember )?
    | ( isSufficient ?= 'all' )?
    ownedRelationship += ItemFlowEndMember 'to'
    ownedRelationship += ItemFlowEndMember

ItemFeatureMember : FeatureMembership =
    ownedRelatedElement = ItemFeature

ItemFeature : Feature =
    Identification ItemFeatureSpecializationPart ValuePart?
    | ( ownedRelationship += OwnedFeatureTyping
    ( ownedRelationship += OwnedMultiplicity )?
    | ownedRelationship += OwnedMultiplicity
    ( ownedRelationship += OwnedFeatureTyping )?

ItemFeatureSpecializationPart : Feature =
    FeatureSpecialization+ MultiplicityPart?
    FeatureSpecialization*
    | MultiplicityPart FeatureSpecialization+

ItemFlowEndMember : EndFeatureMembership =
    ownedRelatedElement += ItemFlowEnd

ItemFlowEnd : ItemFlowEnd =
    ( ownedRelationship += OwnedReferenceSubsetting '.' )?
    ownedRelationship += ItemFlowFeatureMember
ItemFlowFeatureMember : FeatureMembership =
    ownedRelatedElement += ItemFlowFeature

ItemFlowFeature : Feature =
    ownedRelationship += ItemFlowRedefinition
(See Note 1)

ItemFlowRedefinition : Redefinition =
    redefinedFeature = [QualifiedName]

Notes

1. To ensure that an ItemFlowFeature passes the validateRedefinitionDirectionConformance constraint (see 8.3.3.3.8), its direction must be set to the direction of its redefinedFeature, relative to its owning ItemFlowEnd, that is, the result of the following OCL expression:

   \[ \text{owningType.directionOf(ownedRedefinition->at(1).redefinedFeature)} \]

8.2.5.10 Feature Values Concrete Syntax

ValuePart : Feature =
    ownedRelationship += FeatureValue

FeatureValue =
    '{' | isInitial ?= ':' | isDefault ?= 'default' ( '=' | isInitial ?= ':' )?
    ownedRelatedElement += OwnedExpression

8.2.5.11 Multiplicities Concrete Syntax

Multiplicity =
    MultiplicitySubset | MultiplicityRange

MultiplicitySubset : Multiplicity =
    'multiplicity' Identification Subsets TypeBody

MultiplicityRange =
    'multiplicity' Identification MultiplicityBounds TypeBody

OwnedMultiplicity : OwningMembership =
    ownedRelatedElement += OwnedMultiplicityRange

OwnedMultiplicityRange : MultiplicityRange =
    MultiplicityBounds

MultiplicityBounds : MultiplicityRange =
    '[ ' ( ownedRelationship += MultiplicityExpressionMember '..' )? ownedRelationship += MultiplicityExpressionMember ' ]'

MultiplicityExpressionMember : OwningMembership =
    ownedRelatedElement += ( LiteralExpression | FeatureReferenceExpression )
8.2.5.12 Metadata Concrete Syntax

Metaclass =
    TypePrefix 'metaclass'
    ClassifierDeclaration TypeBody

PrefixMetadataAnnotation : Annotation =
    '#' ownedRelatedElement += PrefixMetadataFeature

PrefixMetadataMember : OwningMembership =
    '#' ownedRelatedElement += PrefixMetadataFeature

PrefixMetadataFeature : MetadataFeature :
    ownedRelationship += OwnedFeatureTyping

MetadataFeature =
    ( ownedRelationship += PrefixMetadataMember )*
    ( '0' | 'metadata' )
    MetadataFeatureDeclaration
    ( 'about' annotation += Annotation
      { ownedRelationship += annotation } )
    ( ',' annotation += Annotation
      { ownedRelationship += annotation } )*

MetadataBody

MetadataFeatureDeclaration : MetadataFeature =
    ( Identification ( ':' | 'typed' 'by' ) )?
    ownedRelationship += OwnedFeatureTyping

MetadataBody : Feature =
    ';' | '{' ( ownedRelationship += MetadataBodyElement )* '}'

MetadataBodyElement : Membership =
    NonFeatureMember
    | MetadataBodyFeatureMember
    | AliasMember
    | Import

MetadataBodyFeatureMember : FeatureMembership =
    ownedMemberFeature = MetadataBodyFeature

MetadataBodyFeature : Feature =
    'feature'? ( '::>' | 'redefines')? ownedRelationship += OwnedRedefinition
    FeatureSpecializationPart? ValuePart?
    MetadataBody

8.2.5.13 Packages Concrete Syntax

Package =
    ( ownedRelationship += PrefixMetadataMember )*
    PackageDeclaration PackageBody

LibraryPackage =
    ( isStandard ?= 'standard' ) 'library'
    ( ownedRelationship += PrefixMetadataMember )*
    PackageDeclaration PackageBody

PackageDeclaration : Package =
8.3 Abstract Syntax

8.3.1 Abstract Syntax Overview

The KerML abstract syntax is specified as a UML model conforming to the CMOF conformance point of the Meta Object Facility Core Specification [MOF]. As shown in Fig. 1, this model is divided into three top-level packages corresponding to the three layers of KerML (see 8.1). Each top-level package contains nested packages for the modeling areas it addresses. Further, the Core package imports the Root package and the Kernel package imports the Core package, so that the Kernel package contains (as owned or imported members) all abstract syntax elements. Fig. 2 shows the generalization hierarchy for all abstract syntax elements, other than those that represent KerML Relationships, and Fig. 3 shows a similar hierarchy for all abstract syntax elements that represent Relationships.
The Kernel layer completes the KerML metamodel.

The Core layer provides the semantic foundation for KerML.

The Root layer provides the syntactic foundation for KerML.

Figure 1. KerML Syntax Layers
The MOF-compliant class model for the abstract syntax defines the basic structural representation for any KerML model. It is also the basis for the textual concrete syntax (see Clause 8.2) and for other forms of serialization used for interchanging models (see Clause 10). In addition to this basic structure, the abstract syntax also includes constraints defined on various metaclasses. A conformant tool shall be able to accept any KerML model that conforms to the structural abstract syntax class model, and it may then additionally report on and/or enforce the constraints on a model so represented (as further described below).

The abstract syntax model includes three kinds of constraints:

1. **Derivation constraints.** These constraints specify how the values of the derived properties of a metaclass are computed from the values of other properties in the abstract syntax model. A tool conformant to the KerML abstract syntax shall always enforce derivation constraints. However, the computed values of derived properties may depend on whether implied relationships are included in the
model or not (see below). A derivation constraint has a name starting with the word `derive`, followed by the name of the metaclass it constrains, followed by the name of the derived property it is for. The OCL specification of such a constraint always has the form of an equality, with the derived property on the left-hand side and the derivation expression on the right-hand side. For example, the derivation constraint for the derived property `Element::ownedElement` is called `deriveElementOwnedElement` and has the OCL specification `ownedElement = ownedRelationship.ownedRelatedElement`.

**Note.** Derivation constraints are *not* included for derived properties in the following cases:

- The derived property subsets a property with multiplicity upper bound 1. In this case, if the derived property has a value, it must be the same as that of the subsetted property.
- The derived property redefines another derived property. In this case, the derivation of the redefined property also applies to the redefining property, though the redefining property will generally place additional constraints on type and/or multiplicity.

2. **Semantic constraints.** These constraints specify relationships that are semantically required in a KerML model (see 8.4.2), particularly relationships with elements in the Kernel Semantic Library (see 9.2). These constraints may be violated by a model as entered by a user or as interchanged. In this case, a tool may satisfy the constraints by introducing *implied relationships* into the model, it may simply report their violation, or it may ignore the violations. Semantic constraints have names that start with the word `check`, followed by the name of the constrained metaclass, followed by a descriptive word or phrase. For example, `checkTypeSpecialization`.

3. **Validation constraints.** These constraints specify additional syntactic conditions that must be satisfied in order to give a model a proper semantic interpretation. They are written presuming that all semantic constraints are satisfied. A valid model is a model that satisfies all validation constraints. A tool conformant to the KerML abstract syntax should report violations of validation constraints. A tool conformant to the KerML semantics is only required to operate on valid models. Validation constraints have names that start with the word `validate`, followed by the name of the metaclass, followed by a descriptive word or phrase. For example, `validateConnectorRelatedFeatures`.

### 8.3.2 Root Abstract Syntax

#### 8.3.2.1 Elements and Relationships Abstract Syntax
8.3.2.1.1 Overview

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.

8.3.2.1.2 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

None.

Attributes

aliasIds : String [0..*] {ordered}
Various alternative identifiers for this Element. Generally, these will be set by tools.

declaredName : String [0..1]

The declared name of this Element.

declaredShortName : String [0..1]

An optional alternative name for the Element that is intended to be shorter or in some way more succinct than its primary name. It may act as a modeler-specified identifier for the Element, though it is then the responsibility of the modeler to maintain the uniqueness of this identifier within a model or relative to some other context.

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

The Documentation owned by this Element.

elementId : 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.

isImpliedIncluded : Boolean

Whether all necessary implied Relationships have been included in the ownedRelationships of this Element. This property may be true, even if there are not actually any ownedRelationships with isImplied = true, meaning that no such Relationships are actually implied for this Element. However, if it is false, then ownedRelationships may not contain any implied Relationships. That is, either all required implied Relationships must be included, or none of them.

/isLibraryElement : Boolean

Whether this Element is contained in the ownership tree of a library model.

/name : String [0..1]

The name to be used for this Element during name resolution within its owningNamespace. This is derived using the effectiveName() operation. By default, it is the same as the declaredName, but this is overridden for certain kinds of Elements to compute a name even when the declaredName is null.

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

/owningMembership : OwningMembership [0..1] {subsets owningRelationship, membership}

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

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

The Namespace that owns this Element, which is 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 full ownership-qualified name of this Element, represented in a form that is valid according to the KerML textual concrete syntax for qualified names (including use of unrestricted name notation and escaped characters, as necessary). The qualifiedName is null if this Element has no owningNamespace or if there is not a complete ownership chain of named Namespaces from a root Namespace to this Element.

/shortName : String [0..1]

The short name to be used for this Element during name resolution within its owningNamespace. This is derived using the effectiveShortName() operation. By default, it is the same as the declaredShortName, but this is overridden for certain kinds of Elements to compute a shortName even when the declaredName is null.

/textualRepresentation : TextualRepresentation [0..*] {subsets ownedElement, annotatingElement, ordered}

The TextualRepresentations that annotate this Element.

**Operations**

effectiveName() : String [0..1]

Return an effective name for this Element. By default this is the same as its declaredName.

**body**: declaredName

effectiveShortName() : String [0..1]

Return an effective shortName for this Element. By default this is the same as its declaredShortName.

**body**: declaredShortName

escapedName() : String [0..1]

Return name, if that is not null, otherwise the shortName, if that is not null, otherwise null. If the returned value is non-null, it is returned as-is if it has the form of a basic name, or, otherwise, represented as a restricted name according to the lexical structure of the KerML textual notation (i.e., surrounded by single quote characters and with special characters escaped).

libraryNamespace() : Namespace [0..1]
By default, return the library Namespace of the owningRelationship of this Element, if it has one.

```plaintext
if owningRelationship <> null then owningRelationship.libraryNamespace()
else null endif
```

### Constraints

#### deriveElementDocumentation

The documentation of an Element is its ownedElements that are Documentation.

```plaintext
documentation = ownedElement->selectByKind(Documentation)
```

#### deriveElementIsLibraryElement

An Element isLibraryElement if libraryNamespace() is not null.

```plaintext
isLibraryElement = libraryNamespace() <> null
```

#### deriveElementName

The name of an Element is given by the result of the effectiveName() operation.

```plaintext
name = effectiveName()
```

#### deriveElementOwnedAnnotation

The ownedAnnotations of an Element are its ownedRelationships that are Annotations, for which the Element is the annotatedElement.

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

#### deriveElementOwnedElement

The ownedElements of an Element are the ownedRelatedElements of its ownedRelationships.

```plaintext
ownedElement = ownedRelationship.ownedRelatedElement
```

#### deriveElementOwner

The owner of an Element is the owningRelatedElement of its owningRelationship.

```plaintext
owner = owningRelationship.owningRelatedElement
```

#### deriveElementQualifiedName

If this Element does not have an owningNamespace, then its qualifiedName is null. If the owningNamespace of this Element is a root Namespace, then the qualifiedName of the Element is the escaped name of the Element (if any). If the owningNamespace is non-null but not a root Namespace, then the qualifiedName of this Element is constructed from the qualifiedName of the owningNamespace and the escaped name of the Element, unless the qualifiedName of the owningNamespace is null or the escaped name is null, in which case the qualifiedName of this Element is also null.
qualifiedName =
  if owningNamespace = null then null
  else if owningNamespace.own = null then escapedName()
  else if owningNamespace.qualifiedName = null or
    escapedName() = null then null
  else owningNamespace.qualifiedName + '::' + escapedName()
endif endif endif

deriveElementShortName

The shortName of an Element is given by the result of the effectiveShortName() operation.
shortName = effectiveShortName()
deriveElementTextualRepresentation

The textualRepresentations of an Element are its ownedElements that are TextualRepresentations.
textualRepresentation = ownedElement->selectByKind(TextualRepresentation)
deriveOwningNamespace

The owningNamespace of an Element is the membershipOwningNamespace of its owningMembership (if any).
owningNamespace =
  if owningMembership = null then null
  else owningMembership.membershipOwningNamespace
endif
validateElementIsImpliedIncluded

If an Element has any ownedRelationships for which isImplied = true, then the Element must also have isImpliedIncluded = true. (Note that an Element can have isImplied = true even if no ownedRelationships have isImplied = true, indicating the Element simply has no implied Relationships.
ownedRelationship->exists(isImplied) implies isImpliedIncluded

8.3.2.1.3 Relationship

Description

A Relationship is an Element that relates other Element. 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 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 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 Relationship.

**General Classes**

Element

**Attributes**

isImplied : Boolean

Whether this Relationship was generated by tooling to meet semantic rules, rather than being directly created by a modeler.

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 [0..*] {ordered, nonunique}

The Elements that are related by this Relationship, derived as the union of the source and target Elements of the Relationship.

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**

libraryNamespace() : Namespace [0..1] {redefines libraryNamespace}

Return whether this Relationship has either an owningRelatedElement or owningRelationship that is a library element.

**body**: if owningRelatedElement <> null then owningRelatedElement.libraryNamespace() 
else if owningRelationship <> null then owningRelationship.libraryNamespace() 
else null endif endif

**Constraints**

deriveRelationshipRelatedElement

The relatedElements of a Relationship consist of all of its source Elements followed by all of its target Elements.

relatedElement = source->union(target)
8.3.2.2 Dependencies Abstract Syntax

8.3.2.2.1 Overview

Figure 5. Dependencies

8.3.2.2.2 Dependency

Description

A Dependency is a Relationship that indicates that one or more client Elements require one or more supplier Elements for their complete specification. In general, this means that a change to one of the supplier Elements may necessitate a change to, or re-specification of, the client Elements.

Note that a Dependency is entirely a model-level Relationship, without instance-level semantics.

General Classes

Relationship

Attributes

client : Element [1..*] {redefines source, ordered}

The Element or Elements dependent on the supplier Elements.

supplier : Element [1..*] {redefines target, ordered}

The Element or Elements on which the client Elements depend in some respect.

Operations

None.

Constraints

None.
8.3.2.3.1 Overview

Figure 6. Annotation

8.3.2.3.2 AnnotatingElement

Description

An AnnotatingElement is an Element that provides additional description of or metadata on some other Element. An AnnotatingElement is either attached to its annotatedElements by Annotation Relationships, or it implicitly annotates its owningNamespace.

General Classes

Element

Attributes

/annotatedElement : Element [1..*] {ordered}

The Elements that are annotated by this AnnotatingElement. If annotation is not empty, these are the annotatedElements of the annotations. If annotation is empty, then it is the owningNamespace of the AnnotatingElement.

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

The Annotations that relate this AnnotatingElement to its annotatedElements.

/ownedAnnotatingRelationship : Annotation [0..*] {subsets annotation, ownedRelationship}

The ownedRelationships of this AnnotatingElement that are Annotations, for which this AnnotatingElement is the annotatingElement.
Operations
None.

Constraints

deriveAnnotatingElementAnnotatedElement

If an AnnotatingElement has annotations, then its annotatedElements are the annotatedElements of all its annotations. Otherwise, it's single annotatedElement is its owningNamespace.

annotatedElement =
  if annotation->notEmpty() then annotation.annotatedElement
  else Sequence{owningNamespace} endif

deriveAnnotatingElementOwnedAnnotatingRelationship

The ownedAnnotatingRelationships of an AnnotatingElement are its ownedRelationships that are Annotations, for which the AnnotatingElement is the annotatingElement.

ownedAnnotatingRelationship = ownedRelationship->
  selectByKind(Annotation)->
    select(a | a.annotatingElement = self)

8.3.2.3.3 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, owningRelatedElement}

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

/owningAnnotatingElement : AnnotatingElement [0..1] {subsets annotatingElement, owningRelatedElement}

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

Operations
None.

Constraints

None.

8.3.2.3.4 Comment

Description

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

General Classes

AnnotatingElement

Attributes

body : String

The annotation text for the Comment.

locale : String [0..1]

Identification of the language of the body text and, optionally, the region and/or encoding. The format shall be a POSIX locale conformant to ISO/IEC 15897, with the format [language[_territory][.codeset][@modifier]].

Operations

None.

Constraints

None.

8.3.2.3.5 Documentation

Description

Documentation is a Comment that specifically documents a documentedElement, which must be its owner.

General Classes

Comment

Attributes

/documentatedElement : Element {subsets owner, redefines annotatedElement}

The Element that is documented by this Documentation.

Operations

None.
Constraints
None.

8.3.2.3.6 TextualRepresentation

Description

A TextualRepresentation is an AnnotatingElement whose body represents the representedElement in a given language. The representedElement must be the owner of the TextualRepresentation. 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.

If the named language of a TextualRepresentation 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. The following language names are defined to correspond to the given standard languages:

<table>
<thead>
<tr>
<th>Language</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>kerml</td>
<td>Kernel Modeling Language</td>
</tr>
<tr>
<td>ocl</td>
<td>Object Constraint Language</td>
</tr>
<tr>
<td>alf</td>
<td>Action Language for fUML</td>
</tr>
</tbody>
</table>

Other specifications may define specific language strings, other than those shown above, to be used to indicate the use of languages from those specifications in KerML TextualRepresentation.

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. 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.

An Element with a TextualRepresentation 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.

General Classes
AnnotatingElement

Attributes

body : String

The 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 {subsets owner, redefines annotatedElement}

The Element that is represented by this TextualRepresentation.
Operations
None.

Constraints
None.

8.3.2.4 Namespaces Abstract Syntax
8.3.2.4.1 Overview

Figure 7. Namespaces
Figure 8. Imports

8.3.2.4.2 Import

Description

An Import is an Relationship between its importOwningNamespace and either a Membership (for a MembershipImport) or another Namespace (for a NamespaceImport), which determines a set of Memberships that become importedMemberships of the importOwningNamespace. If isImportAll = false (the default), then only public Memberships are considered "visible". If isImportAll = true, then all Memberships are considered "visible", regardless of their declared visibility. If isRecursive = true, then visible Memberships are also recursively imported from owned sub-Namespace.

General Classes

Relationship

Attributes

/importedElement : Element

The effectively imported Element for this Import. For a MembershipImport, this is the memberElement of the importedMembership. For a NamespaceImport, it is the importedNamespace.

/importOwningNamespace : Namespace {subsets owningRelatedElement, redefines source}

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

isImportAll : Boolean

Whether to import memberships without regard to declared visibility.

isRecursive : Boolean

Whether to recursively import Memberships from visible, owned sub-Namespace.

visibility : VisibilityKind

The visibility level of the imported members from this Import relative to the importOwningNamespace.

Operations
importedMemberships(excluded : Namespace [0..*]) : Membership [0..*]

Returns Memberships that are to become importedMemberships of the importOwningNamespace. (The excluded parameter is used to handle the possibility of circular Import Relationships.)

Constraints

None.

8.3.2.4.3 Membership

Description

A 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. Any memberNames specify how the memberElement is identified in the Namespace and the visibility specifies whether or not the memberElement is publicly visible from outside the Namespace.

If a Membership is an OwningMembership, then it owns its memberElement, which becomes an ownedMember of the membershipOwningNamespace. Otherwise, the memberNames of a Membership are effectively aliases within the membershipOwningNamespace for an Element with a separate OwningMembership in the same or a different Namespace.

General Classes

Relationship

Attributes

memberElement : Element {redefines target}

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

/memberElementId : String

The elementId of the memberElement.

memberName : String [0..1]

The name of the memberElement relative to the membershipOwningNamespace.

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

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

memberShortName : String [0..1]

The short name of the memberElement relative to the membershipOwningNamespace.

visibility : VisibilityKind

Whether or not the Membership of the memberElement in the membershipOwningNamespace is publicly visible outside that Namespace.
Operations

isDistinguishableFrom(other : Membership) : Boolean

Whether this Membership is distinguishable from a given other Membership. By default, this is true if this Membership has no memberShortName or memberName; or each of the memberShortName and memberName are different than both of those of the other Membership; or neither of the metaclasses of the memberElement of this Membership and the memberElement of the other Membership conform to the other. But this may be overridden in specializations of Membership.

body: not (memberElement.oclKindOf(other.memberElement.oclType())) or other.memberElement.oclKindOf(memberElement.oclType()) or
    (shortMemberName = null or
     shortMemberName <> other.memberName) and
    (memberName = null or
     memberName <> other.memberName))

Constraints

deriveMembershipMemberElementId

The memberElementId of a Membership is the elementId of its memberElement.

memberElementId = memberElement.elementId

8.3.2.4.4 MembershipImport

Description

A MembershipImport is an Import that imports its importedMembership into the importOwningNamespace. If isRecursive = true and the memberElement of the importedMembership is a Namespace, then the equivalent of a recursive NamespaceImport is also performed on that Namespace.

General Classes

Import

Attributes

importedMembership : Membership {redefines target}

The Membership to be imported.

Operations

importedMemberships(excluded : Namespace [0..*]) : Membership [0..*] {redefines importedMemberships}

Returns at least the importedMembership. If isRecursive = true and the memberElement of the importedMembership is a Namespace, then Memberships are also recursively imported from that Namespace.

body: if not isRecursive or
    not importedElement.oclIsKindOf(Namespace) or
    excluded->includes(importedElement)
then Sequence{importedMembership}
Constraints

deriveMembershipImportImportedElement

The importedElement of a MembershipImport is the memberElement of its importedMembership.
importedElement = importedMembership.memberElement

8.3.2.4.5 Namespace

Description

A Namespace is an Element that contains other Elements, known as its members, via Membership Relationships with those Elements. The members of a Namespace may be owned by the Namespace, aliased in the Namespace, or imported into the Namespace via Import Relationships.

A Namespace can provide names for its members via the memberNames and memberShortNames specified by the Memberships in the Namespace. If a Membership specifies a memberName and/or memberShortName, then those are names of the corresponding memberElement relative to the Namespace. For an OwningMembership, the owningMemberName and owningMemberShortName are given by the Element name and shortName. 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 the ownedImports of this Namespace.

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

The set of all member Elements of this Namespace, which are the memberElements of all memberships of the Namespace.

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

All Memberships in this Namespace, including (at least) 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, which are the ownedMemberElements of the ownedMemberships of the 

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

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

membershipOwningNamespace.

Operations

importedMemberships(excluded : Namespace [0..*]) : Membership [0..*]

Derive the imported Memberships of this Namespace as the importedMembership of all ownedImports, 
excluding those Imports whose importOwningNamespace is in the excluded set, and excluding Memberships 
that have distinguishability collisions with each other or with any ownedMembership.

body: ownedImport.importedMemberships(excluded->including(self))

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

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

body: let elementMemberships : Sequence(Membership) = 
    memberships->select(memberElement = element) in 
    memberships.memberShortName->
    union(memberships.memberName)->
    asSet()

qualificationOf(qualifiedName : String) : String [0..1]

Return a string with valid KerML syntax representing the qualification part of a given qualifiedName, that is, a 
qualified name with all the segment names of the given name except the last. If the given qualifiedName has only 
one segment, then return null.

body: No OCL

resolve(qualifiedName : String) : Membership [0..1]

Resolve the given qualified name to the named Membership (if any), starting with this Namespace as the local 
scope. The qualified name string must conform to the concrete syntax of the KerML textual notation. According to 
the KerML name resolution rules every qualified name will resolve to either a single Membership, or to none.

body: let qualification : String = qualificationOf(qualifiedName) in 
    let name : String = unqualifiedNameOf(qualifiedName) in 
    if qualification = null then resolveLocal(name) 
    else 
        let namespaceMembership : Membership = resolve(qualification) in 
        if namespaceMembership = null or 
            not namespaceMembership.memberElement.oclIsKindOf(Namespace) 
        then null 
        else 
            namespaceMembership.memberElement.oclAsType(Namespace). 
            resolveVisible(name) 
        endif 
    endif
resolveGlobal(qualifiedName : String) : Membership [0..1]

Resolve the given qualified name to the named Membership (if any) in the effective global Namespace that is the outermost naming scope. The qualified name string must conform to the concrete syntax of the KerML textual notation.

**body**: No OCL

resolveLocal(name : String) : Membership [0..1]

Resolve a simple name starting with this Namespace as the local scope, and continuing with containing outer scopes as necessary. However, if this Namespace is a root Namespace, then the resolution is done directly in global scope.

**body**: if owningNamespace = null then resolveGlobal(name)
else
let memberships : Membership = membership->
select(memberShortName = name or memberName = name) in
if memberships->notEmpty() then memberships->first()
else owningNamespace.resolveLocal(name)
done
endif

resolveVisible(name : String) : Membership [0..1]

Resolve a simple name from the visible Memberships of this Namespace.

**body**: let memberships : Sequence(Membership) =
visibleMemberships(Set{}, false, false)->
select(memberShortName = name or memberName = name) in
if memberships->isEmpty() then null
else memberships->first()
done

unqualifiedNameOf(qualifiedName : String) : String

Return the simple name that is the last segment name of the given qualifiedName. If this segment name has the form of a KerML unrestricted name, then "unescape" it by removing the surrounding single quotes and replacing all escape sequences with the specified character.

**body**: No OCL

visibilityOf(mem : Membership) : VisibilityKind

Returns this visibility of mem relative to this Namespace. If mem is an importedMembership, this is the visibility of its Import. Otherwise it is the visibility of the Membership itself.

**body**: if importedMembership->includes(mem) then
ownedImport->
select(importedMemberships(Set{})->includes(mem)).
first().visibility
else if memberships->includes(mem) then
mem.visibility
else
VisibilityKind::private
done

visibleMemberships(excluded : Namespace [0..*], isRecursive : Boolean, includeAll : Boolean) : Membership [0..*]
If `includeAll = true`, then return all the Memberships of this Namespace. Otherwise, return only the publicly visible Memberships of this Namespace (which includes those ownedMemberships that have a visibility of public and those importedMemberships imported with a visibility of public). If `isRecursive = true`, also recursively include all visible Memberships of any visible owned Namespaces.

```plaintext
body: let visibleMemberships : Sequence(Membership) = 
  if includeAll then memberships 
  else ownedMembership->
    select(visibility = VisibilityKind::public)->
    union(ownedImport->
      select(visibility = VisibilityKind::public).
      importedMemberships(excluded->including(self)))
  endif in 
  if not isRecursive then visibleMemberships 
  else visibleMemberships->union(visibleMemberships->
    selectAsKind(Namespace).
    visibleMemberships(excluded->including(self), true, includeAll))
  endif

Constraints

deriveNamespaceImportedMembership

The importedMemberships of a Namespace are derived using the importedMemberships() operation, with no initially excluded Namespaces.

importedMembership = importedMemberships(Set{})

deriveNamespaceMembers

The members of a Namespace are the memberElements of all its memberships.

member = membership.memberElement

deriveNamespaceOwnedImport

The ownedImports of a Namespace are all its ownedRelationships that are Imports.

ownedImport = ownedRelationship->selectByKind(Import)

deriveNamespaceOwnedMember

The ownedMembers of a Namespace are the ownedMemberElements of all its ownedMemberships that are OwningMemberships.

ownedMember = ownedMembership->selectByKind(OwningMembership).ownedMemberElement

deriveNamespaceOwnedMembership

The ownedMemberships of a Namespace are all its ownedRelationships that are Memberships.

ownedMembership = ownedRelationship->selectByKind(Membership)

validateNamespaceDistinguishibility

All memberships of a Namespace must be distinguishable from each other.
8.3.2.4.6 NamespaceImport

Description

A NamespaceImport is an Import that imports Memberships from its importedNamespace into the importOwningNamespace. If isRecursive = false, then only the visible Memberships of the importedNamespace are imported. If isRecursive = true, then, in addition, Memberships are recursively imported from any ownedMembers of the importedNamespace that are Namespaces.

General Classes

Import

Attributes

importedNamespace : Namespace {redefines target}

The Namespace whose visible Memberships are imported by this NamespaceImport.

Operations

importedMemberships(excluded : Namespace [0..*]) : Membership [0..*] {redefines importedMemberships}

Returns at least the visible Memberships of the importedNamespace. If isRecursive = true, then Memberships are also recursively imported from any ownedMembers of the importedNamespace that are themselves Namespaces.

body: if excluded->includes(importedNamespace) then Sequence{} else importedNamespace.visibleMemberships(excluded, isRecursive, isImportAll)

Constraints

deriveNamespaceImportImportedElement

The importedElement of a NamespaceImport is its importedNamespace.

importedElement = importedNamespace

8.3.2.4.7 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

None.
Literal Values

private

Indicates a Membership is not visible outside its owning Namespace.

protected

An intermediate level of visibility between public and private. By default, it is equivalent to private for the purposes of normal access to and import of Elements from a Namespace. However, other Relationships may be specified to include Memberships with protected visibility in the list of memberships for a Namespace (e.g., Specialization).

public

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

8.3.2.4.8 OwningMembership

Description

An OwningMembership is a Membership that owns its memberElement as an ownedRelatedElement. The ownedMemberElement becomes an ownedMember of the membershipOwningNamespace.

General Classes

Membership

Attributes

/ownedMemberElement : Element {subsets ownedRelatedElement, redefines memberElement}

The Element that becomes an ownedMember of the membershipOwningNamespace due to this OwningMembership.

/ownedMemberElementId : String {redefines memberElementId}

The elementId of the ownedMemberElement.

/ownedMemberName : String [0..1] {redefines modelName}

The name of the ownedMemberElement.

/ownedMemberShortName : String [0..1] {redefines memberShortName}

The shortName of the ownedMemberElement.

Operations

None.

Constraints

deriveOwningMembershipOwnedMemberName
The ownedMemberName of an OwningMembership is the name of its ownedMemberElement.

\[ \text{ownedMemberName} = \text{ownedMemberElement.name} \]

deriveOwningMembershipOwnedMemberShortName

The ownedMemberShortName of an OwningMembership is the shortName of its ownedMemberElement.

\[ \text{ownedMemberShortName} = \text{ownedMemberElement.shortName} \]

### 8.3.3 Core Abstract Syntax

#### 8.3.3.1 Types Abstract Syntax

#### 8.3.3.1.1 Overview

![Figure 9. Types](image-url)
Figure 10. Specialization

Figure 11. Conjugation
Figure 12. Disjoining

Figure 13. Unioning

Figure 14. Intersecting
**Figure 15. Differencing**

### 8.3.3.1.2 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 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 **conjugatedType**. **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 **Specialization** 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 **conjugatedType** of this **Conjugation** that is also its **owningRelatedElement**.

#### Operations

None.

#### Constraints

None.
8.3.3.1.3 Differencing

Description

Differencing is a Relationship that makes its differencingType one of the differencingTypes of its typeDifferenced.

General Classes

Relationship

Attributes

differencingType : Type {redefines target}

Type that partly determines interpretations of typeDifferenced, as described in Type::differencingType.

/typeDifferenced : Type {subsets owningRelatedElement, redefines source}

Type with interpretations partly determined by differencingType, as described in Type::differencingType.

Operations

None.

Constraints

None.

8.3.3.1.4 Disjoining

Description

A Disjoining is a Relationship between Types asserted to have interpretations that are not shared (disjoint) between them, identified as typeDisjoined and disjoiningType. For example, a Classifier for mammals is disjoint from a Classifier for minerals, and a Feature for people's parents is disjoint from a Feature for their children.

General Classes

Relationship

Attributes

disjoiningType : Type {redefines target}

Type asserted to be disjoint with the typeDisjoined.

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

A typeDisjoined that is also an owningRelatedElement.

typeDisjoined : Type {redefines source}

Type asserted to be disjoint with the disjoiningType.
8.3.3.1.5 FeatureDirectionKind

Description

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

General Classes

None.

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.

8.3.3.1.6 FeatureMembership

Description

A FeatureMembership is an OwningMembership between a Feature in an owningType that is also a Featuring Relationship between the Feature and the Type, in which the featuringType is the source and the featureOfType is the target. A FeatureMembership is always owned by its owningType, which is the featuringType for the FeatureMembership considered as a Featuring.

General Classes

Featuring

OwningMembership

Attributes

/ownedMemberFeature : Feature {redefines ownedMemberElement, feature}

The Feature that this FeatureMembership relates to its owningType, making it an ownedFeature of the owningType.

/owningType : Type {subsets type, redefines membershipOwningNamespace, type}
The Type that owns this FeatureMembership.

Operations
None.

Constraints
None.

8.3.3.1.7 Intersecting

Description
Intersecting is a Relationship that makes its intersectingType one of the intersectingTypes of its typeIntersected.

General Classes
Relationship

Attributes
intersectingType : Type {redefines target}

Type that partly determines interpretations of typeIntersected, as described in Type::intersectingType.

/typeIntersected : Type {subsets owningRelatedElement, redefines source}

Type with interpretations partly determined by intersectingType, as described in Type::intersectingType.

Operations
None.

Constraints
None.

8.3.3.1.8 Specialization

Description
Specialization 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 Specialization 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
None.

Constraints

validateSpecificationSpecificNotConjugated

The specific Type of a Specialization cannot be a conjugated Type.

not specific.isConjugated

8.3.3.1.9 Multiplicity

Description

A Multiplicity is a Feature whose co-domain is a set of natural numbers giving the allowed cardinalities of each typeWithMultiplicity. The cardinality of a Type is defined as follows, depending on whether the Type is a Classifier or Feature.

- Classifier – The number of basic instances of the Classifier, that is, those instances representing things, which are not instances of any subtypes of the Classifier that are Features.
- Features – The number of instances with the same featuring instances. In the case of a Feature with a Classifier as its featuringType, this is the number of values of Feature for each basic instance of the Classifier. Note that, for non-unique Features, all duplicate values are included in this count.

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 Base::Anything. If the typeWithMultiplicity is a Feature, the Multiplicity shall have the same domain as the typeWithMultiplicity.

General Classes

Feature

Attributes

None.

Operations

None.

Constraints
checkMultiplicitySpecialization

A Multiplicity must directly or indirectly specialize the Feature `Base::naturals` from the Kernel Semantic Library.

specializesFromLibrary('Base::naturals')

checkMultiplicityTypeFeaturing

If the owningType of a Multiplicity is a Feature, then the Multiplicity must have the same featuringTypes as that Feature. Otherwise, it must have no featuringTypes (meaning that it is implicitly featured by the base Classifier Anything).

if owningType <> null and owningType.oclIsKindOf(Feature) then
  featuringType = owningType.oclAsType(Feature).featuringType
else
  featuringType->isEmpty()
endif

8.3.3.1.10 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

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

The interpretations of a Type with differencingTypes are asserted to be those of the first of those Types, but not including those of the remaining Types. For example, a Classifier might be the difference of a Classifier for people and another for people of a particular nationality, leaving people who are not of that nationality. Similarly, a feature of people might be the difference between a feature for their children and a Classifier for people of a particular sex, identifying their children not of that sex (because the interpretations of the children Feature that identify those of that sex are also interpretations of the Classifier for that sex).

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

The features of this Type that have a non-null direction.

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

All features of this Type with isEnd = true.

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

The ownedMemberFeatures of the featureMemberships of this Type.
The FeatureMemberships for features of this Type, which include all ownedFeatureMemberships and those inheritedMemberships that are FeatureMemberships (but does not include any importedMemberships).

All the memberFeatures of the inheritedMemberships of this Type that are FeatureMemberships.

All Memberships inherited by this Type via Specialization or Conjugation. These are included in the derived union for the memberships of the Type.

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

The interpretations of a Type with intersectingTypes are asserted to be those in common among the intersectingTypes, which are the Types derived from the intersectingType of the ownedIntersectings of this Type. For example, a Classifier might be an intersection of Classifiers for people of a particular sex and of a particular nationality. Similarly, a feature for people's children of a particular sex might be the intersection of a Feature for their children and a Classifier for people of that sex (because the interpretations of the children Feature that identify those of that sex are also interpretations of the Classifier for that sex).

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

Indicates whether this Type has an ownedConjugator.

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 classify as cars. However, if the Type Car were sufficient, it would classify all four-wheeled things.)

An ownedMember of this Type that is a Multiplicity, which constraints the cardinality of the Type. If there is no such ownedMember, then the cardinality of this Type is constrained by all the Multiplicity constraints applicable to any direct supertypes.

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.

/ownedDifferencing : Differencing [0..*] {subsets sourceRelationship, ownedRelationship, ordered}

The ownedRelationships of this Type that are Differencings, having this Type as their typeDifferenced.

/ownedDisjoining : Disjoining [0..*] {subsets ownedRelationship, disjoiningTypeDisjoining}

The ownedRelationships of this Type that are Disjoinings, for which the Type is the typeDisjoined Type.

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

All endFeatures of this Type that are ownedFeatures.

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

The ownedMemberFeatures of the ownedFeatureMemberships of this Type.

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

The ownedMemberships of this Type that are FeatureMemberships, for which the Type is the owningType. Each such FeatureMembership identifies an ownedFeature of the Type.

/ownedIntersecting : Intersecting [0..*] {subsets ownedRelationship, sourceRelationship, ordered}

The ownedRelationships of this Type that are Intersectings, have the Type as their typeIntersected.

/ownedSpecialization : Specialization [0..*] {subsets specialization, ownedRelationship, ordered}

The ownedRelationships of this Type that are Specializations, for which the Type is the specific Type.

/ownedUnioning : Unioning [0..*] {subsets ownedRelationship, sourceRelationship, ordered}

The ownedRelationships of this Type that are Unionings, having the Type as their typeUnioned.

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

The interpretations of a Type with unioningTypes are asserted to be the same as those of all the unioningTypes together, which are the Types derived from the unioningType of the ownedUnionings of this Type. For example, a Classifier for people might be the union of Classifiers for all the sexes. Similarly, a feature for people's children might be the union of features dividing them in the same ways as people in general.

Operations

allSupertypes() : Type [0..*]

Return all Types related to this Type as supertypes directly or transitively by Specialization Relationships.

body: ownedSpecialization->
    closure(general.ownedSpecialization).general->
    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.

**body:** directionOfExcluding(f, Set{})

directionOfExcluding(feature : Feature, excluded : Type [0..*]) : FeatureDirectionKind [0..1]

Return the direction of the given feature relative to this Type, excluding a given set of Types from the search of supertypes of this Type.

**body:** let excludedSelf : Set(Type) = excluded->including(self) in
if feature.owningType = self then feature.direction
else if ownedConjugator <> null then
   if excludedSelf->includes(ownedConjugator.originalType) then null
   else
      let originalDirection: FeatureDirectionKind =
         ownedConjugator.originalType.directionOfExcluding(feature, excludedSelf) in
      if originalDirection = FeatureDirectionKind::_'in' then FeatureDirectionKind::out
      else if originalDirection = FeatureDirectionKind::out then FeatureDirectionKind:_'in'
      else originalDirection
      endif
   endif
else
   let directions: Sequence(FeatureDirectionKind) =
      ownedSpecialization.general->
      excluding(excludedSelf).
      directionOfExcluding(feature, excludedSelf)->
      select(d | d <> null) in
      if directions->isEmpty() then null
      else directions->at(1)
      endif
   endif
endif

inheritedMemberships(excluded : Type [0..*]) : Membership [0..*]

Return the inherited Memberships of this Type, excluding those supertypes in the excluded set.

specializes(supertype : Type) : Boolean

Check whether this Type is a direct or indirect specialization of the given supertype.

**body:** if isConjugated then
   ownedConjugator.originalType.specializes(supertype)
else
   allSupertypes() -> includes(supertype)
endif

specializesFromLibrary(libraryTypeName : String) : Boolean

Check whether this Type is a direct or indirect specialization of the named library Type. libraryTypeName must conform to the syntax of a KerML qualified name and must resolve to a Type in global scope.

**body:** let mem : Membership = resolveGlobal(libraryTypeName) in
mem <> null and mem.memberElement.oclIsKindOf(Type) and
specializes(mem.memberElement.oclAsType(Type))
The visible Memberships of a Type include inheritedMemberships.

**body**: let visibleInheritedMemberships : Sequence(Membership) =
    inheritedMemberships(excluded)->
    select(includeAll or visibility = VisibilityKind::public) in
self.oclAsType(Namespace).visibleMemberships(excluded, isRecursive, includeAll)->
union(visibleInheritedMemberships)

**Constraints**

checkTypeSpecialization

A Type must directly or indirectly specialize `Base::Anything` from the Kernel Semantic Library.

specializesFromLibrary('Base::Anything')

deriveTypeDifferencingType

The differencingTypes of a Type are the differencingTypes of its ownedDifferencings, in the same order.

differencingType = ownedDifferencing.differencingType

deriveTypeDirectedFeature

The directedFeatures of a Type are those features for which the direction is non-null.

directedFeature = feature->select(f | directionOf(f) <> null)

deriveTypeEndFeature

The endFeatures of a Type are all its features for which isEnd = true.

endFeature = feature->select(isEnd)

deriveTypeFeature

The features of a Type are the ownedMemberFeatures of its featureMemberships.

feature = featureMembership.ownedMemberFeature

deriveTypeFeatureMembership

The featureMemberships of a Type is the union of the ownedFeatureMemberships and those inheritedMemberships that are FeatureMemberships.

featureMembership = ownedFeatureMembership->union({
    inheritedMembership->selectByKind(FeatureMembership)})

deriveTypeInheritedFeature

The inheritedFeatures of this Type are the memberFeatures of the inheritedMemberships that are FeatureMemberships.
inheritedFeature = inheritedMemberships->
  selectByKind(FeatureMembership).memberFeature

deriveTypeInheritedMembership

The inheritedMemberships of a Type are determined by the inheritedMemberships() operation.

inheritedMembership = inheritedMemberships(Set{})

deriveTypeInput

The inputs of a Type are those of its features that have a direction of in or inout relative to the Type, taking conjugation into account.

input = feature->select(f |
  let direction: FeatureDirectionKind = directionOf(f) in
  direction = FeatureDirectionKind::_'in' or
  direction = FeatureDirectionKind::inout)

deriveTypeIntersectingType

The intersectingTypes of a Type are the intersectingTypes of its ownedIntersections.

intersectingType = ownedIntersecting.intersectingType

deriveTypeMultiplicity

If a Type has an owned Multiplicity, then that is its multiplicity. Otherwise, if the Type has an ownedSpecialization, then its multiplicity is the multiplicity of the general Type of that Specialization.

multiplicity =
  let ownedMultiplicities: Sequence(Multiplicity) =
    ownedMember->selectByKind(Multiplicity) in
  if ownedMultiplicities->isEmpty() then null
  else ownedMultiplicities->first()
endif

deriveTypeOutput

The outputs of a Type are those of its features that have a direction of out or inout relative to the Type, taking conjugation into account.

output = feature->select(f |
  let direction: FeatureDirectionKind = directionOf(f) in
  direction = FeatureDirectionKind::out or
  direction = FeatureDirectionKind::inout)

deriveTypeOwnedConjugator

The ownedConjugator of a Type is the its single ownedRelationship that is a Conjugation.

ownedConjugator =
  let ownedConjugators: Sequence(Conjugator) =
    ownedRelationship->selectByKind(Conjugation) in
if ownedConjugators->isEmpty() then null
else ownedConjugators->at(1) endif

deriveTypeOwnedDifferencing

The ownedDifferencings of a Type are its ownedRelationships that are Differencings.

ownedDifferencing = 
    ownedRelationship->selectByKind(Differencing)

deriveTypeOwnedDisjoining

The ownedDisjoinings of a Type are the ownedRelationships that are Disjoinings.

ownedDisjoining = 
    ownedRelationship->selectByKind(Disjoining)

deriveTypeOwnedEndFeature

The ownedEndFeatures of a Type are all its ownedFeatures for which isEnd = true.

ownedEndFeature = ownedFeature->select(isEnd)

deriveTypeOwnedFeature

The ownedFeatures of a Type are the ownedMemberFeatures of its ownedFeatureMemberships.

ownedFeature = ownedFeatureMembership.ownedMemberFeature

deriveTypeOwnedFeatureMembership

The ownedFeatureMemberships of a Type are its ownedMemberships that are FeatureMemberships.

ownedFeatureMembership = ownedRelationship->selectByKind(FeatureMembership)

deriveTypeOwnedIntersecting

The ownedIntersectings of a Type are the ownedRelationships that are Intersectings.

ownedRelationship->selectByKind(Intersecting)

deriveTypeOwnedSpecialization

The ownedSpecializations of a Type are the ownedRelationships that are Specializations whose special Type is the owning Type.

ownedSpecialization = ownedRelationship->selectByKind(Specialization)->
    select(s | s.special = self)

deriveTypeOwnedUnioning

The ownedUnionings of a Type are the ownedRelationships that are Unionings.

ownedUnioning = 
    ownedRelationship->selectByKind(Unioning)
deriveTypeUnioningType

The unioningTypes of a Type are the unioningTypes of its ownedUnionings.

unioningType = ownedUnioning.unioningType

validateTypeAtMostOneConjugator

A Type must have at most one owned Conjugation Relationship.

ownedRelationship->selectByKind(Conjugation)->size() <= 1

validateTypeDifferencingTypesNotSelf

A Type cannot be one of its own differencingTypes.

differencingType->excludes(self)

validateTypeIntersectingTypesNotSelf

A Type cannot be one of its own intersectingTypes.

intersectingType->excludes(self)

validateTypeOwnedDifferencingNotOne

A Type must not have exactly one ownedDifferencing.

ownedDifferencing->size() <> 1

validateTypeOwnedIntersectingNotOne

A Type must not have exactly one ownedIntersecting.

ownedIntersecting->size() <> 1

validateTypeOwnedMultiplicity

A Type may have at most one ownedMember that is a Multiplicity.

ownedMember->selectByKind(Multiplicity)->size() <= 1

validateTypeOwnedUnioningNotOne

A Type must not have exactly one ownedUnioning.

ownedUnioning->size() <> 1

validateTypeUnioningTypesNotSelf

A Type cannot be one of its own unioningTypes.

unioningType->excludes(self)
8.3.3.11 Unioning

Description

Unioning is a Relationship that makes its unioningType one of the unioningTypes of its typeUnioned.

General Classes

Relationship

Attributes

/typeUnioned : Type {subsets owningRelatedElement, redefines source}

Type with interpretations partly determined by unioningType, as described in Type::unioningType.

unioningType : Type {redefines target}

Type that partly determines interpretations of typeUnioned, as described in Type::unioningType.

Operations

None.

Constraints

None.

8.3.3.2 Classifiers Abstract Syntax

8.3.3.2.1 Overview

![Classifier Abstract Syntax Diagram]

Figure 16. Classifiers

8.3.3.2.2 Classifier

Description
A Classifier is a Type that classifies:

- Things (in the universe) regardless of how Features relate them. (These are interpreted semantically as sequences of exactly one thing.)
- How the above things are related by Features. (These are interpreted semantically as sequences of multiple things, such that the last thing in the sequence is also classified by the Classifier. Note that this means that a Classifier modeled as specializing a Feature cannot classify anything.)

General Classes

Type

Attributes

/ownedSubclassification : Subclassification [0..*] {subsets ownedSpecialization}

The ownedSpecializations of this Classifier that are Subclassifications, for which this Classifier is the subclassifier.

Operations

None.

Constraints

deriveClassifierOwnedSubclassification

The ownedSubclassifications of a Classifier are its ownedSpecializations that are Subclassifications.

ownedSubclassification =
    ownedSpecialization->selectByKind(Subclassification)

validateClassifierMultiplicityDomain

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

multiplicity <> null implies multiplicity.featuringType->isEmpty()

8.3.3.2.3 Subclassification

Description

Subclassification is Specialization in which both the specific and general Types are Classifier. This means all instances of the specific Classifier are also instances of the general Classifier.

General Classes

Specialization

Attributes

/owningClassifier : Classifier [0..1] {redefines owningType}
The Classifier that owns this Subclassification relationship, which must also be its subclassifier. 

subclassifier : Classifier {redefines specific}

The more specific Classifier in this Subclassification.

superclassifier : Classifier {redefines general}

The more general Classifier in this Subclassification.

Operations

None.

Constraints

None.

8.3.3.3 Features Abstract Syntax

8.3.3.3.1 Overview

![Diagram of Features]

Figure 17. Features
Figure 18. Subsetting

Figure 19. Feature Chaining
8.3.3.3.2 EndFeatureMembership

Description

EndFeatureMembership is a FeatureMembership that requires its memberFeature be owned and have isEnd = true.

General Classes

FeatureMembership

Attributes

/ownedMemberFeature : Feature {redefines ownedMemberFeature}

Operations

None.
Constraints

validateEndFeatureMembershipIsEnd

The ownedMemberFeature of an EndFeatureMembership must be an end Feature.

ownedMemberFeature.isEnd

8.3.3.3 Feature

Description

A Feature is a Type that classifies relations between multiple things (in the universe). The domain of the relation is the intersection of the featuringTypes of the Feature. (The domain of a Feature with no featuringTypes is implicitly the most general Type Base::Anything from the Kernel Semantic Library.) The co-domain of the relation is the intersection of the types of the Feature.

In the simplest cases, the featuringTypes and types are Classifiers and the Feature relates two things, one from the domain and one from the range. 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. In this case, the Feature effectively classifies relations between relations, which can be interpreted as the sequence of things related by the domain Feature concatenated with the sequence of things related by the co-domain Feature.

The values of a Feature for a given instance of its domain are all the instances of its co-domain that are related to that domain instance by the Feature. The values of a Feature with chainingFeatures are the same as values of the last Feature in the chain, which can be found by starting with values of the first Feature, then using those values as domain instances to obtain values of the second Feature, and so on, to values of the last Feature.

General Classes

Type

Attributes

/chainingFeature : Feature [0..*] {ordered, nonunique}

The Feature that are chained together to determine the values of this Feature, derived from the chainingFeatures of the ownedFeatureChainings of this Feature, in the same order. The values of a Feature with chainingFeatures are the same as values of the last Feature in the chain, which can be found by starting with the values of the first Feature (for each instance of the domain of the original Feature), then using each of those as domain instances to find the values of the second Feature in chainingFeatures, and so on, to values of the last Feature.

direction : FeatureDirectionKind [0..1]

Indicates how values of this Feature are determined or used (as specified for the FeatureDirectionKind).

/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.
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 typeFeaturings. If the Feature is chained, then the featuringTypes of the first Feature in the chain are also featuringTypes of the chained Feature.

isComposite : Boolean

Whether the Feature is a composite feature of its featuringType. If so, the values of the Feature cannot exist after its featuring instance no longer does.

isDerived : Boolean

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

isEnd : Boolean

Whether or not the this Feature is an end Feature, requiring a different interpretation of the multiplicity of the Feature.

An end Feature is always considered to map each domain instance to a single co-domain instance, whether or not a Multiplicity is given for it. If a Multiplicity is given for an end Feature, 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.

isOrdered : Boolean

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

isPortion : Boolean

Whether the values of this Feature are contained in the space and time of instances of the domain of the Feature and represent the same thing as those instances.

isReadOnly : Boolean

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

isUnique : Boolean

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

ownedFeatureChaining : FeatureChaining [0..*] {subsets sourceRelationship, ownedRelationship, ordered}

The ownedRelationships of this Feature that are FeatureChainings, for which the Feature will be the featureChained.

ownedFeatureInverting : FeatureInverting [0..*] {subsets ownedRelationship, invertingFeatureInverting}

The ownedRelationships of this Feature that are FeatureInvertings and for which the Feature is the featureInverted.
/ownedRedefinition : Redefinition [0..*] {subsets ownedSubsetting}

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

/ownedReferenceSubsetting : ReferenceSubsetting [0..1] {subsets ownedSubsetting}

The one ownedSubsetting of this Feature, if any, that is a ReferenceSubsetting, for which the Feature is the referencingFeature.

/ownedSubsetting : Subsetting [0..*] {subsets ownedSpecialization, subsetting}

The ownedSpecializations 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 and for which the Feature is the featureOfType.

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

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

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

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 Feature.

/type : Type [0..*] {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 typings and the types of its subsettings. If the Feature is chained, then the types of the last Feature in the chain are also types of the chained Feature.

Operations

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

Return the directionOf this Feature relative to the given type.

body: type.directionOf(self)

effectiveName() : String [0..1] {redefines effectiveName}

If a Feature has no declaredName or declaredShortName, then its effective name is given by the effective name of the Feature returned by the namingFeature() operation, if any.

body: if declaredShortName <> null or declaredName <> null then
declearedName
else
let namingFeature : Feature = namingFeature() in
if namingFeature = null then
    null
else
    namingFeature.effectiveName()
endif
endif

effectiveShortName() : String [0..1] {redefines effectiveShortName}

If a Feature has no declaredShortName or declaredName, then its effective shortName is given by the effective shortName of the Feature returned by the namingFeature() operation, if any.

body: if declaredShortName <> null or declaredName <> null then
    declaredShortName
else
    let namingFeature : Feature = namingFeature() in
    if namingFeature = null then
        null
    else
        namingFeature.effectiveShortName()
    endif
endif

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 explicitly or implicitly featured by Base::Anything.

body: if type = null then
    featuringType->isEmpty() or
    featuringType=Sequence{resolveGlobal('Base::Anything').memberElement})
else
    featuringType->notEmpty() and
    featuringType->forAll(f | type.specializes(f))
endif

namingFeature() : Feature [0..1]

By default, the naming Feature of a Feature is given by its first redefinedFeature of its first ownedRedefinition, if any.

body: if ownedRedefinition->isEmpty() then
    null
else
    ownedRedefinition->at(1).redefinedFeature
endif

redefines(redefinedFeature : Feature) : Boolean

Check whether this Feature directly redefines the given redefinedFeature.

body: ownedRedefinition.redefinedFeature->includes(redefinedFeature)

redefinesFromLibrary(libraryFeatureName : String) : Boolean
Check whether this Feature directly redefines the named library Feature.libraryFeatureName must conform to the syntax of a KerML qualified name and must resolve to a Feature in global scope.

**Body:**
```lisp
let mem: Membership = resolveGlobal(libraryFeatureName) in
mem <> null and mem.memberElement.oclIsKindOf(Feature) and
redefines(mem.memberElement.oclAsType(Feature))
```

**subsetsChain(first : Feature, second : Feature) : Boolean**

Check whether this Feature directly or indirectly specializes a Feature whose last two chainingFeatures are the given Features first and second.

**Body:**
```lisp
allSuperTypes()->selectAsKind(Feature)->
  exists(f | let n: Integer = f.chainingFeature->size() in
      n >= 2 and
      f.chainingFeature->at(n-1) = first and
      f.chainingFeature->at(n) = second)
```

**typingFeatures() : Feature [0..*]**

Return the Features used to determine the types of this Feature (other than this Feature itself), consisting of all subsetted Features and the last chainingFeature (if any), if this Feature is not conjugated, or its originalType, if it is conjugated (and the originalType is a Feature).

**Body:**
```lisp
if not isConjugated then
  let subsettedFeatures : OrderedSet(Feature) = subsetting.subsettedFeatures in
  if chainingFeature->isEmpty() or
    subsettedFeature->includes(chainingFeature->last())
  then subsettedFeatures
  else subsettedFeatures->append(chainingFeature->last())
  elseif conjugator.originalType.oclIsKindOf(Feature) then
    OrderedSet{conjugator.originalType.oclAsType(Feature)}
  else OrderedSet()
endif endif
```

**Constraints**

**checkFeatureDataValueSpecialization**

If a Feature has an ownedTyping relationship to a DataType, then it must directly or indirectly specialize Base::dataValues from the Kernel Semantic Library.

```lisp
ownedTyping.type->exists(selectByKind(DataType)) implies
specializesFromLibrary('Base::dataValues')
```

**checkFeatureEndRedefinition**

If a Feature has isEnd = true and an owningType that is not empty, then, for each direct supertype of its owningType, it must redefine the endFeature at the same position, if any.

```lisp
isEnd and owningType <> null implies
  let i : Integer =
    owningType.ownedEndFeature->indexOf(self) in
    owningType.ownedSpecialization.general->
    forAll(supertype |
checkFeatureEndSpecialization

If a Feature has isEnd = true and an owningType that is an Association or a Connector, then it must directly or indirectly specialize Links::Link::participant from the Kernel Semantic Library.

isEnd and owningType <> null and (owningType.oclIsKindOf(Association) or owningType.oclIsKindOf(Connector)) implies specializesFromLibrary('Links::Link::participant')

checkFeatureItemFlowFeatureRedefinition

If a Feature is the first ownedFeature of a first or second ItemFlowEnd, then it must directly or indirectly specialize either Transfers::Transfer::source::sourceOutput or Transfers::Transfer::target::targetInput, respectively, from the Kernel Semantic Library.

owningType <> null and owningType.oclIsKindOf(ItemFlowEnd) and owningType.ownedFeature->at(1) = self implies
let flowType : Type = owningType.owningType in
flowType <> null implies
let i : Integer = flowType.ownedFeature.indexOf(owningType) in
(i = 1 implies redefinesFromLibrary('Transfers::Transfer::source::sourceOutput')) and
(i = 2 implies redefinesFromLibrary('Transfers::Transfer::source::targetInput'))

checkFeatureObjectSpecialization

If a Feature has an ownedTyping relationship to a Structure, then it must directly or indirectly specialize Objects::objects from the Kernel Semantics Library.

ownedTyping.type->exists(selectByKind(Structure)) implies specializesFromLibrary('Objects::objects')

checkFeatureOccurrenceSpecialization

If a Feature has an ownedTyping relationship to a Class, then it must directly or indirectly specialize Occurrences::occurrences from the Kernel Semantic Library.

ownedTyping.type->exists(selectByKind(Class)) implies specializesFromLibrary('Occurrences::occurrences')

checkFeatureParameterRedefinition

If a Feature is a parameter of an owningType that is a Behavior or Step, other than the result parameter (if any), then, for each direct supertype of its owningType that is also a Behavior or Step, it must redefine the parameter at the same position, if any.

owningType <> null and (owningType.oclIsKindOf(Behavior) or owningType.oclIsKindOf(Step)) implies
let i : Integer = 
    owningType.ownedFeature->select(direction <> null) in 
    owningType.ownedSpecialization.general->
    forAll(supertype | 
        let ownedParameters : Sequence(Feature) = 
            supertype.ownedFeature->select(direction <> null) in 
            ownedParameters->size() >= i implies 
            redefines(ownedParameters->at(i))

checkFeaturePortionSpecialization

If a Feature has isPortion = true, an ownedTyping relationship to a Class, and an owningType that is a Class or another Feature typed by a Class, then it must directly or indirectly specialize Occurrences::Occurrence::portions from the Kernel Semantic Library.

isPortion and
ownedTyping.type->includes(oclIsKindOf(Class)) and
owningType <> null and
(owningType.oclIsKindOf(Class) or
    owningType.oclIsKindOf(Feature) and
    owningType.oclAsType(Feature).type->
    exists(oclIsKindOf(Class))) implies
specializesFromLibrary('Occurrence::Occurrence::portions')

checkFeatureResultRedefinition

If a Feature is a result parameter of an owningType that is a Function or Expression, then, for each direct supertype of its owningType that is also a Function or Expression, it must redefine the result parameter.

owningType <> null and
(owningType.oclIsKindOf(Function) and
    self = owningType.oclAsType(Function).result or
owningType.oclIsKindOf(Expression) and
    self = owningType.oclAsType(Expression).result) implies
owningType.ownedSpecialization.general->
    forAll(supertype | 
        redefines(
            if superType.oclIsKindOf(Function) then
                superType.oclAsType(Function).result
            else
                superType.oclAsType(Expression).result
            endif)

checkFeatureResultSpecialization

If a Feature is the result parameter of a FeatureReferenceExpression, then the Feature must specialize the referent of the FeatureReferenceExpression.

owningType <> null and
owningType.oclIsKindOf(FeatureReferenceExpression) and
self = owningType.oclAsType(FeatureReferenceExpression).result implies
specializes(owningType.oclAsType(FeatureReferenceExpression).referent)

checkFeatureSpecialization

A Feature must directly or indirectly specialize Base::things from the Kernel Semantic Library.
specializesFromLibrary('Base::things')

checkFeatureSubobjectSpecialization

A composite Feature typed by a Structure, and whose ownedType is a Structure or another Feature typed by a Structure must directly or indirectly specialize Objects::Object::subobjects.

isComposite and
ownedTyping.type->includes(oclIsKindOf(Structure)) and
owningType <> null and

(owningType.oclIsKindOf(Structure) or
owningType.type->includes(oclIsKindOf(Structure))) implies

specializesFromLibrary('Occurrence::Occurrence::suboccurrences')

checkFeatureSuboccurrenceSpecialization

A composite Feature that has an ownedTyping relationship to a Class, and whose ownedType is a Class or another Feature typed by a Class, must directly or indirectly specialize Occurrences::Occurrence::suboccurrences.

isComposite and
ownedTyping.type->includes(oclIsKindOf(Class)) and
owningType <> null and

(owningType.oclIsKindOf(Class) or
owningType.oclIsKindOf(Class) or
owningType.oclIsKindOf(Feature) and

owningType.oclAsType(Feature).type->exists(oclIsKindOf(Class))) implies

specializesFromLibrary('Occurrence::Occurrence::suboccurrences')

checkFeatureValuationSpecialization

If a Feature has a FeatureValue, no ownedSpecializations that are not implied, and is not directed, then it must specialize the result of the value Expression of the FeatureValue.

direction = null and
ownedSpecializations->forAll(isImplied) implies

ownedMembership->

selectByKind(FeatureValue)->

forAll(fv | specializes(fv.value.result))

deriveFeatureChainingFeature

The chainingFeatures of a Feature are the chainingFeatures of its ownedFeatureChainings.

chainingFeature = ownedFeatureChaining.chainingFeature

deriveFeatureFeaturingType

The featuringTypes of a Feature include the featuringTypes of all the typeFeaturings of the Feature. If the Feature has chainingFeatures, then its featuringTypes also include the featuringTypes of the first chainingFeature.

featuringType =

let featuringTypes : OrderedSet(Type) =

featuring.type->asOrderedSet() in

if chainingFeature->isEmpty() then featuringTypes
else
deriveFeatureOwnedFeatureChaining

The **ownedFeatureChainings** of a Feature are the **ownedRelationships** that are **FeatureChainings**.

\[
\text{ownedFeatureChaining} = \text{ownedRelationship} \rightarrow \text{selectByKind(FeatureChaining)}
\]

deriveFeatureOwnedFeatureInverting

The **ownedFeatureInvertings** of a Feature are its **ownedRelationships** that are **FeatureInvertings**.

\[
\text{ownedFeatureInverting} = \text{ownedRelationship} \rightarrow \text{selectByKind(FeatureInverting)} \rightarrow \text{select}(fi \mid fi.\text{featureInverted} = \text{self})
\]

deriveFeatureOwnedRedefinition

The **ownedRedefinitions** of a Feature are its **ownedSubsettings** that are **Redefinitions**.

\[
\text{ownedRedefinition} = \text{ownedSubsetting} \rightarrow \text{selectByKind(Redefinition)}
\]

deriveFeatureOwnedReferenceSubsetting

The **ownedReferenceSubsetting** of a Feature is the *first* **ownedSubsetting** that is a **ReferenceSubsetting** (if any).

\[
\text{ownedReferenceSubsetting} = \begin{cases} 
    \text{let referenceSubsettings : OrderedSet(ReferenceSubsetting) =} & \text{ownedSubsetting} \rightarrow \text{selectByKind(ReferenceSubsetting)} \text{ in} \\
    \text{if referenceSubsettings} \rightarrow \text{isEmpty()} \text{ then null} & \text{else referenceSubsettings} \rightarrow \text{first()} \text{ endif}
\end{cases}
\]

deriveFeatureOwnedSubsetting

The **ownedSubsettings** of a Feature are its **ownedSpecializations** that are **Subsettings**.

\[
\text{ownedSubsetting} = \text{ownedSpecialization} \rightarrow \text{selectByKind(Subsetting)}
\]

deriveFeatureOwnedTypeFeaturing

The **ownedTypeFeaturings** of a Feature are its **ownedRelationships** that are **TypeFeaturings** and which have the Feature as their featureOfType.

\[
\text{ownedTypeFeaturing} = \text{ownedRelationship} \rightarrow \text{selectByKind(TypeFeaturing)} \rightarrow \text{select}(tf \mid tf.\text{featureOfType} = \text{self})
\]

deriveFeatureOwnedTyping

The **ownedTypings** of a Feature are its **ownedSpecializations** that are **FeatureTypings**.

\[
\text{ownedTyping} = \text{ownedGeneralization} \rightarrow \text{selectByKind(FeatureTyping)}
\]

deriveFeatureType
The types of a Feature are the union of the types of its typings and the types of the Features it subsets, with all redundant supertypes removed. If the Feature has chainingFeatures, then the union also includes the types of the last chainingFeature.

```plaintext
type =
  let types : OrderedSet(Types) = OrderedSet{self}->
    -- Note: The closure operation automatically handles circular relationships.
    closure(typingFeatures()).typing.type->asOrderedSet() in
    types->reject(t1 | types->exist(t2 | t2 <> t1 and t2.specializes(t1)))
```

validateFeatureChainingFeatureConformance

Each chainingFeature (other than the last) must conform to all the featuringTypes of the next Feature in the chain.

```plaintext
Sequence{1..chainingFeature->size() - 1}->forAll(i |
  chainingFeature->at(i + 1).featuringType->forAll(t |
  chainingFeature->at(i).specializes(t)))
```

validateFeatureChainingFeatureNotOne

A Feature must have either no chainingFeatures or more than one.

```plaintext
chainingFeature->size() <> 1
```

validateFeatureChainingFeaturesNotSelf

A Feature cannot be one of its own chainingFeatures.

```plaintext
chainingFeature->excludes(self)
```

validateFeatureMultiplicityDomain

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

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

validateFeatureOwnedReferenceSubsetting

A Feature must have at most one ownedSubsetting that is a ReferenceSubsetting.

```plaintext
ownedSubsetting->selectByKind(ReferenceSubsetting)->size() <= 1
```

8.3.3.3.4 FeatureChaining

Description

FeatureChaining is a Relationship that makes its target Feature one of the chainingFeatures of its owning Feature.

General Classes

Relationship

Attributes
chainingFeature : Feature {redefines target}

The Feature whose values partly determine values of featureChained, as described in Feature::chainingFeature.

/featureChained : Feature {subsets owningRelatedElement, redefines source}

The Feature whose values are partly determined by values of the chainingFeature, as described in Feature::chainingFeature.

Operations
None.

Constraints
None.

8.3.3.3.5 FeatureInverting

Description
A FeatureInverting is a Relationship between Features asserting that their interpretations (sequences) are the reverse of each other, identified as featureInverted and invertingFeature. For example, a Feature identifying each person's parents is the inverse of a Feature identifying each person's children. A person identified as a parent of another will identify that other as one of their children.

General Classes
Relationship

Attributes
featureInverted : Feature {redefines source}

The Feature that is an inverse of the invertingFeature.

invertingFeature : Feature {redefines target}

The Feature that is an inverse of the invertedFeature.

/owningFeature : Feature [0..1] {subsets owningRelatedElement, featureInverted}

A featureInverted that is also the owningRelatedElement of this FeatureInverting.

Operations
None.

Constraints
None.
8.3.3.3.6 FeatureTyping

Description

FeatureTyping is Specialization in which the specific Type is a Feature. This means the set of instances of the (specific) typedFeature is a subset of the set of instances of the (general) type. In the simplest case, the type is a Classifier, whereupon the typedFeature has values that are instances of the Classifier.

General Classes

Specialization

Attributes

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

A typedFeature that is also the owningRelatedElement of this FeatureTyping.

type : Type {redefines general}

The Type that is being applied by this FeatureTyping.

typedFeature : Feature {redefines specific}

The Feature that has a type determined by this FeatureTyping.

Operations

None.

Constraints

None.

8.3.3.3.7 Featuring

Description

Featuring is a Relationship between a Type and a Feature that is featured by that Type. It asserts that every instance in the domain of the feature must be classified by the type.

Featuring is abstract and does not commit to which of feature or type are the source or target of the Relationship. This commitment is made in the subclasses of Featuring, TypeFeaturing and FeatureMembership, which have opposite directions.

General Classes

Relationship

Attributes

feature : Feature {subsets relatedElement}

The Feature that is featured by the featuringType.
The Type that features the featureOfType.

Operations
None.

Constraints
None.

8.3.3.3.8 Redefinition

Description
Redefinition is a kind of Subsetting that requires 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 domain of the redefiningFeature), and vice versa. The redefinedFeature might have values for instances of the domain of the redefiningFeature, but only as instances of the domain of the redefinedFeature that happen to also be instances of the domain 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 inherited 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 subbedFeature}
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
None.

Constraints
validateRedefinitionDirectionConformance
If the redefinedFeature of a Redefinition has a direction of in or out (relative to any featuringType of the redefiningFeature), then the redefiningFeature must have the same direction. If the redefinedFeature has a direction of inout, then the redefiningFeature must have a non-null direction.
validateRedefinitionFeaturingTypes

The redefiningFeature of a Redefinition must have at least one featuringType that is not also a featuringType of the redefinedFeature.

let anythingType: Type =
    redefiningFeature.resolveGlobal('Base::Anything').modelElement.oclAsType(Type) in
-- Including "Anything" accounts for implicit featuringType of Features
-- with no explicit featuringType.
let redefiningFeaturingTypes: Set(Type) =
    redefiningFeature.featuringTypes->asSet()->including(anythingType) in
let redefinedFeaturingTypes: Set(Type) =
    redefinedFeature.featuringTypes->asSet()->including(anythingType) in
redefiningFeaturingTypes <> redefinedFeaturingType

8.3.3.3.9 ReferenceSubsetting

Description

ReferenceSubsetting is a kind of Subsetting in which the referencedFeature is syntactically distinguished from other Features subsetted by the referencingFeature. ReferenceSubsetting has the same semantics as Subsetting, but the referenceFeature may have a special purpose relative to the referencingFeature. For instance, ReferenceSubsetting is used to identify the relatedFeatures of a Connector.

ReferenceSubsetting is always an ownedRelationship of its referencingFeature. A Feature can have at most one ownedReferenceSubsetting.

General Classes

Subsetting

Attributes

referencedFeature : Feature {redefines subsettedFeature}
The Feature that is referenced by the referencingFeature of this ReferenceSubsetting.

/referencingFeature : Feature {redefines subsettingFeature, owningFeature}
The Feature that owns this ReferenceSubsetting relationship, which is also its subsettingFeature.

Operations
None.

**Constraints**

None.

### 8.3.3.3.10 Subsetting

**Description**

Subsetting is Specialization in which the specific and general Types 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 subsettedFeature (via Specialization), and the co-domain (intersection of the types) of the subsettingFeature must specialize the co-domain of the subsettedFeature.

**General Classes**

Specialization

**Attributes**

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

A subsettingFeature that is also the owningRelatedElement of this Subsetting.

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**

None.

**Constraints**

validateSubsettingFeaturingTypes

For each featuringType of the subsettedFeature of a Subsetting, there must be a featuringType of the subsettingFeature that conforms to it.

```Scheme
let subsettingFeaturingTypes: OrderedSet(Type) = subsettingFeature.featuringTypes in
let subsettedFeaturingTypes: OrderedSet(Type) = subsettedFeature.featuringTypes in
let anythingType: Element = subsettingFeature.resolveGlobal('Base::Anything').memberElement in
subsettedFeaturingTypes->forAll(t | subsettingFeaturingTypes->isEmpty() and t = anythingType or subsettingFeaturingTypes->exists(specializes(t))
```
validateSubsettingUniquenessConformance

If the subsettedFeature of a Subsetting has isUnique = true, then the subsettedFeature must have isUnique = true.

subsettedFeature.isUnique implies subsettingFeature.isUnique

### 8.3.3.3.11 TypeFeaturing

#### Description

A TypeFeaturing is a Featuring Relationship in which the featureOfType is the source and the featuringType is the target.

#### General Classes

Featuring

#### Attributes

**featureOfType :** Feature {redefines source, feature}

The Feature that is featured by the featuringType. It is the source of the TypeFeaturing.

**featuringType :** Type {redefines target, type}

The Type that features the featureOfType. It is the target of the TypeFeaturing.

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

A featureOfType that is also the owningRelatedElement of this TypeFeaturing.

#### Operations

None.

#### Constraints

None.

### 8.3.4 Kernel Abstract Syntax

#### 8.3.4.1 Data Types Abstract Syntax

#### 8.3.4.1.1 Overview

![Diagram](#)

Figure 22. Data Types
8.3.4.1.2 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 different things.
- 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

None.

Operations

None.

Constraints

checkDataTypeSpecialization

A **DataType** must directly or indirectly specialize the base **DataType Base::DataValue** from the Kernel Semantic Library.

specializesFromLibrary('Base::DataValue')

validateDataTypeSpecialization

A **DataType** must not specialize a **Class** or an **Association**.

ownedSpecialization.general->
    forAll(notoclIsKindOf(Class)and
            notoclIsKindOf(Association))

8.3.4.2 Classes Abstract Syntax

8.3.4.2.1 Overview

![Diagram of Classifier and Class](image)
### 8.3.4.2.2 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**

None.

**Operations**

None.

**Constraints**

checkClassSpecialization

A Class must directly or indirectly specialize the base Class `Occurrences::Occurrence` from the Kernel Semantic Library.

`specializesFromLibrary('Occurrences::Occurrence')`

validateClassSpecialization

A Class must not specialize a DataType and it can only specialize an Association if it is also itself a kind of Association (such as an AssociationStructure or Interaction).

`ownedSpecialization.general->
forall(not oclIsKindOf(DataType)) and
not oclIsKindOf(Association) implies
ownedSpecialization.general->
forall(not oclIsKindOf(Association))`

### 8.3.4.3 Structures Abstract Syntax

#### 8.3.4.3.1 Overview

![Class Structure Diagram]

**Figure 24. Structures**

#### 8.3.4.3.2 Structure

**Description**
A Structure is a Class of objects in the modeled universe that are primarily structural in nature. While such 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**

None.

**Operations**

None.

**Constraints**

checkStructureSpecialization

A Structure must directly or indirectly specialize the base Structure Objects::Object from the Kernel Semantic Library.

specializesFromLibrary('Objects::Object')

validateStructureSpecialization

A Structure must not specialize a Behavior.

ownedSpecialization.general->forAll(not oclIsKindOf(Behavior))

**8.3.4.4 Associations Abstract Syntax**
8.3.4.4.2 Association

Description

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

General Classes

Relationship
Classifier

Attributes

/associationEnd : Feature [0..*] {redefines endFeature}

The features of the Association that identify the things that can be related by it. A concrete Association must have at least two associationEnds. When it has exactly two, the Association is called a binary Association.

The ends of the Association determine which elements are eligible to be related by instances of the Association.

/relatedType : Type [0..*] {redefines relatedElement, ordered, nonunique}

The types of the associationEnds of the Association, which are the relatedElements of the Association considered as a Relationship.
The source relatedType for this Association. It is the first relatedType of the Association.

The target relatedTypes for this Association. This includes all the relatedTypes other than the sourceType.

Operations
None.

Constraints

checkAssociationBinarySpecialization
A binary Association must directly or indirectly specialize the base Association Links::binaryLink from the Kernel Semantic Library.

associationEnd->size() = 2 implies
specializesFromLibrary('Links::BinaryLink')

checkAssociationSpecialization
An Association must directly or indirectly specialize the base Association Links::Link from the Kernel Semantic Library.
specializesFromLibrary('Links::Link')

deriveAssociationRelatedType
The relatedTypes of an Association are the types of its associationEnds.
relatedType = associationEnd.type

deriveAssociationSourceType
The sourceType of an Association is its first relatedType (if any).
sourceType =
if relatedType->isEmpty() then null
else relatedType->first() endif

deriveAssociationTargetType
targetType =
if relatedType->size() < 2 then OrderedSet()
else
relatedType->
subSequence(2, relatedType->size())->
asOrderedSet()
endif

validateAssociationBinarySpecialization
If an Association has more than two associationEnds, then it must not specialize, directly or indirectly, the Association BinaryLink from the Kernel Semantic Library.

associationEnds->size() > 2 implies not specializesFromLibrary('Links::BinaryLink')

validateAssociationRelatedTypes

If an Association is concrete (not abstract), then it must have at least two relatedTypes.

not isAbstract implies relatedType->size() >= 2

validateAssociationStructureIntersection

If an Association is also a kind of Structure, then it must be an AssociationStructure.

oclIsKindOf(Structure) = oclIsKindOf(AssociationStructure)

8.3.4.4.3 AssociationStructure

Description

An AssociationStructure is an Association that is also a Structure, classifying link objects that are both links and objects. As objects, link objects can be created and destroyed, and their non-end Features can change over time. However, the values of the end Features of a link object are fixed and cannot change over its lifetime.

General Classes

Structure
Association

Attributes

None.

Operations

None.

Constraints

checkAssociationStructureBinarySpecialization

A binary AssociationStructure must directly or indirectly specialize the base AssociationStructure Objects::BinaryLinkObject from the Kernel Semantic Library.

endFeature->size() = 2 implies specializesFromLibrary('Objects::BinaryLinkObject')

checkAssociationStructureSpecialization

An AssociationStructure must directly or indirectly specialize the base AssociationStructure Objects::LinkObject from the Kernel Semantic Library.

specializesFromLibrary('Objects::LinkObject')
8.3.4.5 Connectors Abstract Syntax

8.3.4.5.1 Overview

Figure 26. Connectors
8.3.4.5.2 Binding Connector

Description

A BindingConnector is a binary Connector that requires its relatedFeatures to identify the same things (have the same values).

General Classes

Connector

Attributes

None.

Operations

None.

Constraints

checkBindingConnectorSpecialization

A BindingConnector must directly or indirectly specialize the base BindingConnector Links::selfLinks from the Kernel Semantic Library.

specializesFromLibrary('Links::selfLinks')

validateBindingConnectorIsBinary

A BindingConnector must be binary.

relatedFeature->size() = 2
8.3.4.5.3 Connector

Description

A Connector is a usage of Associations, with links restricted according to instances of the Type in which they are used (domain of the Connector). The associations of the Connector restrict what kinds of things might be linked. The Connector further restricts these links to be between values of Features on instances of its domain.

General Classes

Relationship
Feature

Attributes

/association : Association [0..*] {redefines type, ordered}

The Associations that type the Connector.

/connectorEnd : Feature [0..*] {redefines endFeature, ordered}

The endFeatures of a Connector, which redefine the endFeatures of the associations of the Connector. The connectorEnds determine via ReferenceSubsetting Relationships which Features are related by the Connector.

/relatedFeature : Feature [0..*] {redefines relatedElement, ordered, nonunique}

The Features that are related by this Connector considered as a Relationship and that restrict the links it identifies, given by the referenced Features of the connectorEnds of the Connector.

[sourceFeature : Feature [0..1] {subsets relatedFeature, redefines source, ordered}

The source relatedFeature for this Connector. It is the first relatedFeature.

/targetFeature : Feature [0..*] {subsets relatedFeature, redefines target, ordered}

The target relatedFeatures for this Connector. This includes all the relatedFeatures other than the sourceFeature.

Operations

None.

Constraints

checkConnectorBinaryObjectSpecialization

A binary Connector for an AssociationStructure must directly or indirectly specialize the base Connector Objects::binaryLinkObjects from the Kernel Semantic Library.

connectorEnds->size() = 2 and
association->exists(oclIsKindOf(AssociationStructure)) implies
specializesFromLibrary('Objects::binaryLinkObjects')

checkConnectorBinarySpecialization
A binary Connector must directly or indirectly specialize the base Connector `Links::binaryLinks` from the Kernel Semantic Library.

\[ \text{connectorEnd}\rightarrow \text{size()} = 2 \implies \text{specializesFromLibrary('Links::binaryLinks')} \]

**checkConnectorObjectSpecialization**

A Connector for an AssociationStructure must directly or indirectly specialize the base Connector `Objects::linkObjects` from the Kernel Semantic Library.

\[ \text{association}\rightarrow \exists \text{ooclIsKindOf(AssociationStructure)} \implies \text{specializesFromLibrary('Objects::linkObjects')} \]

**checkConnectorSpecialization**

A Connector must directly or indirectly specialize the base Connector `Links::links` from the Kernel Semantic Library.

\[ \text{specializesFromLibrary('Links::links')} \]

**checkConnectorTypeFeaturing**

Each relatedFeature of a Connector must have each 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).

\[ \text{relatedFeature}\rightarrow \forall f \mid \\
\quad \text{if } \text{featuringType}\rightarrow \text{isEmpty()} \text{ then } f.\text{isFeaturedWithin(null)} \\text{ else } \text{featuringType}\rightarrow \forall t \mid f.\text{isFeaturedWithin(t)} \quad \text{endif} \]

**deriveConnectorRelatedFeature**

The relatedFeatures of a Connector are the referenced Features of its connectorEnds.

\[ \text{relatedFeature} = \text{connectorEnd.}\text{ownedReferenceSubsetting}\rightarrow \text{select}(s \mid s <> \text{null}).\text{subsettedFeature} \]

**deriveConnectorSourceFeature**

The sourceFeature of a Connector is its first relatedFeature (if any).

\[ \text{sourceFeature} = \]
\[ \quad \text{if } \text{relatedFeature}\rightarrow \text{isEmpty()} \text{ then null } \quad \text{else } \text{relatedFeature}\rightarrow \text{first()} \quad \text{endif} \]

**deriveConnectorTargetFeature**

The targetFeatures of a Connector are the relatedFeatures other than the sourceFeature.

\[ \text{targetFeature} = \]
\[ \quad \text{if } \text{relatedFeature}\rightarrow \text{size()} < 2 \text{ then } \text{OrderedSet{}} \quad \text{else } \]
\[ \quad \text{relatedFeature}-> \]

---

*Kernel Modeling Language (KerML) v1.0 Beta 1*
validateConnectorBinarySpecialization

If a Connector has more than two connectorEnds, then it must not specialize, directly or indirectly, the Association BinaryLink from the Kernel Semantic Library.

costerEnds->size() > 2 implies not specializesFromLibrary('Links::BinaryLink')

validateConnectorRelatedFeatures

If a Connector is concrete (not abstract), then it must have at least two relatedFeatures.

not isAbstract implies relatedFeature->size() >= 2

8.3.4.5.4 Succession

Description

A Succession is a binary Connector that requires its relatedFeatures to happen separately in time.

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]

A Step that is typed by the Behavior TransitionPerformances::TransitionPerformance (from the Kernel Semantic 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

None.

Constraints

checkSuccessionSpecialization
A Succession must directly or indirectly specialize the Feature `Occurrences::happensBeforeLinks` from the Kernel Semantic Library.

specializesFromLibrary('Occurrences::happensBeforeLinks')

deriveSuccessionEffectStep

The **effectStep** of a Succession is the fourth ownedFeature of its transitionStep, which must be a Step.

effectStep =
  if transitionStep = null or
  transitionStep.ownedFeature.size() < 4 or
  not transitionStep.ownedFeature->at(4).oclIsKindOf(Step)
  then Set{}
  else Set{transitionStep.ownedFeature->at(4).oclAsType(Step)}
  endif

deriveSuccessionGuardExpression

The **guardExpression** of a Succession is the third ownedFeature of its transitionStep, which must be an Expression.

guardExpression =
  if transitionStep = null or
  transitionStep.ownedFeature.size() < 3 or
  not transitionStep.ownedFeature->at(3).oclIsKindOf(Expression)
  then Set{}
  else Set{transitionStep.ownedFeature->at(3).oclAsType(Expression)}
  endif

deriveSuccessionTransitionStep

If the owningNamespace of a Succession is a Step that specializes `TransitionPerformances::TransitionPerformance`, then this is presumed to be the transitionStep for the Succession.

transitionStep =
  if owningNamespace.oclIsKindOf(Step) and
  owningNamespace.oclAsType(Step).
    specializesFromLibrary('TransitionPerformances::TransitionPerformance')
    then owningNamespace.oclAsType(Step)
  else null
  endif

deriveSuccessionTriggerStep

The **triggerStep** of a Succession is the second ownedFeature of its transitionStep, which must be a Step.

triggerStep =
  if transitionStep = null or
  transitionStep.ownedFeature.size() < 2 or
  not transitionStep.ownedFeature->at(2).oclIsKindOf(Step)
  then Set{}
  else Set{transitionStep.ownedFeature->at(2).oclAsType(Step)}
  endif
8.3.4.6 Behaviors Abstract Syntax

8.3.4.6.1 Overview

Figure 28. Behaviors

Figure 29. Parameter Memberships

8.3.4.6.2 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..*] \{redefines directedFeature, ordered\}

The parameters of this Behavior, which are defined as its directedFeatures, whose values 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**

None.

**Constraints**

checkBehaviorSpecialization

A Behavior must directly or indirectly specialize the base Behavior Performances::Performance from the Kernel Semantic Library.

specializesFromLibrary('Performances::Performance')

deriveBehaviorStep

The steps of a Behavior are its features that are Steps.

step = feature->selectByKind(Step)

validateBehaviorSpecialization

A Behavior must not specialize a Structure.

ownedSpecialization.general->forAll(not oclIsKindOf(Structure))

**8.3.4.6.3 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 a 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 [0..*] {subsets type, ordered}

The Behaviors that type this Step.

/parameter : Feature [0..*] {redefines directedFeature, ordered}

The parameters of this Step, which are defined as its directedFeatures, whose values are passed into and/or out of a performance of the Step.

Operations

None.

Constraints

checkStepEnclosedPerformanceSpecialization

A Step whose owningType is a Behavior or another Step must directly or indirectly specialize the Step Performances::Performance::enclosedPerformance.

owningType <> null and
   (owningType.oclIsKindOf(Behavior) or
    owningType.oclIsKindOf(Step)) implies
   specializesFromLibrary('Performances::Performance::enclosedPerformance')

checkStepOwnedPerformanceSpecialization

A composite Step whose owningType is a Structure or a Feature typed by a Structure must directly or indirectly specialize the Step Objects::Object::ownedPerformance.

isComposite and owningType <> null and
   (owningType.oclIsKindOf(Structure) or
    owningType.oclIsKindOf(Feature) and
    owningType.oclAsType(Feature).type->
     exists(oclIsKindOf(Structure)) implies
    specializesFromLibrary('Objects::Object::ownedPerformance')

checkStepSpecialization

A Step must directly or indirectly specialize the base Step Performances::performances from the Kernel Semantic Library.

specializesFromLibrary('Performances::performances')

checkStepSubperformanceSpecialization

A Step whose owningType is a Behavior or another Step, and which is composite, must directly or indirectly specialize the Step Performances::Performance::subperformance.

owningType <> null and
   (owningType.oclIsKindOf(Behavior) or
    owningType.oclIsKindOf(Step)) and
   self.isComposite implies
   specializesFromLibrary('Performances::Performance::subperformance')
The behaviors of a Step are all its types that are Behaviors.

behavior = type->selectByKind(Behavior)

8.3.4.6.4 ParameterMembership

Description

A ParameterMembership is a FeatureMembership that identifies its memberFeature as a parameter, which is always owned, and must have a direction. A ParameterMembership must be owned by a Behavior or a Step.

General Classes

FeatureMembership

Attributes

/ownedMemberParameter : Feature {redefines ownedMemberFeature}

The Feature that is identified as a parameter by this ParameterMembership.

Operations

parameterDirection() : FeatureDirectionKind

Return the required value of the direction of the ownedMemberParameter. By default, this is in.

body: FeatureDirectionKind::_'in'

Constraints

validateParameterMembershipOwningType

A ParameterMembership must be owned by a Behavior or a Step.

owningType.oclIsKindOf(Behavior) or owningType.oclIsKindOf(Step)

validateParameterMembershipParameterDirection

The ownedMemberParameter of a ParameterMembership must have a direction equal to the result of the parameterDirection() operation.

ownedMemberParameter.direction = parameterDirection()
8.3.4.7.1 Overview

Figure 30. Functions

Figure 31. Predicates

Figure 32. Function Memberships

8.3.4.7.2 BooleanExpression

Description

A BooleanExpression is a Boolean-valued Expression whose type is a Predicate. It represents a logical condition resulting from the evaluation of the Predicate.
General Classes

Expression

Attributes

/predicate : Predicate [0..1] {redefines function}

The Predicate that types this BooleanExpression.

The Predicate that types the Expression.

Operations

None.

Constraints

checkBooleanExpressionSpecialization

A BooleanExpression must directly or indirectly specialize the base BooleanExpression
Performances::booleanEvaluations from the Kernel Semantic Library.

specializesFromLibrary('Performances::booleanEvaluations')

8.3.4.7.3 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 Expression in the tree.

General Classes

Step

Attributes

/function : Function [0..1] {redefines behavior}

The Function that types this Expression.

This is the Function that types the 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}
An output parameter of the Expression whose value is the result of the Expression. The result of an Expression is either inherited from its function or it is related to the Expression via a ReturnParameterMembership, in which case it redefines the result parameter of its function.

Operations

checkCondition(target : Element) : Boolean

Model-level evaluate this Expression with the given target. If the result is a LiteralBoolean, return its value. Otherwise return false.

body: let results: Sequence(Element) = evaluate(target) in
    result->size() = 1 and
    results->first().oclIsKindOf(LiteralBoolean) and
    results->first().oclAsType(LiteralBoolean).value

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, which, for a fully evaluable Expression, will be a LiteralExpression or a Feature that is not an Expression.

pre: isModelLevelEvaluable

body: let resultExprs : Sequence(Expression) =
    ownedFeatureMembership->
    selectByKind(ResultExpressionMembership).
    ownedResultExpression in
    if resultExpr->isEmpty() then Sequence{}
    else resultExprs->first().evaluate(target)
    endif

modelLevelEvaluable(visited : Feature [0..*]) : Boolean

Return whether this Expression is model-level evaluable. The visited parameter is used to track possible circular Feature references made from FeatureReferenceExpressions (see the redefinition of this operation for FeatureReferenceExpression). Such circular references are not allowed in model-level evaluable expressions.

An Expression that is not otherwise specialized is model-level evaluable if it has no (non-implied) ownedSpecializations and all its ownedFeatures are either in parameters, the result parameter or a result Expression owned via a ResultExpressionMembership. The parameters must not have any ownedFeatures or a FeatureValue, and the result Expression must be model-level evaluable.

body: ownedSpecialization->forall(isImplied) and
    ownedFeature->forall(f |
        (directionOf(f) = FeatureDirectionKind::_'in' or f = result) and
        f.ownedFeature->isEmpty() and f.valuation = null or
        f.owningFeatureMembership.oclIsKindOf(ResultExpressionMembership) and
        f.oclAsType(Expression).modelLevelEvaluable(visited)

Constraints

checkExpressionResultBindingConnector
If an Expression has an Expression owned via a ResultExpressionMembership, then the owning Expression must also own a BindingConnector between its result parameter and the result parameter of the result Expression.

ownedMembership.selectByKind(ResultExpressionMembership)->
  forAll(mem | ownedFeature.selectByKind(BindingConnector)->
    exists(binding |
      binding.relatedFeature->includes(result) and
      binding.relatedFeature->includes(mem.ownedResultExpression.result)))

checkExpressionSpecialization

An Expression must directly or indirectly specialize the base Expression Performances::evaluations from the Kernel Semantic Library.

specializesFromLibrary('Performances::evaluations')

cHECKEXPRESSIONTYPEFEATURING

If this Expression is owned by a FeatureValue, then it must have the same featuringTypes as the featureWithValue of the FeatureValue.

owningMembership <> null and
owningMembership.oclIsKindOf(FeatureValue) implies
  let featureWithValue : Feature =
    owningMembership.oclAsType(FeatureValue).featureWithValue in
    featuringType = featureWithValue.featuringType

deriveExpressionIsModelLevelEvaluable

Whether an Expression isModelLevelEvaluable is determined by the modelLevelEvaluable() operation.

isModelLevelEvaluable = modelLevelEvaluable(Set(Element){})

deriveExpressionResult

If an Expression has a parameter owned via a ReturnParameterMembership, then that is its result parameter. Otherwise, its result parameter is the result parameter inherited from its function.

result =
  let resultParams : Sequence(Feature) =
    ownedFeatureMemberships->
      selectByKind(ReturnParameterMembership).
    ownedParameterMember in
    if resultParams->notEmpty() then resultParams->first()
    else if function <> null then function.result
    else null
  endif endif

validateExpressionResultExpressionMembership

An Expression must have at most one ResultExpressionMembership.

membership->selectByKind(ResultExpressionMembership)->size() <= 1

validateExpressionResultParameterMembership
An Expression must own at most one ResultParameterMembership.

ownedFeatureMembership->
  selectByKind(ReturnParameterMembership)->
  size() <= 1

8.3.4.7.4 Function

Description

A Function is a Behavior that has an out parameter that is identified as its result. A Function represents the performance of a calculation that produces the values of its result parameter. This calculation may be decomposed into Expressions that are steps of the Function.

General Classes

Behavior

Attributes

/expression : Expression [0..*] {subsets step}

The Expressions that are steps in the calculation of the result of this Function.

The set of expressions that represent computational steps or parts of a system of equations within the Function.

/isModelLevelEvaluable : Boolean

Whether this Function can be used as the function of a model-level evaluable InvocationExpression. Certain Functions from the Kernel Functions Library are considered to have isModelLevelEvaluable = true. For all other Functions it is false.

Note: See the specification of the KerML concrete syntax notation for Expressions for an identification of which library Functions are model-level evaluable.

/result : Feature {subsets parameter, output}

The result parameter of the Function, which is owned by the Function via a ReturnParameterMembership.

The object or value that is the result of evaluating the Function.

Operations

None.

Constraints

checkFunctionResultBindingConnector

If a Function has an Expression owned via a ResultExpressionMembership, then the owning Function must also own a BindingConnector between its result parameter and the result parameter of the result Expression.
ownedMembership.selectByKind(ResultExpressionMembership)->
  forAll(mem | ownedFeature.selectByKind(BindingConnector)->
    exists(binding |
      binding.relatedFeature->includes(result) and
      binding.relatedFeature->includes(mem.ownedResultExpression.result)))

checkFunctionSpecialization

A Function must directly or indirectly specialize the base Function Performances::Evaluation from the Kernel Semantic Library.

specializesFromLibrary('Performances::Evaluation')

deriveFunctionResult

The result parameter of a Function is its parameter owned via a ReturnParameterMembership (if any).

result =
  let resultParams : Sequence(Feature) =
    ownedFeatureMemberships->
    selectByKind(ReturnParameterMembership).
    ownedParameterMember in
    if resultParams->notEmpty() then resultParams->first()
    else null
  endif

validateFunctionResultExpressionMembership

A Function must have at most one ResultExpressionMembership.

membership->selectByKind(ResultExpressionMembership)->size() <= 1

validateFunctionResultParameterMembership

A Function must own at most one ResultParameterMembership.

ownedFeatureMembership->
  selectByKind(ReturnParameterMembership)->
  size() <= 1

8.3.4.7.5 Invariant

Description

An Invariant is a BooleanExpression that is asserted to have a specific Boolean result value. If isNegated = false, then the result is asserted to be true. If isNegated = true, then the result is asserted to be false.

General Classes

BooleanExpression

Attributes

isNegated : Boolean

Whether this Invariant is asserted to be false rather than true.
Operations
None.

Constraints
checkInvariantSpecialization

An Invariant must directly or indirectly specialize either of the following BooleanExpressions from the Kernel Semantic Library: \texttt{Performances::trueEvaluations, if isNegated = false}, or \texttt{Performances::falseEvaluations, if isNegated = true}.

\[
\text{if isNegated then}
\quad \text{specializesFromLibrary('Performances::falseEvaluations')}
\]\
\[
\text{else}
\quad \text{specializesFromLibrary('Performances::trueEvaluations')}
\]

8.3.4.7.6 Predicate

Description
A \textit{Predicate} is a \textit{Function} whose \textit{result parameter} has \textit{type Boolean} and \textit{multiplicity 1..1}.

General Classes
Function

Attributes
None.

Operations
None.

Constraints
checkPredicateSpecialization

A Predicate must directly or indirectly specialize the base Predicate \textit{Performances::BooleanEvaluation} from the Kernel Semantic Library.

\text{specializesFromLibrary('Performances::BooleanEvaluation')}

8.3.4.7.7 ResultExpressionMembership

Description
A \textit{ResultExpressionMembership} is a \textit{FeatureMembership} that indicates that the \textit{ownedResultExpression} provides the result values for the \textit{Function} or \textit{Expression} that owns it. The \textit{owning Function} or \textit{Expression} must contain a \textit{BindingConnector} between the \textit{result parameter} of the \textit{ownedResultExpression} and the \textit{result parameter} of the \textit{owning Function} or \textit{Expression}.

General Classes
FeatureMembership

Attributes

/ownedResultExpression : Expression {redefines ownedMemberFeature}

The Expression that provides the result for the owner of the ResultExpressionMembership.

Operations

None.

Constraints

validateResultExpressionMembershipOwningType

The owningType of a ResultExpressionMembership must be a Function or Expression.

owningType.oclIsKindOf(Function) or owningType.oclIsKindOf(Expression)

8.3.4.7.8 ReturnParameterMembership

Description

A ReturnParameterMembership is a ParameterMembership that indicates that the ownedMemberParameter is the result parameter of a Function or Expression. The direction of the ownedMemberParameter must be out.

General Classes

ParameterMembership

Attributes

None.

Operations

parameterDirection() : FeatureDirectionKind {redefines parameterDirection, leaf}

The ownedMemberParameter of a ReturnParameterMembership must have direction out. (This is a leaf operation that cannot be further redefined.)

body : FeatureDirectionKind::out

Constraints

validateReturnParameterMembershipOwningType

The owningType of a ReturnParameterMembership must be a Function or Expression.

owningType.oclIsKindOf(Function) or owningType.oclIsKindOf(Expression)

8.3.4.8 Expressions Abstract Syntax
8.3.4.8.1 Overview

Figure 33. Expressions

Expression

LiteralExpression
+modelLevelEvaluable( visited : Feature [0..*] ) : Boolean{redefines modelLevelEvaluable}
+evaluate( target : Element ) : Element [0..*]{redefines evaluate}

LiteralBoolean
+value : Boolean

LiteralInteger
+value : Integer

LiteralRational
+value : Real

LiteralInfinity
+value : String

Figure 34. Literal Expressions

8.3.4.8.2 CollectExpression

Description

A **CollectExpression** is an **OperatorExpression** whose operator is "collect", which resolves to the Function ControlFunctions::collect from the Kernel Functions Library.

General Classes

OperatorExpression

Attributes
operator : String {redefines operator}

Operations
None.

Constraints

collectExpressionOperator

The operator of a CollectExpression must be "collect".
operator = "collect"

8.3.4.8.3 FeatureChainExpression

Description

A FeatureChainExpression is an OperatorExpression whose operator is ".", which resolves to the Function ControlFunctions::'.' from the Kernel Functions Library. It evaluates to the result of chaining the result Feature of its single argument Expression with its targetFeature.

General Classes
OperatorExpression

Attributes

operator : String {redefines operator}
/targetFeature : Feature {subsets member}

The Feature that is accessed by this FeatureChainExpression, which is its first non-parameter member.

Operations

sourceTargetFeature() : Feature [0..1]

Return the first ownedFeature of the first owned input parameter of this FeatureChainExpression (if any).

body: let inputParameters : Feature = ownedFeatures->
    select(direction = _'in') in
    if inputParameters->isEmpty() or
        inputParameters->first().ownedFeature->isEmpty()
    then null
    else inputParameters->first().ownedFeature->first()
endif

Constraints

sourceTargetRedefinition

The first ownedFeature of the first owned input parameter of a FeatureChainExpression must redefine its targetFeature.
let sourceParameter : Feature = sourceTargetFeature() in
sourceTargetFeature <> null and
sourceTargetFeature.redefines(targetFeature)

checkFeatureChainExpressionTargetRedefinition

The first ownedFeature of the first owned input parameter of a FeatureChainExpression must redefine the Feature ControlFunctions::'.':source::target from the Kernel Functions Library.

let sourceParameter : Feature = sourceTargetFeature() in
sourceTargetFeature <> null and
sourceTargetFeature.redefinesFromLibrary('ControlFunctions::\'.\':source::target')

deriveFeatureChainExpressionTargetFeature

The targetFeature of a FeatureChainExpression is the memberElement of its first ownedMembership that is not a ParameterMembership.

targetFeature =
let nonParameterMemberships : Sequence(Membership) = ownedMembership->
    reject(oclIsKindOf(ParameterMembership)) in
if nonParameterMemberships->isEmpty() or
    not nonParameterMemberships->first().memberElement.oclIsKindOf(Feature)
then null
else nonParameterMemberships->first().memberElement.oclAsType(Feature)
endif

validateFeatureChainExpressionConformance

The featuringTypes of the targetFeature of a FeatureChainExpression must conform to the result parameter of the argument Expression of the FeatureChainExpression.

argument->notEmpty() implies
targetFeature.featuringType->forall(t |
    t.specializes(argument->at(1).result))

8.3.4.8.4 FeatureReferenceExpression

Description

A FeatureReferenceExpression is an Expression whose result is bound to a referent Feature.

General Classes

Expression

Attributes

/referent : Feature {subsets member}

The Feature that is referenced by this FeatureReferenceExpression, which is its first non-parameter member.

Operations

evaluate(target : Element) : Element [0..*] {redefines evaluate}
First, determine a value Expression for the referent:

- If the target Element is a Type that has a feature that is the referent or (directly or indirectly) redefines it, then the value Expression of the FeatureValue for that feature (if any).
- Else, if the referent has no featuringTypes, the value Expression of the FeatureValue for the referent (if any).

Then:

- If such a value Expression exists, return the result of evaluating that Expression on the target.
- Else, if the referent is not an Expression, return the referent.
- Else return the empty sequence.

```plaintext
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.featuringType->isEmpty() then referent
   else Sequence{}
endif endif
endif

modelLevelEvaluable(visited : Feature [0..*]) : Boolean {redefines modelLevelEvaluable}

A FeatureReferenceExpression is model-level evaluable if it's referent

- conforms to the self-reference feature Anything::self,
- is an Expression that is model-level evaluable;
- has an owningType that is a Metaclass or MetadataFeature; or
- has no featuringTypes and, if it has a FeatureValue, the value Expression is model-level evaluable.

```plaintext
body: referent.conformsTo('Anything::self') or
visited->excludes(referent) and
(referent.oclIsKindOf(Expression) and
   referent.oclAsType(Expression).modelLevelEvaluable(visited->including(referent)) or
   referent.owningType <> null and
   (referent.owningType.isOclKindOf(MetaClass) or
    referent.owningType.isOclKindOf(MetadataFeature)) or
   referent.featuringType->isEmpty() and
   (referent.valuation = null or
    referent.valuation.modelLevelEvaluable(visited->including(referent))))

Constraints

checkFeatureReferenceExpressionBindingConnector

A FeatureReferenceExpression must have an ownedMember that is a BindingConnector between the referent and result of the FeatureReferenceExpression.
ownedMember->selectByKind(BindingConnector)->exists(b | 
  b.relatedFeatures->includes(targetFeature) and 
  b.relatedFeatures->includes(result))

deriveFeatureReferenceExpressionReferent

The referent of a FeatureReferenceExpression is the memberElement of its first ownedMembership that is not a ParameterMembership.

referent =
  let nonParameterMemberships : Sequence(Membership) = ownedMembership->
    reject(oclIsKindOf(ParameterMembership)) in
    if nonParameterMemberships->isEmpty() or 
      not nonParameterMemberships->first().memberElement.oclIsKindOf(Feature) 
    then null 
    else nonParameterMemberships->first().memberElement.oclAsType(Feature) 
  endif

validateFeatureReferenceExpressionReferentIsFeature

The first ownedMembership of a FeatureReferenceExpression that is not a ParameterMembership must have a Feature as its memberElement.

let membership : Membership =
  ownedMembership->reject(m | m.oclIsKindOf(ParameterMembership)) in
  membership->notEmpty() and 
  membership->at(1).memberElement.oclIsKindOf(Feature)

8.3.4.8.5 InvocationExpression

Description

An InvocationExpression is an Expression each of whose input parameters are bound to the result of an argument Expression.

General Classes

Expression

Attributes

/argument : Expression [0..*] {subsets ownedFeature, ordered}

The value Expressions of the FeatureValues of the owned input parameters of the InvocationExpression.

Operations

evaluate(target : Element) : Element [0..*] {redefines evaluate}

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.

modelLevelEvaluable(visited : Feature [0..*]) : Boolean {redefines modelLevelEvaluable}
An InvocationExpression is model-level evaluable if all its argument Expressions are model-level evaluable and its function is model-level evaluable.

**body:** argument->forAll(modelLevelEvaluable(visited)) and function.isModelLevelEvaluable

**Constraints**

**checkInvocationExpressionConstructorBindingConnector**

If an InvocationExpression does not have an ownedTyping that is a Behavior or an ownedSubsetting of a Feature that is typed by a Behavior, then it must own a BindingConnector between itself and its result parameter.

not ownedTyping->exists(oclIsKindOf(Behavior)) and not ownedSubsetting.subsettedFeature.type->exists(oclIsKindOf(Behavior)) implies ownedFeature.selectByKind(BindingConnector)->exists(relatedFeature->includes(self) and relatedFeature->includes(result))

**checkInvocationExpressionDefaultValueBindingConnector**

An InvocationExpression must own a BindingConnector between the featureWithValue and value Expression of any FeatureValue that is the effective default value for a Feature of the invoked Type of the InvocationExpression.

TBD

**deriveInvocationExpressionArgument**

The arguments of an InvocationExpression are the value Expressions of the FeatureValues of its owned input parameters.

ownedFeature->
  select(direction = _'in').valuation->
  select(v | v <> null).value

**validateInvocationExpressionNoDuplicateParameterRedefinition**

Two different input parameters of an InvocationExpression must not redefine the same feature of a type of the InvocationExpression.

let features : Set(Feature) = type.feature->asSet() in input->forAll(inp1 | input->forAll(inp2 | inp1 <> inp2 implies
  inp1.ownedRedefinition.redefinedFeature->
  intersection(inp2.ownedRedefinition.redefinedFeature->
  intersection(features)->isEmpty()))

**validateInvocationExpressionParameterRedefinition**

Each input parameter of an InvocationExpression must redefine exactly one feature of a type of the InvocationExpression.
let features : Set(Feature) = type.feature->asSet() in
input->forAll(inp |
    inp.ownedRedefinition.redefinedFeature->
    intersection(features)->size() = 1)

### 8.3.4.8.6 LiteralBoolean

**Description**

LiteralBoolean is a LiteralExpression that provides a Boolean value as a result. Its result parameter must have type Boolean.

**General Classes**

LiteralExpression

**Attributes**

value : Boolean

The Boolean value that is the result of evaluating this Expression.

The Boolean value that is the result of evaluating this LiteralBoolean.

**Operations**

None.

**Constraints**

checkLiteralBooleanSpecialization

specializesFromLibrary('Performances::literalBooleanEvaluations')

### 8.3.4.8.7 LiteralExpression

**Description**

A LiteralExpression is an Expression that provides a basic DataValue as a result.

**General Classes**

Expression

**Attributes**

None.

**Operations**

evaluate(target : Element) : Element {0..*} {redefines evaluate}

The model-level value of a LiteralExpression is itself.

**body**: Sequence{self}
modelLevelEvaluable(visited : Feature [0..*]) : Boolean {redefines modelLevelEvaluable}

A LiteralExpression is always model-level evaluable.

**body**: true

**Constraints**

checkLiteralExpressionSpecialization

A LiteralExpression must directly or indirectly specialize the base LiteralExpression Performances::literalEvaluations from the Kernel Semantic Library.

specializesFromLibrary('Performances::literalEvaluations')

deriveLiteralExpressionIsModelLevelEvaluable

A LiteralExpression is always model-level evaluable.

isModelLevelEvaluable = true

### 8.3.4.8.8 LiteralInfinity

**Description**

A LiteralInfinity is a LiteralExpression that provides the positive infinity value (*). Its result must have the type Positive.

**General Classes**

LiteralExpression

**Attributes**

None.

**Operations**

None.

**Constraints**

checkLiteralInfinitySpecialization

specializesFromLibrary('Performances::literalIntegerEvaluations')

### 8.3.4.8.9 LiteralInteger

**Description**

A LiteralInteger is a LiteralExpression that provides an Integer value as a result. Its result parameter must have the type Integer.

**General Classes**

LiteralExpression
Attributes

value : Integer

The Integer value that is the result of evaluating this LiteralInteger.

The Integer value that is the result of evaluating this Expression.

Operations

None.

Constraints

checkLiteralIntegerSpecialization

specializesFromLibrary('Performances::literalIntegerEvaluations')

8.3.4.8.10 LiteralRational

Description

A LiteralRational is a LiteralExpression that provides a Rational value as a result. Its result parameter must have the type Rational.

General Classes

LiteralExpression

Attributes

value : Real

The value whose rational approximation is the result of evaluating this LiteralRational.

The Real value that is the result of evaluating this Expression.

Operations

None.

Constraints

checkLiteralRationalSpecialization

specializesFromLibrary('Performances::literalRationalEvaluations')

8.3.4.8.11 LiteralString

Description

A LiteralString is a LiteralExpression that provides a String value as a result. Its result parameter must have the type String.

General Classes
LiteralExpression

Attributes

value : String

The String value that is the result of evaluating this LiteralString.

The String value that is the result of evaluating this Expression.

Operations

None.

Constraints

checkLiteralStringSpecialization

specializesFromLibrary('Performances::literalStringEvaluations')

8.3.4.8.12 MetadataAccessExpression

Description

A MetadataAccessExpression is an Expression whose result is a sequence of instances of Metaclasses representing all the MetadataFeature annotations of the referencedElement. In addition, the sequence includes an instance of the reflective Metaclass corresponding to the MOF class of the referencedElement, with values for all the abstract syntax properties of the referencedElement.

General Classes

Expression

Attributes

referencedElement : Element

The Element whose metadata is being accessed.

Operations

evaluate(target : Element) : Element [0..*] {redefines evaluate}

Return the ownedElements of the referencedElement that are MetadataFeatures and have the referencedElement as an annotatedElement, plus a MetadataFeature whose annotatedElement is the referencedElement, whose metaclass is the reflective Metaclass corresponding to the MOF class of the referencedElement and whose ownedFeatures are bound to the values of the MOF properties of the referencedElement.

body : referencedElement.ownedElement->
  select(oclIsKindOf(MetadataFeature) 
    and annotatedElement->includes(referencedElement)->
    including(metaclassFeature()))

metaclassFeature() : MetadataFeature
Return a `MetadataFeature` whose `annotatedElement` is the `referencedElement`, whose `metaclass` is the reflective `Metaclass` corresponding to the MOF class of the `referencedElement` and whose `ownedFeatures` are bound to the MOF properties of the `referencedElement`.

`modelLevelEvaluable(visited : Feature [0..*]) : Boolean {redefines modelLevelEvaluable}`

A `MetadataAccessExpression` is always model-level evaluable.

`body`: true

Constraints

`checkMetadataAccessExpressionSpecialization`

A `MetadataAccessExpression` must directly or indirectly specialize the base `MetadataAccessExpression Performances::metadataAccessEvaluations` from the Kernel Semantic Library.

`specializesFromLibrary('Performances::metadataAccessEvaluations')`

8.3.4.8.13 NullExpression

Description

A `NullExpression` is an `Expression` that results in a null value.

General Classes

Expression

Attributes

None.

Operations

`evaluate(target : Element) : Element [0..*] {redefines evaluate}`

The model-level value of a `NullExpression` is an empty sequence.

`body`: Sequence{}

`modelLevelEvaluable(visited : Feature [0..*]) : Boolean {redefines modelLevelEvaluable}`

A `NullExpression` is always model-level evaluable.

`body`: true

Constraints

`checkNullExpressionSpecialization`

A `NullExpression` must directly or indirectly specialize the base `NullExpression Performances::nullEvaluations` from the Kernel Semantic Library.

`specializesFromLibrary('Performances::nullEvaluations')`
8.3.4.8.14 OperatorExpression

Description

An OperatorExpression is an InvocationExpression whose function is determined by resolving its operator in the context of one of the standard packages from the Kernel Function Library.

General Classes

InvocationExpression

Attributes

operator : String

An operator symbol that names a corresponding Function from one of the standard packages from the Kernel Function Library.

Operations

None.

Constraints

checkOperatorExpressionSpecialization

The function of an OperatorExpression must be the resolution of the operator from one of the packages BaseFunctions, DataFunctions, or ControlFunctions from the Kernel Function Library.

let libFunctions : Sequence(Element) =
  Sequence{'BaseFunctions', 'DataFunctions', 'ControlFunctions'}->
  collect(ns | resolveGlobal(ns + '::'' + operator + '''').
  memberElement) in
  libFunctions->includes(function)

8.3.4.8.15 SelectExpression

Description

A SelectExpression is an OperatorExpression whose operator is "select", which resolves to the Function ControlFunctions::select from the Kernel Functions Library.

General Classes

OperatorExpression

Attributes

operator : String {redefines operator}

Operations

None.

Constraints
The operator of a SelectExpression must be 'select'.

operator = 'select'

### 8.3.4.9 Interactions Abstract Syntax

#### 8.3.4.9.1 Overview

![Figure 35. Interactions](image)

![Figure 36. Item Flows](image)
8.3.4.9.2 ItemFeature

Description

An ItemFeature is the ownedFeature of an ItemFlow that identifies the things carried by the kinds of transfers that are instances of the ItemFlow.

General Classes

Feature

Attributes

None.

Operations

None.

Constraints

checkItemFeatureRedefinition

An ItemFeature must redefine the Feature Transfers::Transfer::item from the Kernel Semantic Library.

ownedRedefinition.redefinedFeature->
  redefinesFromLibrary('Transfers::Transfer::item')

8.3.4.9.3 ItemFlow

Description

An ItemFlow is a Step that represents the transfer of objects or data values from one Feature to another. ItemFlows can take non-zero time to complete.

General Classes

Connector

Step

Attributes

/interaction : Interaction [0..*] {redefines association, behavior, ordered}

The Interactions that type this ItemFlow. Interactions are both Associations and Behaviors, which can type Connectors and Steps, respectively.

/itemFeature : ItemFeature [0..1] {subsets ownedFeature}

The ownedFeature of the ItemFlow that is an ItemFeature (if any).

/itemFlowEnd : ItemFlowEnd [0..2] {subsets connectorEnd, ordered}

The connectorEnds of this ItemFlow that are ItemFlowEnds.
/itemType : Classifier [0..*] {ordered, nonunique}

The type of values transferred, which is the type of the itemFeature of the ItemFlow.

/sourceOutputFeature : Feature [0..1] {ordered, nonunique}

The Feature that provides the items carried by the ItemFlow. It must be an owned output of the source of the ItemFlow.

/targetInputFeature : Feature [0..1] {ordered, nonunique}

The Feature that receives the values carried by the ItemFlow. It must be an owned output of the target participant of the ItemFlow.

Operations

None.

Constraints

checkItemFlowSpecialization

An ItemFlow must directly or indirectly specialize the Step Transfers::transfers from the Kernel Semantic Library. In addition, if the ItemFlow has ItemFlowEnds, it must specialize Transfers::flowTransfers.

if itemFlowEnds->isEmpty() then
    specializesFromLibrary('Transfers::transfers')
else
    specializesFromLibrary('Transfers::flowTransfers')
endif

deriveItemFlowItemFeature

The itemFeature of an ItemFlow is the single one of its ownedFeatures that is an ItemFeature.

itemFeature =
    let itemFeatures : Sequence(ItemFeature) =
        ownedFeature->selectByKind(ItemFeature) in
    if itemFeatures->isEmpty() then null
    else itemFeatures->first()
    endif

deriveItemFlowItemFlowEnd

The itemFlowEnds of a ItemFlow are all its connectorEnds that are ItemFlowEnds.

itemFlowEnd = connectorEnd->selectByKind(ItemFlowEnd)

deriveItemFlowItemType

The itemTypes of an ItemFlow are the types of the itemFeature of the ItemFlow (if any).

itemType =
    if itemFeature = null then Sequence{}
    else itemFeature.type
    endif
**deriveItemFlowSourceOutputFeature**

The **sourceOutputFeature** of a **ItemFlow** is the **first** ownedFeature of the **first** connectorEnd of the **ItemFlow**.

```plaintext
sourceOutputFeature =
  if connectorEnd->isEmpty() or
    connectorEnd.ownedFeature->isEmpty()
    then null
  else connectorEnd.ownedFeature->first()
endif
```

**deriveItemFlowTargetInputFeature**

The **targetInputFeature** of a **ItemFlow** is the **first** ownedFeature of the **second** connectorEnd of the **ItemFlow**.

```plaintext
targetInputFeature =
  if connectorEnd->size() < 2 or
    connectorEnd->at(2).ownedFeature->isEmpty()
    then null
  else connectorEnd->at(2).ownedFeature->first()
endif
```

**validateItemFlowItemFeature**

An **ItemFlow** must have at most one ownedFeature that is an **ItemFeature**.

```plaintext
ownedFeature->selectByKind(ItemFeature)->size() <= 1
```

### 8.3.4.9.4 ItemFlowEnd

**Description**

An **ItemFlowEnd** is a **Feature** that is one of the **connectorEnds** giving the **source** or **target** of an **ItemFlow**. For **ItemFlows** typed by **FlowTransfer** or its specializations, **ItemFlowEnds** must have exactly one ownedFeature, which redefines **Transfer::source::sourceOutput** or **Transfer::target::targetInput** and redefines the corresponding feature of the **relatedElement** for its end.

**General Classes**

**Feature**

**Attributes**

None.

**Operations**

None.

**Constraints**

validateItemFlowEndIsEnd

An **ItemFlowEnd** must be an **end** **Feature**.
isEnd

validateItemFlowEndNestedFeature

An ItemFlowEnd must have exactly one ownedFeature.

ownedFeature->size() = 1

validateItemFlowEndOwningType

The owningType of an ItemFlow must be an ItemFlow.

owningType <> null and owningType.oclIsKindOf(ItemFlow)

### 8.3.4.9.5 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**

None.

**Operations**

None.

**Constraints**

None.

### 8.3.4.9.6 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**

None.
Operations

None.

Constraints

cHECKSuccessionItemFlowSpecialization

A SuccessionItemFlow must directly or indirectly specialize the Step Transfers::flowTransfersBefore from the Kernel Semantic Library.

specializesFromLibrary('Transfers::flowTransfersBefore')

8.3.4.10 Feature Values Abstract Syntax

8.3.4.10.1 Overview

A FeatureValue is a Membership that identifies a particular member Expression that provides the value of the Feature that owns the FeatureValue. The value is specified as either a bound value or an initial value, and as either a concrete or default value. A Feature can have at most one FeatureValue.

The result of the value Expression is bound to the featureWithValue using a BindingConnector. If isInitial = false, then the featuringType of the BindingConnector is the same as the featuringType of the featureWithValue. If isInitial = true, then the featuringType of the BindingConnector is restricted to its startShot.

If isDefault = false, then the above semantics of the FeatureValue are realized for the given featureWithValue. Otherwise, the semantics are realized for any individual of the featuringType of the featureWithValue, unless another value is explicitly given for the featureWithValue for that individual.

General Classes

OwningMembership

Attributes

/featureWithValue : Feature {subsets membershipOwningNamespace}

The Feature to be provided a value.
isDefault : Boolean

Whether this FeatureValue is a concrete specification of the bound or initial value of the featureWithValue, or just a default value that may be overridden.

isInitial : Boolean

Whether this FeatureValue specifies a bound value or an initial value for the featureWithValue.

/value : Expression {redefines ownedMemberElement}

The Expression that provides the value of the featureWithValue as its result.

The Expression that provides the value as a result.

Operations

None.

Constraints

checkFeatureValueBindingConnector

If isDefault = false, then the featureWithValue must have an ownedMember that is a BindingConnector whose relatedElements are the featureWithValue and the result of the value Expression. If isInitial = false, then this BindingConnector must have featuringTypes that are the same as those of the featureWithValue. If isInitial = true, then the BindingConnector must have that.startShot as its featuringType.

not isDefault implies

featureWithValue.ownedMember->
  selectByKind(BindingConnector)->exists(b |
  b.relatedFeature->includes(featureWithValue) and
  b.relatedFeature->includes(value.result) and
  if not isInitial then
    b.featuringType = featureWithValue.featuringType
  else
    b.featuringType->exists(t |
      toclIsKindOf(Feature) and
      toclAsType(Feature).chainingFeature =
      Sequence{
        resolveGlobal('Base::things::that').
        memberElement,
        resolveGlobal('Occurrences::Occurrence::startShot').
        memberElement
      }
  )
endif)

validateFeatureValueOverriding

All Features directly or indirectly redefined by the featureWithValue of a FeatureValue must have only default FeatureValues.
8.3.4.11 Multiplicities Abstract Syntax

8.3.4.11.1 Overview

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 these Expressions shall be of type Natural. 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. If no lowerBound Expression, then the default is that the lower bound has the same value as the upper bound, except if the upperBound evaluates to \(*\), in which case the default for the lower bound is 0.

General Classes

Multiplicity

Attributes

/bound : Expression [1..2] {redefines ownedMember, ordered, union}

The owned Expressions of the MultiplicityRange whose results provide its bounds. These must be the only ownedMembers of the MultiplicityRange.

/lowerBound : Expression [0..1] {subsets bound}
The Expression whose result provides the lower bound of the 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

hasBounds(lower : Integer, upper : UnlimitedNatural) : Boolean

Check whether this MultiplicityRange represents the range bounded by the given values lower and upper, presuming the lowerBound and upperBound Expressions are model-level evaluable.

body: valueOf(upperBound) = upper and
let lowerValue: UnlimitedNatural = valueOf(lowerBound) in
(lowerValue = lower or
lowerValue = null and
(lower = upper or
 lower = 0 and upper = *))

valueOf(bound : Expression [0..1]) : UnlimitedNatural [0..1]

Evaluate the given bound Expression (at model level) and return the result represented as a MOF UnlimitedNatural value.

body: if bound = null or not bound.isModelLevelEvaluable then
null
else
let boundEval: Sequence(Element) = bound.evaluate(owningType) in
if boundEval->size() <> 1 then null else
let valueEval: Element = boundEval->at(1) in
if valueEval.oclIsKindOf(LiteralInfinity) then *
else if valueEval.oclIsKindOf(LiteralInteger) then
let value : Integer = valueEval.oclAsKindOf(LiteralInteger).value in
if value >= 0 then value else null endif
else null
dfi
endif
endif

Constraints

checkMultiplicityRangeExpressionTypeFeaturing

The bounds of a MultiplicityRange must have the same featuringTypes as the MultiplicityRange.

bound->forall(b | b.featuringType = self.featuringType)

deriveMultiplicityRangeLowerBound
If a MultiplicityRange has two ownedMembers, then the lowerBound is the first ownedMember, otherwise it is null.

lowerBound =
   let ownedMembers : Sequence(Element) =
       ownedMembership->selectByKind(OwningMembership).ownedMember in
   if ownedMembers->size() < 2 or
       not ownedMembers->first().oclIsKindOf(Expression) then null
   else ownedMembers->first().oclAsType(Expression)
   endif

deriveMultiplicityRangeUpperBound

If a MultiplicityRange has ownedMembers when considered as a Feature, then upperBound is the last of those, which must be an Expression.

upperBound =
   let ownedMembers : Sequence(Element) =
       ownedMembership->selectByKind(OwningMembership).ownedMember in
   if ownedMembers->isEmpty() or
       not ownedMembers->last().oclIsKindOf(Expression) then null
   else ownedMembers->last().oclAsType(Expression)
   endif

validateMultiplicityRangeBoundResultTypes

The results of the bound Expression(s) of a MultiplicityRange must be typed by ScalarValues::Integer from the Kernel Data Types Library. If a bound is model-level evaluable, then it must evaluate to a non-negative value.

bound->forAll(b |
   b.result.specializesFromLibrary('ScalarValues::Integer') and
   let value : UnlimitedNatural = valueOf(b) in
   value <> null implies value >= 0
)

8.3.4.12 Metadata Abstract Syntax
8.3.4.12.1 Overview

A Metaclass is a Structure used to type MetadataFeatures.

General Classes
Structure

Attributes
None.

Operations
None.

Constraints
checkMetaclassSpecialization

A Metaclass must directly or indirectly specialize the base Metaclass Metaobjects::Metaobject from the Kernel Semantic Library.

specializesFromLibrary('Metaobjects::Metaobject')

8.3.4.12.3 MetadataFeature

Description

A MetadataFeature is a Feature that is an AnnotatingElement used to annotate another Element with metadata. It is typed by a Metaclass. All its ownedFeatures must redefine features of its metaclass and any feature bindings must be model-level evaluable.

General Classes
AnnotatingElement
Feature

Attributes

/metaclass : Metaclass [0..1] {subsets type}

The type of this MetadataFeature, which must be a Metaclass.

Operations

evaluateFeature(baseFeature : Feature) : Element [0..*]

If the given baseFeature is a feature of this MetadataFeature, or is directly or indirectly redefined by a feature, then return the result of evaluating the appropriate (model-level evaluable) value Expression for it (if any), with the MetadataFeature as the target.

body: let selectedFeatures : Sequence(Feature) = feature->
  select(closure(ownedRedefinition.redefinedFeature)->
    includes(baseFeature)) in
  if selectedFeatures->isEmpty() then null
  else
    let selectedFeature : Feature = selectedFeatures->first() in
    let featureValues : FeatureValue = selectedFeature->
      closure(ownedRedefinition.redefinedFeature).ownedMember->
        selectAsKind(FeatureValue) in
      if featureValues->isEmpty() then null
      else featureValues->first().value.evaluate(self)
  endif

isSemantic() : Boolean

Check if this MetadataFeature has a metaclass which is a kind of SemanticMetadata.

body: specializesFromLibrary('Metaobjects::SemanticMetadata')

isSyntactic() : Boolean

Check if this MetadataFeature has a metaclass that is a kind of KerML::Element (that is, it is from the reflective abstract syntax model).

body: specializesFromLibrary('KerML::Element')

syntaxElement() : Element [0..1]

If this MetadataFeature reflectively represents a model element, then return the corresponding Element instance from the MOF abstract syntax representation of the model.

pre: isSyntactic()

body: No OCL

Constraints

checkMetadataFeatureSemanticSpecialization
If this MetadataFeature is an application of SemanticMetadata, then its annotatingElement must be a Type. The annotated Type must then directly or indirectly specialize the specified value of the baseType, unless the Type is a Classifier and the baseType represents a kind of Feature, in which case the Classifier must directly or indirectly specialize each of the types of the Feature.

isSemantic() implies
  let annotatedTypes : Sequence(Type) =
  annotatedElement->selectAsKind(Type) in
  let baseTypes : Sequence(MetadataFeature) =
  evaluateFeature(resolveGlobal({
    'Metaobjects::SemanticMetadata::baseType'.
    memberElement.
    oclAsType(Feature))->
  selectAsKind(MetadataFeature) in
  annotatedTypes->notEmpty() and
  baseTypes()->notEmpty() and
  baseTypes()->first().isSyntactic() implies
  let annotatedType : Type = annotatedTypes->first() in
  let baseType : Element = baseTypes->first().syntaxElement() in
  if annotatedType.oclIsKindOf(Classifier) and
  baseType.oclIsKindOf(Feature) then
    baseType.oclAsType(Feature).type->
    forAll(t | annotatedType.specializes(t))
  else if baseType.oclIsKindOf(Type) then
    annotatedType.specializes(baseType.oclAsType(Type))
  else
    true
  endif

checkMetadataFeatureSpecialization

A MetadataFeature must directly or indirectly specialize the base MetadataFeature Metaobjects::metaobjects from the Kernel Semantic Library.

specializesFromLibrary('Metaobjects::metaobjects')

deriveMetadataFeatureMetaclass

The metaclass of a MetadataFeature is one of its types that is a Metaclass.

metaclass =
  let metaclassTypes : Sequence(Type) = type->selectByKind(Metaclass) in
  if metaclassTypes->isEmpty() then null
  else metaclassTypes->first()
  endif

validateMetadataFeatureAnnotatedElement

The annotatedElements of a MetadataFeature must have an abstract syntax metaclass consistent with the annotatedElement declarations for the MetadataFeature.

let baseAnnotatedElementFeature : Feature =
  resolveGlobal('Metaobjects::Metaobject::annotatedElement').memberElement.
  oclAsType(Feature) in
let annotatedElementFeatures : OrderedSet(Feature) = feature->
  select(specializes(baseAnnotatedElementFeature))->
  excluding(baseAnnotatedElementFeature) in
annotatedElementFeatures->notEmpty() implies
    let annotatedElementTypes : Set(Feature) =
      annotatedElementFeatures.typing.type->asSet() in
    let metaclasses : Set(Metaclass) =
      annotatedElement.oclType().qualifiedName->collect(qn | resolveGlobal(qn).memberElement.oclAsType(Metaclass)) in
    metaclasses->forAll(m | annotatedElementTypes->exists(t | m.specializes(t)))

validateMetadataFeatureBody

Each ownedFeature of a MetadataFeature must have no declared name, redefine a single Feature, either have no featureValue or a featureValue with a value Expression that is model-level evaluable, and only have ownedFeatures that also meet these restrictions.

ownedFeature->closure(ownedFeature)->forAll(f | f.declaredName = null and f.declaredShortName = null and f.valuation <> null implies f.valuation.value.isModelLevelEvaluable and f.redefinition.redefinedFeature->size() = 1)

validateMetadataFeatureMetaclass

A MetadataFeature must have exactly one type that is a Metaclass.

type->selectByKind(Metaclass).size() = 1

validateMetadataFeatureMetaclassNotAbstract

The metaclass of a MetadataFeature must not be abstract.

not metaclass.isAbstract

8.3.4.13 Packages Abstract Syntax

8.3.4.13.1 Overview

Figure 40. Packages

8.3.4.13.2 ElementFilterMembership

Description
ElementFilterMembership is a Membership between a Namespace and a model-level evaluable Boolean-valued 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

OwningMembership

Attributes

/condition : Expression {redefines ownedMemberElement}

The model-level evaluable Boolean-valued Expression used to filter the imported members of the membershipOwningNamespace of this ElementFilterMembership.

Operations

None.

Constraints

validateElementFilterMembershipConditionIsBoolean

The result parameter of the condition Expression must directly or indirectly specialize ScalarValues::Boolean.

c condition.result.specializesFromLibrary('ScalarValues::Boolean')

validateElementFilterMembershipConditionIsModelLevelEvaluable

The condition Expression must be model-level evaluable.

c condition.isModelLevelEvaluable

8.3.4.13.3 LibraryPackage

Description

A LibraryPackage is a Package that is the container for a model library. A LibraryPackage is itself a library Element as are all Elements that are directly or indirectly contained in it.

General Classes

Package

Attributes

isStandard : Boolean

Whether this LibraryPackage contains a standard library model. This should only be set to true for LibraryPackages in the standard Kernel Model Libraries or in normative model libraries for a language built on KerML.

Operations
libraryNamespace() : Namespace [0..1] {redefines libraryNamespace}

The libraryNamespace for a LibraryPackage is itself.

body: self

Constraints

None.

8.3.4.13.4 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-valued Expression used to filter the members of this Package, which are owned by the Package via ElementFilterMemberships.

Operations

importedMemberships(excluded : Namespace [0..*]) : Membership [0..*] {redefines importedMemberships}

Exclude Elements that do not meet all the filterConditions.

body: self.oclAsType(Namespace).importedMemberships(excluded)->select(m | self.includeAsMember(m.memberElement))

includeAsMember(element : Element) : Boolean

Determine whether the given element meets all the filterConditions.

body: let metadataFeatures: Sequence(AnnotatingElement) =
  element.ownedAnnotation.annotatingElement->
  selectByKind(MetadataFeature) in
  self.filterCondition->forAll(cond |
  metadataFeatures->exists(elem |
  cond.checkCondition(elem)))

Constraints

derivePackageFilterCondition

The filterConditions of a Package are the conditions of its owned ElementFilterMemberships.
8.4 Semantics

8.4.1 Semantics Overview

A KerML model is intended to represent a system being modeled. The model is interpreted to make statements about the modeled system. The model may describe an existing system, in which case, if the model is correct, the statements it is interpreted to make about the system should all be true. A model may also be used to specify an imagined or planned system, in which case the statements the model is interpreted to make should be true for any system that is properly constructed and operated according to the model.

The semantics of KerML specify how a KerML model is to be interpreted. The semantics are defined in terms of the abstract syntax representation of the model, and only for models which are valid relative to the structure and constraints specified for the KerML abstract syntax (see 8.3). As further specified in this subclause, models expressed in KerML are given semantics by implicitly reusing elements from the semantic models in the Kernel Model Library (see Clause 9). These library models represent conditions on the structure and behavior of the system being modeled, which are further augmented in a user model as appropriate.

A formal specification of semantics allows models to be interpreted consistently. In particular, all KerML models extend library models expressed in KerML itself, understandable by KerML modelers. These library models can then be ultimately reduced to a small, core subset of KerML, which is grounded in mathematical logic. The goal is to provide uniform model interpretation, which improves communication between everyone involved in modeling, including modelers and tool builders.

KerML semantics are specified by a combination of mathematics and model libraries, as illustrated in Fig. 41. The left side of this diagram shows the abstract syntax packages corresponding to the three layers of KerML (see 6.1). The right side shows the corresponding semantic layering.

1. The Root Layer defines the syntactic foundation KerML and, as such, does not have a semantic interpretation relative to the modeled system.
2. The Core Layer is grounded in mathematical semantics, supported by the Base package from the Kernel Model Library (see 9.2.2). Subclause 8.4.3 specifies the semantics of the Core layer.
3. The Kernel Layer is given semantics fully through its relationship to the Model Library (see Clause 9). Subclause 8.4.4 specifies the semantics of the Kernel layer.
8.4.2 Semantic Constraints and Implied Relationships

As described in 8.4.1, KerML semantics are specified by a combination of a mathematical interpretation of the Core layer and a set of required relationships between Core and Kernel model elements and elements of the Kernel Semantic Library (see 9.2). The latter requirements are formalized by semantic constraints included in the KerML abstract syntax (see also 8.3.1 on the various kinds of constraints in the abstract syntax). Additionally, other semantic constraints require relationships between elements within a user model necessary for the model to be semantically well formed.

Specifically, there are four categories of semantic constraints, each dealing with a different kind of relationship.

1. **Specialization constraints.** These constraints require that Type elements of a certain kind directly or indirectly specialize some specific base Type from the Kernel Semantic Library. They are the fundamental means for providing semantics to abstract syntax elements in the Kernel layer. Specialization constraints always have the word Specialization in their name. For example, checkDataTypeSpecialization...
requires that a `DataType` directly or indirectly specialize the Semantic Library `DataType Base::DataValue`.

2. **Redefinition constraints.** These constraints require that certain Features in a model have Redefinition relationships with certain other Features in the model. While Redefinitions are kinds of Specializations, redefinition constraints differ from the specialization constraints described above in that they are between two elements of a user model, rather than between an element of a user model and an element of a library model. Redefinition constraints always have the word Redefinition in their name. For example, `checkConnectorEndRedefinition` requires that the ends of a Connector redefine any ends of the Types that it specializes.

3. **Type-featuring constraints.** These constraints require that certain Features in a model have TypeFeaturing relationships with certain other Types in the model. They arise at points in a model in which the OwningMembership structure is different than the required Featuring relationship, so FeatureMembership cannot be used. Type-featuring constraints always have the words TypeFeaturing in their name. For example, `checkFeatureValueExpressionFeatureTyping` requires that the value Expression owned by a FeatureValue relationship (a kind of OwningMembership) have the same featuringTypes as the owning featureWithValue of the FeatureValue, rather than being featured by the featureWithValue itself (as would have been the case for a FeatureMembership).

4. **Binding-connector constraints.** These constraints require that BindingConnectors exist between certain Features in a model. The primary example of such a constraint is `checkFeatureValueBindingConnector`, which requires that the featureWithValue of a FeatureValue own a BindingConnector between itself and the result parameter of the value Expression of the FeatureValue.

A KerML model parsed from the textual concrete syntax (see 8.2) or obtained through model interchange (see Clause 10) will not necessarily meet the semantic constraints specified for the abstract syntax. In this case, a tool may insert certain implied Relationships into the model in order to meet the semantic constraints. The overview subclauses for the Core Semantics (see 8.4.3.1) and Kernel Semantics (see 8.4.4.1) include tables that define what implied Relationships should be included to satisfy each semantic constraint when it would otherwise be violated. In all cases, the semantics of a model are only defined if it meets all semantic and validation constraints (see 8.3.1).

When including implied Relationships for specialization constraints, it is possible that multiple such constraints may apply to a single element. For example, a `Structure` is a kind of `Class`, which is a kind of `Classifier`, and there are specialization constraints for all three of these metaclasses, with corresponding implied Subclassification Relationships. However, simply including all three implied Subclassification would be redundant, because the Subclassification implied by the `checkStructureSpecialization` constraint will also automatically satisfy the `checkClassSpecialization` and `checkClassifierSpecialization` constraints.

Therefore, in order to avoid redundant Relationships, a tool should observe the following rules when selecting which Specializations to actually include for a certain specific Type, out of the set of those implied by all specialization constraints applicable to the Type:

1. If there is any ownedSpecialization or other implied Specialization whose general Type is a direct or indirect subtype of (but not the same as) the general Type of an implied Specialization, or if there is an ownedSpecialization with the same general Type, then that implied Specialization should not be included.

2. If there are two implied Specializations with the same general Type, then only one should be included.

Note that the above rules do not apply to Redefinitions implied by redefinition constraints, because Redefinition relationships have semantics beyond just basic Specialization.
8.4.3 Core Semantics

8.4.3.1 Core Semantics Overview

8.4.3.1.1 Core Semantic Constraints

The Core semantics are primarily specified mathematically, but the Core metaclasses Type, Classifier, and Feature also have certain semantic constraints (see 8.4.2). Subclause 8.4.3.1.2 describes the general mathematical framework for Core semantics, with specific rules for Types, Classifiers and Features given in 8.4.3.3, 8.4.3.4, and 8.4.3.4, respectively. The following summarizes the corresponding semantic constraints.

The checkTypeSpecialization and checkFeatureSpecialization constraints are actually already implied by the mathematical semantics for Types and Features, but they are included in the abstract syntax so that they can also be reflected syntactically in models by the implied Relationships shown in Table 8. In addition, Table 9 lists the implied Relationships for semantic constraints on the Core metaclass Feature that actually support the semantics of various Kernel-layer constructs, as further described in the Kernel Semantics (8.4.4) subclauses referenced in the table entries for those constraints. In all cases, the source and owningRelatedElement of the Relationship is the Element being constrained, with the target being as given in the last column of the table.

Table 8. Core Semantics Implied Relationships

<table>
<thead>
<tr>
<th>Semantic Constraint</th>
<th>Implied Relationship</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>checkTypeSpecialization</td>
<td>Subclassification</td>
<td>Base::Anything (see 9.2.2.2.1)</td>
</tr>
<tr>
<td>checkFeatureSpecialization</td>
<td>Subsetting</td>
<td>Base::things (see 9.2.2.2.7)</td>
</tr>
</tbody>
</table>

Notes

1. The checkTypeSpecialization constraint applies to all Types, but the Subclassification Relationship is only implied for Classifiers (see 8.4.3.3).
2. Satisfaction of the checkFeatureSpecialization constraint implies satisfaction of the checkTypeSpecialization constraint (see 8.4.3.4).

Table 9. Core Semantics Implied Relationships Supporting Kernel Semantics

<table>
<thead>
<tr>
<th>Semantic Constraint</th>
<th>Implied Relationship</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>checkFeatureDataValue Specialization</td>
<td>Subsetting</td>
<td>Base::dataValues (see 9.2.2.2.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supports Data Types Semantics (see 8.4.4.2)</td>
</tr>
<tr>
<td>checkFeatureOccurrence Specialization</td>
<td>Subsetting</td>
<td>Occurrences::occurrences (see 9.2.4.2.14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supports Classes Semantics (see 8.4.4.3)</td>
</tr>
<tr>
<td>checkFeatureSuboccurrence Specialization</td>
<td></td>
<td>Occurrences::Occurrence::suboccurrences (see 9.2.4.2.13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supports Classes Semantics (see 8.4.4.3)</td>
</tr>
<tr>
<td>checkFeatureObject Specialization</td>
<td>Subsetting</td>
<td>Objects::objects (see 9.2.5.2.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supports Structures Semantics (see 8.4.4.4)</td>
</tr>
<tr>
<td>Semantic Constraint</td>
<td>Implied Relationship</td>
<td>Target</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------</td>
<td>--------</td>
</tr>
<tr>
<td>checkFeatureSubobjectSpecialization</td>
<td>Subsetting</td>
<td>Objects::Object::subobjects (see 9.2.5.2.7) Supports Structures Semantics (see 8.4.4.4)</td>
</tr>
<tr>
<td>checkFeatureEndSpecialization</td>
<td>Subsetting</td>
<td>Links::Link::participant (see 9.2.3.2.3) Supports Associations Semantics (see 8.4.4.5)</td>
</tr>
<tr>
<td>checkFeatureEndRedefinition</td>
<td>Redefinition</td>
<td>endFeatures of supertypes of the owning Type of the Feature Supports Associations and Connectors Semantics (see 8.4.4.5 and 8.4.4.6)</td>
</tr>
<tr>
<td>checkFeatureParameterRedefinition</td>
<td>Redefinition</td>
<td>parameters of supertypes of the owning Behavior or Step of the Feature Supports Behaviors and Steps Semantics (see 8.4.4.7)</td>
</tr>
<tr>
<td>checkFeatureResultRedefinition</td>
<td>Redefinition</td>
<td>result parameters of supertypes of the owning Function or Expression of the Feature Supports Functions and Expressions Semantics (see 8.4.4.8)</td>
</tr>
<tr>
<td>checkFeatureResultSpecialization</td>
<td>FeatureTyping</td>
<td>The referent of the owning FeatureReferenceExpression of the Feature Supports Expressions Semantics (see 8.4.4.9)</td>
</tr>
<tr>
<td>checkFeatureItemFlowFeatureRedefinition</td>
<td>Redefinition</td>
<td>Transfer::source::sourceOutput or Transfer::target::targetInput (see 9.2.7.2.9) Supports Item Flows Semantics (see 8.4.4.10)</td>
</tr>
<tr>
<td>checkFeatureValuationSpecialization</td>
<td>Subsetting</td>
<td>The result of the value Expression of an owned FeatureValue of a Feature Supports Feature Values Semantics (see 8.4.4.11)</td>
</tr>
</tbody>
</table>

Notes

1. For the `checkFeatureResultSpecialization` constraint, the implied Specialization is a FeatureTyping if the owningType of the Feature is a LiteralExpression and a Subsetting if the owningType is a FeatureReferenceExpression.
The mathematical specification of Core semantics uses a model-theoretic approach. Core mathematical semantics are expressed in first order logic notation, extended as follows:

1. A conjunction specifying that multiple variables are members of the same set can be shortened to a comma-delimited series of variables followed by a single membership symbol \((s_1, s_2 \in S)\) is short for \(s_1 \in S \land s_2 \in S\). Quantifiers can use this in variable declarations, rather than leaving it to the body of the statement before an implication \((\forall t_1, t_2 \in V_T \land t_3 \in V_T \Rightarrow \ldots)\).
2. Dots (\(\ldots\)) appearing between metaproperty names have the same meaning as in OCL, including implicit collections [OCL].
3. Sets are identified in the usual set-builder notation, which specifies members of a set between curly braces \(\{\}\). The notation is extended with "#" before an opening brace to refer to the cardinality of a set.

Element names appearing in the mathematical semantics refer to the Element itself, rather than its instances, using the same font conventions as given in 8.1.

The mathematical semantics use the following model-theoretic terms, explained in terms of this specification:

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

The above terms are mathematically defined below.

- 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 8.3.3.1).
  - \(V_C \subseteq V_T\) is a set of classifiers (model elements classified by Classifier or its specializations, see 8.3.3.2), including at least Base::Anything from KerML Semantic Model Library, see 9.2.2).
  - \(V_F \subseteq V_T\) is a set of features (model elements classified by Feature or its specializations, see 8.3.3.3), including at least Base::things from the KerML Semantic Model Library (see 9.2.2).
  - \(V_T = V_C \cup V_F\)

- An interpretation \(I = (\mathcal{A}, \Sigma, \cdot^T)\) for \(V\) is a 2-tuple where:
  - \(\mathcal{A}\) is a non-empty set (universe),
  - \(\Sigma = (P, <_P)\) is a non-empty set \(P\) with a strict partial ordering \(<_P\) (marking set), and
  - \(\cdot^T\) is an (interpretation) function relating elements of the vocabulary to sets of all non-empty tuples (sequences) of elements of the universe, with an element of the marking set in between each one for sequences of multiple elements. It has domain \(V_T\) and co-domain that is the power set of \(\mathcal{A}\), where
    \[
    S = \{ (d_1) \} \cup \{ (d_1, p_1, d_2) \} \cup \ldots \cup \{ (d_1, p_1, d_2, \ldots, p_{i+1}, d_{i+2}) \} \cup \ldots \n    \]
    such that \(i \in \mathbb{Z}^+, \ d_i \in \mathcal{A}, \ p_i \in P\)

The semantics of KerML are restrictions on the interpretation relationship, as given mathematically in this and subsequent subclauses on the Core semantics. The phrase result of interpreting a model (vocabulary) element refers to sequences paired with the element by \(\cdot^T\), also called the interpretation of the model element, for short.

The (minimal interpretation) function \(\cdot^\text{min}_T\) specializes \(\cdot^T\) to the subset of sequences that have no others in the interpretation as tails, except when applied to Anything.
Functions and predicates for sequences are introduced below. Predicates prefixed with `form:` are defined in [UML], Clause 10 (Base Semantics).

- **length** is a function version of fUML's `sequence-length`.
  \[
  \forall s, n \ n = \text{length}(s) \equiv (\text{form:sequence-length } s \ n)
  \]

- **at** is a function version of fUML's `in-position-count`.
  \[
  \forall x, s, n \ x = \text{at}(s, n) \equiv (\text{form:in-position-count } s \ n \ x)
  \]

- **head** is true if the first sequence is the same as the second for some or all of the second starting at the beginning, otherwise is false.
  \[
  \forall s_1, s_2 \ \text{head}(s_1, s_2) \Rightarrow \text{form:Sequence}(s_1) \land \text{form:Sequence}(s_2)
  \\
  \forall s_1, s_2 \ \text{head}(s_1, s_2) \equiv (\text{length}(s_1) \leq \text{length}(s_2)) \land
  \\
  (\forall i \in \mathbb{Z}^+ \ i \geq 1 \land i \leq \text{length}(s_1) \Rightarrow \text{at}(s_1, i) = \text{at}(s_2, i))
  \]

- **tail** is true if the first sequence is the same as the second for some or all of the second finishing at the end, otherwise is false.
  \[
  \forall s_1, s_2 \ \text{tail}(s_1, s_2) \Rightarrow \text{form:Sequence}(s_1) \land \text{form:Sequence}(s_2)
  \\
  \forall s_1, s_2 \ \text{tail}(s_1, s_2) \equiv (\text{length}(s_1) \leq \text{length}(s_2)) \land
  \\
  (\forall h, i \in \mathbb{Z}^+ (h = \text{length}(s_2) - \text{length}(s_1)) \land i > h \land i \leq \text{length}(s_2) \Rightarrow \text{at}(s_1, i - h) = \text{at}(s_2, i))
  \]

- **head-tail** is true if the first and second sequences are the head and tail of the third sequence, respectively, otherwise is false.
  \[
  \forall s_1, s_2 \ \text{head-tail}(s_1, s_2, s_0) \Rightarrow
  \\
  \text{form:Sequence}(s_1) \land \text{form:Sequence}(s_2) \land \text{form:Sequence}(s_0)
  \\
  \forall s_1, s_2 \ \text{head-tail}(s_1, s_2, s_0) \equiv \text{head}(s_1, s_0) \land \text{tail}(s_2, s_0)
  \]

- **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.
  \[
  \forall s_0, s_1, s_2 \ \text{concat}(s_0, s_1, s_2) \Rightarrow \text{form:Sequence}(s_0) \land \text{form:Sequence}(s_1) \land \text{form:Sequence}(s_2)
  \\
  \forall s_0, s_1, s_2 \ \text{concat}(s_0, s_1, s_2) \equiv (\text{length}(s_0) = \text{length}(s_1) + \text{length}(s_2)) \land \text{head-tail}(s_1, s_2, s_0)
  \]

- **concat-around** is true if the first sequence has the second as head, the fourth as tail, and the third element in between.
  \[
  \forall s_0, s_1, p, s_2 \ \text{concat-around}(s_0, s_1, p, s_2) \Rightarrow
  \\
  \text{form:Sequence}(s_0) \land \text{form:Sequence}(s_1) \land \text{form:Sequence}(s_2)
  \\
  \forall s_0, s_1, p, s_2 \ \text{concat-around}(s_0, s_1, p, s_2) \equiv (\text{length}(s_0) = \text{length}(s_1) + \text{length}(s_2) + 1) \land
  \\
  \text{head-tail}(s_1, s_2, s_0) \land \text{at}(p, \text{length}(s_1)+1)
  \]

- **reverse** is true if the sequences have the same elements, but in reverse order, otherwise is false.
  \[
  \forall s_1, s_2 \ \text{reverse}(s_1, s_2) \Rightarrow \text{form:Sequence}(s_1) \land \text{form:Sequence}(s_2)
  \\
  \forall s_1, s_2 \ \text{reverse}(s_1, s_2) \equiv (\text{length}(s_1) = \text{length}(s_2)) \land
  \\
  (\forall i \in \mathbb{Z}^+ \ i \geq 1 \land i \leq \text{length}(s_1) \Rightarrow \text{at}(s_1, (\text{length}(s_1) - i+1) = \text{at}(s_2, i))
  \]
8.4.3.2 Types Semantics

Abstract syntax reference: 8.3.3.1

The checkTypeSpecialization constraint requires that all Types directly or indirectly specialize Base::Anything (see 9.2.2.2.1). However, there is no implied relationship shall be inserted to satisfy this constraint for a Type that is not a Classifier or a Feature (see also 8.4.3.3 and 8.4.3.4 on Classifiers and Features, respectively).

The mathematical interpretation (see 8.4.3.2) of Types in a model shall satisfy the following rules:

1. All sequences in the interpretation of a Type are in the interpretations of the Types it specializes.
   \[ \forall t_g, t_s \in V_T \ t_g \subseteq t_s \]  

2. No sequences in the interpretation of a Type are in the interpretations of its disjoining Types.
   \[ \forall t, t_d \in V_T \ (t \cap t_d = \emptyset) \]

8.4.3.3 Classifiers Semantics

Abstract syntax reference: 8.3.3.2

The checkTypeSpecialization constraint is semantically required for Classifiers by the rules below. If necessary, it may be syntactically satisfied in a model by inserting an implied Subclassification Relationship to Base::Anything (see also Table 8).

The mathematical interpretation (see 8.4.3.2) 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.
   \[ \forall c \in V_C, s_1 \in S \ s_1 \in (c) \Rightarrow (\forall s_2 \in S \ tail(s_2, s_1) \land length(s_2) = 1) \Rightarrow s_2 \in (c) \]

2. The interpretation of the Classifier Anything includes all sequences of all elements of the universe and markings.
   \[ (\text{Anything}) = S \]

8.4.3.4 Features Semantics

Abstract syntax reference: 8.3.3.3

The checkFeatureSpecialization constraint is semantically required by the first two rules below, combined with the definition of \( T \) in 8.4.3.2. If necessary, it may be syntactically satisfied in a model by inserting an implied Subsetting Relationship to Base::things (see also Table 8). Note that satisfaction of the checkFeatureSpecialization constraint implies satisfaction of the checkTypeSpecialization constraint, because Base::things is a FeatureTyping specialization of Base::Anything.

The mathematical interpretation (see 8.4.3.2) of the Features in a model shall satisfy the following rules:

1. The interpretations of Features must have length greater than two.
   \[ \forall s \in S, f \in V_F \ s \in (f) \Rightarrow length(s) > 2 \]

2. The interpretation of the Feature things is all sequences of length greater than two.
\[(\text{things})^T = \{ s \mid s \in S \land \text{length}(s) > 2 \}\]

See other rules below.

**Features** interpreted as sequences of length three or more can be treated as if they were interpreted as ordered triples ("marked" binary relations), where the first and third elements are interpretations of the domain and co-domain of the Feature, respectively, while the second element is a marking from \(P\). The predicate **feature-pair** 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:

- \(s_0\) is the concatenation of the two sequences, in order, with an elements of \(P\) (marking) marking in between them.
- The first sequence is in the minimal interpretation of all featuringTypes of the Feature.
- The second sequence is in the minimal interpretations of all types of the Feature.

\[
\forall s_1, s_2 \in S, p \in P, f \in V_F \; \text{feature-pair}(s_1, p, s_2, f) \equiv \\
\exists s_0 \in S \; s_0 \in (f)^T \land \text{concat-around}(s_0, s_1, p, s_2) \land \\
(\forall t_1 \in V_T \; t_1 \in f_{\text{featuringType}} \Rightarrow s_1 \in (t_1)^{\text{min}T}) \land \\
(\forall t_2 \in V_T \; t_2 \in f_{\text{type}} \Rightarrow s_2 \in (t_2)^{\text{min}T})
\]

Markings for the same \(s_1\) above can be related by \(<_p\) to order \(s_2\) across multiple interpretations (values) of \(f\). Interpretations of \(f\) can have the same \(s_1\) and \(s_2\), differing only in \(p\) to distinguish duplicate \(s_2\) (values of \(f\)).

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

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

\[
\forall s_0 \in S, f \in V_F \; s_0 \in (f)^T \Rightarrow \exists s_1, s_2 \in S, p \in P \; \text{tail}(s_1, s_2) \land \\
\text{head-tail}(s_1, s_2, s_1) \land \\
\text{length}(s_1) > \text{length}(s_1) + \text{length}(s_2) \land \text{feature-pair}(s_1, p, s_2, f)
\]

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

\[
\forall f_g, f_s \in V_F \; f_g \in f_s, \text{redefinedFeature} \Rightarrow \\
(\forall s_1 \in S \; (\forall t_1 \in V_T \; t_1 \in f_s \Rightarrow s_1 \in (t_1)^{\text{min}T} ) \Rightarrow \\
(\forall s_2 \in S, p \in P \; \text{feature-pair}(s_1, p, s_2, f_s) \equiv \text{feature-pair}(s_1, p, s_2, f_g)))
\]

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

\[
\forall s_1 \in S, f \in V_F, n \in \mathbb{Z}^+ \; (\forall t_1 \in V_T \; t_1 \in f_{\text{featuringType}} \Rightarrow s_1 \in (t_1)^{\text{min}T} ) \land \\
\exists p \in P \; \text{feature-pair}(s_1, p, (n), f_{\text{multiplicity}})
\]

6. If a Feature is unique, there are no values with the same markings.

\[
\forall s_1, s_2 \in S, p_1, p_2 \in P, f \in V_F \; f_{\text{isUnique}} \Rightarrow \\
(\text{feature-pair}(s_1, p_1, s_2, f) \land \text{feature-pair}(s_1, p_2, s_2, f) \Rightarrow \neg(p_1 \equiv p_2))
\]

7. If a Feature is ordered, the markings of its values are totally ordered and mark exactly one value each.
8. Sequences in the interpretation of an inverting feature are the reverse of those in the inverted feature.

\[\forall f_1, f_2 \in V_F \; f_2 \in f_1.inv\text{ertingFeature} \Rightarrow
(\forall s_1 \in S \; s_1 \in (f_1)^T \Rightarrow (\exists s_2 \in S \; s_2 \in (f_2)^T \land \text{reverse}(s_2, s_1)))\]

9. The interpretation of a Feature with a chain is determined by the interpretations of the subchains, see additional predicates below.

\[\forall f \in V_F, \; \text{cfl} = f.chainingFeature \land \text{form:Sequence(cfl)} \land \text{length(cfl)} > 1 \Rightarrow \text{chain-feature-n(f, cfl)}\]

The interpretations of a Feature \(f\) specified as a chain of two others \((f_1 \text{ and } f_2)\) are all sequences formed from Feature pairs of the two others that share the same sequence as second and first in their pairs, respectively. If \(f\) is ordered, marking order in interpretations of \(f\) applies the order of \(f_1\) values to those of \(f_2\) found via each value of \(f_1\). If \(f\) is non-unique, duplicate values of \(f_2\) (which might be due to multiple values of \(f_1\)) are preserved in \(f\), otherwise \(f_2\) can have no duplicate values (including any due to multiple values of \(f_1\)).

A Feature \(f\) specified as a chain of two or more others \((f_l, a \text{ list of features longer than 1})\) is the last in a series of Features specified by incremental subchains \((fcl)\), starting with the first two Features in \(f_l\) (specifying the first Feature in \(fcl\)), then the first three in \(f\) (specifying the second Feature in \(fcl\)), and so on, to all the Features in \(f\) (specifying the last feature in \(fcl\), which is the original Feature \(f\)). If \(f\) is ordered, marking order in interpretations of each subchain apply to values of later subchains. If \(f\) is non-unique, duplicate values of the last Feature in \(f\) (which might be due to multiple values of the other Features) are preserved in \(f\), otherwise the last Feature in \(f\) can have no duplicates (including any due to multiple values of the other Features).
∀f, fl \ chain-feature-n(f, fl) \Rightarrow
\ f \in V_F \land fl \subseteq V_F \land \text{form:Sequence}(fl) \land \text{length}(fl) > 1

∀f, fl \ chain-feature-n(f, fl) \equiv
\exists flc \subseteq V_F \land \text{form:Sequence}(flc) \land \text{length}(flc) = \text{length}(fl) - 1 \land
\ (\forall i \in \mathbb{Z}^+ \ | i > 1 \land i \leq \text{length}(fl) \Rightarrow
\ \text{chain-feature-2}(at(flc, i-1), \ at(fl, i-1), \ at(fl, i)) \land f = \text{at}(flc, \text{length}(flc)))

8.4.4 Kernel Semantics

8.4.4.1 Kernel Semantics Overview

The semantics of constructs in the Kernel Layer are specified in terms of the foundational constructs defined in the Core layer supported by reuse of model elements from the Kernel Semantic Model Library (see 9.2). The most common way in which library model elements are used is through specialization, in order to meet subtyping constraints specified in the abstract syntax. For example, Classes are required to (directly or indirectly) subclassify Object from the Objects library model, while Features typed by Classes must subset objects. Similarly, Behaviors must subclassify Performance from the Performances library model, while Steps (Features typed by Behaviors) must subset performances. The requirement for such specialization is specified by specialization constraints in the abstract syntax, as listed in Table 10 along with the implied Specializations that may be used to satisfy them (see 8.4.2 for discussion of specialization constraints and implied Relationships).

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 to redefine the source and target ends of BinaryLink. Such patterns are specified by redefinition constraints and other kinds of semantic constraints in the abstract syntax, as listed in Table 11 along with the implied Relationships that may be used to satisfy them (see 8.4.2). In addition the Core semantic constraints listed in Table 9 actually support the semantics of Kernel layer constructs.

In all cases, all Kernel syntactic constructs can be ultimately reduced to semantically equivalent Core patterns. Various elements of the Kernel abstract syntax essentially act as "markers" for modeling patterns typing the Kernel to the Core. The following subclauses specify the semantics for each syntactic area of the Kernel Layer in terms of the semantic constraints that must be satisfied for various Kernel elements, the pattern of relationships these imply, and the model library elements that are reused to support this.

Table 10. Kernel Semantics Implied Specializations

<table>
<thead>
<tr>
<th>Semantic Constraint</th>
<th>Implied Relationship</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>checkDataTypeSpecialization</td>
<td>Subclassification</td>
<td>Base::DataValue (see 9.2.2.2)</td>
</tr>
<tr>
<td>checkClassSpecialization</td>
<td>Subclassification</td>
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Notes.

1. For all constraints other than checkMetadataFeatureSemanticSpecialization, the source of any implied Relationship is the annotated element of the constraint, with the target as given in the table.

2. The checkMetadataFeatureSemanticSpecialization constraint only applies to a MetadataFeature that has a metaclass that is a kind of SemanticMetadata (see 9.2.16.2.3). The source of the implied Relationship for this constraint is not the MetadataFeature but, rather, the Type annotated by the MetadataFeature, and a conforming tool need only insert the Relationship if the MetadataFeature is an ownedMember of the Type. The kind of Relationship that is implied and its target are determined as follows:
   - If the annotated Type and the baseType are both Classifiers, then Subclassification targeting the baseType.
   - If the annotated Type is a Feature and the baseType is a Classifier, then FeatureTyping targeting the baseType.
   - If the annotated Type and the baseType are both Features, then Subsetting targeting the baseType.
   - If the annotated Type is a Classifier and the baseType is a Feature, then Subclassifications targeting each of the types of the Feature.

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### Semantic Constraint

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### Notes

1. For redefinition and type featuring constraints, the annotated element of the constraint is the source and owningRelatedElement of the implied Relationship, with the target as given in the last column table. For binding connector constraints, the annotated element of the constraint is the owningNamespace of the implied Relationship, with the source and target of the Relationship as given in the last column of the table.

2. For the checkConnectorTypeFeaturing constraint, an implied TypeFeaturing shall only be included to satisfy the constraint if the Connector has no owningType and no ownedTypeFeaturings.

3. The checkInvocationExpressionConstructorBindingConnector constraint only applies if the invoked type is not a Behavior or a Feature typed by a Behavior.

4. The checkInvocationExpressionDefaultValueBindingConnector constraint applies to each feature of an InvocationExpression that redefines a Feature for which there is an effective default value (see 8.4.4.11).

5. For the checkFeatureChainExpressionTargetRedefinition and checkFeatureChainExpressionSourceTargetRedefinition constraints, the redefiningFeature of the implied Redefinition is a nested Feature of the first owned input parameter of the FeatureChainExpression (corresponding to the source parameter of the '.' Function).

### 8.4.4.2 Data Types Semantics

*Abstract syntax reference: 8.3.4.1*

The checkDataTypeSpecialization constraint requires that DataTypes specialize the base DataType Base::DataValue (see 9.2.2.2.2). The checkFeatureDataValueSpecialization constraint requires that Features typed by a DataType specialize the Feature Base::dataValues (see 9.2.2.2.3), which is typed by Base::DataValue.

```plaintext
datatype D specialize Base::DataValue {  
  feature a : ScalarValue::String subsets Base::dataValues;
}
```

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The Type Base::DataValue is disjoint with Occurrences::Occurrence and Links::Link, the base Types for Classes and Associations (see 8.4.4.3 and 8.4.4.5, respectively). This means that a DataType cannot specialize a Class or Association and that a Feature typed by a DataType cannot also be typed by a Class or Association.

8.4.4.3 Classes Semantics

Abstract syntax reference: 8.3.4.2

The checkClassSpecialization constraint requires that Classes specialize the base Class Occurrences::Occurrence (see 9.2.4.2.13). The checkFeatureOccurrenceSpecialization constraint requires that Features typed by a Class specialize the Feature Occurrences::occurrences (see 9.2.4.2.14), which is typed by Occurrences::Occurrence. Further, the checkFeatureSuboccurrenceSpecialization constraint requires that composite Features typed by a Class, and whose ownedType is a Class or another Feature typed by a Class, specialize the Feature Occurrences::Occurrence::suboccurrences (see 9.2.4.2.13), which subsets Occurrences::occurrences.

```plaintext
class C specializes Occurrences::Occurrence {
    feature a : C subsets Occurrences::occurrences;
    composite feature b : C subsets Occurrences::Occurrence::suboccurrences;
}
```

The Class Occurrences::Occurrence is disjoint with Base::DataValues, the base Type for DataTypes (see 8.4.4.2). This means that a Class cannot specialize a DataType and that a Feature typed by a Class cannot also be typed by a DataType. Note that Occurrences::Occurrence is not disjoint with Link::Links, because an AssociationStructure is both an Association and a Structure (which is a kind of Class), so the base AssociationStructure Objects::LinkObject specializes both Link::Links and (indirectly) Occurrences::Occurrence.

Unlike DataValues,Occurrences are modeled as occurring in three-dimensional space and persisting over time. The Occurrences library model includes an extensive set of Associations between Occurrences that model various spatial and temporal relations, such as InsideOf, OutsideOf, HappensBefore, HappensDuring, etc. In particular, the Association HappensBefore is the base Type for Successions, the basic modeling construct for time-ordering Occurrences (see 8.4.4.6 on the semantics of Successions). For further detail on the Occurrences model, see 9.2.4.1.

8.4.4.4 Structures Semantics

Abstract syntax reference: 8.3.4.3

The checkStructureSpecialization constraint requires that Structures specialize the base Structure Objects::Object (see 9.2.5.2.7). The checkFeatureObjectSpecialization constraint requires that Features typed by a Structure specialize the Feature Objects::objects (see 9.2.5.2.8), which is typed by Objects::Object. Further, the checkFeatureSubobjectSpecialization constraint requires that composite Features typed by a Structure, and whose ownedType is a Structure or another Feature typed by a Structure, specialize the Feature Objects::Object::subobjects (see 9.2.5.2.7), which subsets Object::objects.

```plaintext
struct S specializes Objects::Object {
    feature a : S subsets Object::objects;
}
```
composite feature b : S subsets Objects::Object::subobjects;
}

Objects are Occurrences representing physical or virtual structures that occur over time. For physical structures, the Objects library model also provides the specialization StructuredSpaceObject, which models Objects that can be spatially decomposed into cells of the same or lower dimension. The Type Object is disjoint with the Type Performance, another specialization of Occurrence, which is the base Type for Behaviors (see 8.4.4.7 on the semantics of Behaviors). For further detail on the Objects model, see 9.2.5.1.

8.4.4.5 Associations Semantics

Abstract Syntax Reference: 8.3.4.4

8.4.4.5.1 Associations

The checkAssociationSpecialization and checkFeatureEndSpecialization constraints require that an Association specialize the base Association Links::Link (see 9.2.3.2.3) and that its associationEnds subset Links::Link::participant. These constraints essentially require an N-ary Association to have the form (with implied relationships included):

assoc 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 Link instance for an Association is thus a tuple of participants, where each participant is a single value of an associationEnd of the Association.

As endFeatures, the associationEnds of an Association are given a special semantics compared to other Features. Even if an associationEnd has a declared multiplicity other than 1..1, the associationEnd is required to effectively have multiplicity 1..1 as a participant in the Link. 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 declared multiplicity other than 1..1, then this shall be interpreted as follows: For an Association with N associationEnds, consider the i-th associationEnd ei. The multiplicities, ordering and uniqueness constraints specified for ei apply to each set of instances of the Association that have the same (singleton) values for each of the N-1 associationEnds other than ei.

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 \( c \).

The `checkFeatureEndRedefinition` constraint requires that, if an Association has an ownedSubclassification to another Association, then its associationEnds redefine the associationEnds of the superclassifier Association. In this case, the subclassifier Association will indirectly specialize `Link` through a chain of Subclassifications, and each of its associationEnds will indirectly subset `Links::participant` through a chain of redefinitions and a subsettings.

The `checkAssociationBinarySpecialization` constraint requires that a binary Association (one with exactly two associationEnds) specialize `Links::BinaryLink`. *BinaryLink* specializes *Link* to have exactly two participants corresponding to two ends called `source` and `target`. As required by the `checkFeatureEndRedefinition` constraint, the first associationEnd of a binary Association will redefine `Links::BinaryLink::source` and its second associationEnd will redefine `Links::BinaryLink::target`.

```plaintext
assoc B specializes Links::BinaryLink {
    end feature e1 redefines Links::BinaryLink::source;
    end feature e2 redefines Links::BinaryLink::target;
}
```

### 8.4.4.5.2 Association Structures

An AssociationStructure is both an Association and a Structure and, therefore, the semantic constraints of both Associations and Structures (see 8.4.4.4) apply to AssociationStructures. The `checkAssociationStructureSpecialization` constraint requires an AssociationStructure to specialize `Objects::LinkObject` (see 9.2.5.2.5), which specializes both `Links::Link` and `Objects::Object`. The `checkAssociationStructureBinarySpecialization` constraint requires a binary AssociationStructure to specialize `Objects::BinaryLinkObject` (see 9.2.5.2.1), which specializes both `Links::BinaryLink` and an `Objects::LinkObject`.

### 8.4.4.6 Connectors Semantics

*Abstract syntax reference: 8.3.4.5*

#### 8.4.4.6.1 Connectors

A Connector can only be typed by Associations. The `checkConnectorSpecialization` constraint then requires that Connectors specialize the base Feature `Link::links` (see 9.2.3.2.4), which is typed by the base Association `Links::Link` (see 9.2.3.2.3). Further, the `checkFeatureEndRedefinition` constraint requires that the connectorEnds of a Connector redefine the associationEnds of its typing Associations. As a result, a Connector typed by an N-ary Association is essentially required to have the form (with implicit relationships included):

```plaintext
connector a : A subsets Links::links {
    end feature e1 redefines A::e1 references f1;
    end feature e2 redefines A::e2 references f2;
    ...
    end feature eN redefines A::eN references fN;
}
```

where \( e1, e2, ..., eN \) are the names of associationEnds of the Association \( A \), in the order they are defined in \( A \), and the \( f1, f2, ..., fN \) are the relatedFeatures of the Connector. Multiplicities declared for connectorEnds...
have the same special semantics as for associationEnds (see 8.4.4.5). If A is an AssociationStructure, then the checkConnectorObjectSpecialization constraint requires that the Connector subsets Objects::linkObjects (see 9.2.5.2.6) instead of Links::link.

A binary Connector is a Connector with exactly two connectorEnds, that is, a Connector typed by a binary Association. The checkConnectorBinarySpecialization constraint requires that binary Connectors specialize the base Feature Link::binaryLinks (see 9.2.3.2.2), which is typed by the Association Links::BinaryLink (see 9.2.3.2.1). 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.

    connector b : B subsets Links::binaryLinks {
        end feature source redefines B::source references f1;
        end feature target redefines B::target references f2;
    }

If B is an AssociationStructure, then the checkConnectorBinaryObjectSpecialization constraint requires that the Connector subsets Objects::binaryLinkObjects (see 9.2.5.2.2) instead of Links::binaryLinks.

A Connector therefore specifies a subset of the Links of its typing Associations for which the participants are values of the relatedFeatures of the Connector. In addition, the checkConnectorTypeFeaturing constraint requires that the featuringTypes of a Connector be consistent with those of its relatedFeatures. Typically, a Connector will have an owningType that is its featuringType, in which case all of its relatedFeatures must also be featured in the context of this Type. An implicit TypeFeaturing may be included to satisfy the checkConnectorTypeFeaturing constraint, but only if the Connector has no explicit owningType or ownedTypeFeaturings. The primary case in which an implicit TypeFeaturing is necessary is for a BindingConnector that is itself added implicitly for a FeatureValue (see 8.4.4.11).

    // This is the simplest case of a Connector satisfying checkConnectorTypeFeaturing,
    // in which the Connector and its relatedFeatures all have the same owningType.
    classifier C {
        feature f1;
        feature f2;
        connector b subsets Links::binaryLinks {
            end feature references f1 redefines Links::BinaryLink::source;
            end feature references f2 redefines Links::BinaryLink::target;
        }
    }

8.4.4.6.2 Binding Connectors

The checkBindingConnectorSpecialization constraint requires that BindingConnectors specialize the Feature Links::selfLinks (see 9.2.3.2.6), which is typed by the Association SelfLink (see 9.2.3.2.5). SelfLink has two associationEnds that subset each other, meaning they identify the same things (have the same values), which then also applies to BindingConnector connectorEnds that redefine the associationEnds of SelfLink. Since both associationEnds of SelfLink have multiplicity 1..1, both connectorEnds of a BindingConnector do also. The general semantic constraints for Connectors also apply to BindingConnectors.

Thus, a BindingConnector declaration of the form

    binding f1 = f2;

is, with implied Relationships included, semantically equivalent to
connector subsets Links::selfLinks {
    end feature thisThing redefines Links::SelfLink::thisThing references f1;
    end feature sameThing redefines Links::SelfLink::sameThing references f2;
}

8.4.4.6.3 Successions

The checkSuccessionSpecialization constraint requires that Successions specialize the Feature Occurrences::happensBeforeLinks (see 9.2.4.2.2), which is typed by the Association HappensBefore (see 9.2.4.2.1). HappensBefore (see 9.2.4.2.1) has two associationEnds, asserting that the Occurrence identified by its first associationEnd (earlierOccurrence) temporally precedes the one identified by its second (laterOccurrence), which then also applies to Succession connectorEnds that redefine the associationEnds of HappensBefore. The general semantic constraints for Connectors also apply to Successions.

This, a Succession declaration of the form

succession first f1 then f2;

is, with implied Relationships included, semantically equivalent to

connector subsets Occurrences::happensBeforeLinks {
    end feature earlierOccurrence references f1
    redefines Occurrences::HappensBefore::earlierOccurrence;
    end feature laterOccurrence references f2
    redefines Occurrences::HappensBefore::laterOccurrence;
}

8.4.4.7 Behaviors Semantics

Abstract syntax reference: 8.3.4.6

8.4.4.7.1 Behaviors

The checkBehaviorSpecialization constraint requires that Behaviors specialize Performances::Performance (see 9.2.6.2.13). In addition, the checkFeatureParameterRedefinition constraint requires that any owned parameters (i.e., directed ownedFeatures) of a Behavior redefine corresponding parameters of any other Behaviors it specializes.

behavior B specializes Performances::Performance {
    in feature x[0..*] subsets Base::things;
    out feature y[0..1] subsets Base::things;
    inout feature z subsets Base::things;
}
behavior B1 specializes B {
    in feature x1[1] redefines B::x;
    out feature y1[1] redefines B::y;
    // z is inherited without redefinition
}

8.4.4.7.2 Steps

The checkStepSpecialization constraint requires that Steps specialize Performances::performances (see 9.2.6.2.14). In addition, the checkFeatureParameterRedefinition constraint requires that any owned parameters (i.e., directed ownedFeatures) of a Step redefine corresponding parameters of any other Steps
or Behaviors it specializes. In particular, a Step explicitly typed by a Behavior will generally redefine the parameters of that Behavior.

```plaintext
step b : B subsets Performances::performances {
    in feature x redefines B::x = x1;
    out feature y redefines B::y;
    inout feature z redefines B::z := z1;
}

step b1 : B1 subsets b {
    in feature x redefines B1::x, b::x;
    out feature y redefines B2::y, b::y;
}
```

Further, the checkStepEnclosedPerformanceSpecialization and checkStepSubperformanceSpecialization constraints require that a Step whose owningType is a Behavior or another Step specialize Performances::Performance::enclosedPerformance or, if it is composite, Performances::Performance::subperformance (see 9.2.6.2.13). Finally, the checkStepOwnedPerformanceSpecialization constraint requires that a composite Step whose owningType is a Structure or a Feature typed by a Structure specialize Objects::Object::ownedPerformance (see 9.2.5.2.7).

```plaintext
step s subsets Performances::performances {
    step s1 subsets Performances::Performance::enclosedPerformance;
    composite step s2 subsets Performances::Performance::subperformance;
}
struct S specializes Objects::Object {
    composite step ss subsets Objects::Object::ownedPerformance;
}
```

8.4.4.8 Functions Semantics

Abstract syntax reference: 8.3.4.7

8.4.4.8.1 Functions and Predicates

Functions are kinds of Behaviors. The checkFunctionSpecialization constraint requires that Functions specialize the base Function Performances::Evaluation (see 9.2.6.2.3), which is a specialization of Performances::Performance. All other semantic constraints on Behaviors (see 8.4.4.7) also apply to Functions. In addition, the checkFeatureResultRedefinition constraint requires that the result parameter of a Function always redefine the result of any its supertypes that are also Functions, regardless of their parameter position.

```plaintext
function F specializes Performances::Evaluation {
    in a;
    in b;
    return result redefines Performances::Evaluation::result;
}
function G specializes F {
    in a redefines F::a;
    return result redefines F::result;
    in b redefines F::b;
}
```

Further, if a Function owns an Expression via a ResultExpressionMembership, then the checkFunctionResultBindingConnector constraint requires that the Function have, as an ownedFeature, a
BindingConnector between the result parameter of the Expression and the result parameter of the Function.

```plaintext
function H specializes Performances::Evaluation {
    return redefines Performances::Evaluation::result;
    binding result = resultExpr.result; // Implied
    resultExpr
}
```

where resultExpr is an arbitrary Expression and resultExpr.result represents a Feature chain to the Expression result.

A Predicate is a kind of Function, so all semantic constraints for Functions also apply to Predicates. In addition, the checkPredicateSpecialization constraint requires that Predicates specialize the base Predicate Performances::BooleanEvaluation (see 9.2.6.2.1), which is a specialization of Performances::Evaluation. BooleanEvaluation has a result parameter typed by Boolean, so Predicates always have a Boolean result.

```plaintext
predicate P specializes Performances::BooleanEvaluation {
    in x : ScalarValues::Real;
    return redefines Performances::BooleanEvaluation::result;
    x > 0
}
```

8.4.4.8.2 Expressions and Invariants

Expressions are kinds of Steps. The checkExpressionSpecialization constraint requires that Expressions specialize the base Expression Performances::evaluations (see 9.2.6.2.3), which is a specialization of Performances::performances. All other semantic constraints on Steps (see 8.4.4.7) also apply to Functions. In addition, the checkFeatureResultRedefinition constraint requires that the result parameter of an Expression always redefine the result of any its supertypes that are Functions or other Expressions, regardless of their parameter position.

```plaintext
expr f : F subsets Performances::evaluations {
    in a redefines F::a;
    in b redefines F::b;
    return result redefines F::result, Performances::evaluations::result;
}
expr g : G subsets f {
    return result redefines G::result, f::result;
}
```

Further, if an Expression owns another Expression via a ResultExpressionMembership, then the checkExpressionResultBindingConnector constraint requires that the Expression have, as an ownedFeature, a BindingConnector between the result parameter of the owned Expression and the result parameter of the owning Expression.

```plaintext
expr h subsets Performances::Evaluation {
    binding result = resultExpr.result; // Implied
    resultExpr
}
```

where resultExpr is an arbitrary Expression and resultExpr.result represents a Feature chain to the Expression result.
A **BooleanExpression** is a kind of **Expression**, so all semantic constraints for **Expressions** also apply to **BooleanExpressions**. In addition, the **checkBooleanExpressionSpecialization** constraint requires that **BooleanExpressions** specialize the base **BooleanExpression Performances::booleanEvaluations** (see 9.2.6.2.2), which is a specialization of **Performances::evaluations**.

```kermel
eqr p : P subsets Performances::booleanEvaluations {
  in x : ScalarValues::Integer redefines P::x;
  return redefines P::x, Performance::BooleanEvaluation::result;
}
```

An **Invariant** is a kind of **BooleanExpression**, so all semantic constraints for **BooleanExpressions** also apply to **Invariants**. In addition, the **checkInvariantSpecialization** constraint requires that **Invariants** specialize *either* the **BooleanExpression Performances::trueEvaluations** (see 9.2.6.2.2) or, if the **Invariant** is negated, the **BooleanExpression Performances::falseEvaluations** (see 9.2.6.2.2), both of which are specializations of **Performances::booleanEvaluations**. The **BooleanExpression trueEvaluations** has its result bound to **true**, while the **BooleanExpression falseEvaluations** has its result bound to **false**.

```kermel
inv true i1 subsets Performances::trueEvaluations {
  p(3)
}
inv false i2 subsets Performances::falseEvaluations {
  p(-3)
}
```

### 8.4.4.9 Expressions Semantics

*Abstract syntax reference:* [8.3.4.8](#)

#### 8.4.4.9.1 Null Expressions

The **checkNullExpressionSpecialization** constraint requires that **NullExpressions** specialize the **Expression Performances::nullEvaluations** (see 9.2.6.2.12), which is typed by the **Function Performances::NullEvaluation** (see 9.2.6.2.11). The result parameter of **NullEvaluation** has multiplicity 0..0, which means that a **NullExpression** always produces an empty result. The general semantic constraints for **Expressions** (see 8.4.4.8) also apply to **NullExpressions**.

#### 8.4.4.9.2 Literal Expressions

The **checkLiteralExpressionSpecialization** constraint requires that **LiteralExpressions** specialize the **Expression Performances::literalEvaluations** (see 9.2.6.2.8), which is typed by the **Function Performances::LiteralEvaluation** (see 8.3.4.8.7). The result parameter of **LiteralEvaluation** has multiplicity 1..1 and is typed by **Base::DataValue** (see 9.2.2.2.2). This means that a **LiteralExpression** always produces a single **DataValue** as its result. What value is actually produced depends on the kind of **LiteralExpression**. The general semantic constraints for **Expressions** (see 8.4.4.8) also apply to **LiteralExpressions**.

With the exception of **LiteralInfinity**, each kind of **LiteralExpression** has a value property typed by a UML primitive type [UML, MOF]. The result produced by such a **LiteralExpression** is given by this value. **LiteralInfinity** does not have a value property, because its result is always "infinity" (written * the KerML textual notation; see 8.2.5.8.4), which is a number from the **DataType ScalarValues::Positive** that is greater than all the integers. The **checkFeatureResultSpecialization** requires that the result parameter of a **LiteralExpression** have the corresponding **DataType** from the KerML **ScalarValues** library (see 9.3.2), e.g., **Positive** for **LiteralInfinity**, **String** for **LiteralString**, etc.
Note. In the abstract syntax, the value property of LiteralRational has type Real (see 8.3.4.8.10), because that is the available UML/MOF primitive type. However, only the rational-number subset of the real numbers can be represented using a finite literal. So the result of a LiteralRational is actually always classified in the KerML DataType Rational.

8.4.4.9.3 Feature Reference Expressions

There is no specific specialization requirement for a FeatureReferenceExpression. However, the general checkExpressionSpecialization constraint (see 8.4.4.8) requires that a FeatureReferenceExpression specialize Performances::Evaluation (see 9.2.6.2.3). All other general semantic constraints for Expressions (see 8.4.4.8) also apply to FeatureReferenceExpressions.

A FeatureReferenceExpression is parsed with a non-owning Membership relationship to its referent Feature (see 8.2.5.8.3). The checkFeatureReferenceExpressionBindingConnector constraint then requires that there be a BindingConnector between this member Feature and the result parameter of the FeatureReferenceExpression. The checkFeatureResultSpecialization constraint further requires that the result parameter also subset the Feature. While this subsetting is technically implied by the semantics of the BindingConnector (see 8.4.4.6), including the Subsetting relationship allows for simpler static type checking of the result of the FeatureReferenceExpression.

Given the above, a FeatureReferenceExpression whose referent is a Feature f is semantically equivalent to the Expression

```expression
expr subsets Performances::evaluations {
    alias for f;
    return result
    redefines Performances::Evaluation::result
    subsets f;
    member binding result = f;
}
```

A body Expression (see 8.2.5.8.3) is parsed as a FeatureReferenceExpression that contains the Expression body as its owned referent. That is, a body Expression of the form

```expression
{ body }
```

is semantically equivalent to

```expression
expr subsets Performances::evaluations {
    expr e subsets Performances::evaluation { body }
    return result
    redefines Performances::Evaluation::result
    subsets e;
    binding result = e;
}
```

This means that the result of the Expression is the Evaluation of the body Expression itself, rather than the result of actually evaluating the body. If and when this Evaluation actually occurs can then be further constrained, e.g., within an invoked Function for which the body Expression is an argument (as done, for example, by ControlFunctions – see below).

8.4.4.9.4 Invocation Expressions

An InvocationExpression of the form $F(e_1, e_2, \ldots)$, where $F$ is the name of a Function and $e_1, e_2, \ldots$ are argument Expressions, is parsed with a FeatureTyping relationship to $F$ and input parameters that have
FeatureValue relationships to the arguments (see 8.2.5.8.3). There is no specific specialization requirement for an InvocationExpression. However, the general semantic constraints for Expressions (see 8.4.4.8) also apply to InvocationExpressions. Thus, an InvocationExpression of this form is semantically equivalent to

```plaintext
expr : F subsets Performances::evaluations {
    in a redefines F::a = e1;
    in b redefines F::b = e2;
    ...
    return result redefines F::result;
}
```

If the named-argument notation $F(a = e_1, b = e_2, ...)$ is used, then the InvocationExpression parameters redefine the named parameters of $F$, regardless of order.

The semantic constraints for FeatureValues then require that each parameter is bound to the result of the corresponding expression (i.e., $a$ is bound to $e_1.result$, etc.). Thus, an InvocationExpression represents an Evaluation of the Function $F$ with inputs corresponding to the results of evaluating the argument Expressions, producing result values in its result output parameter.

An InvocationExpression may also have the form $T(e_1, e_2, ...)$, where the invoked Type $T$ is not a Function. If $T$ is a Behavior other than a Function, then the InvocationExpression performs the Behavior, but has a null (empty) result value. If $T$ is a Type that is not a Behavior, then the InvocationExpression acts as a constructor for an instance of the Type $T$. In this case the checkInvocationExpressionBindingConnector constraint requires that the InvocationExpression have an owned BindingConnector between itself and its result parameter (inherited from Performances::evaluations) – that is, the InvocationExpression evaluates, as an Expression, to itself, as an instance of $T$. Any argument Expressions are bound to features of the type $T$ in the same way as describe above for parameters, with undirected Features treated as implicit inputs.

```plaintext
expr e : T subsets Performances::evaluations {
    in a redefines T::a = e1;
    b redefines T::b = e2;
    ...
    return result : T redefines Performances::evaluation::result;
    binding result = e;
}
```

Note that, in this case, the derived function of the InvocationExpression will always be the Performances::Evaluation, the type of Performances::evaluations.

If the invoked Type $T$ names a Feature, or is a Feature chain, the semantics are similar, except that the InvocationExpression has a Subsetting relationship with $T$, instead of a FeatureTyping relationship. If the Feature is typed by a Function, then the InvocationExpression is effectively treated as an invocation of that Function. If the Feature is not typed by a Function, but is typed by a Behavior, then the InvocationExpression is treated as an invocation of that Behavior with a null result. Otherwise, the InvocationExpression is treated as a construction of an instance of the non-Behavior type(s) of the the Feature.

See also 8.4.4.11 on the semantic requirements for binding default FeatureValues in InvocationExpressions.

### 8.4.4.9.5 Operator Expressions

An OperatorExpression is an InvocationExpression in which the invoked Function is identified by an operator symbol. The checkOperatorExpressionSpecialization constraint requires that this Function be
the resolution of the operator symbol as a name in one of the library Packages BaseFunctions, DataFunctions or ControlFunctions. The general semantic constraints for Expressions (see 8.4.4) also apply to OperatorExpressions.

With the exception of operators for ControlFunctions (see below), the concrete syntax for OperatorExpressions (see 8.2.5.8.1) is thus essentially just a special surface syntax for InvocationExpressions of the standard library Functions identified by their operator symbols. For example, a unary OperatorExpression such as

```
not expr
```

is equivalent to the InvocationExpression

```
DataFunctions::'not' (expr)
```

and a binary OperatorExpression such as

```
expr_1 + expr_2
```

is equivalent to the InvocationExpression

```
DataFunctions::'+' (expr_1, expr_2)
```

where these InvocationExpressions are then semantically interpreted as described 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.

Functions in the library models BaseFunctions and ScalarFunctions are extensively specialized in other library models to constrain their parameter types (e.g., the Package RealFunctions constrains parameter types to be Real, etc.). The result values the evaluation of such a Function shall be determined by the most specialized of its subtypes that is consistent with the types of its the dynamics result values from evaluating its argument Expressions.

Control Functions

Certain OperatorExpressions denote invocations of Functions in the ControlFunctions library model (see 9.4.17) that have one or more parameters that are Expressions. In the concrete syntax for such OperatorExpressions (see 8.2.5.8.1), the arguments corresponding to these parameters are parsed as if they were body Expressions (as described in 8.4.4.9.3), so they can effectively be passed without being immediately evaluated.

The second and third arguments of the ternary conditional test operator if are for Expression parameters. Therefore, the notation for a conditional test OperatorExpression of the form

```
if expr_1 ? expr_2 else expr_3
```

is parsed as

```
ControlFunctions::'if' (expr_1, { expr_2 }, { expr_3 })
```

The second arguments of the binary conditional logical operators and, or, and implies are for Expression parameters. Therefore, the notation for a conditional logical OperatorExpression of the form
expr_1 and expr_2

is parsed as

ControlFunctions::'and' (expr_1, [ expr_2 ])

and similarly for or and implies.

A FeatureChainExpression is an OperatorExpression whose operator corresponds to the Function ControlFunctions::'.'. This Function has a single parameter called source, but this parameter has a nested Feature called target. A FeatureChainExpression is parsed with an argument Expression for the source parameter and, additionally, a non-parameter Membership for its targetFeature, which is an alias Membership if the targetFeature is not a chain and an OwningMembership if the targetFeature is a chain. The checkFeatureChainExpressionTargetRedefinition constraint requires that the source parameter of the FeatureChainExpression have a nested Feature that redefines ControlFunctions::'.':source::target, and the checkFeatureChainExpressionSourceTargetRedefinition requires that this nested Feature also redefine the targetFeature.

Given the above, a FeatureChainExpression of the form

src.f

(where src is an Expression) semantically equivalent to the Expression

expr : ControlFunctions::'.': subsets Performances::evaluations {
  feature redefines ControlFunctions::'.':source = src {
  feature redefines ControlFunctions::'.':source::target
    redefines f;
  }
  alias for f;
}

A FeatureChainExpression whose targetFeature is a Feature chain, of the form

src.f.g.h

is semantically equivalent to the Expression

expr : ControlFunctions::'.': subsets Performances::evaluations {
  feature redefines ControlFunctions::'.':source = src {
  feature redefines ControlFunctions::'.':source::target
    redefines tgt;
  }
  feature tgt chains f.g.h;
}

The performance of the Function '.' then results in the effective chaining of the value of its source parameter (which will be the result of the argument Expression of the FeatureChainExpression) and the source::target Feature (which will be the targetFeature of the FeatureChainExpression).

8.4.4.9.6 Metadata Access Expressions

The checkMetadataAccessExpressionSpecialization constraint requires that a MetadataAccessExpression specialize the Expression Performances::metadataAccessEvaluations (see 9.2.6.2.10), which is typed by the Function Performances::MetadataAccessEvaluation (see 9.2.6.2.9).
The result parameter of MetadataAccessEvaluation is ordered and typed by Metaobjects::Metaobject (see 9.2.16.2.1). The general semantic constraints for Expressions (see 8.4.4.9) also apply to MetadataAccessExpressions.

A MetadataAccessExpression evaluates to an ordered set of Metaobjects, which are determined as follows:

- A Metaobject representing each MetadataFeature (see 8.3.4.12.3) owned by the referencedElement of the MetadataAccessExpression that has the referenceElement as an annotatedElement, in the order that the MetadataFeatures appear in the model. Each of these Metaobjects is an instance of the metaclass of the corresponding MetadataFeature, with the features of each instance having values determined by evaluating the bound Expressions of the features in the MetadataFeature as model-level evaluable Expressions (see below).
- Followed by a Metaobject that is an instance of the Metaclass from the reflective KerML abstract syntax library model (see 9.2.17) corresponding to the MOF metaclass of the referencedElement of the MetadataAccessExpression, with features having values corresponding to the values of the MOF properties for the referencedElement.

Note that every Metaclass is required to specialize Metaobjects::Metaobject, so the typing of the results of a MetadataAccessExpression is consistent.

For example, the MetadataAccessExpression C.metadata for the following referencedElement:

```cpp
class C {
    metadata M;
}
```

would evaluate to two Metaobjects: an instance of the Metaclass M representing the MetadataFeature annotation on C and an instance of KerML::Class representing the referencedElement C itself.

8.4.4.9.7 Model-Level Evaluable Expressions

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. A model-level evaluable Expression is evaluated on a given target Element (see 8.4.4.13 and 8.4.4.14 for the targets used in the case of metadata values and filterConditions, respectively), using the Expression::evaluate operation, resulting in an ordered list of Elements. The rules for this operation are specified in the abstract syntax (see 8.3.4.8) and are summarized below:

1. A NullExpression evaluates to the empty list.
2. A LiteralExpression evaluates to itself.
3. A FeatureReferenceExpression is evaluated by first determining a value Expression for the referent:
   - If the target Element is a Type that has a feature that is the referent or (directly or indirectly) redefines it, then use the value Expression of the FeatureValue for that feature (if any).
   - Else, if the referent has no featuringTypes, then use the value Expression of the FeatureValue for the referent (if any).

   Then:
   - If such a value Expression exists, the FeatureReferenceExpression evaluates to the result of evaluating that Expression on the target.
   - Else, if the referent is not an Expression, the FeatureReferenceExpression evaluates to the referent.
   - Else, the FeatureReferenceExpression evaluates to the empty list.
4. A **MetadataAccessExpression** evaluates to the `ownedElements` of the `referencedFeature` that are `MetadataFeatures` and have the `referencedElement` as an `annotatedElement`, plus a `MetadataFeature` whose `annotatedElement` is the `referencedElement`, whose metaclass is the reflective Metaclass in the *KerML* library model (see 9.2.17) corresponding to the MOF class of the `referencedElement`, and whose `ownedFeatures` are bound to the values of the MOF properties of the `referencedElement`.

5. An **InvocationExpression** evaluates to an application of its `function` to argument values corresponding to 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 that is not an `Expression`. 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.

### 8.4.4.10 Interactions Semantics

*Abstract syntax reference:* 8.3.4.9

#### 8.4.4.10.1 Interactions

An Interaction is both an Association and a Behavior, and, therefore, the semantic constraints for both Associations (see 8.4.4.5) and Behaviors (see 8.4.4.7) apply. In particular, the `checkAssociationSpecialization` constraint requires that an Interaction specialize `Links::Link` (see 9.2.3.2.3), or, if it is a binary Interaction (with exactly two end Features), the `checkAssociationBinarySpecialization` constraint requires that it specializes `Links::BinaryLink` (see 9.2.3.2.1). And the `checkBehaviorSpecialization` constraint requires that it also specialize `Performances::Performance` (see 9.2.6.2.13).

These constraints require an N-ary Interaction to have the form (with implied relationships included)

```plaintext
interaction I specializes Link::Link, Performances::Performance {
  end feature e1 subsets Links::Link::participant;
  end feature e2 subsets Links::Link::participant;
  ...
  end feature eN subsets Links::Link::participant;
}
```

with a binary Interaction having the form

```plaintext
interaction B specializes Links::BinaryLink, Performances::Performance {
  end feature e1 redefines Links::BinaryLink::source;
  end feature e2 redefines Links::BinaryLink::target;
}
```

The `checkFeatureEndRedefinition` and `checkFeatureParameterRefinition` constraints also apply to Interactions.

```plaintext
interaction I1 specializes Links::BinaryLink, Performances::Performance {
  in feature x1;
  out feature y1;
  end feature e1;
  end feature f1;
```
interaction I2 specializes I1 {
    in feature x2 redefines x1;
    out feature y2 redefines y1;
    end feature e2 redefines e1;
    end feature f2 redefines f1;
}

8.4.4.10.2 Item Flows

An ItemFlow is both a Connector and a Step and, therefore, the semantic constraints for both Connectors (see 8.4.4.6) and Steps (see 8.4.4.7) also apply to ItemFlows. In addition, the checkItemFlowSpecialization constraint requires that ItemFlows specialize Transfers::transfers (see 9.2.7.2.11). In addition, if the ItemFlow has itemFlowEnds (see below), then it must specialize Transfers::flowTransfers (see 9.2.7.2.4).

The textual notation for an ItemFlow, of the form

    flow of i : T from f1.f1_out to f2.f2_in;

is parsed with i : T as an ItemFeature and having two ItemFlowEnds, one referencing f1 with an owned Feature redefining f1_out and one referencing f2 with an owned Feature redefining f2_in (see 8.2.5.9.2). An ItemFlowFeature is just a Feature owned by an ItemFlow that has the special semantic constraint checkItemFeatureRedefinition that requires that an ItemFeature redefine Transfers::Transfer::item (see 9.2.7.2.9). An ItemFlowEnd is an end Feature owned by an ItemFlow that is required to have a single ownedFeature. The general checkFeatureEndRedefinition constraint (see 8.4.4.6) requires that the two ItemFlowEnds of an ItemFlow redefine Transfers::Transfer::source and Transfers::Transfer::target (see 9.2.7.2.9), respectively. The checkFeatureItemFlowFeatureRedefinition constraint then requires that the ownedFeatures of the ItemFlowEnds redefine Transfers::source::sourceOutput or Transfer::target::targetInput.

    flow subsets Transfers::flowTransfers {
        // ItemFeature
        feature i : T redefines Transfers::Transfer::item;

        // First ItemFlowEnd
        end feature redefines Transfers::Transfer::source references f1 {
            feature redefines Transfers::Transfer::source::sourceOutput, f1_out;
        }

        // Second ItemFlowEnd
        end feature references f2 redefines Transfers::Transfer::target {
            feature redefines Transfers::Transfer::target::targetInput, f2_in;
        }
    }

A SuccessionItemFlow is semantically the same, except that the checkSuccessionItemFlowSpecialization constraint requires that it specialize Transfers::flowTransfersBefore (see 9.2.7.2.3).

8.4.4.11 Feature Values Semantics

Abstract syntax reference: 8.3.4.10

A FeatureValue is a kind of OwningMembership between a Feature and an Expression. Note that the FeatureValue relationship is not a Featuring relationship, so its featureWithValue (that is, its owning
Feature) is not the featuringType of the the value Expression. Instead, the 
checkExpressionFeaturingType constraint requires that the value Expression have the same 
featuringTypes as the featureWithValue. Most commonly, if the featureWithValue is an ownedFeature 
of a Type, this means that the Expression will have that Type as its featuringType.

The checkFeatureValuationSpecialization constraint requires that, if the featureWithValue has no 
explicit ownedSpecializations and is not directed, then it subsets the result parameter of the value 
Expression. This reflects the semantics that the values of the featureWithValue is determined by the value 
Expression, giving the featureWithValue an implied typing that is useful for static type checking. On the other 
hand, if the featureWithValue has ownedSpecializations or is directed, then its static typing can be 
considered determined by its declaration excluding the FeatureValue (but including any implied 
Specializations), which should then be validated against the typing of the result of the value Expression.

If the FeatureValue has isDefault = false, the checkFeatureValueBindingConnector constraint 
requires that its featureWithValue have an ownedMember that is a BindingConnector between that Feature 
and the result parameter of the value Expression of the FeatureValue. In addition, if the FeatureValue has 
isInitial = false, then the featuringTypes of this BindingConnector must be the same as those of 
the featureWithValue. Most commonly, if the featureWithValue is an ownedFeature of a Type, then the 
BindingConnector will have that Type as its featuringType. Other general semantic constraints for 
Connectors (see 8.4.4.6) also apply to the BindingConnector required for a FeatureValue.

Given the above, the textual notation for a FeatureValue with isDefault = false and isInitial = false, 
of the form

```plaintext
type T { 
    feature f = expr; 
}
```

is semantically equivalent to

```plaintext
type T { 
    feature f { 
        member expr e featured by T { ... } 
        member binding f = e.result featured by T; 
    } 
}
```

where e is the semantic interpretation of expr as described in 8.4.4.9.

If a FeatureValue has isDefault = false but isInitial = true, then the 
checkFeatureValueBindingConnector constraint requires different featuringTypes for the 
BindingConnector than when isInitial = false. In this case, the BindingConnector must be featured by the 
startShot (see 9.2.4.2.13) of the that reference of its owning featureWithValue (see 9.2.2.2.7). Note that 
this is only possible if the featureWithValue is featured by a Class (see also 8.4.4.3 on the semantics of 
Classes). Most commonly, if the featureWithValue is an ownedFeature of a Class or a Feature typed by a 
Class, then the BindingConnector will have the startShot of that Class as its featuringType, meaning 
that the binding only applies initially, that is, at the very start of an Occurrence that is an instance of the Class.

Thus, the textual notation for a FeatureValue with isDefault = false and isInitial = true, of the form

```plaintext
class C { 
    feature f := expr; 
}
```

is semantically equivalent to

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class C {
  feature f {
    member expr e featured by C { ... }
    member binding f = e.result featured by that.startShot;
  }
}

(note that the that is considered to be implicitly typed by Occurrence in this case).

If a FeatureValue has isDefault = true, then no BindingConnector is required for the featureWithValue at its point of declaration. Instead, the checkInvocationExpressionDefaultValueBindingConnector constraint requires that an InvocationExpression own a BindingConnector between the featureWithValue and value Expression of any FeatureValue that is the effective default value for a Feature of the invoked Type of the InvocationExpression, where effective default value is defined as follows:

• If the Feature has an owned FeatureValue with isDefault = true, then this is its effective default value.
• If the Feature does not have an owned FeatureValue, but the set of effective default values of the Features it redefines has a single unique member, then this is the effective default value of the original Feature.
• Otherwise the Feature does not have an effective default value.

For example, given the Type declaration

type T {
  feature f default = e;
}

a binding for f is included for the invocation T(), which is then semantically equivalent to

expr : T {
  binding f = f::e.result;
}

where f::e.result is the result of the value Expression from the default FeatureValue. On the other hand, for the invocation T(f = 1), the Feature f will be bound to 1 rather than the FeatureValue default. A similar construction applies for FeatureValues with isDefault = true and isInitial = true. (See also 8.4.4.9 on the general semantics of InvocationExpressions.)

8.4.4.12 Multiplicities Semantics

Abstract syntax reference: 8.3.4.11

8.4.4.12.1 Multiplicities

A Multiplicity is a kind of Feature, so the general semantics of Features (see 8.4.3.4) also apply to a Multiplicity. In addition, the checkMultiplicitySpecialization constraint requires that a Multiplicity specialize the Feature Base::naturals (see 9.2.2.2.5), which is typed by the DataType ScalarValues::Natural (see 9.3.2.2.4). This constraint effectively requires that the co-domain of a Multiplicity be a subset of the natural numbers, which can be specified by reference to a library Multiplicity (such as Base::exactlyOne or Base::oneToMany) or using a MultiplicityRange from the Kernel layer (see 8.4.4.12.2).
The `validateTypeOwnedMultiplicity` constraint requires that a `Type` have at most one `ownedMember` that is a `Multiplicity`. If a `Type` has such an owned `Multiplicity`, then it is the `typeWithMultiplicity` of that `Multiplicity`. The value of the `Multiplicity` is then the `cardinality` of its `typeWithMultiplicity` and, therefore, the type (co-domain) of the `Multiplicity` restricts that cardinality. The cardinality of a `Type` is defined generally as follows:

- For a `Classifier`, the cardinality is the number of basic instances of the `Classifier`, that is, those instances that represent the things classified by the `Classifier` and are not instances of any subtype of the `Classifier` that is a `Feature`.
- For a `Feature`, the cardinality is the number of values of the `Feature` for any specific featuring instance (where duplicate features are included in the count, if the `Feature` is non-unique).

However, there are special rules for the semantics of `Multiplicity` for end `Features` (see 8.4.4.5).

The `checkMultiplicityTypeFeaturing` constraint requires that a `Multiplicity` with a `Feature` as its `owningNamespace` have the same `featuringTypes` (domain) as that `Feature`, and, otherwise, have no `featuringTypes`. In particular, a `Multiplicity` is owned by a `Feature` that has an `owningType`, then the `featuringType` of the `Multiplicity` is the `owningType` of its `owning Feature`. This means that the `Multiplicity` has a value for each instance of the `featuringType` that is the cardinality of the instances of its `owning Feature` that are featured by that same instance of the `featuringType`.

```java
classifier C1 {
  feature f {
    // Implied TypeFeaturing by C2.
    // Gives the cardinality of the values of f for each
    // instance of C2 (which is constrained to be 1).
    multiplicity subsets Base::exactlyOne;
  }
}
```

If a `Type` does not have an owned `Multiplicity`, but has `ownedSpecializations`, then its cardinality is constrained by the `Multiplicities` for all of the general `Types` of those `ownedSpecializations` (i.e., its direct supertypes). In practice, this means that the effective `Multiplicity` of the `Type` is the most restrictive `Multiplicity` of its direct supertypes.

```java
classifier C2 {
  feature f {
    multiplicity subsets Base::exactlyOne;
  }
  feature g {
    multiplicity subsets Base::oneToMany;
  }
  feature h subsets f,g;
}
```

8.4.4.12.2 Multiplicity Ranges

A `MultiplicityRange` is a `Multiplicity` whose co-domain is given as an inclusive range of values of the type `Natural`. It thus constrains the cardinality of its `typeWithMultiplicity` to be within this range. A `MultiplicityRange` of the form

```
[expr_1.. expr_2]
```
represents the range of values 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`. Note that all other `Natural` values are less than the value of `*`, representing positive infinity, so the MultiplicityRange `[0..*)` is the range of all values of `Natural` (that is, no restriction on cardinality).

A MultiplicityRange having only a single expression:

```
[expr]
```

is interpreted in one of the following ways:

- If `expr` evaluates to `*`, then it is equivalent to the range `[0..*)` (i.e., the entire extent of `Natural`).
- Otherwise, it is equivalent to `[expr..expr]` (that is, the cardinality is restricted to the single value given by the result of `expr`).

Note. The KerML textual notation grammar only allows `LiteralExpressions` and `FeatureReferenceExpressions` as the bound Expressions in a MultiplicityRange (see 8.2.5.11). However, the abstract syntax allows arbitrary Expressions (see 8.3.4.11).

The `checkMultiplicityRangeExpressionTypeFeaturing` constraint requires that the bound Expressions of a MultiplicityRange have the same featuringTypes as the MultiplicityRange. The featuringTypes of a MultiplicityRange are determined by the `checkMultiplicityTypeFeaturing` constraint (8.4.4.12.1). If the MultiplicityRange has an owningNamespace that is not a Feature, then it has no featuringTypes, so its domain is implicitly `Base::Anything`, and its bound Expressions can only reference other Features in that context.

```'
package P {
    // Implicitly featured by Anything.
    feature n : ScalarValues::Natural;
    classifier C3 {
        // An ownedMember, not an ownedFeature.
        // Implicitly featured by Anything.
        // Implied Subsetting of Base::naturals.
        multiplicity [P::n];
    }
}
```

If the MultiplicityRange has an owningNamespace that is a Feature, then it is required to have featuringTypes that are the same as the owning Feature. In particular, if its owning Feature has an owningType, then the featuringType of the MultiplicityRange (and its bound Expressions) is the owningType of its owning Feature.

```'
classifier C4 {
    feature n : ScalarValues::Natural;
    feature m : Member {
        // Implied TypeFeaturing by C4.
        // Implied Subsetting of Base::naturals.
        multiplicity [1..C4::n];
    }
}
```

### 8.4.4.13 Metadata Semantics

*Abstract syntax reference:* 8.3.4.12
8.4.4.13.1 Metaclasses

The checkMetaclassSpecialization constraint requires that Metaclasses specialize the base Metaclass Metaobjects::Metaobject (see 9.2.16.2.1). A Metaclass is a kind of Structure (see 8.4.4.4), but it's instances are Metaobjects that are part of the structure of a model itself, rather than as an instance in the system represented by the model. The KerML library model is a reflective model of the MOF abstract syntax for KerML, containing one KerML Metaclass corresponding to each MOF metaclass in the abstract syntax model (see 9.2.17 for more details on the relationship between the KerML model and the abstract syntax).

8.4.4.13.2 Metadata Features

A MetadataFeature is both a Feature typed by a Metaclass and an AnnotatingElement that annotates other Elements in a model. The checkMetadataFeatureSpecialization constraint requires that MetadataFeatures specialize the Feature Metaobjects::metaobjects (see 9.2.16.2.2). At a meta-level, a MetadataFeature can be treated as if the reflective Metaclasses of its annotatedElements were its featuringTypes. In this case, the MetadataFeature defines a map from its annotatedElements, as instances of their Metaclasses, to a single instance of the metaclass of the MetadataFeature.

Further, a model-level evaluable Expression is an Expression that can be evaluated using metadata available within a model itself (see 8.4.4.9). If a model-level evaluable Expression is evaluated on such metadata according to the regular semantics of Expressions, then the result will correspond to the static evaluation of the Expression within the model. Therefore, if a MetadataFeature is instantiated as above, the binding of its features to the results of evaluating the model-level evaluable value Expressions of its FeatureValues can be interpreted according to the regular semantics of FeatureValues (see 8.4.4.11) and BindingConnectors (see 8.4.4.6).

When a value Expression is model-level evaluated (as described in 8.4.4.9), its target is the MetadataFeature that owns the featureWithValue. This means that the value Expression for a nested Feature of a MetadataFeature may reference other Features of the MetadataFeature, as well as Features with no featuringTypes or Anything as a featuringType.

8.4.4.13.3 Semantic Metadata

A semantic MetadataFeature is one that directly or indirectly specializes Metaobjects::SemanticMetadata (see 9.2.16.2.3) It is used to introduce a user-defined specialization constraint on the Type annotated by the MetadataFeature. SemanticMetadata has the Feature baseType typed by the reflective Metaclass KerML::Type (see 9.2.17) that is redefined by a semantic MetadataFeature. The target of the effective specialization constraint defined by a semantic MetadataFeature is determined by the value Expression bound to its baseType Feature using a FeatureValue (see 8.4.4.11), which is evaluated as a model-level evaluable Expression (see 8.4.4.9).

Specifically, for each semantic MetadataFeature annotating a Type, the checkMetadataFeatureSemanticSpecialization constraint requires that the annotated Type directly or indirectly specialize the Type bound to the baseType of the MetadataFeature, unless the annotated Type is a Classifier and the baseType is a Feature. For the case when the Type is a Classifier and the baseType is a Feature, the constraint requires that the annotated Classifier directly or indirectly specialize each type of the baseType Feature.

8.4.4.14 Packages Semantics

Abstract syntax reference: 8.3.4.13

Packages do not have instance-level semantics (they do not affect instances).
The filterConditions of a Package are model-level evaluable Expressions that are evaluated as described in 8.4.4.9. All filterConditions are checked against every Membership that would otherwise be imported into the Package if it had no filterConditions. 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 MetadataFeature of the memberElement of the Membership as the target Element.
9 Model Libraries

9.1 Model Libraries Overview

A *model library* is a collection of library models that can be reused across many user models. KerML includes three standard model libraries: the Semantic Library (see 9.2), the Data Type Library (see 9.3), and the Function Library (see 9.4). Each library model in these standard model libraries consists of a single root namespace with one top-level element that is a standard library package, with no subpackages. All of these library models are described for reference in subclauses of this clause.

The normative machine-readable representation for each of these model libraries is a project interchange file, formatted according to the standard for KerML model interchange given in Clause 10. Each library model is packaged as a model interchange file in the project interchange file for its corresponding model library. Regardless of whether such a library model is interchanged in textual notation, XMI or JSON format, the elementId for any Element in the library model that has a non-null qualifiedName shall be a name-based (version 5, using SHA-1) UUID (see [UUID, 14.3]), which are constructed from a name space identifier and a name determined as follows:

- For the top-level standard library package:
  - *name space identifier* shall be the NameSpace_URL UUID, as given in [UUID, D.9] (which is 6ba7b812-9dad-11d1-80b4-00c04fd430c8).
  - *name* shall be the URL constructed by prepending https://www.omg.org/KerML/ to the name of the package, converted to bytes using a UTF-8 encoding (see [ISO10646, Annex D]).
- For any element directly or indirectly contained in the top-level standard library package (for which that package will be the libraryNamespace):
  - *name space identifier* shall be the UUID of the top-level standard library package (as determined above).
  - *name* shall be the qualifiedName of the element, converted to bytes using a UTF-8 encoding (see [ISO10646, Annex D]).

The elementIds constructed as given above shall be normative across all forms of interchange of the library models and shall remain stable for future versions of the library models, though future revisions of this specification may deprecate certain existing Elements and their names, or introduce new Elements with new names and hence UUIDs that are distinct (with a high probability). However, the elementIds for library Elements for which the qualifiedName is null are not determined by this specification, and representations of the models with different elementIds for these Elements (such as may happen when parsing the textual representation of a library model) are still considered conformant to the specification.

9.2 Semantic Library

9.2.1 Semantic Library Overview

The Semantic Library is a collection of KerML models that are part of the semantics of the metamodel (see Clause 8). They are reused when constructing KerML user models (instantiating the abstract syntax), as specified by constraints and semantics of metaelements, such as Types being required to specialize Anything from the library and Behaviors specializing Performance (see 8.4). The library can be specialized for particular applications, such as systems modeling.

The Semantic Library contains a set of packages, one for each library model, as described in a subsequent subclauses. The following are the major areas covered in the Semantic Library.

1. The *Base* library model (see 9.2.2) begins the Specialization hierarchy for all KerML Types, including the most general Classifier *Anything* and the most general Feature *things*. It also
contains the most general \textit{DataType DataValue} and its corresponding \textit{Feature dataValues}. The \textit{Links} library model (see \ref{9.2.3}) specializes \textit{Base} to provide the semantics for \textit{Associations} between things.

2. The \textit{Occurrences} library model (see \ref{9.2.4}) introduces \textit{Occurrence}, the most general \textit{Class} of things that exist or happen in time and space, as well as the basic temporal \textit{Associations} between them. The \textit{Objects} library model (see \ref{9.2.5}) specializes \textit{Occurrences} to provide a model of \textit{Objects} and \textit{LinkObjects}, giving semantics to Structures and \textit{AssociationStructures}, respectively. The \textit{Performances} library model (see \ref{9.2.6}) specializes \textit{Occurrences} to provide a model of \textit{Performances} and \textit{Evaluations}, giving semantics to \textit{Behaviors} and \textit{Expressions}, respectively. Temporal associations can be used by \textit{Successions} to specify the order in which \textit{Performances} are carried out during other \textit{Performances}, or when \textit{Objects} exist in relation to each other, or combinations involving \textit{Performances} and \textit{Objects}. The \textit{Transfers} library model (see \ref{9.2.7}) models asynchronous flow of items between \textit{Occurrences}, giving semantics to \textit{Interactions} and \textit{ItemFlows}. The \textit{FeatureAccessPerformances} library model (see \ref{9.2.8}) defines specialized \textit{Performances} for access and modifying the values of \textit{features} at specific points in time.

3. The \textit{ControlPerformances}, \textit{TransitionPerformances} and \textit{StatePerformances} library models (see \ref{9.2.9}, \ref{9.2.10}, and \ref{9.2.11}) provide for coordination of multiple \textit{Performances} to carry out some task by using them as \textit{types} of \textit{Steps} in an overall containing \textit{Behavior}. KerML does not provide syntax specific to these library elements (e.g., KerML does not have any "control node" or "state machine" syntax), though it is expected that other languages built on KerML, and using these library models, can add syntax as needed by their applications.

9.2.2 Base

9.2.2.1 Base Overview

This library model begins the \textit{Specialization} hierarchy for all KerML \textit{Types} (see \ref{8.3.3.1} and \ref{8.4.3.2}), starting with the most general \textit{Classifier Anything}, the \textit{type} of the most general \textit{Feature things}, which classify everything in the modeled universe and the relations between them, respectively. Being the most general library elements for their \textit{metaclasses} means all \textit{Classifiers} and \textit{Features} in models, including in libraries, specialize them, respectively. They are specialized into the most general \textit{DataType DataValue}, the \textit{type} of \textit{dataValues}, the most general \textit{Feature} typed by \textit{DataTypes}, respectively (see \ref{8.3.4.1}). \textit{DataValues} are \textit{Anything} that can only be distinguished by how they are related to other things (via \textit{Features} and \textit{Associations}). These are further specialized into \textit{Natural} and \textit{naturals}, respectively, an extension for mathematical natural numbers (integers zero and greater) extended with a number greater than all the integers ("infinity"), but treated like one, notated as * (see \ref{9.3.2.1}). The \textit{Feature self} of \textit{Anything} relates each thing in the universe to itself only (see \textit{SelfLinks} in \ref{9.2.3.1}).

9.2.2.2 Elements

9.2.2.2.1 Anything

Element

Classifier

Description

\textit{Anything} is the most general \textit{Classifier} (M1 instance of M2 \textit{Classifier}). All other M1 \textit{Elements} (in libraries or user models) specialize it (directly or indirectly). \textit{Anything} is the \textit{type for things}, the most general \textit{Feature}. Since \textit{FeatureTyping} is a kind of \textit{Specialization}, this means that \textit{things} also specializes \textit{Anything}.

General Types
None.

**Features**

self : Anything \{subsets things\}

The source of a SelfLink of this thing to itself. *self* is thus a feature that relates everything to itself. It is also the value of the nested that feature of all other things featured by this thing.

**Constraints**

None.

**9.2.2.2.2 DataValue**

**Element**

DataType

**Description**

A *DataValue* is *Anything* that can only be distinguished by how it is related to other things (via Features). *DataValue* 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 Types**

Anything

**Features**

None.

**Constraints**

None.

**9.2.2.2.3 dataValues**

**Element**

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 Types**

DataValue

things

**Features**
None.

Constraints
None.

9.2.2.4.4 exactlyOne

Element
MultiplicityRange

Description

*exactlyOne* is a *MultiplicityRange* requiring a cardinality of exactly one.

General Types

naturals

Features
None.

Constraints
None.

9.2.2.5 naturals

Element
Feature

Description

*naturals* is a specialization of *dataValues* restricted to type *Natural*. It is the root *Feature* of all multiplicities, which map from a *Feature* to the set of *Natural* numbers representing allowable cardinalities of the *Feature*.

General Types

dataValues

Natural

Features
None.

Constraints
None.
9.2.2.6 oneToMany

Element

MultiplicityRange

Description

OneToMany is a MultiplicityRange requiring a cardinality of one or more.

General Types

naturals

Features

None.

Constraints

None.

9.2.2.7 things

Element

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.

Things has multiplicity lower bound 1 because, for any featuring instance, it includes at least that instance as the value of Anything::self.

General Types

Anything

Features

that : Anything

For each value of things, the "featuring instance" of that value. Formally, for any sequence s classified by things, the that includes a sequence whose prefix is s, followed by the second-to-last element of s. This is enforced by declaring Anything::self to be the chaining of things.that, restricting that to the single value of self for all things.

Constraints

None.
9.2.2.8 zeroOrOne

Element
MultiplicityRange

Description

zeroOrOne is a MultiplicityRange requiring a cardinality of zero or one.

General Types
naturals

Features
None.

Constraints
None.

9.2.2.9 zeroToMany

Element
MultiplicityRange

Description

zeroToMany is a MultiplicityRange requiring a cardinality of zero or more.

General Types
naturals

Features
None.

Constraints
None.

9.2.3 Links

9.2.3.1 Links Overview

This library model introduces the most general Association Link, the type of links, the most general Feature typed by Associations (see 8.3.4.4 and 8.4.4.5). The participant Feature of Link generalizes all associationEnds (directly or indirectly), identifying the things being linked by (at the "ends" of) each Link (exactly one thing per end, which might be the same things). Link is specialized into BinaryLink, the most general Association with exactly two associationEnds, source and target, which subset participant and identify the two things linked, which might be the same thing. BinaryLink is the type of binaryLinks, the most general Feature typed by binary Associations. They are specialized into SelfLink and selfLinks,
respectively, for links that have the same thing on both ends, identified by \textit{thisThing} and \textit{thatThing}, redefining \textit{source} and \textit{target}, respectively. These are used by \texttt{BindingConnectors} to specify that Features have the same values (see \ref{sect:features}). \textit{SelfLinks} are not in time or space (they are not \texttt{Occurrences}, see \ref{sect:occurrences}).

\subsection*{9.2.3.2 Elements}

\subsubsection*{9.2.3.2.1 BinaryLink}

\textbf{Element}

\textbf{Association}

\textbf{Description}

\textit{BinaryLink} is a \texttt{Link} with exactly two participant \texttt{Features} ("binary" \texttt{Association}). All other binary \texttt{Associations} (in libraries or user models) specialize it (directly or indirectly).

\textbf{General Types}

\texttt{Link}

\textbf{Features}

\texttt{participant}: Anything [2] \{redefines participant, ordered, nonunique\}

The participants of this \textit{BinaryLink}, which are restricted to be exactly two.

\texttt{source}: Anything \{subsets participant, nonunique\}

The participant that is the source of this \textit{BinaryLink}.

\texttt{target}: Anything \{subsets participant, nonunique\}

The participant that is the target of this \textit{BinaryLink}.

\texttt{toSources}: Anything [0..*]

The end \texttt{Feature} of this \textit{BinaryLink} corresponding to the \texttt{sourceParticipant}.

\texttt{toTargets}: Anything [0..*]

The end \texttt{Feature} of this \textit{BinaryLink} corresponding to the \texttt{targetParticipant}.

\textbf{Constraints}

None.

\subsubsection*{9.2.3.2.2 binaryLinks}

\textbf{Element}

\textbf{Feature}

\textbf{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 Types

links

BinaryLink

Features

None.

Constraints

None.

9.2.3.2.3 Link

Element

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::participant, exactly as many as associationEnds of the Association classifying it, each with multiplicity 1. Values of Link::participant on specialized Links must be a value of at least one of its subsetting Features.

General Types

Anything

Features

participant : Anything [2..*] {ordered, nonunique}

The participants that are associated by this Link.

Constraints

None.

9.2.3.2.4 links

Element

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 Types
things
Link

Features
None.

Constraints
None.

9.2.3.2.5 SelfLink

Element
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 Types
SelfSameLifeLink

BinaryLink

Features

sameThing : Anything {subsets thisThing, redefines source}
The source participant of this SelfLink, which must be the same as the target participant.

self2 : Anything {subsets myselfSameLife}
The target end of a SelfLink.

thisThing : Anything {subsets sameThing, redefines target}
The target participant of this SelfLink, which must be the same as the source participant.

Constraints
None.

9.2.3.2.6 selfLinks

Element
Feature
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 Types
SelfLink

binaryLinks

Features
None.

Constraints
None.

9.2.4 Occurrences
9.2.4.1 Occurrences Overview

Occurrences
This library adds a model of things existing in time and space, starting with Occurrence, the most general Class (see 8.3.4.2), which classifies Anything that takes up time and space, and occurrences, the most general Feature typed by Classes. Occurrences can take up the same or overlapping time and space when they represent different things happening or existing in it. For example, the time and space taken by a room might have air moving in it, as well as light, radio waves, and so on.

Occurrences divide into Objects and Performances (see 9.2.5.1 and 9.2.6.1, respectively), corresponding to Classes dividing into Structures and Behaviors (see 7.4.4 and 7.4.7.1, respectively). This subclause covers what is in common between Objects and Performances.

Temporal and Spatial Associations

Occurrences can be completely separated in time or space, or both, as indicated by these specialized Links:

- HappensBefore Links between Occurrences indicate they are completely separate in time, with one happening or existing completely before another. The predecessors and successors of Occurrences are those that HappenBefore them and after them (those that they HappenBefore), respectively. HappensJustBefore Links are HappensBefore Links between Occurrences where there is no possibility of other Occurrences happening or existing in the time between them. The immediatePredecessors and immediateSuccessors of Occurrences are those that HappenJustBefore them and just after them (those that they HappenJustBefore), respectively. Occurrences separated in time are not necessarily separated in space.

- OutsideOf Links between Occurrences indicate they are completely separate in space, without specifying their relative positions (such as above or to the left). The outsideOccurrences of Occurrences are those that exist OutsideOf them. JustOutsideOf Links are OutsideOf Links between Occurrences where there is no possibility of other Occurrences happening or existing in the space between at least some of their spaceBoundaries, see space boundaries below. The
justOutsideOccurrences of Occurrences are those that exist JustOutsideOf them. Occurrences separated in space are not necessarily separated in time.

Without Links between Occurrences are provided as a convenience to indicate one HappenBefore another or is OutsideOf the other or both (they do not overlap at all in space-time), with the withoutOccurrences of an Occurrence being the ones that are Without it.

Occurrences can completely overlap others in time or space, or both, as indicated by these specialized Links:

- HappensDuring Links between Occurrences indicate one happens or exists completely within the time taken by another, with the timeEnclosedOccurrences of an Occurrence being the ones that HappenDuring it. Occurrences overlapping in time do not necessarily overlap in space.

- InsideOf Links between Occurrences indicate one happens or exists completely within the space taken by another, with the spaceEnclosedOccurrences of an Occurrence being the ones that InsideOf it. Occurrences overlapping in space do not necessarily overlap in time.

Within Links between Occurrences are provided as a convenience to indicate one HappensDuring another and is InsideOf that other (one is completely overlapped by the other in space-time), with the spaceTimeEnclosedOccurrences of an Occurrence being the ones that are Within it.

Occurrences cannot be linked by both HappensBefore and HappensDuring, OutsideOf and InsideOf, or Within and Without. They also cannot HappenBefore or be OutsideOf or Without themselves, but always HappensDuring and are InsideOf and Within themselves. When an Occurrence HappensBefore another, all Occurrences that HappenDuring the earlier one (including itself) also HappenBefore those that HappenDuring the later one (including itself).

Occurrences that HappenDuring each other both ways (circularly) happen or exist at the same time, which is provided for convenience by HappensWhile, a specialization of HappensDuring, with the timeCoincidentOccurrences of an Occurrence being the ones that HappenWhile it. Occurrences that are InsideOf each other both ways occupy exactly the same space, even though they might happen or exist at separate times. Occurrences that are Within each other both ways happen at exactly the same time and occupy exactly the same space, which is provided for convenience by WithinBoth, a specialization of Within, with the spaceTimeCoincidentOccurrences of an Occurrence being the ones that are WithinBoth it.

The Links above to do not take up time or space, they are temporal and spatial relations between things that do (they are disjoint with LinkObject, see 9.2.5.1).

Other Time-Space Relations

The time and space taken by an Occurrence can be related in three ways to the time and space taken by others, identified by the Features below. An Occurrence with values for these Features takes the same time and space as

- unionOf: taken by all the other Occurrences together.
- intersectionOf: is common to all the other Occurrences.
- differencesOf: the first other Occurrence that is not taken by the rest.

The values of the above Features are Sets of Occurrences to enable the time and space of an Occurrence to be specified in multiple ways, with each set taken as a complete specification of the time and space taken by the Occurrence.
**Portions**

It is useful to consider *Occurrences* during only some of the time and space they take up, which are other *Occurrences* identified as *portions* (the most general portion Feature, see 9.2.4.2.13 and 8.3.3.3). These are the same "thing" as their larger *Occurrences*, just considered for a potentially smaller period of time and region in space.

*Occurrences* are always *portionsOf* themselves. *Occurrences* that are only *portionsOf* of themselves are *Lives* (classified by the library Class *Life*). *Lives* take up the entire time and space of a thing that happens or exists. *Occurrences* have the same *Life* as those they are *portionsOf*, identified by *portionOfLife*. This means following *portionsOf* repeatedly will always reach a single *Life*, even though some *Occurrences* along the way might be *portionsOf* of more than one other *Occurrence*.

*SelfSameLifeLinks* include *SelfLinks* (Links between each thing and itself, see 9.2.3.1), as well as *Links* between *Occurrences* that are *portionsOf* the same *Life* (have the same *portionOfLife*).

**Time and Space Slices**

Time slices are *portions* that include all the space of their larger *Occurrences* within a potentially smaller period of time of the whole *Occurrence*, identified as *timeSlices* of the *Occurrences* they are *portionsOf*. Time slices might have Feature values and *Links* to other things peculiar to their smaller period of time. *Occurrences* are always *timeSlices* of themselves. The *snap Shots* of *Occurrences* are *timeSlices* that take no time. The earliest *snap Shot* of an *Occurrence* is its *start Shot*, the latest is its *end Shot*. All the others happen during its *middle Time Slice*. *Occurrences* with a *start Shot* the same as their *end Shot* take no time, have no *middle Time Slice*, and *vice-versa*.

Space slices are *portions* that include all the space of their larger *Occurrences*, but not necessarily all their time, identified as *space Slices* of the *Occurrences* they are *portionsOf*. Space slices might have Feature values and *Links* to other things peculiar to their smaller region in space. *Occurrences* are always *space Slices* of themselves. The *space Shots* of *Occurrences* are *space Slices* that have a lower *inner Space Dimension* than the *Occurrences* they are *space Slices* of, which is the number of variables needed to identify any space point occupied by an *Occurrence*, without regard to higher dimensional spaces in which it might be embedded. For example, the *inner Space Dimension* of a *Curve* is 1 (see 9.2.5.1), because points on it can be identified by the distance from one end, even if the curve bends in two or three dimensions. A *Curve* can be a *space Shot* of a *Surface* or *Body*, which have *inner Space Dimensions* of 2 and 3, respectively. The *space Slices* of an *Occurrence* that are not *space Shots* must have the same *inner Space Dimension* as the *Occurrence*. How much an *Occurrence* bends in higher dimensions is its *outer Space Dimension* (see 9.2.5.1). For example, the *outer Space Dimension* of a planar curve is 2 or 1 (*Line*), while it is 3 for non-planar.

**Space Boundaries and Interiors**

The *space Slices* of each *Occurrence* are divided into a *space Boundary*, which is a *space Shot*, and a *space Interior*, which is a *space Shot* that is not a *space Shot* (has the same *inner Space Dimension* as the *Occurrence*). They are *Just Outside Of* each other and union (see below) to the entire *Occurrence*. Space boundaries cannot have a *space Boundary*, which means they also cannot have a *space Interior*, indicated by *is Closed* = true. For example, a ball has a sphere as its *space Boundary*, but the sphere is *Closed*.

A *space Boundary* might have *space Slices* that are also closed and have the same *inner Space Dimension* as the *space Boundary* (not among its *space Shots*). In some cases one of these *space Slices* surrounds the others, identified as the *outer*, a nested feature of *space Boundary*, and the others as the *inner* ones. This means the *outer* one can be taken as the *space Boundary* of another *Occurrence* with a *space Interior* that completely includes the *inners*. The *inner space Boundaries* can also be taken as *space Boundaries* of their own *Occurrences*, the *space Interiors* of which are identified as the *inner Space Occurrences* ("holes") of the...
Occurrence having the spaceBoundary. These two cases are covered by SurroundedBy Links between Occurrences, with the surroundedByOccurrences of an Occurrence being the ones they are SurroundedBy.

MatesWith Links are JustOutsideOf Links between Occurrences indicating that they union (see below) to an Occurrence with a spaceBoundary but no spaceInterior. This means there is no possibility of other Occurrences happening or existing in the space between them. JustOutsideOf Links additionally include those between Occurrences where only some of their spaceSlices (of their spaceBoundaries) are linked by MatesWith.

9.2.4.2 Elements

9.2.4.2.1 HappensBefore

Element

Association

Description

HappensBefore is a Without Association linking an earlierOccurrence to a laterOccurrence, indicating that the Occurrences do not overlap in time (not necessarily in space, see OutsideOf; none of their snapshots happen at the same time), and the earlierOccurrence happens first. This means no Occurrence HappensBefore itself. Every Occurrence that HappensDuring the earlierOccurrence (including itself) also HappensBefore every Occurrence that HappensDuring the laterOccurrence (including itself).

General Types

HappensLink

Without

Features

earlierOccurrence : Occurrence {subsets sourceOccurrence, redefines separateOccurrenceToo}

The participant of this HappensBefore link that happens (ends) earlier than the other participant (starts).

laterOccurrence : Occurrence {subsets targetOccurrence, redefines separateOccurrence}

The participant of this HappensBefore link that happens later than (starts after) the other participant (ends).

Constraints

None.

9.2.4.2.2 happensBeforeLinks

Element

Feature

Description
happensBeforeLinks is a specialization of binaryLinks restricted to type earlierOccurrence. 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 Types**

HappensBefore

binaryLinks

**Features**

None.

**Constraints**

None.

**9.2.4.2.3 HappensDuring**

**Element**

Association

**Description**

HappensDuring links its shorterOccurrence to its longerOccurrence, indicating that the shorterOccurrence completely overlaps the longerOccurrence in time (not necessarily in space, see InsideOf; all snapshots of the shorterOccurrence happen at the same time as some snapshot of the longerOccurrence). This means every Occurrence HappensDuring itself and that HappensDuring is transitive. Every Occurrence that HappensDuring the longerOccurrence also HappensBefore the shorterOccurrence. The shorterOccurrence also HappensBefore every Occurrence that the longerOccurrence does.

**General Types**

HappensLink

**Features**

happensDuring : Occurrence [1..*] {subsets happensTarget}

Occurrences that completely overlap this one in time (not necessarily in space, see insideOf; they start when this one does or earlier and end when this one does or later), including this one.

longerOccurrence : Occurrence {redefines targetOccurrence}

The participant in this HappensDuring Link that completely overlaps the other in time.

shorterOccurrence : Occurrence {redefines sourceOccurrence}

The participant in this HappensDuring Link that is completely overlapped by the other in time.

**Constraints**
None.

**9.2.4.2.4 HappensJustBefore**

**Element**

**Association**

**Description**

HappensJustBefore is HappensBefore asserting that there is no possibility of other Occurrences happening in the time between the earlierOccurrence and laterOccurrence.

**General Types**

HappensBefore

**Features**

- earlierOccurrence : Occurrence {redefines earlierOccurrence}
- laterOccurrence : Occurrence {redefines laterOccurrence}

**Constraints**

None.

**9.2.4.2.5 HappensLink**

**Element**

**Association**

**Description**

HappensLink is the most general Association that asserts temporal relationships between a sourceOccurrence and a targetOccurrence. They cannot happen in time (be Occurrences), making them disjoint with LinkObject.

**General Types**

BinaryLink

**Features**

- happensSource : Occurrence [0..*] {subsets toSources}
- happensTarget : Occurrence [0..*] {subsets toTargets}
- sourceOccurrence : Occurrence {redefines source}
- targetOccurrence : Occurrence {redefines target}

**Constraints**
9.2.4.2.6 HappensWhile

Element
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 and that HappensWhile is transitive.

General Types

HappensDuring

Features

thatOccurrence : Occurrence {redefines longerOccurrence}
thisOccurrence : Occurrence {redefines shorterOccurrence}
timeCoincidentOccurrences : Occurrence [1..*] {subsets happensDuring}
Occurrences that start and end at the same time as this one.

Constraints

None.

9.2.4.2.7 IncomingTransferSort

Element
Predicate

Description

A Predicate of two Transfers that is true when the first should be accepted instead of the other.

General Types

BooleanEvaluation

Features

None.

Constraints

None.
9.2.4.2.8 InnerSpaceOf

Element

Association

Description

InnerSpace is an OutsideOf asserting that the space surrounded by an inner space boundary of one occurrence (outerSpace) is completely occupied by another occurrence (innerSpace).

General Types

OutsideOf

Features

innerSpace : Occurrence {redefines separateSpace}

The participant of this InnerSpaceOf link that completely occupy the space surrounded by an inner space boundary of the other.

innerSpaceOccurrenceOf : Occurrence [0..*] {subsets outsideOfOccurrences}

outerSpace : Occurrence {redefines separateSpaceToo}

The participant of this InnerSpaceOf link with an inner space boundary is completely occupied by the other.

Constraints

None.

9.2.4.2.9 InsideOf

Element

Association

Description

InsideOf is a BinaryLink between its smallerSpace and largerSpace, indicating that the largerSpace completely overlaps the smallerSpace in space (not necessarily in time, see HappensDuring; all four dimensional points of the smallerSpace are in the spatial extent of the largerSpace). This means every Occurrence is InsideOf itself and that InsideOf is transitive.

General Types

BinaryLink

Features

insideOf : Occurrence [1..*] {subsets toTargets}

Occurrences that completely overlap this one in space (not necessarily in time, see happensDuring), including this one.
largerSpace : Occurrence {redefines target}
The participant in this InsideOf Link that completely overlaps the other in space.

smallerSpace : Occurrence {redefines source}
The participant in this InsideOf Link that is completely overlapped by the other in space.

Constraints
None.

9.2.4.2.10 JustOutsideOf

Element
Association

Description

JustInsideOf is an OutsideOf Association linking two Occurrences that have some space slices with no space between them.

General Types

OutsideOf

Features

justOutsideOfOccurrences : Occurrence [0..*] {subsets outsideOfOccurrences}
Occurrences that have no space between some of their space slices and some space slices of this occurrence.

separateSpace : Occurrence {redefines separateSpace}

separateSpaceToo : Occurrence {redefines separateSpaceToo}

Constraints
None.

9.2.4.2.11 Life

Element
Class

Description

Life is the class of Occurrences that are "maximal portions". That is, they are only portions of themselves.

General Types

Occurrence
Features

portion : Occurrence [1..*]

Occurrences that are portions of this Life, including at least this Life.

Constraints

None.

9.2.4.2.12 MatesWith

Element

Description

General Types

None.

Features

matesWith : Occurrence [0..*] {subsets justOutsideOfOccurrences}

Constraints

None.

9.2.4.2.13 Occurrence

Element

Class

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 Types

Anything

Features

difference : Occurrence [0..1]

A (nested) Feature of differencesOf identifying an Occurrence that is the intersectionsOf of the Occurrences identified by interdiff (minuend and interdiff.notSubtrahend).

differencesOf : OrderedSet [0..*]

Ordered sets of Occurrences, where the time and space taken by first Occurrence in each set (minuend) that is not in the time and space taken by the remaining Occurrences (subtrahend, resulting in difference) is the
same as taken by this Occurrence (all four dimensional points in the minuend that are not in any subtrahend are at the same time and space as those in this Occurrence).

dispatchScope : Occurrence
elements : Occurrence [0..*]

A nested Feature of unionsOf, intersectionsOf, and differencesOf for the elements of each of their (Ordered)Sets separately.

derendScope : Occurrence {subsets snapshots}
The snapshot of this Occurrence that happensAfter all its other snapshots.
immediatePredecessors : Occurrence [0..*] {subsets predecessors}

Occurrences that start just after this Occurrence ends, with no possibility of other Occurrences happening in the time between them.
immediateSuccessors : Occurrence [0..*] {subsets successors}

Occurrences that end just before this Occurrence starts, with no possibility of other Occurrences happening in the time between them.
imcomingTransfer : Transfer [0..*]
imcomingTransferSort : IncomingTransferSort [0..*]

Determines which Transfers to accept when multiple are available and which of the unaccepted Transfers are never to be accepted (dispatched), by comparing two Transfers at a time. Defaults to earlierFirstIncomingTransferSort, which is true if the first Transfer ends (arrives) before the other.
imcomingTransferToSelf : Transfer [0..*] {subsets incomingTransfer}

Transfers for which this Occurrence is the targetParticipant.
ininner : Occurrence [0..*]

A spaceSlice of spaceBoundary, see spaceBoundary.
ininnerSpaceDimension : Natural

The number of variables needed to identify space points in this Occurrence, from 0 to 3, without regard to higher dimensional spaces it might be embedded in. For example, the innerSpaceDimension of a curve is 1, even if it twists in three dimensions, see outerSpaceDimension.
ininnerSpaceOccurences : Occurrence [0..*] {subsets outsideOfOccurrences}

Occurrences that completely occupy the space surrounded by an inner space boundary of this occurrence.

interdiff : Set [0..*]

A (nested) Feature of differencesOf identifying a set that includes its minuend and all Occurrences that are not in its subtrahend.
intersection : Occurrence [0..1]

A (nested) Feature of intersectionsOf identifying an Occurrence that a) is completely Within (the space and time of) all intersectionsOf elements, and b) satisfies the conditions of the same element's nonIntersection.

intersectionsOf : Set [0..*]

Sets of Occurrences, where the time and space taken in common between the Occurrences in each set (intersectionsOf::intersection) is at the same as taken by this Occurrence (all four dimensional points common to the Occurrences in each set are at the same time and space as those in this Occurrence).

/isClosed : Boolean

True if this Occurrence has a spaceBoundary, false otherwise.

isDispatch : Boolean

Determines whether the same incoming transfer can be accepted more than once by StatePerformances composed under dispatchScope. It defaults to true for Performances, and false for other Occurrences (including Objects).

isRunToCompletion : Boolean

Determines whether TransitionPerformances composed under runToCompletionScope can happen during StatePerformance entry Performances composed under this Occurrence.

justOutsideOfOccurrences : Occurrence [0..*] {subsets outsideOfOccurrences}

Occurrences that have no space between some of their spaceSlices and some spaceSlices of this Occurrence.

localClock : Clock

A local Clock to be used as the corresponding time reference for this Occurrence and, by default, all ownedOccurrences. By default this is the singleton Clocks::universalClock.

matingOccurrences : Occurrence [0..*] {subsets justOutsideOfOccurrences}

Occurrences that have no space between them and this one.

middleTimeSlice : Occurrence [0..1] {subsets timeSlices}

timeSlice of this Occurrence that takes all of the time between its startShot and endShot. Occurrences do not have middleTimeSlice if their startShot is the same as their endShot (such as being a snapshot of another Occurrence), otherwise they do.

minuend : Occurrence [0..1] {subsets elements, ordered}

A (nested) Feature of differencesOf that identifies the first Occurrence in its elements.

nonIntersection : Occurrence [0..*] {subsets spaceTimeEnclosedPoints}
A nested Feature of \texttt{intersectionsOf.elements} identifying all the \texttt{spaceTimeEnclosedPoints} of each \texttt{element} that are not identified by \texttt{intersection}. These must be Without (separate in space or time from) at least one other \texttt{element}.

\texttt{notSubtrahend} : Occurrence [0..*]

A (nested) Feature of \texttt{differencesOf.interdiff} identifying all \texttt{Occurrences} that are not identified by the \texttt{subtrahend} in each value \texttt{differencesOf} separately.

\texttt{outer} : Occurrence [0..1]

A \texttt{spaceSlice} of \texttt{spaceBoundary}, see \texttt{spaceBoundary}.

\texttt{outerSpaceDimension} : Natural [0..1]

For \texttt{Occurrence} of \texttt{innerSpaceDimension} 1 or 2, the number of variables needed to identify their space points in higher dimensional spaces they might be embedded in, from the \texttt{innerSpaceDimension} to 3. For example, an \texttt{outerSpaceDimension} 3 for a curve indicates it twists in three dimensions. An \texttt{outerSpaceDimension} equal to \texttt{innerSpaceDimension} indicates the occurrence is spatially straight (\texttt{innerSpaceDimension} 1 embedded in 2 or 3 dimensions) or flat (\texttt{innerSpaceDimension} 2 embedded in 3 dimensions).

\texttt{outgoingTransfer} : Transfer [0..*]

\texttt{outgoingTransferFromSelf} : Transfer [0..*] \{subsets outgoingTransfer\}

\texttt{Transfers} for which this \texttt{Occurrence} is the \texttt{sourceParticipant}.

\texttt{outsideOfOccurrences} : Occurrence [0..*] \{subsets withoutOccurrences\}

\texttt{Occurrences} that are completely separate from this one in space (not necessarily in time, see \texttt{successors} and \texttt{predecessors}).

\texttt{portionOf} : Occurrence [1..*] \{subsets within\}

All \texttt{Occurrences} that this one is \texttt{Within} that are considered the same thing occurring (same \texttt{portionOfLife}), including this one.

\texttt{portionOfLife} : Life

The \texttt{Life} of which this \texttt{Occurrence} is a \texttt{portion}.

\texttt{portions} : Occurrence [1..*] \{subsets \texttt{spaceTimeEnclosedOccurrences}\}

All \texttt{Occurrences} \texttt{Within} this one that are considered the same thing occurring (same \texttt{portionOfLife}), including this one.

\texttt{predecessors} : Occurrence [0..*] \{subsets withoutOccurrences\}

\texttt{Occurrences} that are completely separate from this one in time (not necessarily in space, see \texttt{outsideOfOccurrences}) and that happen before this one (end earlier than this one starts).

\texttt{runToCompletionScope} : Occurrence

\texttt{sameLifeOccurrences} : Occurrence [1..*]
self : Occurrence {subsets timeSlices, spaceSlices, spaceTimeCoincidentOccurrences, sameLifeOccurrences, redefines self}

This Occurrence (related to itself via a SelfLink).

snapshotOf : Occurrence [0..*] {subsets timeSliceOf}

Occurrences of which this Occurrence is a snapshot.

snapshots : Occurrence [1..*] {subsets timeSlices}

All timeSlices of this Occurrence that happen at a single instant of time (zero duration).

spaceBoundary : Occurrence [0..1] {subsets spaceShots}

A spaceShot of this Occurrence that is not among those of its spaceInterior, which it must be OutsideOf. It must not have a spaceBoundary (isClosed = true). It can be divided into spaceSlices that also have no spaceBoundary, where the inner ones are SurroundedBy the outer one.

spaceEnclosedOccurrences : Occurrence [1..*] {subsets toSources}

Occurrences that this one completely overlaps in space (not necessarily in time, see timeEnclosedOccurrences), including this one.

spaceInterior : Occurrence [0..1] {subsets spaceSlices}

A spaceSlice of this Occurrence that includes all its spaceShots except the spaceBoundary, which must exist and be outsideOf it. The spaceInterior must be of the same innerSpaceDimension as this Occurrence, except if it is zero, whereupon there is no spaceInterior.

spaceShots : Occurrence [1..*] {subsets spaceSlices}

All spaceSlices of this Occurrence that are of a lower innerSpaceDimension than it.

spaceSliceOf : Occurrence [1..*] {subsets portionOf}

An Occurrence this one is a spaceSlices of.

spaceSlices : Occurrence [1..*] {subsets portions}

All portions of this Occurrence that extend for exactly the same time and some or all the space, relative to spatial location of this Occurrence. This means every Occurrence is a spaceSlice of itself.

spaceTimeCoincidentOccurrences : Occurrence [1..*] {subsets timeCoincidentOccurrences, spaceEnclosedOccurrences}

Occurrences that this one completely includes in both space and time, and vice-versa, including this one.

spaceTimeEnclosedOccurrences : Occurrence [1..*] {subsets spaceEnclosedOccurrences, timeEnclosedOccurrences}

All timeEnclosedOccurrences of this Occurrence that are also spaceEnclosedOccurrences, including itself.
spaceTimeEnclosedPoints : Occurrence [1..*] \{subsets spaceTimeEnclosedOccurrences\}

All spaceTimeEnclosedOccurrences of this Occurrence that take up no time or space (innerSpaceDimension 0 and startShot the same as endShot).

startShot : Occurrence \{subsets snapshots\}

The snapshot of this Occurrence that happensBefore all its other snapshots.

suboccurrences : Occurrence [0..*]

Composite suboccurrences of this Occurrence. The localClock of all suboccurrences defaults to the localClock of its containing Occurrence.

subtrahend : Occurrence [0..*] \{subsets elements\}

A (nested) Feature of differencesOf that identifies all the Occurrences in its elements except the first one.

successors : Occurrence [0..*] \{subsets withoutOccurrences\}

Occurrences that are completely separate from this one in time (not necessarily in space, see \texttt{outsideOfOccurrences}) and that happen after this one (start later than this one ends).

surroundedByOccurrences : Occurrence [0..*] \{subsets outsideOfOccurrences\}

Occurrences that have inner spaces that completely include this Occurrence.

this : Occurrence

The "context" Occurrence within which this Occurrence takes place. By default, it is this Occurrence itself. However, this is overridden for ownedPerformances of Objects and subperformances of Performances.

timeCoincidentOccurrences : Occurrence [1..*] \{subsets timeEnclosedOccurrences\}

Occurrences that HappenWhile this one does (Occurrences that start and end at the same time as this one).

timeEnclosedOccurrences : Occurrence [1..*] \{subsets happensSource\}

Occurrences that this one completely overlaps in time (not necessarily in space, see spaceEnclosedOccurrences; they start at the same time or later and end at the same time or earlier), including this one.

timeSliceOf : Occurrence [1..*] \{subsets portionOf\}

Occurrences of which this one is a timeSlice, including this one.

timeSlices : Occurrence [1..*] \{subsets portions\}

portions that extend for some or all the time of this Occurrence, but all its space during that time, including itself.

union : Occurrence [0..1]
A (nested) Feature of unionsOf identifying an Occurrence with a) spaceTimeEnclosedOccurrences including all those identified by a unionsOf of element, and b) all the Occurrence’s spaceTimeEnclosedPoints Within (the space and time of) at least one of the elements.

unionsOf: Set [0..*]

Sets of Occurrences, where the time and space taken by all the Occurrences in each set together (unionsOf::union) is the same as taken by this Occurrence (all four dimensional points in the Occurrences of each set are at the same time and space as those of this Occurrence).

withoutOccurrences: Occurrence [0..*] {subsets toTargets}

All Occurrences that are successors, successors, and/or OutsideOf of this one.

Constraints
None.

9.2.4.2.14 occurrences

Element
Feature

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 Types
things
Occurrence

Features
None.

Constraints
None.

9.2.4.2.15 OutsideOf

Element
Association

Description
OutsideOf is a Without Association linking its separateSpaceToo and its separateOccurrence, indicating that these Occurrences do not overlap in space (not necessarily in time, see HappensBefore; no four dimensional points of the Occurrences
are in the spatial extent of both of them). This means no Occurrence is OutsideOf itself.

**General Types**

Without

**Features**

outsideOfOccurrences : Occurrence [0..*] {subsets withoutOccurrences}

Occurrences that are completely separate from this one in space (not necessarily in time, see successors and predecessors).

separateSpace : Occurrence {redefines separateOccurrence}

The second participant in this OutsideOf Link.

separateSpaceToo : Occurrence {redefines separateOccurrenceToo}

The first participant in this OutsideOf Link.

**Constraints**

None.

9.2.4.2.16 PortionOf

**Element**

Association

**Description**

PortionOf is a Within Association that links its portionOccurrence to its portionedOccurrence, indicating they are considered the same thing occurring (same portionOfLife), but with the portionOccurrence potentially taking up less time and space than the portionedOccurrence. This means every Occurrence is a PortionOf itself. The innerSpaceDimension of portionOccurrence is the same or lower than of the portionedOccurrence.

**General Types**

Within

**Features**

portionedOccurrence : Occurrence {redefines largerOccurrence}

The participant in this PortionOf Link that is the largerOccurrence.

portionOccurrence : Occurrence {redefines smallerOccurrence}

The participant in this PortionOf Link that is the smallerOccurrence.

**Constraints**
9.2.4.2.17 SelfSameLifeLink

Element

Association

Description

SelfSameLinks are all the BinaryLinks such that the sourceParticipant and targetParticipant are either

- Occurrences (which might be lives) that are portions of the same life, or
- DataValues that are equal.

General Types

BinaryLink

Features

myselfSameLife : Anything [1..*] {redefines toSources}
The target end of a SelfLifeLink.

selfSameLife : Anything [1..*] {redefines toTargets}
The source end of a SelfLifeLink.

sourceDataValue : DataValue [0..1] {subsets source}
Same as the sourceParticipant when it is a data value.

sourceOccurrence : Occurrence [0..1] {subsets source}
Same as the sourceParticipant when it is an occurrence.

targetDataValue : DataValue [0..1] {subsets target}
Same as the targetParticipant when it is a data value.

targetOccurrence : Occurrence [0..1] {subsets target}
Same as the targetParticipant when it is an occurrence.

Constraints

None.

9.2.4.2.18 SnapshotOf

Element

Association
Description

SnapshotOf is a TimeSliceOf that links its snapshotOccurrence to its snapshottedOccurrence, indicating that snapshotOccurrence takes no time (startShot and endShot are the same).

General Types

TimeSliceOf

Features

snapshotOccurrence : Occurrence {redefines timeSliceOccurrence}
The participant in this SnapshotOf Link that is the timeSliceOccurrence.

snapshottedOccurrence : Occurrence {redefines timeSlicedOccurrence}
The participant in this SnapshotOf Link that is the timeSlicedOccurrence.

Constraints

None.

9.2.4.2.19 SpaceShotOf

Element

Association

Description

SpaceShotOf is a SpaceSliceOf that links its spaceShotOccurrence to its spaceSnapshottedOccurrence, indicating the spaceShotOccurrence is of a lower innerSpaceDimension than the spaceShottedOccurrence.

General Types

SpaceSliceOf

Features

spaceShotOccurrence : Occurrence {redefines spaceSliceOccurrence}
The participant in this SpaceShotOf Link that is the spaceSliceOccurrence.

spaceShotOf : Occurrence [1..*] {subsets spaceSliceOf}
All spaceSlicesOf this Occurrence that are of a higher innerSpaceDimension than this Occurrence.

spaceShottedOccurrence : Occurrence {redefines spaceSlicedOccurrence}
The participant in this SpaceShotOf Link that is the spaceSliced Occurrence.

Constraints
None.

9.2.4.2.20 SpaceSliceOf

Element

Association

Description

SpaceSliceOf is a PortionOf that links its spaceSliceOccurrence to its spaceSlicedOccurrence, indicating the spaceSliceOccurrence extends for exactly the same time and some or all the space of the spaceSlicedOccurrence and that the spaceSliceOccurrence is of the same of lower innerSpaceDimension than the spaceSliceOccurrence. This means every Occurrence is a SpaceSliceOf itself and SpaceSliceOf is transitive.

General Types

PortionOf

Features

spaceSlicedOccurrence : Occurrence {redefines portionedOccurrence}

The participant in this SpaceSliceOf Link that is the portionedOccurrence.

spaceSliceOccurrence : Occurrence {redefines portionOccurrence}

The participant in this SpaceSliceOf Link that is the portionOccurrence.

Constraints

None.

9.2.4.2.21 SurroundedBy

Element

Association

Description

SurroundedBy is an OutsideOf asserting that one occurrence (surroundedSpace) is included in space by an innerSpaceOccurrence of another (surroundingSpace).

General Types

OutsideOf

Features

surroundedSpace : Occurrence {redefines separateSpaceToo}

The participant of this SurroundedBy link that is completely included in the an inner space of the other.
surroundingSpace : Occurrence {redefines separateSpace}

The participant of this SurroundedBy link that has an inner space that completely includes the other.

surroundsOccurrences : Occurrence [0..*] {subsets outsideOfOccurrences}

Constraints
None.

9.2.4.2.22 TimeSliceOf

Element

Association

Description

TimeSliceOf is a PortionOf that links its timeSliceOccurrence to its timeSlicedOccurrence, indicating that extend for exactly the same time and some or all the space of this Occurrence, including itself. This means every Occurrence is a PortionOf itself.

General Types
PortionOf

Features

timeSlicedOccurrence : Occurrence {redefines portionedOccurrence}

The participant in this TimeSliceOf Link that is the portionedOccurrence.

timeSliceOccurrence : Occurrence {redefines portionOccurrence}

The participant in this TimeSliceOf Link that is the portionOccurrence.

Constraints
None.

9.2.4.2.23 Within

Element

Association

Description

Within classifies all and only links that are HappensDuring and InsideOf. They link their largerOccurrence to their smallerOccurrence, indicating the largerOccurrence completely overlaps the smallerOccurrence in time and space (all four dimensional points of the smallerOccurrence HappensDuring and InsideOf the largerOccurrence). This means every Occurrence is Within itself and Within is transitive.

General Types
HappensDuring
InsideOf

Features

largerOccurrence : Occurrence \{redefines largerSpace, longerOccurrence\}
The participant in this Within Link that is the longerOccurrence and largerSpace.

smallerOccurrence : Occurrence \{redefines shorterOccurrence, smallerSpace\}
The participant in this Within Link that is the shorterOccurrence and smallerSpace.

within : Occurrence [1..*] \{subsets insideOf, happensDuring\}
All Occurrences that this one happensDuring and is insideOf, including this one.

Constraints
None.

9.2.4.2.24 WithinBoth

Element

Association

Description

WithinBoth is a Within and its inverse. This means the linked Occurrences completely overlap each other in space and time (they occupy the same four dimensional region). This means every Occurrence is Within with itself and Within is transitive.

General Types

Within
HappensWhile

Features

spaceTimeCoincidentOccurrences : Occurrence [1..*] \{subsets timeCoincidentOccurrences, within\}
Occurrences that this one completely includes in both space and time, including this one.

thatOccurrence : Occurrence \{redefines largerOccurrence\}

thisOccurrence : Occurrence \{redefines smallerOccurrence\}

Constraints
None.
9.2.4.2.25 Without

Element

Association

Description

*Without* classifies all links that are *HappensDuring* or *InsideOf*, or both. They link their *separateOccurrenceToo* to their *separateOccurrence*, indicating that the *Occurrences* do not overlap in time and/or space (no four dimensional point is in both *Occurrences*). This means no *Occurrence* is *Without* itself.

General Types

BinaryLink

Features

*separateOccurrence* : *Occurrence* {redefines target}

The second participant in this *Without* Link.

*separateOccurrenceToo* : *Occurrence* {redefines source}

The first participant in this *Without* Link.

*withoutOccurrences* : *Occurrence* [0..*] {subsets toSources}

All *Occurrences* that are *successors, successorsoutsideOf* of this one.

Constraints

None.

9.2.5 Objects

9.2.5.1 Objects Overview

*Objects* are *Occurrences* that take up a single region of time and space, even though they might be in multiple places over time. *Object* is the most general *Structure*, while *objects* is the most general Feature typed by *Structures* (see 8.3.4.3 and compare to *Performances* in 9.2.6.1). *Objects* and *Performances* do not overlap, but *Performances* can Involve *Objects*, which can Perform *Performances*.

*LinkObjects* are *Objects* that are also *Links*, and *linkObjects* is the most general Feature typed by *LinkObject*. *LinkObjects* occupy time and space, like other *Objects*, with potentially varying relationships to other things over time, except for which things are its *participants* (the things being linked), identified by its *associationEnd* Features (the "ends" of a link are permanent, though *participants* can be *Occurrences* with changing relationships to other things). The values of *LinkObject* Features that are not *associationEnds* can change over time. *LinkObjects* can exist between the same *Occurrences* for only some of the time those *Occurrences* exist, reflecting changing relationships of those *Occurrences*. *BinaryLinkObjects* are *BinaryLinks* that are also *LinkObjects*, and *binaryLinkObjects* is the most general Feature typed by *BinaryLinkObject*.

*Body(s)*, *Surfaces*, *Curves*, and *Points* are *Objects* with *innerSpaceDimension* of 3, 2, 1, and 0, respectively.
Structured Space Objects

*StructuredSpaceObjects* are *Objects* with three Features Subsetting *spaceSlices*:

- *faces*, identifying *Surfaces*.
- *edges*, identifying *Curves*.
- *vertices*, identifying *Points*.

The above are collectively *structuredSpaceCells*, which are also *StructuredSpaceObjects*, enabling *faces* to identify *edges* and *vertices* among the *spaceSlices* of their *spaceBoundaries*, if any, and *edges* to identify *vertices* among theirs. Cells of closed *StructuredSpaceObjects* (*isClosed = true*) must be *JustOutside* others along their entire *spaceBoundary* (every cell's *spaceSlices* must *MateWith* some *spaceSlice* of another cell, see Space Boundaries and Interiors in 9.2.4.1), which usually means all the *edges* and *vertices* of cells *MateWith* those of other cells, enabling the *StructuredSpaceObject* to be the *spaceBoundary* for other *Objects*. The *innerSpaceDimension* of a *StructuredSpaceObject* is the highest *innerSpaceDimension* of its *structuredSpaceCells*.

Models can specialize the three Features above for various kinds of *Objects*, for example, one for cylinders would include:

- Three Features Subsetting *faces* for the top, bottom, and middle *Surfaces* of a cylinder. The *edges* of these Features are *Curves* (circles) that are *spaceBoundaries* of the top and bottom *Surfaces* (discs), and *spaceSlices* of the *spaceBoundary* of the middle *Surface* (a rectangle joined at two opposite sides).
- Two Features Subsetting *edges* for the top and bottom of the cylinder. Each Feature identifies two *Curves* that are the *edges* of adjacent *faces*, specified by *BindingConnectors* between the Feature and required *edges*. These two *Curves* must mate, specified by a *MateWith* Connector between the Feature and itself.
- A Feature redefining *vertices* to multiplicity 0.

9.2.5.2 Elements

9.2.5.2.1 BinaryLinkObject

Element

AssociationStructure

Description

General Types

LinkObject

BinaryLink

Features

toSources : Anything [0..*] {redefines toSources}

toTargets : Anything [0..*] {redefines toTargets}

Constraints

None.
9.2.5.2.2 binaryLinkObjects

Element

Feature

Description

General Types

linkObjects

BinaryLinkObject

binaryLinks

Features

None.

Constraints

None.

9.2.5.2.3 Body

Element

Structure

Description

Objects of innerSpaceDimension 3.

General Types

Object

Features

innerSpaceDimension : Integer {redefines innerSpaceDimension}

Constraints

None.

9.2.5.2.4 Curve

Element

Structure

Description

Objects of innerSpaceDimension 1.
General Types

Object

Features

innerSpaceDimension : Integer {redefines innerSpaceDimension}

Constraints

None.

9.2.5.2.5 LinkObject

Element

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 Types

Object

Link

Features

None.

Constraints

None.

9.2.5.2.6 linkObjects

Element

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 Types

objects

LinkObject
Features

None.

Constraints

None.

9.2.5.2.7 Object

Element

Structure

Description

An Object is an Occurrence that is not a Performance. It is the most general Structure. All other Structures specialize it directly or indirectly.

General Types

Occurrence

Features

enactedPerformances : Performance [0..*] {subsets timeEnclosedOccurrences, involvingPerformances}

Performances that are enacted by this Object.

involvingPerformances : Performance [0..*]

Performances in which this Object is involved.

ownedPerformances : Performance [0..*] {subsets timeEnclosedOccurrences, involvingPerformances, suboccurrences}

Performances that are owned by this Object. The owning Object is the default this reference for all ownedPerformances.

structuredSpaceBoundary : StructuredSpaceObject [0..1] {subsets spaceBoundary}

A spaceBoundary that is a StructuredSpaceObject.

subobjects : Object [0..*] {subsets suboccurrences}

The suboccurrences of this Object that are also Objects.

Constraints

None.
9.2.5.2.8 objects

Element
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 Types

occurrences
Object

Features

None.

Constraints

None.

9.2.5.2.9 Point

Element
Structure

Description

Objects of innerSpaceDimension 0.

General Types

Object

Features

innerSpaceDimension : Integer {redefines innerSpaceDimension}

Constraints

None.

9.2.5.2.10 StructuredSpaceObject

Element
Structure

Description
A \textit{StructuredSpaceObject} is an \textit{Object} that is broken up into smaller \textit{structuredSpaceCells} of the same or lower \textit{innerSpaceDimension}: faces of \textit{innerSpaceDimension} 2, edges of \textit{innerSpaceDimension} 1, and vertices of \textit{innerSpaceDimension} 0, with the highest of these being the \textit{innerSpaceDimension} of the \textit{StructuredSpaceObject}. Boundaries of \textit{structuredSpaceObjectCells} are the union of others of lower \textit{innerSpaceDimension} (edges and vertices on the boundary of faces, and vertices on the boundary of edges), some of which meet when this \textit{StructuredSpaceObject} \textit{isClosed} (faces meet at their edges and/or vertices, while edges meet at their vertices), as required to be a \textit{spaceBoundary} of an \textit{Object}.

\textbf{General Types}

\textit{Object}

\textbf{Features}

\textit{cellOrientation} : Integer [0..1]

A nested \textit{Feature} of \textit{structuredSpaceObjectCell} that gives them a "direction" (1 or -1) or none (0). For example, the \textit{cellOrientation} of a \textit{face} indicates to which side the "positive" normal vector points, of an \textit{edge} the positive direction along the \textit{edge}, and of a \textit{vertex} the positive direction "in or out" of it. When the \textit{cellOrientation} of all \textit{edges} and \textit{vertices} are given, and the \textit{StructuredSpaceObject} \textit{isClosed}, the \textit{cellOrientations} of the (completely) overlapping ones sum to zero.

\textit{edges} : Curve [0..*] \{subsets \textit{structuredSpaceObjectCells}, ordered\}

The \textit{structuredSpaceObjectCells} of \textit{innerSpaceDimension} 1 in this \textit{StructuredSpaceObject}.

\textit{faces} : Surface [0..*] \{subsets \textit{structuredSpaceObjectCells}, ordered\}

The \textit{structuredSpaceObjectCells} of \textit{innerSpaceDimension} 2 in this \textit{StructuredSpaceObject}.

/\textit{innerSpaceDimension} : Integer \{redefines \textit{innerSpaceDimension}\}

Highest \textit{innerSpaceDimension} of the \textit{structuredSpaceObjectCells}.

\textit{structuredSpaceObjectCells} : \textit{StructuredSpaceObject} [1..*] \{subsets \textit{spaceSlices}\}

All and only the \textit{spaceSlices} of this \textit{StructuredSpaceObject} that are its \textit{faces}, \textit{edges}, and \textit{vertices}.

\textit{vertices} : Point [0..*] \{subsets \textit{structuredSpaceObjectCells}, ordered\}

The \textit{structuredSpaceObjectCells} of \textit{innerSpaceDimension} 0 in this \textit{StructuredSpaceObject}.

\textbf{Constraints}

None.

\textbf{9.2.5.2.11 Surface}

\textbf{Element}

\textbf{Structure}

\textbf{Description}
Objects of innerSpaceDimension 2.

General Types

Object

Features

genus : Integer [0..1]

The number of "holes" in this Surface, assuming it isClosed. For example, it is 0 for spheres and 1 for toruses, including one-handed coffee cups.

innerSpaceDimension : Integer {redefines innerSpaceDimension}

Constraints

None.

9.2.6 Performances

9.2.6.1 Performances Overview

Performances

Performances are Occurrences that can be spread out in disconnected portions of space and time. Performance is the most general Behavior, while performances is the most general Feature typed by Behaviors (see 8.3.4.6 and compare to Objects in 9.2.5). Performances can coordinate others that HappenDuring them, identified as their subperformances (see Steps in 8.3.4.6 and 8.4.4.7). Performances also coordinate and potentially affect other things, some of which might come into existence (start, be "created") or cease to exist (end, be "destroyed") during a Performance, and some that might be used without being affected at all ("catalysts"). Some of these other things might be Objects, identified as a Performance's involvedObjects, some of which might be "responsible" for (enact, Perform) a Performance, identified as its performers. Performances can also accept things as input or provide them as output (as parameters, see 8.3.4.6).

Evaluations

Evaluations are Performances that produce at most one thing (value) identified by their result parameter. Evaluation is the most general Function, while evaluations is the most general Feature identifying them, typed by Functions (see 8.3.4.7). In other respects Evaluations are like any other Performance.

LiteralEvaluations are Evaluations with exactly one result, specified as a constant in a model via classification by LiteralExpression (see 8.3.4.8 for this and the rest of the paragraph). LiteralEvaluation is the most general LiteralExpression, specialized in the same way, and literalEvaluations is the most general feature identifying them, also similarly specialized.

BooleanEvaluations are Evaluations (but not LiteralEvaluations) with exactly one true or false result. BooleanEvaluation is the most general Predicate, and booleanEvaluations is the most general feature identifying them, specialized (incompletely) into those that always have true or always false results, trueEvaluations and falseEvaluations, respectively. LiteralBooleanEvaluations are LiteralEvaluations and BooleanEvaluations, with result specified in a model, potentially identified by trueEvaluations or falseEvaluations, or one of their specializations.
NullEvaluations are Evaluations that produce no values for their result. NullEvaluation is the most general NullExpression, and nullEvalutions is the most general Feature typed by NullExpression (see 8.3.4.8).

9.2.6.2 Elements

9.2.6.2.1 BooleanEvaluation

Element

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 Types

Evaluation

Features

result : Boolean {redefines result}

The Boolean result of this BooleanExpression.

Constraints

None.

9.2.6.2.2 booleanEvaluations

Element

BooleanExpression

Description

booleanEvaluations is a specialization of evaluations restricted to type BooleanEvaluation.

General Types

evaluations

BooleanEvaluation

Features

None.

Constraints

None.
9.2.6.2.3 Evaluation

**Element**

**Function**

**Description**

An *Evaluation* is a *Performance* that ends with the production of a *result*.

**General Types**

Performance

**Features**

result : Anything [0..*] {nonunique}

The outcome of the *Evaluation*.

**Constraints**

None.

9.2.6.2.4 evaluations

**Element**

Expression

**Description**

evaluations is a specialization of *performances* for Evaluations of functions.

**General Types**

Evaluation

performances

**Features**

None.

**Constraints**

None.

9.2.6.2.5 falseEvaluations

**Element**

BooleanExpression

**Description**
falseEvaluations is a subset of booleanEvaluations that result in false. It is the most general Feature of Invariants that are negated.

General Types

booleanEvaluations

Features

[no name] : LiteralEvaluation

Constraints

None.

9.2.6.2.6 Involves

Element

Association

Description

Involves classifies relationships between Performances and Objects.

General Types

None.

Features

None.

Constraints

None.

9.2.6.2.7 LiteralEvaluation

Element

Function

Description

LiteralEvaluation is a specialization of Evaluation for the case of LiteralExpressions.

General Types

Evaluation

Features

result : DataValue {redefines result}
The **result** of this *LiteralEvaluation*, which is always a single *DataValue*.

**Constraints**
None.

### 9.2.6.2.8 literalEvaluations

**Element**
Expression

**Description**

*literalEvaluations* is a specialization of *evaluations restricted to type* *LiteralEvaluation*.

**General Types**
evaluations
LiteralEvaluation

**Features**
None.

**Constraints**
None.

### 9.2.6.2.9 MetadataAccessEvaluation

**Element**
Function

**Description**

*MetadataAccessEvaluation* is a specialization of *Evaluation for the case of MetadataAccessExpressions*.

**General Types**
Evaluation

**Features**

result : *Metaobject [0..*] {redefines result}*
The **result** of this *MetadataEvaluation*.

**Constraints**
None.
9.2.6.2.10 metadataAccessEvaluations

Element

Expression

Description

metadataAccessEvaluations is a specialization of evaluations restricted to type MetadataAccessEvaluation.

General Types

evaluations

MetadataAccessEvaluation

Features

None.

Constraints

None.

9.2.6.2.11 NullEvaluation

Element

Function

Description

NullEvaluation is a specialization of Evaluation for the case of NullExpressions.

General Types

Evaluation

Features

result : Anything [0] {redefines result}

The result of this NullEvaluation, which always must be empty (i.e., "null").

Constraints

None.

9.2.6.2.12 nullEvaluations

Element

Expression
**Description**

nullEvaluations is a specialization of evaluations restricted to type NullEvaluation.

**General Types**

NullEvaluation

evaluations

**Features**

None.

**Constraints**

None.

**9.2.6.2.13 Performance**

**Element**

Behavior

**Description**

A Performance is an Occurrence that is not a Object. It is the most general Behavior. All other Behaviors specialize it directly or indirectly.

**General Types**

Occurrence

**Features**

enclosedPerformances : Performance [0..*] {subsets timeEnclosedOccurrences}

<<em>code>timeEnclosedOccurrences of this Performance that are also Performances.

involvedObjects : Object [0..*]

Objects that are involved in this Performance.

performers : Object [0..*] {subsets involvedObjects}

Objects that enact this Performance.

subperformances : Performance [0..*] {subsets enclosedPerformances, suboccurrences}

enclosedPerformances that are composite. The default this context of a subperformance is by default the same as that of its owning Performance. This means that the context for any Performance that is in a composition tree rooted in a Performance that is not itself owned by an Object is the root Performance. If the root Performance is an ownedPerformance of an Object, then that Object is the context.

thisPerformance : Performance
The "context" Performance during which this Performance takes place. It defaults to the root of the subperformances composition tree. It is the default dispatchScope for Performances.

Constraints

None.

9.2.6.2.14 performances

Element

Step

Description

performances is the most general feature for Performances of Behaviors.

General Types

things

Performance

Features

None.

Constraints

None.

9.2.6.2.15 Performs

Element

Association

Description

Performs is a specialization of Involves that asserts that the performer enacts the behavior carried out by the enactedPerformance.

General Types

Involves

Features

None.

Constraints

None.
9.2.6.2.16 trueEvaluations

Element
BooleanExpression

Description
falseEvaluations is a subset of booleanEvaluations that result in false. It is the most general Feature of Invariants that are not negated.

General Types
booleanEvaluations

Features
None.

Constraints
None.

9.2.7 Transfers

9.2.7.1 Transfers Overview

Transfers are Performances and BinaryLinks that carry items from their source Occurrence to their target Occurrence. FlowTransfers are Transfers that start by "picking up" their items from the sourceOutput Feature (or one of its redefinitions) of the source and end with "dropping them off" at the targetInput Feature of the target (or one of its redefinitions, see 8.3.1.5 about outputs and inputs). FlowTransfers do this by specifying the existence of BinaryLinkObjects between their source / target and values of sourceOutput / targetInput Features of those, identified by the Connectors sourceOutputLink and targetOutputLink, respectively (these can be redefined to specialized associations when FlowTransfer is used). Each sourceOutputLink identifies an output as its transferPayload (one of the values of sourceOutput on the source at the time a FlowTransfer starts). Each targetInputLink identifies an input also as its transferPayload (one of the values of targetInput on the target at the time a Transfer ends). Both collections of transferPayloads are the same as the FlowTransfer's items, and do not change while it is carried out.

Transfers are required to take zero time when their isInstant Feature is true (startShot and endShot are the same, see Portions and Time Slices in 9.2.4.1), otherwise they might take time to carry out.

Two Boolean Features of FlowTransfers affect timing of their sourceOutputLinks and targetOutputLinks:

- isMove true requires sourceOutputLinks to end (cease to exist) when the Transfer starts, otherwise the Transfer has no effect on the sourceOutputLinks.
- isPush true requires the Transfer to start when its sourceOutputLinks do (begin to exist), otherwise the Transfer can start anytime after the sourceOutputLinks do.

MessageTransfers are Transfers that do not have the additional capabilities of FlowTransfers. SendPerformances and AcceptPerformances are Performances for specifying when MessageTransfers come into and go out of Occurrences, respectively. SendPerformances require a MessageTransfer as outgoingTransferFromSelf from a designated sender (defaulting to this, see 9.2.4.2.13), carrying a sentItem, optionally to a designated
receiver. *AcceptPerformances* require an *incomingTransferToSelf* to a designated *receiver* (defaulting to this), carrying an *acceptedItem*.

*Transfer* and its specializations are binary Interactions, while *transfers* is the most general Feature typed by *Transfer* or its specializations, and the most general ItemFlow (see 8.3.4.9). *Transfer* is not the most general binary Interaction, and *transfers* is not the most general feature typed by binary Interactions, because binary Interactions can include more than one ItemFlow, as well as other Interactions.

ItemFlow's *itemType* gives the kind of things being transferred (most generally the type of *item*, above). For *FlowTransfers*, ItemFlow's *sourceOutputFeature* and *targetInputFeature* specify which Features of its connected Feature *Occurrences* identify outputs and inputs, respectively (most generally *sourceOutput* and *targetInput* above, respectively).

### 9.2.7.2 Elements

#### 9.2.7.2.1 AcceptPerformance

**Element**

**Behavior**

**Description**

*AcceptPerformances* are *Performances* that require an *incomingTransferToSelf* of a designated *receiver Occurrence* (defaulting to this), providing an *acceptedItem* as output.

**General Types**

Performance

**Features**

*acceptedItem*: Anything [0..*]

*acceptedTransfer*: MessageTransfer [0..1] {subsets receiver.incomingTransfersToSelf}

*receiver*: Occurrence

*receiver.incomingTransfersToSelf*: Transfer [0..*]

**Constraints**

None.

#### 9.2.7.2.2 FlowTransfer

**Element**

Interaction

**Description**

A *FlowTransfer* is a *Transfer* identifying an output feature of the *source* to pick up items from and an input feature of the *target* to drop them off. They can start when items are available at the *source* and move or copy them to the *target*.  

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General Types
Transfer

Features
isMove : Boolean
isPush : Boolean
sourceOutputLink : BinaryLinkObject [1..*]
targetInputLink : BinaryLinkObject [1..*]

Constraints
None.

9.2.7.2.3 FlowTransferBefore

Element
Interaction

Description
General Types
FlowTransfer
TransferBefore

Features
source : Occurrence {redefines source, source}
target : Occurrence {redefines target, target}

Constraints
None.

9.2.7.2.4 flowTransfers

Element
ItemFlow

Description
General Types
FlowTransfer
transfers
Features
source : Occurrence {redefines source, source}
target : Occurrence {redefines target, target}

Constraints
None.

9.2.7.2.5 flowTransfersBefore

Element
ItemFlow

Description

General Types
FlowTransferBefore
flowTransfers
transfersBefore

Features
source : Occurrence {redefines source, source, source}
target : Occurrence {redefines target, target, target}

Constraints
None.

9.2.7.2.6 MessageTransfer

Element
Interaction

Description

A MessageTransfer is a Transfer that does not specify where items are picked up and dropped off (see FlowTransfer). They are sent by SendPerformances and accepted by AcceptPerformances.

General Types
Transfer

Features
None.
Constraints

None.

9.2.7.2.7 messageTransfers

Element

ItemFlow

Description

General Types

transfers

MessageTransfer

Features

source : Occurrence {redefines source, source}

target : Occurrence {redefines target, target}

Constraints

None.

9.2.7.2.8 SendPerformance

Element

Behavior

Description

SendPerformances are Performances that require an outgoingTransferFromSelf from a designated sender Occurrence (defaulting to this), carrying a given sentItem, optionally to a designated receiver.

General Types

Performance

Features

receiver : Occurrence [0..1]

receiver.incomingTransfersToSelf : Transfer [0..*]

sender : Occurrence

sender.outgoingTransfersToSelf : Transfer [0..*]

sentItem : Anything [0..*]
sentTransfer : MessageTransfer {subsets sender.outgoingTransfersToSelf}

Constraints
None.

9.2.7.2.9 Transfer

Element
Interaction

Description
A Transfer is a Performance and BinaryLink that carries items from its source to its target.

General Types
Performance
BinaryLink

Features
isInstant : Boolean
item : Anything [1..*]
self : Transfer {redefines self}
source : Occurrence {redefines source}
sourceSendShot : Occurrence
target : Occurrence {redefines target}
targetReceiveShot : Occurrence
toTransferSources : Occurrence [0..*] {subsets toSources}
toTransferTargets : Occurrence [0..*] {subsets toTargets}

Constraints
None.

9.2.7.2.10 TransferBefore

Element
Interaction

Description
A TransferBefore is Transfer that happens after its source and before its target.
General Types
HappensBefore
Transfer

Features
source : Occurrence {redefines earlierOccurrence, source}
target : Occurrence {redefines laterOccurrence, target}
toTransferSources : Occurrence [0..*] {redefines predecessors, toTransferSources}
toTransferTargets : Occurrence [0..*] {redefines toTransferTargets, successors}

Occurrences whose input is the target of a TransferBefore of items from this Occurrence.

Constraints
None.

9.2.7.2.11 transfers

Element
ItemFlow

Description
General Types
Transfer
performances
binaryLinks

Features
source : Occurrence {redefines source, source}
target : Occurrence {redefines target, target}

Constraints
None.

9.2.7.2.12 transfersBefore

Element
ItemFlow

Description
**General Types**

transfers

happensBeforeLinks

TransferBefore

**Features**

source : Occurrence {redefines source, source, earlierOccurrence}

target : Occurrence {redefines target, target, laterOccurrence}

**Constraints**

None.

### 9.2.8 Feature Referencing Performances

#### 9.2.8.1 Feature Referencing Performances Overview

The FeatureReferencingPerformances package defines Behaviors used to read and write values of a referenced Feature of an Occurrence as of the time the Performance of the Behavior ends.

#### 9.2.8.2 Elements

##### 9.2.8.2.1 BooleanEvaluationResultMonitorPerformance

**Element**

**Description**

A BooleanEvaluationResultMonitorPerformance is a EvaluationResultMonitorPerformance that waits for changes in the result of a BooleanEvaluation identified by onOccurrence.

**General Types**

EvaluationResultMonitorPerformance

**Features**

afterValues : Boolean {redefines afterValues}

beforeValues : Boolean {redefines beforeValues}

monitoredOccurrence : BooleanEvaluation {subsets timeSlices, redefines monitoredOccurrence}

A timeSlice of onOccurrence during which its values for result change.

onOccurrence : BooleanEvaluation {redefines onOccurrence}

The BooleanEvaluation being monitored for changes in its result values.

result : Boolean {redefines result, nonunique}
Redefines `BooleanEvaluation::result` and `monitoredFeature`.

Constraints

None.

9.2.8.2.2 BooleanEvaluationResultToMonitorPerformance

Element

Description

A `BooleanEvaluationResultToMonitorPerformance` is a `FeatureReferencingPerformance` that waits for the `result` of a `BooleanEvaluation` (identified by `onOccurrence`) to change to either true or false, as indicated by `isToTrue` (defaulting to true). If the result is already true (or false), the performance waits for the result to become false (or true) before waiting again for it to change back.

General Types

FeatureReferencingPerformance

Features

afterValues : Boolean [redefines values, nonunique]

The values of `monitoredFeature` for `onOccurrence` immediately after they change. Always the same as `isToTrue`.

endWhen : HappensJustBefore

See `FeatureMonitorPerformance::endWhen`. It is restricted to `HappensJustBefore` in `monitor1` and `monitor2`.

isToTrue : Boolean

monitor1 : BooleanEvaluationResultMonitorPerformance

Waits for the `result` of `onOccurrence` to change.

monitor2 : BooleanEvaluationResultMonitorPerformance [0..1]

Waits for the `result` of `onOccurrence` to change again, only if the change detected by `monitor1` was not the same as `isToTrue`.

onOccurrence : BooleanEvaluation [redefines `onOccurrence`]

The `BooleanEvaluation` being monitored for changes in its `result` values.

Constraints

bertmpMonitor1ElseMonitor2

isEmpty(monitor2) == (monitor1.afterValues == isToTrue)
9.2.8.2.3 EvaluationResultMonitorPerformance

Element

Behavior

Description

An EvaluationResultMonitorPerformance is a FeatureMonitorPerformance that waits for changes in result of an Evaluation identified by onOccurrence. The Predicate being evaluated must be able to produce multiple results over time, for example by only using BindingConnectors (SelfLinks) between Steps, rather than Successions or ItemFlows, including in its Step behaviors.

General Types

FeatureMonitorPerformance

Features

monitoredOccurrence : Evaluation {subsets timeSlices, redefines monitoredOccurrence}

A timeSlice of onOccurrence during which its values for result change.

onOccurrence : Evaluation {redefines onOccurrence}

The Evaluation being monitored for changes in its result values.

result : Anything [0..*] {redefines monitoredFeature, nonunique}

Redefines Evaluation::result and monitoredFeature.

Constraints

None.

9.2.8.2.4 FeatureAccessPerformance

Element

Behavior

Description

A FeatureAccessPerformance is a FeatureReferencingPerformance where values are all the values of accessedFeature for onOccurrence at the time the Performance ends. Specializations or usages of this narrow accessedFeature to particular Features.

General Types

FeatureReferencingPerformance

Features

accessedFeature : Anything [0..*] {nonunique}
The Feature of onOccurrence that has values at the time this FeatureAccessPerformance ends.

startingAt : Occurrence {subsets timeSlices}

A timeslice of onOccurrence that starts when this FeatureAccessPerformance ends.

Constraints

None.

9.2.8.2.5 FeatureMonitorPerformance

Element

Behavior

Description

A FeatureMonitorPerformance is a FeatureReferencingPerformance that waits for values of monitoredFeature to change on onOccurrence from what they were when the Performance started. The values before and after the change are given by beforeValues and afterValues.

General Types

FeatureReferencingPerformance

Features

afterSnapshot : Occurrence {subsets snapshots}

A snapshot of monitoredOccurrence just after its values for monitoredFeature change.

afterValues : Anything [0..*] {redefines values}

The values of monitoredFeature for monitoredOccurrence immediately after they change

beforeTimeSlice : Occurrence {subsets timeSlices}

A timeSlice of monitoredOccurrence, starting at the same time, and ending just before its values for monitoredFeature change.

beforeValues : Anything [0..*]

The values of monitoredFeature for monitoredOccurrence before any change

endWhen : HappensBefore

A Succession (Connector typed by HappensBefore) from afterSnapshot to the endShot of this FeatureMonitorPerformance. Can be specialized to specify how soon the Performance should end after the change in monitoredFeature.

monitoredFeature : Anything [0..*] {nonunique}

The Feature being monitored for changes in values on monitoredOccurrence.
monitoredOccurrence : Occurrence \{subsets timeSlices\}

A timeSlice of onOccurrence, starting when this FeatureMonitorPerformance starts, during which the values of monitoredFeature change.

Constraints

fmpBeforeAfterValuesNotSame

not beforeValues == afterValues

9.2.8.2.6 FeatureReadEvaluation

Element

Function

Description

A FeatureReadEvaluation is a FeatureAccessPerformance that is a Function providing as its result the values of accessedFeature of onOccurrence at the time the Evaluation ends.

General Types

Evaluation

FeatureAccessPerformance

Features

result : Anything [0..*] \{redefines result, values, nonunique\}

Values of the Feature being accessed, as an out parameter.

Constraints

None.

9.2.8.2.7 FeatureReferencingPerformance

Element

Behavior

Description

A FeatureReferencingPerformance is a Performance generalizing other Behaviors relating to values of a Feature of onOccurrence, as specified in the specialized Behaviors.

General Types

Performance

Features
onOccurrence : Occurrence

An Occurrence that has values for a Feature determined in specializations of this Behavior.

values : Anything [0..*] {nonunique}

Values of a Feature of onOccurrence, determined in specializations of this Behavior.

Constraints

None.

9.2.8.2.8 FeatureWritePerformance

Element

Behavior

Description

A FeatureWritePerformance is a FeatureAccessPerformance that ensures the values of accessedFeature of onOccurrence are exactly the replacementValues at the time the Performance ends.

General Types

FeatureAccessPerformance

Features

replacementValues : Anything [0..*] {redefines values, nonunique}

Values of the Feature being accessed, as an inout parameter to replace all the values.

Constraints

None.

9.2.9 Control Performances

9.2.9.1 Control Performances Overview

The ControlPerformances package defines Behaviors used to type Steps that control the sequencing of performance of other Steps, including the following.

DecisionPerformances are Performances used by ("decision") Steps to ensure that each DecisionPerformance (value) of the Step is the earlierOccurrence of exactly one HappensBefore link of the Successions going out of the Step. Successions going out of Steps typed by DecisionPerformance or its specializations must:

- have connector end multiplicities of 1 towards the Step, and 0..1 away from it.
- be included in a Feature of its featuringBehavior that unions (see 7.3.2.7) all the outgoing Successions, and is bound to the outgoingHBLink of the Step (see 7.3.4.6 on feature chaining).
MergePerformances are Performances used by ("merge") Steps to ensure that each MergePerformance (value) of the Step is the laterOccurrence of exactly one HappensBefore link of the Successions coming into the step. Successions coming into Steps typed by MergePerformance or its specializations must:

- have connector end multiplicities of 1 towards the Step, and 0..1 away from it.
- subset a Feature of its featuringBehavior that unions all the incoming Successions, and is bound to the incomingHBLink of the Step.

IfPerformances are Performances that determine whether a clause occurs based on the result of a BooleanEvaluation (see 9.2.6.1). Two specializations IfThenPerformance and IfElsePerformance have one clause each, thenClause and elseClause, respectively, that occur when the BooleanEvaluation is true or false, respectively. IfThenElsePerformance is an IfPerformance that has both a thenClause and an elseClause.

LoopPerformances are Performances with a body that occurs iteratively as determined by BooleanEvaluations whileTest and untilTest. The body occurs repeatedly in sequence (iteratively) as long as the result of whileTest is true before each iteration (and after the previous one, if any), and the result of untilTest is false after each iteration and before the next one (except after the last one, when it is false).

9.2.9.2 Elements

9.2.9.2.1 DecisionPerformance

Element
Behavior
Description

A DecisionPerformance is a Performance that represents the selection of one of the Successions that have the DecisionPerformance behavior as their source. All such Successions must subset the outgoingHBLink feature of the source DecisionPerformance. For each instance of DecisionPerformance, the outgoingHBLink is an instance of exactly one of the Successions, ordering the DecisionPerformance as happening before an instance of the target of that Succession.

General Types
Performance
Features
outgoingHBLink : HappensBefore
Specializations subset this from the union of all Successions going out of a decision step.

Constraints
None.

9.2.9.2.2 IfElsePerformance

Element
Behavior
Description

An **IfElsePerformance** is an **IfPerformance** where **elseClause** occurs after and only after the **ifTest** Evaluation result is not true.

**General Types**
IfPerformance

**Features**
elseClause : Occurrence [0..1]

**Constraints**
None.

### 9.2.9.2.3 IfPerformance

**Element**
Behavior

**Description**

An **IfPerformance** is a **Performance** that determines whether the **ifTest** Evaluation result is true (by whether the **ifTrue** connector has a value).

**General Types**
Performance

**Features**
ifTest : BooleanEvaluation
trueLiteral : LiteralEvaluation

**Constraints**
None.

### 9.2.9.2.4 IfThenElsePerformance

**Element**
Behavior

**Description**

An **IfThenElsePerformance** is an **IfPerformance** that has both a **thenClause** and an **elseClause**.

**General Types**
IfThenPerformance
Features
elseClause : Occurrence [0..1]

Constraints
None.

9.2.9.2.5 IfThenPerformance

Element
Behavior

Description
An IfThenPerformance is an IfPerformance where thenClause occurs after and only after the ifTest Evaluation result is true.

General Types
IfPerformance

Features
thenClause : Occurrence [0..1]

Constraints
None.

9.2.9.2.6 LoopPerformance

Element
Behavior

Description
A LoopPerformance is a Performance where body occurs repeatedly in sequence (iterates) as long as the while evaluation result is true before each iteration (and after the previous one, except the first time) and the until evaluation result is not true after each iteration and before the next one (except the last one).

General Types
Performance

Features
body : Occurrence [0..*]

untilDecision : IfElsePerformance [0..*]

untilTest : BooleanEvaluation [0..*]
whileDecision : IfThenPerformance [1..*]
whileTest : BooleanEvaluation [1..*]

Constraints
None.

9.2.9.2.7 MergePerformance

Element
Behavior

Description
A MergePerformance is a Performance that represents the merging of all Successions that target the MergePerformance behavior. All such Successions must subset the incomingHBLink feature of the target MergePerformance. For each instance of MergePerformance, the incomingHBLink is an instance of exactly one of the Successions, ordering the MergePerformance as happening after an instance of the source of that Succession.

General Types
Performance

Features
incomingHBLink : HappensBefore

Specializations subset this from the union of all successions coming into a merge step.

Constraints
None.

9.2.10 Transition Performances

9.2.10.1 Transition Performances Overview

The TransitionPerformances package contains a library model of the semantics of conditional transitions between Occurrences, including the performance of specified Behaviors when the transition occurs.

TransitionPerformances are Performances used to

- determine whether a Succession (see 7.4.6.4) going out of an Occurrence Feature (Succession::sourceFeature) has values (HappensBefore links), based on values of sourceFeature (Occurrences) and other conditions, including ending of Transfers.
- perform specified Behaviors for each value of the Succession above.

The Succession constrained by a TransitionPerformance is specified by a Connector between the Succession and its transitionStep, a unique Step typed by TransitionPerformance or a specialization of it, of the same Behavior as the Succession. This connector is

- typed by an Association defined to give a value to the transitionLink of TransitionPerformances,
has connector end multiplicity 0..1 on the Succession end and 1 on the TransitionPerformance Step end.

The connector end multiplicities above ensure every HappensBefore link of the Succession is paired with a unique TransitionPerformance that has its conditions satisfied for that Link, while all the other TransitionPerformances of transitionStep fail their conditions and have no values for transitionLink.

The transitionStep above is also connected to the Succession's sourceFeature, because conditions on the Succession depend on each Occurrence of its sourceFeature separately, which TransitionPerformances identify as their transitionLinkSource. This connector is

- typed by an Association defined to give a value to the transitionLinkSource of TransitionPerformances.
- with connector end multiplicity 1 on both ends.

The connector end multiplicities above ensure every Occurrence of the Succession's sourceFeature is paired with a unique TransitionPerformance, and vice-versa, that determines whether the Succession has a value (HappensBefore link) for that Occurrence.

TransitionPerformances with a transitionLink must satisfy these conditions:

- identify at least one Transfer as trigger that targets triggerTarget.
- all Transfers identified by trigger must happen before all Evaluations identified by guard.
- all Evaluations identified by guard must have result value true.

The effect of a TransitionPerformance can have values (Performances) only if the above conditions hold. The effect Performances must happen after the guards and before the laterOccurrence of transitionLink.

Usages of (Steps typed by) TransitionPerformance or its specializations can redefine or subset guard and effect to specify how they are carried out, as well as specify how triggers are identified. These usages can

- be steps of any Behavior (not only "state machines"), as well as constrain Successions going out of any kind of Step (not only those identifying StatePerformances, see 9.2.11.1).
- employ any method of identifying triggers, including requiring none at all, as well as constraining Transfer targets to be, for example, the StatePerformance itself, or a Performance it is a subperformance of, or an Object enacting that Performance.

TransitionPerformances are either StateTransitionPerformances or NonStateTransitionPerformances, depending on whether the transitionLinkSource is a StatePerformance or not. Both ensure guards happen before the laterOccurrence of transitionLink, in case there are no effects, but do this in different ways. NonStateTransitionPerformances require their guards to happen after transitionLinkSource (see 9.2.11.1 about StateTransitionPerformances).

9.2.10.2 Elements

9.2.10.2.1 NonStateTransitionPerformance

Element

Behavior

Description

General Types
TransitionPerformance

Features

isTriggerAfter : Boolean

Constraints

None.

9.2.10.2.2 TPCGuardConstraint

Element

Association

Description

General Types

BinaryLink

Features

constrainedGuard : Evaluation {redefines target}

constrainedHBLink : HappensBefore {redefines source}

guardedBy : Evaluation [0..*] {redefines toTargets}

guards : HappensBefore [0..1] {redefines toSources}

ture : Boolean

Constraints

None.

9.2.10.2.3 TransitionPerformance

Element

Behavior

Description

General Types

Performance

Features

accept : AcceptPerformance [0..1] {subsets enclosedPerformances}

effect : Performance [0..*] {subsets enclosedPerformances}
guard : Evaluation [0..*] {subsets enclosedPerformances}
guardConstraint : TPCGuardConstraint [0..*]
transitionLink : HappensBefore [0..1]
transitionLinkSource : Performance
trigger : MessageTransfer [0..*]
triggerTarget : Occurrence

Constraints
None.

9.2.11 State Performances

9.2.11.1 State Performances Overview

The StatePerformance package contains a library model for the semantics of state-based behavior, including StatePerformances and StateTransitionPerformances.

StatePerformances are DecisionPerformances (see 9.2.9.1) that

• only have Steps defined in this library, or specialized from them.
• can identify Transfers that might be followed by taking the last of the above Steps (see exit below).

Usages of StatePerformance can specialize its library-defined Steps to specify how they are carried out, as well as how the Transfers above are identified. Any Behavior can use (have steps typed by) StatePerformances, not only "state machines".

The StatePerformance Steps defined in this library are:

• entry [1]: happens before all Performances of middle.
• middle [1..*]: happen before the exit Performance (see below). Additional modeler-defined Steps must subset this one.
• do [1]: a middle Performance that starts before the others.
• exit [1]: happens after the end of Transfers identified by the StatePerformance (see acceptable below).

StatePerformances identify Transfers that happen before (potentially "trigger") their exit with these Features:

• acceptable [*]: candidates for being identified as accepted.
• accepted [0..1]: one of the acceptable transfers that enables exit to start. This must have a value if acceptable does.

The accepted Transfer must end (arrive) during a StatePerformance when its isTriggerDuring is true.

StateTransitionPerformances are one way to determine which Transfers are acceptable to a StatePerformance. They are TransitionPerformances (see 9.2.10.1) that

• have a StatePerformance as their transitionLinkSource.
• are the type of Steps connected to Successions (see 7.4.6.4) going out of a StatePerformance Step (as in "state machines").
StateTransitionPerformances identify MessageTransfers (see 9.2.7.1) by these Features:

- acceptable [*]: candidates for being identified as trigger. This subsets acceptable of their transitionLinkSource.
- trigger [0..1]: one of the acceptable transfers. This subsets accepted of their transitionLinkSource.

The trigger Transfer must end (arrive) during the transitionLinkSource when StateTransitionPerformance isTriggerDuring is true.

The Subsettings above enable a StatePerformance Step to constrain all the StateTransitionPerformances Steps connected to its outgoing Successions, including to decide which of the MessageTransfers acceptable to those StateTransitionPerformances will be accepted by the StatePerformance and trigger which outgoing Succession (will have a HappenBeforeLink value).

StateTransitionPerformances require their guards to happen after the nonDoMiddle Step of the transitionLinkSource (all the middle Performances except for do) and before the exit Step (compare to NonStateTransitionPerformances in 9.2.10.1).

StatePerformances identify the Transfer that triggered a transition into it (a StateTransitionPerformance trigger), if any, by the Feature incomingTransitionTrigger.

Some Features of Occurrences constrain StatePerformances and TransitionPerformances composed under them, as sometimes needed in state machines:

- incomingTransferSort determines which Transfer should be accepted when multiple are acceptable ones, by comparing two Transfers at a time. It defaults to earlierFirstIncomingTransferSort for Occurrences, including StatePerformances, which is true if the first Transfer ends (arrives) before the other.
- isDispatch being true prevents the same Transfer from being accepted more than once by StatePerformances composed under dispatchScope, and prevents from being accepted at all any acceptable Transfers that are not accepted and are higher in incomingTransferSort order than the one that is. It defaults to true for Performances, including StatePerformances, and false for other Occurrences, while dispatchScope defaults to thisPerformance for StatePerformances, the top Performance (indirectly) composing the StatePerformance (see 9.2.6.2.3), and self for other Occurrences (see 9.2.2.1).
- isRunToCompletion being true prevents TransitionPerformances composed under runToCompletionScope from happening during entry. It defaults to the same as it is on this for StatePerformances, the Object directly composing thisPerformance, or thisPerformance if there is none (see 9.2.4.2.13), and true for other Occurrences, while runToCompletionScope defaults to the same as it is on this for StatePerformances, and self for other Occurrences.

9.2.11.2 Elements

9.2.11.2.1 StatePerformance

Element

Behavior

Description

General Types
DecisionPerformance

**Features**

acceptable : MessageTransfer [0..*] \{union\}

accepted : MessageTransfer [0..1] \{subsets acceptable\}

deferrable : MessageTransfer [0..*] \{subsets acceptable\}

do : Performance \{subsets middle\}

do : Performance \{subsets timeEnclosedOccurrences\}

exit : Performance \{subsets timeEnclosedOccurrences\}

incomingTransitionTrigger : MessageTransfer [0..1]

Transfer that triggered a transition into this state performance.

isTriggerDuring : Boolean

\middle : Performance [1..*] \{subsets timeEnclosedOccurrences, union\}

\nonDoMiddle : Performance [0..*] \{subsets middle\}

**Constraints**

None.

**9.2.11.2.2 StateTransitionPerformance**

**Element**

Behavior

**Description**

**General Types**

TransitionPerformance

**Features**

acceptable : MessageTransfer [0..*] \{subsets triggerTarget.incomingTransfersToSelf, transitionLinkSource.acceptable\}

isTriggerDuring : Boolean

transitionLinkSource : StatePerformance \{redefines transitionLinkSource\}

transitionLinkSource.acceptable : MessageTransfer [0..*]

transitionLinkSource.accepted : MessageTransfer [0..1]
transitionLinkTarget : Occurrence [0..1]

trigger : MessageTransfer [0..1] {subsets acceptable, transitionLinkSource.accepted, redefines trigger}

triggerTarget.incomingTransfersToSelf : Transfer [0..*]

Constraints
None.

9.2.12 Clocks

9.2.12.1 Clocks Overview

This package models *Clocks* that provide an advancing numerical reference usable for quantifying the time of an *Occurrence*.

9.2.12.2 Elements

9.2.12.2.1 BasicClock

Element

Structure

Description

A *BasicClock* is a *Clock* whose *currentTime* is a *Real* number.

General Types

Clock

Features

currentTime : Real {redefines currentTime}

Constraints
None.

9.2.12.2.2 BasicDurationOf

Element

Function

Description

*BasicDurationOf* returns the *DurationOf* an *Occurrence* as a *Real* number relative to a *BasicClock*.

General Types

DurationOf

Features
clock : BasicClock {redefines clock}
Default is inherited Occurrence::localClock.
duration : Real {redefines duration}
o : Occurrence {redefines o}

Constraints
None.

9.2.12.2.3 BasicTimeOf

Element
Function

Description

BasicTimeOf returns the TimeOf an Occurrence as a Real number relative to a BasicClock.

General Types
TimeOf

Features
clock : BasicClock {redefines clock}
Default is inherited Occurrence::localClock.
o : Occurrence {redefines o}
timeValue : Real {redefines timeInstant}

Constraints
None.

9.2.12.2.4 Clock

Element
Structure

Description

A Clock provides a scalar currentTime that advances montonically over its lifetime. Clock is an abstract base Structure that can be specialized for different kinds of time quantification (e.g., discrete time, continuous time, time with units, etc.).

General Types
Object
Features

currentTime : NumericalValue

A numerical time reference that advances over the lifetime of the Clock.

Constraints

timeFlowConstraint

The currentTime of a snapshot of a Clock is equal to the TimeOf the snapshot relative to that Clock.

9.2.12.2.5 DurationOf

Element

Function

Description

DurationOf returns the duration of a given Occurrence relative to a given Clock, which is equal to the TimeOf the end snapshot of the Occurrence minus the TimeOf its start snapshot.

General Types

Evaluation

Features

clock : Clock

Default is inherited Occurrence::localClock.

duration : NumericalValue

o : Occurrence

Constraints

None.

9.2.12.2.6 TimeOf

Element

Function

Description

TimeOf returns a scalar timeValue for a given Occurrence relative to a given Clock. The timeValue is the time of the start of the Occurrence, which is considered to be synchronized with the snapshot of the Clock with a currentTime.

General Types
Evaluation

Features

clock : Clock

Default is inherited Occurrence::localClock.

o : Occurrence
timeInstant : NumericalValue

Constraints

startTimeConstraint

The TimeOf an Occurrence is equal to the time of its start snapshot.

timeContinuityConstraint

If one Occurrence happens immediately before another, then the TimeOf the end snapshot of the first Occurrence equals the TimeOf the second Occurrence.

timeOrderingConstraint

If one Occurrence happens before another, then the TimeOf the end snapshot of the first Occurrence is no greater than the TimeOf the second Occurrence.

9.2.12.2.7 universalClock

Element

Feature

Description

universalClock is a single Clock that can be used as a default universal time reference.

General Types

objects

UniversalClockLife

Features

None.

Constraints

None.

9.2.12.2.8 UniversalClockLife

Element
UniversalClockLife is the classifier of the singleton Life of the universalClock.

General Types

Life
Clock

Features

None.

Constraints

None.

9.2.13 Observation

9.2.13.1 Observation Overview

This package models a framework for monitoring Boolean conditions and notifying registered observers when they change from false to true.

9.2.13.2 Elements

9.2.13.2.1 CancelObservation

Element

Behavior

Description

Cancel all observations of a given ChangeSignal for a given Occurrence.

General Types

Performance

Features

observer : Occurrence
signal : ChangeSignal

Constraints

None.

9.2.13.2.2 ChangeMonitor

Element
Structure

Description

A ChangeMonitor is a collection of ongoing ChangeSignal observations for various observer Occurrences. It provides convenient operations for starting and canceling the observations it manages.

General Types

Object

Features

cancelObservation : CancelObservation [0..*]
Cancel all observations of a given ChangeSignal for a given Occurrence.

observations : ObserveChange [0..*]

startObservation : StartObservation [0..*]
Start an observation of a given ChangeSignal for a given Occurrence.

Constraints

None.

9.2.13.2.3 ChangeSignal

Element

Structure

Description

A ChangeSignal is a signal to be sent when the Boolean result of its changeCondition Expression changes from false to true.

General Types

Object

Features

signalCondition : BooleanEvaluation

A BooleanExpression whose result is being monitored.

signalMonitor : ChangeMonitor

The ChangeMonitor responsible for monitoring the signalCondition.

Constraints

None.
9.2.13.2.4 defaultMonitor

Element

Feature

Description

defaultMonitor is a single ChangeMonitor that can be used as a default.

General Types

DefaultMonitorLife

objects

Features

None.

Constraints

None.

9.2.13.2.5 DefaultMonitorLife

Element

Structure

Description

DefaultMonitorLife is the classifier of the singleton Life of the defaultMonitor.

General Types

Life

ChangeMonitor

Features

None.

Constraints

None.

9.2.13.2.6 ObserveChange

Element

Behavior

Description
Each `Performance of ObserveChange` waits for the result of the `Boolean changeCondition` of a given `ChangeSignal` to change from false to true, and, when it does, sends the `ChangeSignal` to a given observer `Occurrence`.

**General Types**

Performance

**Features**

`changeObserver : Occurrence`

`changeSignal : ChangeSignal`

`transfer : TransferBefore [0..1]`

After waiting for the condition change (if necessary), then send `changeSignal` to `changeObserver`.

`wait : IfThenPerformance`

If the result of the `changeSignal.signalCondition` is false, then wait for it to become true:

```kernel
in ifTest { not changeSignal.signalCondition() } 
in thenClause : BooleanEvaluationResultToMonitorPerformance { 
  in onOccurrence = changeSignal.signalCondition; 
}
```

**Constraints**

None.

**9.2.13.2.7 StartObservation**

**Element**

Behavior

**Description**

Start an observation of a given `ChangeSignal` for a given `Occurrence`.

**General Types**

Performance

**Features**

`observer : Occurrence`

`signal : ChangeSignal`

**Constraints**

None.
9.2.14 Triggers

9.2.14.1 Triggers Overview

This package contains functions that return ChangeSignals for triggering when a Boolean condition changes from false to true, at a specific time or after a specific time delay.

9.2.14.2 Elements

9.2.14.2.1 TimeSignal

Element

Structure

Description

A TimeSignal is a ChangeSignal whose condition is the currentTime of a given Clock reaching a specific signalTime.

General Types

ChangeSignal

Features

signalClock : Clock

The Clock whose currentTime is being monitored.

signalCondition : BooleanEvaluation {redefines signalCondition}

The Boolean condition of the currentTime of the signalClock being equal to the signalTime.

signalTime : NumericalValue

The time at which the TimeSignal should be sent.

Constraints

None.

9.2.14.2.2 TriggerAfter

Element

Function

Description

TriggerAfter returns a monitored TimeSignal to be sent to a receiver after a certain time delay relative to a given Clock.

General Types
Evaluation

**Features**

clock : Clock

The *Clock* to be used as the reference for the time *delay*. The default is the *localClock*, which will be bound when the function is invoked.

delay : NumericalValue

The time duration, relative to the *clock*, after which the *TimeSignal* is sent.

monitor : ChangeMonitor

The *ChangeMonitor* to be used to monitor the *TimeSignal* condition. The default is the *Observation::defaultMonitor*.

receiver : Occurrence

The *Occurrence* to which the *TimeSignal* is to be sent.

signal : TimeSignal

**Constraints**

None.

**9.2.14.2.3 TriggerAt**

**Element**

**Function**

**Description**

*TriggerAt* returns a monitored *TimeSignal* to be sent to a *receiver* when the *currentTime* of a given *Clock* reaches a specific *time*.

**General Types**

Evaluation

**Features**

clock : Clock

The *Clock* to be used as the reference for the *timeInstant*. The default is the *localClock*, which will be bound when the function is invoked.

monitor : ChangeMonitor

The *ChangeMonitor* to be used to monitor the *TimeSignal* condition. The default is the *Observation::defaultMonitor*. 
receiver : Occurrence

The occurrence to which the TimeSignal is to be sent.

signal : TimeSignal

timeInstant : NumericalValue

The time instant, relative to the clock, at which the TimeSignal should be sent.

Constraints
None.

9.2.14.2.4 TriggerWhen

Element

Function

Description

TriggerWhen returns a monitored ChangeSignal for a given condition, to be sent to a given receiver when the condition occurs.

General Types

Evaluation

Features

condition : BooleanEvaluation

The BooleanExpression to be monitored for changing from false to true.

monitor : ChangeMonitor

The ChangeMonitor to be used to monitor the ChangeSignal condition. The default is the Observation::defaultMonitor.

receiver : Occurrence

The occurrence to which the ChangeSignal is to be sent.

signal : ChangeSignal

Constraints
None.

9.2.15 SpatialFrames

9.2.15.1 SpatialFrames Overview

This package models spatial frames of reference for quantifying the position of points in a three-dimensional space.
9.2.15.2 Elements

9.2.15.2.1 CartesianCurrentDisplacementOf Element

Function

Description

The CurrentDisplacementOf two Points relative to a CartesianSpatialFrame is a CartesianThreeVectorValue.

General Types

CurrentDisplacementOf

Features

clock : Clock {redefines clock}
displacementVector : CartesianThreeVectorValue {redefines displacementVector}
frame : CartesianSpatialFrame {redefines frame}
point1 : Point {redefines point1}
point2 : Point {redefines point2}

Constraints

None.

9.2.15.2.2 CartesianCurrentPositionOf Element

Function

Description

The CurrentPositionOf a Point relative to a CartesianSpatialFrame is a CartesianThreeVectorValue.

General Types

CurrentPositionOf

Features

clock : Clock {redefines clock}
frame : CartesianSpatialFrame {redefines frame}

Defaults to the localClock of the frame.
point : Point {redefines point}
positionVector : CartesianThreeVectorValue {redefines positionVector}

Constraints
None.

9.2.15.2.3 CartesianDisplacementOf

Element
Function

Description
The DisplacementOf two Points relative to a CartesianSpatialFrame is a CartesianThreeVectorValue.

General Types
DisplacementOf

Features
clock : Clock {redefines clock}
Defaults to the localClock of the frame.
displacementVector : CartesianThreeVectorValue {redefines displacementVector}
frame : CartesianSpatialFrame {redefines frame}
point1 : Point {redefines point1}
point2 : Point {redefines point2}
time : NumericalValue {redefines time}

Constraints
None.

9.2.15.2.4 CartesianPositionOf

Element
Function

Description
The PositionOf a Point relative to a CartesianSpatialFrame is a CartesianThreeVectorValue.

General Types
PositionOf
**Features**

clock : Clock {redefines clock}

Defaults to the localClock of the frame.

frame : CartesianSpatialFrame {redefines frame}

point : Point {redefines point}

positionVector : CartesianThreeVectorValue {redefines positionVector}

time : NumericalValue {redefines time}

**Constraints**

None.

**9.2.15.2.5 CartesianSpatialFrame**

**Element**

**Structure**

**Description**

A CartesianSpatialFrame is a SpatialFrame relative to which all position and displacement vectors can be represented as CartesianThreeVectorValues.

**General Types**

SpatialFrame

**Features**

None.

**Constraints**

None.

**9.2.15.2.6 CurrentDisplacementOf**

**Element**

**Function**

**Description**

The CurrentDisplacementOf two Points relative to a SpatialFrame and Clock is the DisplacementOf the Points relative to the SpatialFrame at the currentTime of the Clock.

**General Types**

Evaluation
Features

clock : Clock

Defaults to the *localClock* of the *frame*.

displacementVector : ThreeVectorValue

frame : SpatialFrame

point1 : Point

point2 : Point

Constraints

None.

9.2.15.2.7 CurrentPositionOf

Element

Function

Description

The *CurrentPositionOf* a *Point* relative to a *SpatialFrame* and a *Clock* is the *PositionOf* the *Point* relative to the *SpatialFrame* at the *currentTime* of the *Clock*.

General Types

Evaluation

Features

clock : Clock

Defaults to the *localClock* of the *frame*.

frame : SpatialFrame

point : Point

positionVector : ThreeVectorValue

Constraints

None.

9.2.15.2.8 defaultFrame

Element

Feature
Description

defaultFrame is a fixed SpatialFrame used as a universal default.

General Types

objects

DefaultFrameLife

Features

None.

Constraints

None.

9.2.15.2.9 DefaultFrameLife

Element

Structure

Description

DefaultFrameLife is the classifier of the singleton Life of the defaultFrame.

General Types

SpatialFrame

Life

Features

None.

Constraints

None.

9.2.15.2.10 DisplacementOf

Element

Function

Description

The DisplacementOf two Points relative to a SpatialFrame, at a specific time relative to a given Clock, is the displacementVector computed as the difference between the PositionOf the first Point and PositionOf the second Point, relative to that SpatialFrame, at that time.

General Types
Evaluation

Features

clock : Clock

Defaults to the localClock of the frame.

displacementVector : ThreeVectorValue

frame : SpatialFrame

point1 : Point

point2 : Point

time : NumericalValue

Constraints

zeroDisplacementConstraint

If either point1 or point2 occurs within the other, then the displacementVector is the zero vector.

(point1.spaceTimeEnclosedOccurrences->includes(point2) or point2.spaceTimeEnclosedOccurrences->includes(point1)) implies isZeroVector(displacementVector)

9.2.15.2.11 PositionOf

Element

Description

The PositionOf a Point relative to a SpatialFrame, at a specific time relative to a given Clock, as a positionVector that is a ThreeVectorValue.

General Types

Evaluation

Features

clock : Clock

Defaults to the localClock of the frame.

frame : SpatialFrame

point : Point

positionVector : ThreeVectorValue
time : NumericalValue

Constraints

positionTimePrecondition

The given point must exist at the given time.

TimeOf(point.startShot) <= time and
time <= TimeOf(point.endShot)

spacePositionConstraint

The result positionVector is equal to the PositionOf the Point spaceShot of the frame that encloses the given point, at the given time.

(frame.spaceShots as Point)->forAll{in p : Point;
   p.spaceTimeEnclosedOccurrences->includes(point) implies
   positionVector == PositionOf(p, time, frame)
}

9.2.15.2.12 SpatialFrame

Element

Structure

Description

A SpatialFrame is a three-dimensional Body that provides a spatial extent that acts as a frame of reference for defining the physical position and displacement vectors of Points over time.

General Types

Body

Features

None.

Constraints

None.

9.2.16 Metaobjects

9.2.16.1 Metaobjects Overview

This package defines Metaclasses and Features that are related to the typing of syntactic and semantic metadata.

9.2.16.2 Elements

9.2.16.2.1 Metaobject

Element
Metaobject

Description

A Metaobject contains syntactic or semantic information about one or more annotatedElements. It is the most general Metaclass. All other Metaclasses must subclassify it directly or indirectly.

General Types

Object

Features

annotatedElement : Element [1..*]

The Elements annotated by this Metaobject. This is set automatically when a Metaobject is instantiated as the value of a MetadataFeature.

Constraints

None.

9.2.16.2.2 metaobjects

Element

Feature

Description

metaobjects is a specialization of objects restricted to type Metaobject. It is the most general MetadataFeature. All other MetadataFeatures must subset it directly or indirectly.

General Types

objects

Metaobject

Features

None.

Constraints

None.

9.2.16.2.3 SemanticMetadata

Element

Metaobject

Description
SemanticMetadata is Metadata that requires its single annotatedElement to directly or indirectly specialize a baseType that models the semantics for the annotatedElement.

General Types

Metaobject

Features

annotatedElement : Type {redefines annotatedElement}

The single annotatedElement of this SemanticMetadata, which must be a Type.

baseType : Type

The required base Type for the annotatedElement.

Constraints

None.

9.2.17 KerML

This package contains a reflective KerML model of the KerML abstract syntax. It is generated from the normative MOF abstract syntax model (see 8.3) as follows.

1. The KerML model contains subpackages for Root, Core, and Kernel, but all elements are also imported into the top-level package, so they can be referenced directly from the KerML namespace.

2. A metaclass from the MOF model is mapped into a Metaclass in the KerML package.
   ◦ The MOF metaclass name is mapped unchanged.
   ◦ Generalizations of the MOF metaclass are mapped to ownedSpecializations.
   ◦ All properties from the MOF metaclass are mapped to features of the corresponding KerML Metaclass (see below). All non-association-end properties are grouped before association-end properties.

3. A property from the MOF model is mapped into a Feature.
   ◦ The following feature properties are set as appropriate:
     ▪ isAbstract = true if the MOF property is a derived union
     ▪ isComposite = true if the MOF property is composite.
     ▪ isReadonly = true if the MOF property is read-only.
     ▪ isDerived = true if the MOF property is derived.
   ◦ The MOF property name is mapped unchanged.
   ◦ The MOF property type is mapped to an ownedTyping relationship.
     ▪ If the MOF property type is a primitive type, the relationship is to the corresponding type from the ScalarValues package (see 9.3.2).
     ▪ If the MOF property type is a metaclass, the relationship is to the corresponding reflective Metaclass.
   ◦ The MOF property multiplicity is mapped to an owned MultiplicityRange with bounds given by LiteralExpressions.
   ◦ Subsetted properties from the MOF property are mapped to ownedSubsettings of the corresponding reflective Features.
   ◦ Redefined properties from the MOF property are mapped to ownedRedefinitions of the corresponding reflective Features.
If the MOF property is `annotatedElement`, then `Metaobject::annotatedElement` is added to the list of redefined properties for the mapping.

4. An enumeration from the MOF model is mapped into a `DataType`.
   - The MOF enumeration name is mapped unchanged.
   - Each enumeration literal from the MOF enumeration is mapped into an `ownedMember Feature` *(not an ownedFeature)*.
     - The MOF enumeration literal name is mapped unchanged.
     - The member `Feature` is given an owned `MultiplicityRange` of `1..1`.

Note that associations are not mapped from the MOF model and, hence, non-navigable association-owned end properties are not included in the reflective model.

### 9.3 Data Type Library

#### 9.3.1 Data Types Library Overview

The Data Types Library provides a standard set of commonly used `DataTypes` for scalar, vector and collection values.

#### 9.3.2 Scalar Values

##### 9.3.2.1 Scalar Values Overview

This package contains a basic set of primitive scalar (non-collection) data types. These include `Boolean` and `String` types and a hierarchy of concrete `Number` types, from the most general type of `Complex` numbers to the most specific type of `Positive` integers.

##### 9.3.2.2 Elements

#### 9.3.2.2.1 Boolean

**Element**

**DataType**

**Description**

`Boolean` is a `ScalarValue` type whose instances are true and false.

**General Types**

`ScalarValue`

**Features**

None.

**Constraints**

None.

#### 9.3.2.2.2 Complex

**Element**
**DataType**

**Description**

*Complex* is the type of complex numbers.

**General Types**

Number

**Features**

None.

**Constraints**

None.

**9.3.2.2.3 Integer**

**Element**

DataType

**Description**

*Integer* is the type of mathematical integers, extended with values for positive and negative infinity.

**General Types**

Rational

**Features**

None.

**Constraints**

None.

**9.3.2.2.4 Natural**

**Element**

DataType

**Description**

*Natural* is the type of non-negative integers, extended with a value for positive infinity.

**General Types**

Integer

**Features**
9.3.2.2.5 Number

Element

DataType

Description

Number is the base type for all NumericalValue types that represent numbers.

General Types

NumericalValue

Features

None.

Constraints

None.

9.3.2.2.6 NumericalValue

Element

DataType

Description

NumericalValue is the base type for all ScalarValue types that represent numerical values.

General Types

ScalarValue

Features

None.

Constraints

None.

9.3.2.2.7 Positive

Element

DataType
Description

Positive is the type of positive integers (not including zero), extended with a value for positive infinity.

General Types

Natural

Features

None.

Constraints

None.

9.3.2.2.8 Rational

Element

DataType

Description

Rational is the type of rational numbers, extended with values for positive and negative infinity.

General Types

Real

Features

None.

Constraints

None.

9.3.2.2.9 Real

Element

DataType

Description

Real Real is the type of mathematical (extended) real numbers. This includes both rational and irrational numbers, and values for positive and negative infinity.

General Types

Complex

Features
None.

Constraints
None.

9.3.2.2.10 ScalarValue

Element
DataType

Description
A ScalarValue is a DataValue whose instances are considered to be primitive, not collections or structures of other values.

General Types
DataValue

Features
None.

Constraints
None.

9.3.2.2.11 String

Element
DataType

Description
String is a ScalarValue type whose instances are strings of characters.

General Types
ScalarValue

Features
None.

Constraints
None.

9.3.3 Collections
9.3.3.1 Collections Overview

This package defines a standard set of Collection data types. Unlike sequences of values defined directly using multiplicity, these data types allow for the possibility of collections as elements of collections.

9.3.3.2 Elements

9.3.3.2.1 Array

Element

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.

Feature elements is a flattened sequence of all elements of an Array and can be accessed by a tuple of indices. The number of indices is equal to rank. The elements are packed according to row-major convention, as in the C programming language.

Note 1. Feature dimensions may be empty, which denotes a zero dimensional Array, allowing an Array to collapse to a single element. This is useful to allow for specialization of an Array into a type restricted to represent a scalar. The flattenedSize of a zero dimensional Array is 1.

Note 2. An Array can also represent the generalized concept of a mathematical matrix of any rank, i.e. not limited to rank two.

General Types

OrderedCollection

Features

dimensions : Positive [0..*] {ordered, nonunique}

flattenedSize : Positive

rank : Natural

Constraints

sizeConstraint

flattenedSize == size(elements)

9.3.3.2.2 Bag

Element

DataType
Description

A Bag is a variable size Collection of which the elements are unordered and nonunique.

General Types

Collection

Features

None.

Constraints

None.

9.3.3.2.3 Collection

Element

DataType

Description

A Collection is an abstract DataType that represents a collection of elements of a given type.

General Types

Anything

Features

elements : Anything [0..*] {nonunique}

Constraints

None.

9.3.3.2.4 KeyValuePair

Element

DataType

Description

A KeyValuePair is an abstract DataType that represents a tuple of a key and an associated value val.

General Types

DataValue

Features

key : Anything
val : Anything

Constraints
None.

9.3.3.2.5 List

Element

DataType

Description
A List is a variable size Collection of which the elements are nonunique and ordered.

General Types
OrderedCollection

Features
None.

Constraints
None.

9.3.3.2.6 Map

Element

DataType

Description
A Map is a variable size Collection of which the elements are Key Value Pairs. The keys must be unique within in the Map. The values need not be unique.

General Types
UniqueCollection

Features

elements : KeyValuePair [0..*] {redefines elements}

Constraints
None.

9.3.3.2.7 OrderedCollection

Element
Data Type

**Description**

An **OrderedCollection** is a **Collection** of which the **elements** are ordered and not necessarily unique.

**General Types**

**Collection**

**Features**

elements : Anything [0..*] {redefines elements, ordered, nonunique}

**Constraints**

None.

### 9.3.3.2.8 OrderedMap

**Element**

**DataType**

**Description**

An **OrderedMap** is a variable size **Map** that maintains ordering of its elements.

The ordering may be by key of the **KeyValuePair** elements, or by order of construction, or any other method. The essential aspect is that ordering is maintained and guaranteed across accesses to the **OrderedMap**.

**General Types**

OrderedCollection

**Map**

**Features**

elements : KeyValuePair [0..*] {redefines elements, ordered}

**Constraints**

None.

### 9.3.3.2.9 OrderedSet

**Element**

**DataType**

**Description**

An **OrderedSet** is a variable size **Collection** of which the **elements** are unique and ordered.
General Types
OrderedCollection
UniqueCollection

Features

elements : Anything [0..*] {redefines elements, ordered}

Constraints

None.

9.3.3.2.10 Set

Element

DataType

Description

A Set is a variable size Collection of which the elements are unique and unordered.

General Types
UniqueCollection

Features

None.

Constraints

None.

9.3.3.2.11 UniqueCollection

Element

DataType

Description

A UniqueCollection is a Collection of which the elements are unique and not necessarily ordered.

General Types
Collection

Features

elements : Anything [0..*] {redefines elements}

Constraints
9.3.4 Vector Values

9.3.4.1 Vector Values Overview

9.3.4.2 Elements

9.3.4.2.1 CartesianThreeVectorValue

Element

DataType

Description

A `CartesianThreeVectorValue` is a `NumericalVectorValue` that is both Cartesian and has dimension 3.

General Types

CartesianVectorValue

ThreeVectorValue

Features

None.

Constraints

None.

9.3.4.2.2 CartesianVectorValue

Element

DataType

Description

A `CartesianVectorValue` is a `NumericalVectorValue` for which there are specific implementations in `VectorFunctions` of the abstract vector-space functions.

Note: The restriction of the element type to `Real` is to facilitate the complete definition of these functions.

General Types

NumericalVectorValue

Features

`elements : Real [0..*]` {redefines elements}

Constraints

None.
9.3.4.2.3 NumericalVectorValue

Element

DataType

Description

A `NumericalVectorValue` is a kind of `VectorValue` that is specifically represented as a one-dimensional `Array` of `NumericalValues`. The dimension is allowed to be empty, permitting a `NumericalVectorValue` of rank 0, which is essentially isomorphic to a scalar `NumericalValue`.

General Types

Array

VectorValue

Features

dimension : Positive [0..1] {redefines dimensions}

elements : NumericalValue [0..*] {redefines elements}

Constraints

None.

9.3.4.2.4 ThreeVectorValue

Element

DataType

Description

A `ThreeVectorValue` is a `NumericalVectorValue` that has dimension 3.

General Types

NumericalVectorValue

Features

dimension : Positive [0..*] {redefines elements}

Constraints

None.

9.3.4.2.5 VectorValue

Element

DataType
Description

A `VectorValue` is an abstract data type whose values may be operated on using `VectorFunctions`.

General Types

None.

Features

None.

Constraints

None.

9.4 Function Library

The Function Library includes library models of basic Functions that operate on DataTypes from the Data Type Library (see 9.3). The KerML operator expression notation translates to invocations of some of these library Functions. It is expected that other languages built on KerML will provide additional domain models as needed by their applications, which can include specializations of the library Functions for domain-specific DataTypes. The same KerML concrete syntax for Expressions can be used with these specialized Functions and DataTypes, extended with domain-specific semantics.

9.4.1 Function Library Overview

The Function Library includes library models of basic Functions that operate on DataTypes from the Data Type Library (see 9.3). The KerML operator expression notation translates to invocations of some of these library Functions. It is expected that other languages built on KerML will provide additional domain models as needed by their applications, which can include specializations of the library Functions for domain-specific DataTypes. The same KerML concrete syntax for Expressions can be used with these specialized Functions and DataTypes, extended with domain-specific semantics.

9.4.2 Base Functions

9.4.2.1 Base Functions Overview

This package defines a basic set of Functions defined on all kinds of values. Most correspond to similarly named operators in the KerML expression notation.

9.4.2.2 Elements

```plaintext
abstract function '=='{
    in x: Anything[0..1];
    in y: Anything[0..1];
    return : Boolean[1];
}

function '!='{
    in x: Anything[0..1];
    in y: Anything[0..1];
    return : Boolean[1] = not (x == y);
}

abstract function '==='{
```
in x: Anything[0..1];
in y: Anything[0..1];
return : Boolean[1];
}

function '!=='{
in x: Anything[0..1];
in y: Anything[0..1];
return : Boolean[1] = not (x === y);
}

function ToString{
in x: Anything[0..1];
return : String;
}

function '['{
in x: Anything[0..*] nonunique;
in y: Anything[0..*] nonunique;
return : Anything[0..*] nonunique;
}

function '#'{
in seq: Anything[0..*] ordered nonunique;
in index: Positive[1..*] ordered nonunique;
return : Anything[0..1];
}

function ','{
in seq1: Anything[0..*] ordered nonunique;
in seq2: Anything[0..*] ordered nonunique;
return : Anything[0..*] ordered nonunique;
}

abstract function 'all'{
return : Object[0..*];
}

abstract function 'istype'{
in seq: Anything[0..*];
abstract feature 'type': Anything;
return : Boolean[1];
}

abstract function 'hastype'{
in seq: Anything[0..*];
abstract feature 'type': Anything;
return : Boolean;
}

abstract function '@'{
in seq: Anything[0..*];
abstract feature 'type': Anything;
return : Boolean[1];
}

abstract function '@@'{
in seq: Metaobject[0..*];
abstract feature 'type': Metaobject;
return : Boolean[1];
}
9.4.3 Data Functions

9.4.3.1 Data Functions Overview

This package defines the abstract base functions corresponding to all the unary and binary operators in the KerML expression notation that might be defined on various kinds of DataValues.

9.4.3.2 Elements

abstract function 'as' {
    in seq: Anything[0..*] ordered nonunique;
    return : Anything[0..*] ordered nonunique;
}

abstract function 'meta' {
    in seq: Metaobject[0..*] ordered nonunique;
    return : Metaobject[0..*] ordered nonunique;
}
9.4.4 Scalar Functions

9.4.4.1 Scalar Functions Overview

This package defines abstract Functions that specialize the DataFunctions for use with ScalarValues.

9.4.4.2 Elements

abstract function '+' specializes DataFunctions::'+'
   { in x: ScalarValue[1]; in y: ScalarValue[0..1]; return : ScalarValue[1]; }  
abstract function '-' specializes DataFunctions::'-'
   { in x: ScalarValue[1]; in y: ScalarValue[0..1]; return : ScalarValue[1]; }  
abstract function '*' specializes DataFunctions::'*'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '/' specializes DataFunctions::'/'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '**' specializes DataFunctions::'**'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '^' specializes DataFunctions::'^'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '%' specializes DataFunctions::'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function 'not' specializes DataFunctions::'not'
   { in x: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function 'xor' specializes DataFunctions::'xor'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '-' specializes DataFunctions::'-'
   { in x: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '|' specializes DataFunctions::'|
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '&' specializes DataFunctions::'&'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function '<' specializes DataFunctions::'<'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : Boolean[1]; }  
abstract function '>' specializes DataFunctions::'>'
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : Boolean[1]; }  
abstract function '<=' specializes DataFunctions::'<='
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : Boolean[1]; }  
abstract function '>=' specializes DataFunctions::'>='
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : Boolean[1]; }  
abstract function max specializes DataFunctions::max
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }  
abstract function min specializes DataFunctions::min
   { in x: ScalarValue[1]; in y: ScalarValue[1]; return : ScalarValue[1]; }
abstract function '..' specializes DataFunctions::'..'
    { in lower: ScalarValue[1]; in upper: ScalarValue[1];
      return : ScalarValue[0..*]; }}

9.4.5 Boolean Functions

9.4.5.1 Boolean Functions Overview

This package defines Functions on Boolean values, including those corresponding to (non-conditional) logical operators in the KerML expression notation.

9.4.5.2 Elements

function 'not' specializes ScalarFunctions::'not'
    { in x: Boolean[1]; return : Boolean[1]; } 
function 'xor' specializes ScalarFunctions::'xor'
    { in x: Boolean[1]; in y: Boolean[1]; return : Boolean[1]; } 
function '|' specializes ScalarFunctions::'|'
    { in x: Boolean[1]; in y: Boolean[1]; return : Boolean[1]; } 
function '&' specializes ScalarFunctions::'&'
    { in x: Boolean[1]; in y: Boolean[1]; return : Boolean[1]; } 
function '==' specializes DataFunctions::'=='
    { in x: Boolean[0..1]; in y: Boolean[0..1]; return : Boolean[1]; } 
function ToString specializes BaseFunctions::ToString
    { in x: Boolean[1]; return : String[1]; } 
function ToBoolean
    { in x: String[1]; return : Boolean[1]; } 

9.4.6 String Functions

9.4.6.1 String Functions Overview

This package defines Functions on String values, including those corresponding to string concatenation and comparison operators in the KerML expression notation.

9.4.6.2 Elements

function '+' specializes ScalarFunctions::'+'
    { in x: String[1]; in y: String[1]; return : String[1]; } 
function Length
    { in x: String[1]; return : Natural[1]; } 
function Substring
    { in x: String[1]; in lower: Integer[1]; in upper: Integer[1];
      return : String[1]; } 
function '<' specializes ScalarFunctions::'<'
    { in x: String[1]; in y: String[1]; return : Boolean[1]; } 
function '>' specializes ScalarFunctions::'>'
    { in x: String[1]; in y: String[1]; return : Boolean[1]; } 
function '<=' specializes ScalarFunctions::'<='
    { in x: String[1]; in y: String[1]; return : Boolean[1]; } 
function '>=' specializes ScalarFunctions::'>='
    { in x: String[1]; in y: String[1]; return : Boolean[1]; } 
function '==' specializes DataFunctions::'=='
9.4.7 Numerical Functions

9.4.7.1 Numerical Functions Overview

This package defines abstract Functions on Numerical values for general arithmetic and comparison operations.

9.4.7.2 Elements

abstract function isZero
{ in x: NumericalValue[1]; return : Boolean; }

abstract function isUnit
{ in x : NumericalValue[1]; return : Boolean; }

abstract function abs
{ in x: NumericalValue[1]; return : NumericalValue[1]; }

abstract function '+' specializes ScalarFunctions::'+'
{ in x: NumericalValue[1]; in y: NumericalValue[0..1];
return : NumericalValue[1]; }

abstract function '-' specializes ScalarFunctions::'-'
{ in x: NumericalValue[1]; in y: NumericalValue[0..1];
return : NumericalValue[1]; }

abstract function '*' specializes ScalarFunctions::'*'
{ in x: NumericalValue[1]; in y: NumericalValue[1];
return : NumericalValue[1]; }

abstract function '/' specializes ScalarFunctions::'/'
{ in x: NumericalValue[1]; in y: NumericalValue[1];
return : NumericalValue[1]; }

abstract function '**' specializes ScalarFunctions::'**'
{ in x: NumericalValue[1]; in y: NumericalValue[1];
return : NumericalValue[1]; }

abstract function '^' specializes ScalarFunctions::'^'
{ in x: NumericalValue[1]; in y: NumericalValue[1];
return : NumericalValue[1]; }

abstract function '%' specializes ScalarFunctions::'%'
{ in x: NumericalValue[1]; in y: NumericalValue[1];
return : NumericalValue[1]; }

abstract function '<' specializes ScalarFunctions::'<'
{ in x: NumericalValue[1]; in y: NumericalValue[1]; return : Boolean[1]; }

abstract function '>' specializes ScalarFunctions::'>'
{ in x: NumericalValue[1]; in y: NumericalValue[1]; return : Boolean[1]; }

abstract function '<=' specializes ScalarFunctions::'<='
{ in x: NumericalValue[1]; in y: NumericalValue[1]; return : Boolean[1]; }

abstract function '>=' specializes ScalarFunctions::'>='
{ in x: NumericalValue[1]; in y: NumericalValue[1]; return : Boolean[1]; }

abstract function max specializes ScalarFunctions::max
{ in x: NumericalValue[1]; in y: NumericalValue[1];
return : NumericalValue[1]; }

abstract function min specializes ScalarFunctions::min
{ in x: NumericalValue[1]; in y: NumericalValue[1];
return : NumericalValue[1]; }

abstract function sum
9.4.8 Complex Functions

9.4.8.1 Complex Functions Overview

This package defines Functions on Complex values, including concrete specializations of the general arithmetic and comparison operations.

9.4.8.2 Elements

feature i: Complex[1] = rect(0.0, 1.0);

function rect
    { in re: Real[1]; in im: Real[1]; return : Complex[1]; }
function polar
    { in abs: Real[1]; in arg: Real[1]; return : Complex[1]; }

function re
    { in x: Complex[1]; return : Real[1]; }
function im
    { in x: Complex[1]; return : Real[1]; }

function isZero specializes NumericalFunctions::isZero
    { in x: Complex[1]; return : Boolean[1]; }
function isUnit specializes NumericalFunctions::isUnit
    { in x: Complex[1]; return : Boolean[1]; }

function abs specializes NumericalFunctions::abs
    { in x: Complex[1]; return : Real[1]; }
function arg
    { in x: Complex[1]; return : Real[1]; }

function '+' specializes NumericalFunctions::'+'
    { in x: Complex[1]; in y: Complex[0..1]; return : Complex[1]; }
function '-' specializes NumericalFunctions::'-'
    { in x: Complex[1]; in y: Complex[0..1]; return : Complex[1]; }
function '*' specializes NumericalFunctions::'*'
    { in x: Complex[1]; in y: Complex[1]; return : Complex[1]; }
function '/' specializes NumericalFunctions::'/'
    { in x: Complex[1]; in y: Complex[1]; return : Complex[1]; }
function '**' specializes NumericalFunctions::'**'
    { in x: Complex[1]; in y: Complex[1]; return : Complex[1]; }
function '^' specializes NumericalFunctions::'^'
    { in x: Complex[1]; in y: Complex[1]; return : Complex[1]; }

function '==' specializes DataFunctions::'=='
    { in x: Complex[0..1]; in y: Complex[0..1]; return : Boolean[1]; }

function ToString specializes BaseFunctions::ToString
    { in x: Complex[1]; return : String[1]; }
function ToComplex
    { in x: String[1]; return : Complex[1]; }

function sum specializes NumericalFunctions::sum
    { in collection: Complex[0..*]; return : Complex[1]; }
9.4.9 Real Functions

9.4.9.1 Real Functions Overview

This package defines Functions on Real values, including concrete specializations of the general arithmetic and comparison operations.

9.4.9.2 Elements

function re :> ComplexFunctions::re
   { in x: Real[1]; return : Real[1] = x; }
function im :> ComplexFunctions::im
   { in x: Real[1]; return : Real[1] = 0.0; }
function abs specializes ComplexFunctions::abs
   { in x: Real[1]; return : Real[1] = 0.0; }
function arg specializes ComplexFunctions::arg
   { in x: Real[1]; return : Real[1] = 0.0; }
function '+' specializes ComplexFunctions::'+'
   { in x: Real[1]; in y: Real[0..1]; return : Real[1]; }
function '-' specializes ComplexFunctions::'-'
   { in x: Real[1]; in y: Real[0..1]; return : Real[1]; }
function '*' specializes ComplexFunctions::'*'
   { in x: Real[1]; in y: Real[1]; return : Real[1]; }
function '/' specializes ComplexFunctions::'/'
   { in x: Real[1]; in y: Real[1]; return : Real[1]; }
function '**' specializes ComplexFunctions::'^'
   { in x: Real[1]; in y: Real[1]; return : Real[1]; }
function '<' specializes NumericalFunctions::'<'
   { in x: Real[1]; in y: Real[1]; return : Boolean[1]; }
function '>' specializes NumericalFunctions::'>'
   { in x: Real[1]; in y: Real[1]; return : Boolean[1]; }
function '<=' specializes NumericalFunctions::'<='
   { in x: Real[1]; in y: Real[1]; return : Boolean[1]; }
function '>=' specializes NumericalFunctions::'>'
   { in x: Real[1]; in y: Real[1]; return : Boolean[1]; }
function max specializes NumericalFunctions::max
   { in x: Real[1]; in y: Real[1]; return : Real[1]; }
function min specializes NumericalFunctions::min
   { in x: Real[1]; in y: Real[1]; return : Real[1]; }
function '==' specializes ComplexFunctions::'=='
   { in x: Real[0..1]; in y: Real[0..1]; return : Boolean[1]; }
function sqrt
   { in x: Real[1]; return : Real[1]; }
function floor
   { in x: Real[1]; return : Integer[1]; }
function round
   { in x: Real[1]; return : Integer[1]; }
function ToString specializes ComplexFunctions::ToString
    { in x: Real[1]; return : String[1]; }
function ToInteger
    { in x: Real[1]; return : Integer[1]; }
function ToRational
    { in x: Real[1]; return : Rational[1]; }
function ToReal
    { in x: String[1]; return : Real[1]; }

function sum specializes ComplexFunctions::sum
    { in collection: Real[0..*]; return : Real; }

function product specializes ComplexFunctions::product
    { in collection: Real[0..*]; return : Real; }

9.4.10 Rational Functions

9.4.10.1 Rational Functions Overview

This package defines Functions on Rational values, including concrete specializations of the general arithmetic and comparison operations.

9.4.10.2 Elements

function rat
    { in numer: Integer[1]; in denum: Integer[1]; return : Rational[1]; }
function numer
    { in rat: Rational[1]; return : Integer[1]; }
function denom
    { in rat: Rational[1]; return : Integer[1]; }

function abs specializes RealFunctions::abs
    { in x: Rational[1]; return : Rational[1]; }
function '+' specializes RealFunctions::'+'
    { in x: Rational[1]; in y: Rational[0..1]; return : Rational[1]; }
function '-' specializes RealFunctions::'-' 
    { in x: Rational[1]; in y: Rational[0..1]; return : Rational[1]; }
function '*' specializes RealFunctions::'*'
    { in x: Rational[1]; in y: Rational[1]; return : Rational[1]; }
function '/' specializes RealFunctions::'/'
    { in x: Rational[1]; in y: Rational[1]; return : Rational[1]; }
function '**' specializes RealFunctions::''
    { in x: Rational[1]; in y: Rational[1]; return : Rational[1]; }
function '^' specializes RealFunctions::''
    { in x: Rational[1]; in y: Rational[1]; return : Rational[1]; }
function '<' specializes RealFunctions::'<'
    { in x: Rational[1]; in y: Rational[1]; return : Boolean[1]; }
function '>' specializes RealFunctions::'>'
    { in x: Rational[1]; in y: Rational[1]; return : Boolean[1]; }
function '<=' specializes RealFunctions::'='
    { in x: Rational[1]; in y: Rational[1]; return : Boolean[1]; }
function '>=' specializes RealFunctions::'='
    { in x: Rational[1]; in y: Rational[1]; return : Boolean[1]; }

function max specializes RealFunctions::max
    { in x: Rational[1]; in y: Rational[1]; return : Rational[1]; }
function min specializes RealFunctions::min
    { in x: Rational[1]; in y: Rational[1]; return : Rational[1]; }
function '==' specializes RealFunctions::'=='
    { in x: Rational[0..1]; in y: Rational[0..1]; return : Boolean[1]; } 

function gcd
    { in x: Rational[1]; in y: Rational[1]; return : Integer[1]; }

function floor specializes RealFunctions::floor
    { in x: Rational[1]; return : Integer[1]; }

function round specializes RealFunctions::round
    { in x: Rational[1]; return : Integer[1]; }

function ToString specializes RealFunctions::ToString
    { in x: Rational[1]; return : String[1]; }

function ToInteger
    { in x: Rational[1]; return : Integer[1]; }

function ToRational
    { in x: String[1]; return : Rational[1]; }

function sum specializes RealFunctions::sum
    { in collection: Rational[0..*]; return : Rational[1]; }

function product specializes RealFunctions::product
    { in collection: Rational[0..*]; return : Rational[1]; }

9.4.11 Integer Functions

9.4.11.1 Integer Functions Overview

This package defines Functions on Integer values, including concrete specializations of the general arithmetic and comparison operations.

9.4.11.2 Elements

function abs specializes RationalFunctions::abs
    { in x: Integer[1]; return : Natural[1]; }

function '+' specializes RationalFunctions::'+'
    { in x: Integer[1]; in y: Integer[0..1]; return : Integer[1]; }

function '-' specializes RationalFunctions::'-'
    { in x: Integer[1]; in y: Integer[0..1]; return : Integer[1]; }

function '*' specializes RationalFunctions::'*'
    { in x: Integer[1]; in y: Integer[1]; return : Integer[1]; }

function '/' specializes RationalFunctions::'/'
    { in x: Integer[1]; in y: Integer[1]; return : Rational[1]; }

function '**' specializes RationalFunctions::'**'
    { in x: Integer[1]; in y: Natural[1]; return : Integer[1]; }

function '^' specializes RationalFunctions::'^'
    { in x: Integer[1]; in y: Natural[1]; return : Integer[1]; }

function '%' specializes NumericalFunctions::'%' 
    { in x: Integer[1]; in y: Integer[1]; return : Integer[1]; }

function '<' specializes RationalFunctions::'<'
    { in x: Integer[1]; in y: Integer[1]; return : Boolean[1]; }

function '>' specializes RationalFunctions::'>'
    { in x: Integer[1]; in y: Integer[1]; return : Boolean[1]; }

function '<=' specializes RationalFunctions::'<='
    { in x: Integer[1]; in y: Integer[1]; return : Boolean[1]; }

function '>=' specializes RationalFunctions::'='
    { in x: Integer[1]; in y: Integer[1]; return : Boolean[1]; }
function max specializes RationalFunctions::max
  { in x: Integer[1]; in y: Integer[1]; return : Integer[1]; }
function min specializes RationalFunctions::min
  { in x: Integer[1]; in y: Integer[1]; return : Integer[1]; }

function '==' specializes DataFunctions::'=='
  { in x: Integer[0..1]; in y: Integer[0..1]; return : Boolean[1]; }

function '..' specializes ScalarFunctions:'..
  { in lower: Integer[1]; in upper: Integer[1]; return : Integer[0..*]; }

function ToString specializes RationalFunctions::ToString
  { in x: Integer[1]; return : String[1]; }
function ToNatural
  { in x: Integer[1]; return : Natural[1]; }
function ToInteger
  { in x: String[1]; return : Integer[1]; }

function sum specializes RationalFunctions::sum
  { in collection: Integer[0..*]; return : Integer[1]; }
function product specializes RationalFunctions::product
  { in collection: Integer[0..*]; return : Integer[1]; }

9.4.12 Natural Functions

9.4.12.1 Natural Functions Overview

This package defines Functions on Natural values, including concrete specializations of the general arithmetic and comparison operations.

9.4.12.2 Elements

function '+' specializes IntegerFunctions::'+'
  { in x: Natural[1]; in y: Natural[0..1]; return : Natural[1]; }
function '*' specializes IntegerFunctions:'*'
  { in x: Natural[1]; in y: Natural[1]; return : Natural[1]; }
function '/' specializes IntegerFunctions:'/'
  { in x: Natural[1]; in y: Natural[1]; return : Natural[1]; }
function '%' specializes IntegerFunctions:'%
  { in x: Natural[1]; in y: Natural[1]; return : Natural[1]; }

function '<' specializes IntegerFunctions:'<'
  { in x: Natural[1]; in y: Natural[1]; return : Boolean[1]; }
function '>' specializes IntegerFunctions:'>'
  { in x: Natural[1]; in y: Natural[1]; return : Boolean[1]; }
function '<=' specializes IntegerFunctions:'<='
  { in x: Natural[1]; in y: Natural[1]; return : Boolean[1]; }
function '>=' specializes IntegerFunctions:'>='
  { in x: Natural[1]; in y: Natural[1]; return : Boolean[1]; }

function max specializes IntegerFunctions::max
  { in x: Natural[1]; in y: Natural[1]; return : Natural[1]; }
function min specializes IntegerFunctions::min
  { in x: Natural[1]; in y: Natural[1]; return : Natural[1]; }

function '==' specializes IntegerFunctions::'=='
  { in x: Natural[0..1]; in y: Natural[0..1]; return : Boolean[1]; }
function ToString specializes IntegerFunctions::ToString
    { in x: Natural[1]; return : String[1]; } 
function ToNatural
    { in x: String[1]; return : Natural[1]; } 

9.4.13 Trig Functions

9.4.13.1 Trig Functions Overview

This package defines basic trigonometric functions on real numbers.

9.4.13.2 Elements

feature pi : Real;
inv piPrecision { RealFunctions::round(pi * 1E20) == 314159265358979323846.0 } 

function deg {
    in theta_rad : Real[1];
    return : Real[1] = theta_rad * 180 / pi;
}
function rad {
    in theta_deg : Real;
    return : Real[1] = theta_deg * pi / 180;
}

datatype UnitBoundedReal :> Real {
    inv unitBound { -1.0 <= that & that <= 1.0 }
}

function sin {
    in theta : Real[1];
    return : UnitBoundedReal[1];
}
function cos {
    in theta : Real[1];
    return : UnitBoundedReal[1];
}
function tan {
    in theta : Real[1];
    return : Real = sin(theta) / cos(theta);
}
function cot {
    in theta : Real;
    return : Real = cos(theta) / sin(theta);
}

function arcsin {
    in x : UnitBoundedReal[1];
    return : Real[1];
}
function arccos {
    in x : UnitBoundedReal[1];
    return : Real[1];
}
function arctan {
    in x : Real[1];
    return : Real[1];
}
9.4.14 Sequence Functions

9.4.14.1 Sequence Functions Overview

This package defines Functions that operate on general sequences of values. (For Functions that operate on Collection values, see CollectionFunctions.)

9.4.14.2 Elements

```plaintext
function '#' specializes BaseFunctions::'#' {  
    in seq: Anything[0..*] ordered nonunique;  
    in index: Positive[1];  
    return : Anything[0..1];  
}

function equals{  
    in x: Anything[0..*] ordered nonunique;  
    in y: Anything[0..*] ordered nonunique;  
    return : Boolean[1];  
}

function same{  
    in x: Anything[0..*] ordered nonunique;  
    in y: Anything[0..*] ordered nonunique;  
    return : Boolean[1];  
}

function size{  
    in seq: Anything[0..*] nonunique;  
    return : Natural[1];  
}

function isEmpty{  
    in seq: Anything[0..*] nonunique;  
    return : Boolean[1];  
}

function notEmpty{  
    in seq: Anything[0..*] nonunique;  
    return : Boolean[1];  
}

function includes{  
    in seq1: Anything[0..*] nonunique;  
    in seq2: Anything[0..*] nonunique;  
    return : Boolean[1];  
}

function includesOnly{  
    in seq1: Anything[0..*] nonunique;  
    in seq2: Anything[0..*] nonunique;  
    return : Boolean[1];  
}

function excludes{  
    in seq1: Anything[0..*] nonunique;  
    in seq2: Anything[0..*] nonunique;  
    return : Boolean[1];  
}

function union{  
    in seq1: Anything[0..*] ordered nonunique;  
    in seq2: Anything[0..*] ordered nonunique;  
    return : Anything[0..*] ordered nonunique;  
}
```

Kernel Modeling Language (KerML) v1.0 Beta 1
function intersection{
    in seq1: Anything[0..*] ordered nonunique;
    in seq2: Anything[0..*] ordered nonunique;
    return : Anything[0..*] ordered nonunique;
}

function including{
    in seq1: Anything[0..*] ordered nonunique;
    in seq2: Anything[0..*] ordered nonunique;
    return : Anything[0..*] ordered nonunique;
}

function includingAt{
    in seq1: Anything[0..*] ordered nonunique;
    in seq2: Anything[0..*] ordered nonunique;
    in index: Positive[1];
    return : Anything[0..*] ordered nonunique;
}

function excluding{
    in seq1: Anything[0..*] ordered nonunique;
    in seq2: Anything[0..*] ordered nonunique;
    return : Anything[0..*] ordered nonunique;
}

function excludingAt{
    in seq1: Anything[0..*] ordered nonunique;
    in seq2: Anything[0..*] ordered nonunique;
    in startIndex: Positive[1];
    in endIndex: Positive[1] default startIndex;
    return : Anything[0..*] ordered nonunique;
}

function subsequence{
    in seq: Anything[0..*] ordered nonunique;
    in startIndex: Positive[1];
    in endIndex: Positive[1] default size(seq);
    return : Anything[0..*];
}

function head{
    in seq: Anything[0..*] ordered nonunique;
    return : Anything[0..1] = seq[1];
}

function tail{
    in seq: Anything[0..*] ordered nonunique;
    return : Anything[0..*] ordered nonunique;
}

function last{
    in seq: Anything[0..*] ordered nonunique;
    return : Anything[0..1];
}

behavior add {
    inout seq: Anything[0..*] ordered nonunique;
    in values: Anything[0..*] ordered nonunique;
}

behavior addAt {
    inout seq: Anything[0..*] ordered nonunique;
    in values: Anything[0..*] ordered nonunique;
    in index: Positive[1];
}
behavior remove{
    inout seq: Anything[0..*] ordered nonunique;
    in values: Anything[0..*];
}
behavior removeAt{
    inout seq: Anything[0..*] ordered nonunique;
    in startIndex: Positive[1];
    in endIndex: Positive[1] default startIndex;
}

9.4.15 Collection Functions

9.4.15.1 Collection Functions Overview

This package defines Functions on Collections (as defined in the Collections package). For Functions on general sequences of values, see the SequenceFunctions package.

9.4.15.2 Elements

function '==' specializes BaseFunctions::'==' {
    in col1: Collection[0..1];
    in col2: Collection[0..1];
    return : Boolean[1];
}

function size {
    in col: Collection[1];
    return : Natural[1];
}

function isEmpty {
    in col: Collection[1];
    return : Boolean[1];
}

function notEmpty {
    in col: Collection[1];
    return : Boolean[1];
}

function contains {
    in col: Collection[1];
    in values: Anything[*];
    return : Boolean[1];
}

function containsAll {
    in col1: Collection[1];
    in col2: Collection[2];
    return : Boolean[1];
}

function head {
    in col: OrderedCollection[1];
    return : Anything[0..1];
}

function tail {
    in col: OrderedCollection[1];
    return : Anything[0..*] ordered nonunique;
function last {  
    in col: OrderedCollection[1];  
    return : Anything[0..1];  
}

function '#' specializes BaseFunctions::'#' {  
    in col: OrderedCollection[1];  
    in index: Positive[1];  
    return : Anything[0..1];  
}

function 'array#' specializes BaseFunctions::'#' {  
    in arr: Array[1];  
    in indexes: Positive[n] ordered nonunique;  
    return : Anything[0..1];  
    private feature n: Natural[1] = arr.rank;  
}

9.4.16 Vector Functions

9.4.16.1 Vector Functions Overview

This package defines abstract functions on VectorValues corresponding to the algebraic operations provided by a vector space with inner product. It also includes concrete implementations of these functions specifically for CartesianVectorValues.

9.4.16.2 Elements

abstract function isZeroVector {  
    doc  
    /*  
    * Return whether a VectorValue is a zero vector.  
    */  
    in v: VectorValue[1];  
    return : Boolean[1];  
}

abstract function '+' specializes DataFunctions::'+' {  
    doc  
    /*  
    * With two arguments, returns the sum of two VectorValues.  
    * With one argument, returns that VectorValue.  
    */  
    in v: VectorValue[1];  
    in w: VectorValue[0..1];  
    return u: VectorValue[1];  
    inv zeroAddition { w == null or isZeroVector(w) implies u == w }  
    inv commutivity { w != null implies u == w + v }  
}

abstract function '-' specializes DataFunctions::'- ' {  
    doc  
    /*  
    * With two arguments, returns the difference of two VectorValues.  
    * With one arguments, returns the inverse

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* of the given VectorValue, that is, the VectorValue that,
* when added to the original VectorValue, results in
* the zeroVector.
*/

in v: VectorValue[1];
in w: VectorValue[0..1];
return u: VectorValue[1];
inv negation { w == null implies isZeroVector(v + u) }
inv difference { w != null implies v + u == w }
}

abstract function sum0 {
  doc
  /*
   * Return the sum of a collection of VectorValues.
   * If the collection is empty, return a given zero vector.
   */
  
in coll: VectorValue[*] nonunique;
in zero: VectorValue[1];
inv precondition { isZeroVector(zero) }
return s: VectorValue[1] = coll->reduce '+' ?? zero;
}

/* Functions specific to NumericalVectorValues. */

function VectorOf {
  doc
  /*
   * Construct a NumericalVectorValue whose elements are a
   * non-empty list of component NumericalValues.
   * The dimension of the NumericalVectorValue is equal to
   * the number of components.
   */
  
in components: NumericalValue[1..*] ordered nonunique;
return : NumericalVectorValue[1] {
  >>> dimension = size(components);
  >>> elements = components;
}
}

abstract function scalarVectorMult specializes DataFunctions::'*' {
  doc
  /*
   * Scalar product of a NumericalValue and a NumericalVectorValue.
   */
  
in x: NumericalValue[1];
in v: NumericalVectorValue[1];
return w: NumericalVectorValue[1];
inv scaling { norm(w) == x * norm(v) }
inv zeroLength { isZeroVector(w) implies isZero(norm(w)) }
}
alias '*' for scalarVectorMult;

abstract function vectorScalarMult specializes DataFunctions::'*' {
  doc
  /*
* Scalar product of a NumericalVectorValue and a NumericalValue, * which has the same value as the scalar product of the * NumericalValue and the NumericalVectorValue.

\[
\text{in } v: \text{NumericalVectorValue}[1]; \\
\text{in } x: \text{NumericalValue}[1]; \\
\text{return } w: \text{NumericalVectorValue}[1] = \text{scalarVectorMult}(x, v);
\]

abstract function vectorScalarDiv specializes DataFunctions::'/' { 
  doc 
  /* 
   * Scalar quotient of a NumericalVectorValue and a NumericalValue, 
   * defined as the scalar product of the inverse of the 
   * NumericalValue and the NumericalVectorValue. 
   */ 
  in v: NumericalVectorValue[1]; 
  in x: NumericalValue[1]; 
  return w: NumericalVectorValue[1] = scalarVectorMult(1.0 / x, v);
}

abstract function inner specializes DataFunctions::'*' { 
  doc 
  /* 
   * Inner product of two NumericalVectorValues. 
   */ 
  in v: NumericalVectorValue[1]; 
  in w: NumericalVectorValue[1]; 
  return x: NumericalValue[1]; 
  inv commmutivity { x == inner(w, v) } 
  inv zeroInner { isZeroVector(v) or isZeroVector(w) implies isZero(x) }
}

abstract function norm { 
  doc 
  /* 
   * The norm (magnitude) of a NumericalVectorValue, as a NumericalValue. 
   */ 
  in v: NumericalVectorValue[1]; 
  return l : NumericalValue[1]; 
  inv squareNorm { l * l == inner(v,v) } 
  inv lengthZero { isZero(l) == isZeroVector(v) }
}

abstract function angle { 
  doc 
  /* 
   * The angle between two NumericalVectorValues, as a NumericalValue. 
   */ 
  in v: NumericalVectorValue[1]; 
  in w: NumericalVectorValue[1]; 
  return theta: NumericalValue[1]; 
  inv commmutivity { theta == angle(w, v) } 
  inv lengthInsensitive { theta == angle(w / norm(w), v / norm(v)) }
}
/ * Specialized functions with concrete definitions for CartesianVectorValues. */

function CartesianVectorOf { 
    doc
    /*
    * Construct a CartesianVectorValue whose elements are
    * a non-empty list of Real components.
    * The dimension of the NumericalVectorValue is equal
    * to the number of components.
    */
    
in components: Real[*] ordered nonunique;
    return : CartesianVectorValue[1] {
        :>> dimension = size(components);
        :>> elements = components;
    }
}

function CartesianThreeVectorOf specializes CartesianVectorOf { 
    in components: Real[3] ordered nonunique;
    return : CartesianThreeVectorValue[1];
}

feature cartesianZeroVector: CartesianVectorValue[3] =
    { 
        CartesianVectorOf(0.0),
        CartesianVectorOf((0.0, 0.0)),
        CartesianThreeVectorOf((0.0, 0.0, 0.0))
    } 
    doc
    /*
    * Cartesian zero vectors of 1, 2 and 3 dimensions.
    */

feature cartesian3DZeroVector: CartesianThreeVectorValue[1] =
    cartesianZeroVector[3];

function isCartesianZeroVector specializes isZeroVector { 
    doc
    /*
    * A CartesianVectorValue is a zero vector if all its elements are zero.
    */
    
in v: CartesianVectorValue[1];
    return : Boolean[1] = v.elements->forAll(in x; x == 0.0);
}

function 'cartesian+' specializes '+' { 
    in v: CartesianVectorValue[1];
    in w: CartesianVectorValue[0..1];
    inv precondition { w != null implies v.dimension == w.dimension }
    return u: CartesianVectorValue[1] =
        if w == null? v
        else CartesianVectorOf(
            (1..w.dimension)->collect(in i : Positive; v[i] + w[i])
        );
}

function 'cartesian-' specializes '-' { 
    in v: CartesianVectorValue[1];
}
in w: CartesianVectorValue[0..1];
inv precondition { w != null implies v.dimension == w.dimension } return u: CartesianVectorValue[1] = CartesianVectorOf(
    if w == null?
        CartesianVectorOf(v.elements->collect{in x : Real; -x})
    else CartesianVectorOf(
        (1..v.dimension)->collect{in i : Positive; v[i] - w[i]}
    )
);
}

function cartesianScalarVectorMult specializes scalarVectorMult {
in x: Real[1];
in v: CartesianVectorValue[1]; return w: CartesianVectorValue[1] = CartesianVectorOf(
    v.elements->collect{in y : Real; x * y}
);
}

function cartesianVectorScalarMult specializes vectorScalarMult {
in v: CartesianVectorValue[1];
in x: Real[1]; return w: CartesianVectorValue[1] = cartesianScalarVectorMult(x, v);
}

function cartesianInner specializes inner {
in v: CartesianVectorValue[1];
in w: CartesianVectorValue[1];
inv precondition { v.dimension == w.dimension }
return x: Real[1] = (1..v.dimension)->collect{in i : Positive; v[i] * w[i]}->reduce RealFunctions::'+';
}

function cartesianNorm specializes norm {
in v: CartesianVectorValue[1];
return l : NumericalValue[1] = sqrt(cartesianInner(v, v));
}

function cartesianAngle specializes angle {
in v: CartesianVectorValue[1]; in w: CartesianVectorValue[1];
inv precondition { v.dimension == w.dimension }
return theta: Real[1] = arccos(cartesianInner(v, w) / (norm(v) * norm(w)));
}

function sum {
in coll: CartesianThreeVectorValue[*];
return : CartesianThreeVectorValue[1] = sum0(coll, cartesian3DZeroVector);
}

9.4.17 Control Functions
9.4.17.1 Control Functions Overview

This package defines Functions that correspond to operators in the KerML expression notation for which one or more operands are Expressions whose evaluation is determined by another operand.
9.4.17.2 Elements

abstract function '.' {
    in feature source : Anything[0..*] nonunique {
        abstract feature target : Anything[0..*] nonunique;
    }
    private feature chain chains source.target;
}

abstract function 'if' {
    in test: Boolean[1];
    in expr thenValue[0..1] { return : Anything[0..*] ordered nonunique; } 
    in expr elseValue[0..1] { return : Anything[0..*] ordered nonunique; }
    return : Anything[0..*] ordered nonunique;
}

abstract function '?' {
    in firstValue: Anything[0..*] ordered nonunique;
    in expr secondValue[0..1] { return : Anything[0..*] ordered nonunique; }
    return : Anything[0..*] ordered nonunique;
}

function 'and' {
    in firstValue: Boolean[1];
    in expr secondValue[0..1] { return : Boolean[1]; }
    return : Boolean[1];
}

function 'or' {
    in firstValue: Boolean[1];
    in expr secondValue[0..1] { return : Boolean[1]; }
    return : Boolean[1];
}

function 'implies' {
    in firstValue: Boolean[1];
    in expr secondValue[0..1] { return : Boolean[1]; }
    return : Boolean[1];
}

abstract function collect {
    in collection: Anything[0..*] ordered nonunique;
    in expr mapper[0..*] {
        in argument: Anything[1];
        return : Anything[0..*] ordered nonunique;
    }
    return : Anything[0..*] ordered nonunique;
}

abstract function select {
    in collection: Anything[0..*] ordered nonunique;
    in expr selector[0..*] {
        in argument: Anything[1];
        return : Boolean[1];
    }
    return : Anything[0..*] ordered nonunique;
}
function selectOne {
    in collection: Anything[0..*] ordered nonunique;
    in expr selector1[0..*] {
        in argument: Anything[1];
        return : Boolean[1];
    }
    return : Anything[0..1] =
    collection->select {in x; selector1(x)}[1];
}

abstract function reject{
    in collection: Anything[0..*] ordered nonunique;
    in expr rejector[0..*] {
        in argument: Anything[1];
        return : Boolean[1];
    }
    return : Anything[0..*] ordered nonunique;
}

abstract function reduce {
    in collection: Anything[0..*] ordered nonunique;
    in expr reducer[0..*] {
        in firstArg: Anything[1];
        in secondArg: Anything[1];
        return : Anything[1];
    }
    return : Anything[0..*] ordered nonunique;
}

abstract function forAll {
    in collection: Anything[0..*] ordered nonunique;
    in expr test[0..*] {
        in argument: Anything[1];
        return : Boolean[1];
    }
    return : Boolean[1];
}

abstract function exists {
    in collection: Anything[0..*] ordered nonunique;
    in expr test[0..*] {
        in argument: Anything[1];
        return : Boolean[1];
    }
    return : Boolean[1];
}

function allTrue {
    in collection: Boolean[0..*];
    return : Boolean[1] = collection->forAll {in x; x};
}

function anyTrue {
    in collection: Boolean[0..*];
    return : Boolean[1] = collection->exists {in x; x};
}

function minimize {
    in collection: ScalarValue[1..*];
    in expr fn[0..*] {
        in argument: ScalarValue[1];

function maximize {
    in collection: ScalarValue[1..*];
    in expr fn[0..*] {
        in argument: ScalarValue[1];
        return : ScalarValue[1];
    }
    return : ScalarValue =
        collection->collect {in x; fn(x)}->reduce max;
}

9.4.18 Occurrence Functions

9.4.18.1 Occurrence Functions Overview

This package defines utility functions that operate on occurrences, primarily related to the time during which those occurrences exist.

9.4.18.2 Elements

function '=>' specializes BaseFunctions::'=' {
    doc
    /*
     * Test whether two occurrences are portions of the same life. That is, whether they
     * represent different portions of the same entity (colloquially, whether they have
     * the same "identity").
     */
    in x: Occurrence[0..1];
    in y: Occurrence[0..1];
    return : Boolean[1] = x.portionOfLife == y.portionOfLife;
}

function isDuring {
    doc
    /*
     * Test whether a performance of this function happens during the input occurrence.
     */
    in occ: Occurrence[1];
    private connector all during: HappensDuring[0..1] from self to occ;
    return : Boolean[1] = notEmpty(during);
}

function create {
    doc
    /*
     * Ensure that the start of a given occurrence happens during a performance of this
     * function. The occurrence is also returned from the function.
     */

inout occ: Occurrence[1];

private connector : HappensDuring from occ.startShot to self;

return : Occurrence[1] = occ;
}

function destroy {
  doc
  /*
   * Ensure that the end of a given occurrence happens during a performance of this
   * function. The occurrence is also returned from the function.
   */
  inout occ: Occurrence[0..1];

  private connector : HappensDuring from occ.endShot[0..1] to self;

  return : Occurrence[0..1] = occ;
}

function addNew {
  doc
  /*
   * Add a newly created occurrence to the given group of occurrences and return the
   * new occurrence.
   */

  inout group: Occurrence[0..*] nonunique;
  inout occ: Occurrence[1];

  private composite step : add {
    inout seq1 = group;
    in seq2 = create(occ);
  }

  return : Occurrence[1] = occ;
}

function addNewAt {
  doc
  /*
   * Add a newly created occurrence to the given ordered group of occurrences at the given
   * index and return the new occurrence.
   */

  inout group: Occurrence[0..*] ordered nonunique;
  inout occ: Occurrence[1];
  in index: Positive[1];

  private composite step : addAt {
    inout seq = group;
    in values = create(occ);
    in startIndex = index;
  }

  return : Occurrence[1] = occ;
}

behavior removeOld {

/*
 * Remove a given occurrence from a group of occurrences and destroy it.
 */

inout group: Occurrence[0..*] nonunique;
inout occ: Occurrence[0..1];

private composite step removeStep : remove {
    inout seq = group;
in values = occ;
}
private succession removeStep then destroyStep;
private composite step destroyStep : destroy {
    inout occ = removeOld::occ;
}

behavior removeOldAt {
    doc
    /*
     * Removes the occurrence at a given index in an ordered group of occurrences
     * and destroy it.
     */
    inout group: Occurrence[0..*] ordered nonunique;
in index: Positive[1];

    private feature oldOcc = group[index];

    private composite step removeStep : remove {
        inout seq = group;
in index = removeOldAt::index;
    }
    private succession removeStep then destroyStep;
    private composite step destroyStep : destroy {
        inout occ = oldOcc;
    }
}
10 Model Interchange

10.1 Model Interchange Overview

Model interchange is the capability to interchange models between tools using file-base resources (see Clause 2). The unit of interchange is the project, which is defined as follows:

A project is a set of root namespaces (see 7.2.5.3 and 8.2.3.4.1), including all elements in the ownership trees of those namespaces, and a set of references to used projects, such that every cross reference from an element in the project is to another element in that project or to an element in one of the used projects.

The root namespaces in a project may be serialized into model interchange files, using any of the formats given in 10.2. A project interchange file is then a compressed archive of model interchange files and additional required metadata, as described in 10.3.

KerML is intended to be used as the basis for building other modeling languages. Project-based model interchange as defined in this clause may also be used to interchange models in such languages. Each of the following subclauses includes descriptions of the allowed adaptations for interchanging models in KerML-based languages.

10.2 Model Interchange Formats

A model interchange file contains a textual representation (known as a serialization) of a single root namespace (see 7.2.5.3 and 8.2.3.4.1) and all the elements in the ownership tree root in that namespace. A model interchange file shall have one 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. A model interchange file in this format shall have the file extension .kerml.
2. JSON, using a format according to the JSON serialization mapping defined in 10.4. A model interchange file in this format shall have the file extension .json.
3. XML, using the XML Metadata Interchange [XMI] format based on the MOF-conformant abstract syntax metamodel for KerML. A model interchange file in this format shall have the file extension .xmi.

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.

For a KerML-based language:

1. Textual Notation. If the language has a textual concrete syntax, then this textual notation may be used as a model interchange file format. The language shall define a distinguishing file extension for files of its textual notation.
2. JSON. It shall always be possible to use JSON format as a model interchange file format, using the mapping strategy defined in 10.4, as applied to the abstract syntax of the language.
3. XML. If the language is defined using a MOF-conformant abstract syntax, then XMI may be used as a model interchange file format.

A KerML-based-language specification may specify further requirements on what interchange formats must be supported by conforming language tools.
## 10.3 Model Interchange Projects

A **project interchange file** is a single project serialized as a set of model interchange files, archived using the ZIP format [ZIP]. The archive shall contain a model interchange file for each of the root namespaces in the project, each formatted in one of the formats listed in 10.2. In addition, the archive shall contain, at its top level, exactly one file named `.project.json` and exactly one file named `.meta.json`. A KerML project interchange file shall have the file extension `.kpar` (KerML Project Archive).

Other than the use of the file extensions given in 10.2, there are no requirements on the naming of the model interchange files. Nevertheless, they should be named in a way that is compatible across different file systems and that allows for easy reference using International Resource Identifiers (IRIs). The model interchange files may be organized into subdirectories, but this has no impact on the global scope for the project, which is always a flat namespace derived from the root namespaces of the project (see 8.2.3.5). However, each model interchange file shall be identifiable by a unique path in the archive directory structure.

The `.project.json` file shall contain the `InterchangeProject` information shown in Fig. 42, serialized as a single JSON object according to the `Project` schema definition in the `ModelInterchange.json` artifact provided with this specification. *Table 12* gives all the properties of the `InterchangeProject` and `InterchangeProjectUsage` elements, consistent with the normative JSON schema. Every element referenced in a model interchange file in a project interchange file shall either also be contained in a model interchange file in that project interchange file, or in one of the projects referenced in the `usage` list for the project interchange file.

The `usage` information for each used project includes an optional `versionConstraint` property. If given, then only versions of the project identified by the `resource` property that meet this constraint may be used. For an interchanged project, the version is as given in its `version` property. It is recommended, but not required, that **semantic versioning** (see [https://semver.org/](https://semver.org/)) be used for the version numbering of interchange projects and **semantic versioning ranges** (see, e.g., [https://docs.npmjs.com/cli/v6/using-npm/semver#ranges](https://docs.npmjs.com/cli/v6/using-npm/semver#ranges)) be used for version constraints. Tools that support such version formatting should report any version constraint violations when importing an interchange project, for any used projects with dereferencable `resource` IRIs.

The `.meta.json` file shall contain further metadata on the project interchange file, serialized as a single JSON object according to the `Meta` schema definition in the `ModelInterchange.json` artifact provided with this specification. *Table 13* describes all the fields specified in the normative JSON schema.

A project interchange file for a KerML-based language shall include model interchange files specific to that language (as described in 10.2). Such a project interchange file may use the generic `.kpar` extension, or it may define its own language-specific extension. If it uses the `.kpar` extension, then the metadata for the file shall identify the KerML-based language metamodel (see *Table 13*). Each project interchange file shall only contain models in a single language, but it shall be able to have used projects both in the same language and in KerML (such as from the Kernel Model Libraries). A KerML-based-language specification may also allow for project interchange files that use projects in other KerML-based languages.
Figure 42. Interchange Projects

Table 12. Interchange Project Information

<table>
<thead>
<tr>
<th>Property</th>
<th>Type</th>
<th>Mandatory</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>string</td>
<td>yes</td>
<td>The name of the project.</td>
</tr>
<tr>
<td>description</td>
<td>string</td>
<td>no</td>
<td>A description of the project.</td>
</tr>
<tr>
<td>version</td>
<td>string</td>
<td>yes</td>
<td>The version of the project being interchanged.</td>
</tr>
<tr>
<td>license</td>
<td>string</td>
<td>no</td>
<td>The license by which project content may be used.</td>
</tr>
<tr>
<td>maintainer</td>
<td>array (of strings)</td>
<td>no</td>
<td>A list of names of maintainers of the project.</td>
</tr>
<tr>
<td>website</td>
<td>IRI</td>
<td>no</td>
<td>An IRI for a Web site with further information on the project.</td>
</tr>
<tr>
<td>topic</td>
<td>array (of strings)</td>
<td>no</td>
<td>A list of topics relevant to the project.</td>
</tr>
<tr>
<td>usage</td>
<td>array (of objects)</td>
<td>no</td>
<td>A list of project usage entries, one for each project used by the project being interchanged, with properties as given below.</td>
</tr>
<tr>
<td>resource</td>
<td>IRI</td>
<td>yes</td>
<td>An IRI identifying the project being used. If the IRI is dereferenceable, it should resolve to a project interchange file for the used project.</td>
</tr>
<tr>
<td>Property</td>
<td>Type</td>
<td>Mandatory</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------</td>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>versionConstraint</td>
<td>string</td>
<td>no (within a usage)</td>
<td>A constraint on the allowable versions of a used project.</td>
</tr>
</tbody>
</table>

**Table 13. Interchange Project Metadata**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Mandatory</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>index</td>
<td>object</td>
<td>yes</td>
<td>An index of the global scope of the project, specified as a JSON object with a key for each name, whose associated value is the path to the model interchange file containing the root namespace for the named element. (See Notes 1 and 2.)</td>
</tr>
<tr>
<td>created</td>
<td>string</td>
<td>yes</td>
<td>The date and time of the creation of the project interchange file, in ISO 8601 format [ISO8601].</td>
</tr>
<tr>
<td>metamodel</td>
<td>IRI</td>
<td>no</td>
<td>An IRI identifying the metamodel of the modeling language of the models being interchanged in this project interchange file. (See Note 3.)</td>
</tr>
<tr>
<td>includesDerived</td>
<td>Boolean</td>
<td>no</td>
<td>Whether derived property values are included in the model interchange files. (See Note 4.)</td>
</tr>
<tr>
<td>includesImplied</td>
<td>Boolean</td>
<td>no</td>
<td>Whether implied relationships are included in the model interchange files. (See Note 5.)</td>
</tr>
<tr>
<td>checksum</td>
<td>object</td>
<td>no</td>
<td>A dictionary mapping paths to some or all of the model interchange files to a list of one or more objects with the two properties given below. (See Note 2.)</td>
</tr>
<tr>
<td>value</td>
<td>string</td>
<td>yes (within a checksum)</td>
<td>The checksum computed according to the checksum algorithm.</td>
</tr>
<tr>
<td>Name</td>
<td>Type</td>
<td>Mandatory</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>---------</td>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>algorithm</td>
<td>string</td>
<td>yes</td>
<td>(within a checksum) Identification of the algorithm used to computed the checksum value. (See Note 6.)</td>
</tr>
</tbody>
</table>

Notes

1. The index cross-references all the non-null shortNames and names of all the top-level elements of the root namespaces of the project (see 7.2.5.3 and 8.2.3.5) to the model interchange file of the root namespace that contains the element. Note that, while the names of all top-level elements in a root namespace must be unique, it is allowable (though not recommended) for top-level elements in different root namespaces of a project to have the same name.

2. File paths are always relative to the root of the project interchange file archive, with path segments separated by the forward slash symbol /, ending in a file name with extension (e.g., structure/assembly/Body.json)

3. For an OMG-standardized language, metamodel shall be the version-specific URI specified by OMG to identify the language. For KerML, this URI has the form https://www.omg.org/spec/KerML/yyyyymmxx, with a version-specific date stamp "yyyyymmxx". If metamodel is not given, the default is KerML (for a project interchange file with the .kpar extension).

4. If includesDerived = true, then the serializations in all XMI and JSON format model interchange files in the project interchange file shall include values for all derived properties. If includesDerived = false, then XMI and JSON formatted model interchanges files shall not include values for any derived properties. If includesDerived is not given, then whether derived property values are included may vary one model interchange file to another, and it is also allowable for some values to be included for some derived properties and not others.

5. If includesImplied = true, then the serializations in all XMI and JSON formatted model interchange files in the project interchange file shall include all implied relationships, and the isImpliedIncluded property shall have the value true for all elements (see 8.3.2.1 on isImpliedIncluded). If includesImplied = false, then XMI and JSON formatted model interchange files shall not include any implied relationships, and the isImpliedIncluded property shall have the value false for all elements. If includesImplied is not given, then whether implied relationships are included may vary from one model interchange file to another, and from element to element, as recorded by the value of the includesImplied property for each element.

6. Valid values for the checksum algorithm are
   - SHA1, SHA224, SHA256, SHA-384, SHA3-256, SHA3-384, SHA3-512 [SHS]
   - BLAKE2b-256, BLAKE2b-384, BLAKE2b-512, BLAKE3 [BLAKE]
   - MD2, MD4, MD5, MD6 [MD]
   - ADLER32 [ADLER]

10.4 JSON Serialization

10.4.1 Serialization Overview

The JSON serialization format can be used to interchange any model conformant with the KerML abstract syntax. Each root namespace shall correspond with a model interchange file with the file extension .json and contain serializations of all model elements in the ownership tree root in that namespace. The contents of this file shall be in the JSON (JavaScript Object Notation) format [JSON] and, for KerML, conform to the JSON schema definitions in the KerML.json artifact provided with this specification. Other KerML-based languages may extend this schema or define their own schema, consistent with the serialization strategy defined here as applied to the abstract syntax of those languages.
The following subclauses describe the serialization strategy, as realized in the normative JSON schema for KerML.

### 10.4.2 Primitive Type Serialization

The UML primitive types used in the KerML abstract syntax map directly to core JSON Schema types, as shown in Table 14.

<table>
<thead>
<tr>
<th>UML Primitive Type</th>
<th>JSON Schema Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean</td>
<td>boolean</td>
</tr>
<tr>
<td>Integer</td>
<td>integer</td>
</tr>
<tr>
<td>Real</td>
<td>number</td>
</tr>
<tr>
<td>String</td>
<td>string</td>
</tr>
</tbody>
</table>

### 10.4.3 Enumeration Serialization

Enumeration values map to a JSON Schema string with a value that is the name of the enumeration literal, with the same capitalization as defined for the literal in the abstract syntax. For example, `VisibilityKind::public` maps to the string "public".

### 10.4.4 Element Reference Serialization

Values of abstract syntax properties typed by a metaclass (that is, `Element` or one of its subclasses) map to a JSON Schema object with a single field @id. The value of @id is a JSON Schema string with a value equal to the value of the elementId of the Element. For example:

```
{
    "$id": "15fe7607-ceb8-38bb-bd04-dde8ca657cec"
}
```

### 10.4.5 Element Serialization

A model element maps to a JSON Schema object with fields @id, @type, and a set of its attributes. The field @id has a string value equal to the value of `Element::elementId`. The field @type has a string value equal to the name of the specific MOF type of the element, e.g. "Structure".

The remaining JSON Schema fields are mapped from the set of MOF properties specified as attributes of the MOF type of the element. This shall include all owned and inherited properties. In addition, while redefined properties are not inherited under MOF/UML rules, they shall be included in the set of properties serialized for the element if they have a different name than the redefining property.

Each of these maps to a JSON Schema field, where the name of the field is equal to the name of the attribute and the value is equal to the serialization of the attribute value as described in the preceding subclauses. The value must adhere to the allowed multiplicity of the MOF attribute:

- A multiplicity of [1..1] requires a non-null value.
- A multiplicity of [0..1] allows a value or null
- A multiplicity with an upper bound greater than 1 maps to a JSON Schema array with values equal to the serialization of the attribute values described in the preceding subclauses.
10.4.6 Model Serialization

A root namespace maps to a JSON Schema `array` with values equal to the serialization, as described in the preceding subclauses, of all model elements in the ownership tree rooted in that namespace.
A Annex: Model Execution

(Informative)

A.1 Overview

The language semantics in this specification give conditions to check whether classifiers have been instantiated properly (see 7.3.2.1). For structures this includes their parts and other required objects, as well as feature values and links between them. For behaviors, this includes their steps and other required performances, as well as timing links between them. These two kinds of classifiers are typically interrelated, structures can require behaviors for proper instantiation and vice-versa.

This annex outlines a procedure for incrementally instantiating (executing) classifiers to ensure the completed instances will pass the check above (satisfy classifier conditions). The order of instantiation obeys any timing specified by the classifier. For example, some structures might require others to exist first, such as parents before their children, or parts of a car before assembly, while behaviors typically require some steps to happen only after others finish, such as painting objects before drying them. It covers the basic patterns needed to aid development of a complete execution procedure.

A.2 Modeling Instances and Feature Values

Instances in this annex are modeled in KerML, rather than as runtime data structures. Execution is taken to be creating these modeled instances in an order specified by their classifiers.

Instances are also modeled as classifiers (called atoms in this annex) that each correspond to their own single (runtime) instance. Atoms are all disjoint from each other, but not necessarily from other (non-atom) classifiers (such as the ones being instantiated). In the example below, MyBike and YourBike are atoms. They are both classified by Bicycle (and Vehicle by specialization).

```kerml
classifier Vehicle;
classifier Bicycle specializes Vehicle;
classifier MyBike [1] specializes Bicycle;
classifier YourBike [1] specializes Bicycle disjoint from MyBike;
```

Atoms in this annex are indicated by a user-defined keyword before classifier definitions, with multiplicity and disjointness implied by the keyword, as below.

```kerml
classifier Atom;
metaclass <atom> AtomMetadata specializes Metaobject {
    baseType = Atom meta KerML::Classifier;
}
classifier Vehicle;
classifier Bicycle specializes Vehicle;

#atom
classifier MyBike specializes Bicycle;
#atom
classifier YourBike specializes Bicycle;
```

Atoms are assigned as feature values by typing a feature with them, or a union of atoms, and restricting the feature multiplicity as needed to match the number of atoms being assigned. The example below creates a classifier for the bicycle atoms above (OurBicycle), then redefines a feature (stores) to be typed by it. The multiplicity is restricted to the exact number of atoms creating during execution (2).

```kerml
classifier Atom;
metaclass <atom> AtomMetadata specializes Metaobject {
    baseType = Atom meta KerML::Classifier;
}
classifier Vehicle;
classifier Bicycle specializes Vehicle;

#atom
classifier MyBike specializes Bicycle;
#atom
classifier YourBike specializes Bicycle;

classifier Stores specialize Atom {
    baseType = Atom meta KerML::Classifier;
}
classifier OurBicycle [2] specializes Bicycle disjoint from MyBike;
classifier Stores specializes OurBicycle;
```
classifier Garage {
    feature stores : Bicycle [*];
}
classifier OurBicycle unions MyBike, YourBike;

#atom
classifier OurGarage specializes Garage {
    feature redefines stores : OurBicycle [2];
}

A.3 Instantiation Procedure

A.3.1 Overview

The instantiation procedure is described in cases of increasing capability. A.3.2 through A.3.4 cover features, including connectors, without any timing specified. These are applicable to structure and behavior, though the examples are structural. The rest of the procedure adds timing, first for structures, then behaviors.

A.3.2 Without connectors

Take the example below to illustrate the procedure, a (non-association) classifier without connectors (features typed by associations).

classifier Bicycle {
    feature rollsOn : Wheel [2];
    feature holdsWheel : BikeFork [*];
}
classifier Wheel;
classifier BikeFork;

The instantiation procedure starts with

1. Create an atom of the classifier being instantiated (Bicycle).
2. Identify features of the instantiated classifier with lower multiplicity greater than zero that are not connectors or other features typed by associations (rollsOn).
3. Create atoms for the types of the above features (Wheel), at least up to the lower multiplicity of each feature (2), and assign them as values of the feature.

The model being executed in this example does not specify timing, though it is typically expected that

- classifiers are produced before their atoms.
- Atoms are produced before they are assigned as values or otherwise used by another atom.

The first instantiation step produces the first atom below

#atom
classifier MyBike specializes Bicycle;

The third creates the rest and modifies the one above. Atoms appear each time they are modified (MyBike), to highlight execution order.

#atom
classifier MyWheel1 specializes Wheel;
#atom
classifier MyWheel2 specializes Wheel;
classifier MyWheel unions MyWheel1, MyWheel2;

#atom
classifier MyBike specializes Bicycle {
    feature redefines rollsOn : MyWheel;
}

A.3.3 One-to-one connectors

This covers connectors that

• have multiplicity 1 at both ends, but unrestricted (*) overall.
• are not timing or binding connectors.

The first above requires the connected features to have the same number of values. When this is not possible, such as the multiplicities of the connected features being incompatible (do not overlap, as in 0..1 and 2..*), the classifier is not instantiable (satisfiable).

The example below adds a connector to the example in Without Connectors, with end multiplicities requiring each wheel to be fixed to its own fork, and vice-versa.

classifier Bicycle {
    feature rollsOn : Wheel [2];
    feature holdsWheel : BikeFork [*];
    connector fixWheel : BikeWheelFixed from rollsOn [1] to holdsWheel [1];
}
assoc BikeWheelFixed {
    end feature wheel : Wheel;
    end feature fixedTo : BikeFork;
}

The instantiation procedure from Without connectors continues with

4. Identify connectors of the classifier being instantiated (fixWheel).
5. For each connector above
   a. Create association atoms for the types of the connectors identified in step 4 (BikeWheelFixed). See below for how many.
   b. Assign the two participant (end) features (wheel and fixed) in each association atom, with values taken from the corresponding connected feature (rollsOn and holdsWheel). See below for which values are taken.
   c. Assign the association atoms above as values of the corresponding connectors.

For end multiplicity 1 on both ends

◦ Create the same number of association atoms as there are values of the connected features with the most values at the time the association atoms are created (2).
◦ Assign each connected feature value as participant in exactly one association atom. If one connected feature has fewer values than the other, create atoms for the type of that feature (holdsWheel) up to the number in the other feature (rollsOn, 2), and assign them as values of the feature with fewer values.

The model being executed in this example does not specify timing, though it is typically expected that

• association atoms are created just after values are assigned to connected features, whereupon the instantiation steps above could be taken on each connector right after its connected features are assigned values during step 3, see A.3.2.
After the instantiations in *Without connectors*, the steps above produce the following atoms. First, 5.a creates as many association atoms for the connector (fixWheel) as the connected feature with the most values (2 in rollsOn, assigned in *Without connectors*).

```plaintext
#atom
assoc MyBikeWheel1_Fork1_BWF_Link specializes BikeWheelFixed;
#atom
assoc MyBikeWheel2_Fork2_BWF_Link specializes BikeWheelFixed;
```

Before 5.b assigns participant features, the one-to-one connector end multiplicities require additional atoms for the connected feature with fewer values (holdsWheel), to match the number of the values of the other connected feature (rollsOn).

```plaintext
#atom
classifier MyBikeFork1 specializes BikeFork;
#atom
classifier MyBikeFork2 specializes BikeFork;

classifier MyBikeFork unions MyBikeFork1, MyBikeFork2;

#atom
classifier MyBike specializes Bicycle {
    feature redefines rollsOn : MyWheel;
    feature redefines holdsWheel : MyBikeFork;
}
```

Then 5.b assigns participant feature values to the association atoms created in 5.a, choosing in this execution to fix the first and second wheels to the first and second forks, respectively,

```plaintext
#atom
assoc MyBikeWheel1_Fork1_BWF_Link specializes BikeWheelFixed {
    end feature redefines wheel : MyWheel1;
    end feature redefines fixedTo : MyBikeFork1;
}

#atom
assoc MyBikeWheel2_Fork2_BWF_Link specializes BikeWheelFixed {
    end feature redefines wheel : MyWheel2;
    end feature redefines fixedTo : MyBikeFork2;
}
```

Finally 5.c assigns the association atoms to the connector.

```plaintext
classifier MyBikeWheel_Fork_BWF_Link
    unions MyBikeWheel1_Fork1_BWF_Link, MyBikeWheel2_Fork2_BWF_Link;
#atom
classifier MyBike specializes Bicycle {
    feature redefines rollsOn : MyWheel;
    feature redefines holdsWheel : MyBikeFork;
    connector redefines fixWheel : MyBikeWheel_Fork_BWF_Link [2]
        from rollsOn [1] to holdsWheel [1];
}
```

**A.3.4 One-to-unrestricted connectors**

This covers connectors that

- have multiplicity 1 at one end and unrestricted (*) at the other, and unrestricted overall.
• are not timing or binding connectors.

The first above enables the feature connected at the unrestricted end to have any number of values in satisfiable models, but if it has any values, all those values must be linked to exactly one (not necessarily unique) value of the other connected feature (at the multiplicity 1 end) in the same instance of the classifier being instantiated. When this is not possible, for example due to the connector's association multiplicities being too restrictive (such as not allowing for links to all the values of the connected features), the classifier is not instantiable (satisfiable).

The example below adds another feature and connector to the example in A.3.3. Every basket is intended to be fixed to one of the forks, though more than one basket might be fixed to the same fork, or some forks might have no baskets, or there might be no baskets at all.

```
classifier Bicycle {
    feature carrier : BikeBasket [*];
    connector carrierFixed : BikeBasketFixed from carrier [*] to holdsWheel [1];
}
classifier BikeBasket;
assoc BikeBasketFixed {
    end feature basket : BikeBasket;
    end feature fixedTo : BikeFork;
}
```

Then the instantiation procedure from A.3.3 is amended for one unrestricted end:

5. For each connector above
   a. ..., b., ..., c., ..., ...
   For end multiplicity 1 on one end and unrestricted on the other
      ◦ Create the same number of association atoms as there are values of the connected feature at the unrestricted end (carrier) at the time the association atoms are created.
      ◦ Assign each connected feature value at the unrestricted end as participant in exactly one association atom.

Instantiation proceeds as in A.3.3, modifying the classifier atom created there (MyBike), except the number of association atoms created is determined by the number of values of the connected feature at the unrestricted end (carrier), choosing in this execution to fix two baskets to the same fork.

```
#atom
classifier MyBikeBasket1 specializes BikeBasket;
#atom
classifier MyBikeBasket2 specializes BikeBasket;
classifier MyBikeBasket unions MyBikeBasket1, MyBikeBasket2;
#atom
classifier MyBike specializes Bicycle {
    feature redefines carrier : MyBikeBasket [2];
}
#atom
assoc MyBikeBasket1_Fork1_BBF_Link specializes BikeBasketFixed {
    end feature redefines basket : MyBikeBasket1;
    end feature redefines fixedTo : MyBikeFork1;
}
#atom
assoc MyBikeBasket2_Fork1_BBF_Link specializes BikeBasketFixed {
    end feature redefines basket : MyBikeBasket2;
    end feature redefines fixedTo : MyBikeFork1;
```
A.3.5 Timing for structures

Classes are classifiers for things that exist in time (occurrences), as compared to numbers or other mathematical entities. It usually matters when these things come into and go out of existence, at least relative to each other. For example, in structures it is typically intended that parts exist for at least as long as the thing they are part of. In the bicycle example above, the wheel atoms should exist at least as long as the bicycle atom. A simple way to do this is for a structure and its parts to all exist at exactly the same time, as shown below. Bicycle is class with its part features subset from timeCoincidentOccurrences, ensuring the values of rollsOn and holdsWheel happen (start and end) at exactly the same time as the bicycle occurrence they are part of, see 9.2.4.1.

```latex
class Bicycle specializes Occurrence {
    feature holdsWheel : BikeFork [2] subsets timeCoincidentOccurrences;
}
```

The keyword `struct` implies specialization from `Occurrence` and highlights the structural application of classes. With it the example above becomes

```latex
struct Bicycle {
    feature holdsWheel : BikeFork [2] subsets timeCoincidentOccurrences;
}
```

Some features always include the thing featuring them as a value (logically reflexive), such as self (see 9.2.2.1), which subsets timeCoincidentOccurrences, because occurrences always exist at the same time as themselves (see 7.3.4.4 about feature subsetting). The instantiation procedure in A.3.2 is amended below assign values to reflexive features when it creates atoms for features with lower multiplicity greater than zero (3a), as well as assign values to features being subsetted (3b).

3. ...
   a. For features that always have their featuring thing as a value (at least self and the features it subsets), assign that atom as a value.
   b. If a feature subsets others (rollsOn and holdsWheel subset timeCoincidentOccurrences, which subsets self), assign values to the others also.

The additional instantiation steps produce the atom below by

- Assigning MyBike with itself for `self`.
- Introducing a class for all part atoms of MyBike, as well as the assembled MyBike, and assigning timeCoincidentOccurrences with it.

The model being executed requires all the occurrences to come into and go out of existence at the same time, but since this is not possible when sequentially creating atoms, the ones below appear before they are assigned as values or otherwise used by another atom.
struct MyBikeTimeCoincident unions MyWheel, MyBikeFork, MyBike;

#atom
struct MyBike specializes Bicycle {
    feature redefines self : MyBike;
    feature redefines timeCoincidentOccurrences : MyBikeTimeCoincident [5];
    feature redefines rollsOn : MyWheel;
    feature redefines holdsWheel : MyBikeFork;
}

It is more realistic for parts to exist before the things they are a part of, such as the wheels and forks above existing before they are assembled into a bicycle. It also might be that the parts outlive the bicycle, if it's only disassembled rather than completely destroyed. A simple way to do this is for parts to exist longer than their assembly, as specified below by a HappensDuring connector (see 9.2.4.1) linking the bicycle (self) to all its parts (allParts), specified as a union of the part features (equivalent to part features subsetting the union feature, but excluding values that are not in the part features). This ensures each bicycle exists during the time their parts do, but enables the parts to exist before assembly into a bicycle, and after disassembly, when the bicycle no longer exists. They still might all exist at the exactly the same time, as in the previous example, because things that exist at the same time all happen during each other.

struct Bicycle {
    feature rollsOn : Wheel [2];
    feature holdsWheel : BikeFork [2];
    feature allParts : Occurrence unions rollsOn, holdsWheel;
    connector b_during_ap : HappensDuring from self [1] to allParts [*];
}

The instantiation procedure above is amended again to assign values to union features.

3. ...
   a. ..., b ...
   c. If a feature unions others (allParts unions rollsOn and holdsWheel), treat the others as subsetting the union feature, but only assigning values that are in the subsets.

The instantiation procedure in A.3.4, with the amendments above to A.3.2, produces the additional or modified atoms below.

#atom
assoc MyBike_During_Wheel1_Link specializes HappensDuring {
    end feature redefines shorterOccurrence : MyBike;
    end feature redefines longerOccurrence : MyWheel1;
}

#atom
assoc MyBike_During_Wheel2_Link specializes HappensDuring {
    end feature redefines shorterOccurrence : MyBike;
    end feature redefines longerOccurrence : MyWheel2;
}

#atom
assoc MyBike_During_Fork1_Link specializes HappensDuring {
    end feature redefines shorterOccurrence : MyBike;
    end feature redefines longerOccurrence : MyBikeFork1;
}

#atom
assoc MyBike_During_Fork2_Link specializes HappensDuring {
    end feature redefines shorterOccurrence : MyBike;
    end feature redefines longerOccurrence : MyBikeFork2;
}
assoc MyBike_During_Parts_Link specializes HappensDuring
  unions MyBike_During_Wheel1_Link, MyBike_During_Fork1_Link,
  MyBike_During_Wheel2_Link, MyBike_During_Fork2_Link;

struct MyBikeParts unions MyWheel, MyBikeFork;

#atom
struct MyBike specializes Bicycle {
  feature redefines rollsOn : MyWheel;
  feature redefines holdsWheel : MyBikeFork;
  feature redefines allParts : MyBikeParts [4];

  feature redefines self : MyBike;
  connector redefines b_during_ap : MyBike_During_Parts_Link [4]
    from self [1] to allParts [*];
}

Parts are sometimes expected not to exist after their structures, such as when a bicycle is completely destroyed, rather than just disassembled. The wheels and forks above would not exist after the bicycle they are part of, even though they might have existed before it (was assembled). Since parts can be replaced over time, the only ones destroyed are those in the bicycle at the time it is destroyed (the parts replaced earlier are not affected because they are no longer in the bicycle). This is specified below by a HappensWhile connector, equivalent to a HappenDuring connector in both directions, ensuring the ends (endShot) of the parts (at the time the bicycle ends) happen at the same time as the bicycle (the connected feature values are timeCoincidentOccurrences of each other). End shots are instantaneous occurrences that happen at the end of another occurrence (life), but represent the same thing as that occurrence, see 9.2.4.1. The ends of the parts are identified by "navigating" (chaining) through a series of features, each providing a value on which to get the next value in the navigation, starting with the end of the bicycle, see 7.3.4.6.

struct Bicycle {
  ... 
  feature redefines endShot : Bicycle;
  connector be_while_pe : HappensWhile 
    from endShot [1] to endShot.allParts.endShot[*];
}

The keyword composite implies the end timing above when used in defining rollsOn and holdsWheel, as below.

struct Bicycle {
  composite feature rollsOn : Wheel [2];
  composite feature holdsWheel : BikeFork [2];
  ... 
}

The instantiation steps in A.3.2 will assign a value to endShot, because it has multiplicity [1], but this is delayed until everything else required in the structure has occurred, due to mandatory HappensBefore connectors to endShot. With the amendments above, the steps in A.3.4 produce the additional or modified atoms below.

/* End atoms */
#atom
struct MyWheel1End specializes Wheel;
#atom
struct MyWheel1 specializes Wheel {
  feature redefines endShot : MyWheel1End;
}
A.3.6 Timing for behaviors, Sequences

Behaviors also exist in time, but they come into and go out of existence differently than structures, relative to each other. For example, in behaviors it is typically intended that its steps happen

- during the behavior occurrence they are part of, but not last as long as it does.
• before or after other steps in the same behavior occurrence.

These can be modeled by

• subsetting step features (those typed by behaviors) from timeEnclosedOccurrences, ensuring they happen during the occurrence they are a step of, but are not required to happen the entire time, as with timeCoincidentOccurrences.

• linking steps by HappensBefore connectors to specify the order they should occur in.

The example below does this for a behavior with three steps. Only the first one (paint) is required (by its multiplicity), indicating the behavior starts there, while the rest (dry and ship) are unrestricted, to prevent the instantiation procedure from giving values to (performing) them too early. This is left to the end multiplicities of the timing connectors (p_before_d and d_before_s), which require their later step to happen once each time the earlier step does, and vice-versa, see A.3.3.

```plaintext
class Manufacture specializes Occurrence {
    feature paint : Paint [1] subsets timeEnclosedOccurrences;
    feature dry : Dry [*] subsets timeEnclosedOccurrences;
    connector p_before_d: HappensBefore from paint [1] to dry [1];
    feature ship : Ship [*] subsets timeEnclosedOccurrences;
    connector d_before_s: HappensBefore from dry [1] to ship [1];
} paint; dry; ship;
```

The keyword

• step implies subsetting timeEnclosedOccurrences. These are features of behaviors typed by behaviors.

• succession implies typing connectors by HappensBefore, and indicates the ends with first and then, instead of from and to, respectively.

With these the example above becomes

```plaintext
behavior Manufacture {
    step paint : Paint [1];
    step dry : Dry [1];
    succession p_before_d first paint [1] then dry [1];
    step ship : Ship [*];
    succession d_before_s first dry [1] then ship [1];
}
```

The instantiation procedure in A.3.3 produces the atoms below, including

• creating step atoms required by one-to-one connectors, and

• the typically expected order to create association atoms (association atoms are created and assigned just after values are assigned to connected features), taken as required for behavioral connectors.

In this example, it results in creating the atoms below ("taking" steps) in the order typically expected for behavioral execution, even though the procedure is the same as for structural execution. Atoms appear below each time they are modified (MyManufacture), to highlight this.

It starts by creating and assigning an atom for paint, to satisfy its multiplicity, see A.3.2. The procedure ignores the others because their multiplicities do not require any values.
#atom
behavior MyManufacture specializes Manufacture;

#atom
behavior MyPaint specializes Paint;

#atom
behavior MyManufacture specializes Manufacture {
    feature redefines timeEnclosedOccurrences : MyPaint [1];
    step redefines paint : MyPaint;
}

Step 5 in A.3.3 reacts to the new step atom above by looking for connectors from it with multiplicity [1] at the opposite end, finding p_before_d, then creating and assigning an atom for the step connected at that end (dry), to satisfy that end's multiplicity.

#atom
behavior MyDry specializes Dry;

#atom
assoc MyPaint_Before_Dry_Link specializes HappensBefore {
    end feature redefines earlierOccurrence : MyPaint;
    end feature redefines laterOccurrence : MyDry;
}

behavior MyManufactureStepsPD unions MyPaint, MyDry;

#atom
behavior MyManufacture specializes Manufacture {
    feature redefines timeEnclosedOccurrences : MyManufactureStepsPD [2];
    step redefines paint : MyPaint;
    step redefines dry : MyDry [1];
    succession redefines p_before_d : MyPaint_Before_Dry_Link [1]
        first paint then dry;
}

Step 5 repeats for the remaining connector and step (d_before_s and ship).

#atom
behavior MyShip specializes Ship;

#atom
assoc MyDry_Before_Ship_Link specializes HappensBefore {
    end feature redefines earlierOccurrence : MyDry;
    end feature redefines laterOccurrence : MyShip;
}

behavior MyManufactureStepsPDS unions MyManufactureStepsPD, MyShip;

#atom
behavior MyManufacture specializes Manufacture {
    feature redefines timeEnclosedOccurrences : MyManufactureStepsPDS [3];
    step redefines paint : MyPaint;
    step redefines dry : MyDry [1];
    succession redefines p_before_d : MyPaint_Before_Dry_Link [1] first paint then dry;
    step redefines ship : MyShip [1];
    succession redefines d_before_s : MyDry_Before_Ship_Link [1] first dry then ship;
}
A.3.7 Timing for behaviors, Decisions and merges

Decisions and merges are steps that enable sequences to be selected during execution, rather than ahead of time in models, as in A.3.6:

- Decisions are steps with multiple outgoing successions, but only one is traversed during each execution of the decision.
- Merges are steps with multiple incoming successions, but only one is traversed during each execution of the merge.

These are modeled by

- Optional connector end multiplicities ([0..1]) on ends of the outgoing and incoming successions opposite decision and merge steps, respectively. This enables execution to determine which succession is traversed for each decision and merge.
- Decision and merges steps typed by DecisionPerformance and MergePerformance from the Kernel library, respectively. These enable additional timing constraints that require exactly one succession to be traversed for each decision and merge.

The example below includes a decision and merge, which appear in sequence like other steps, except with optional branching successions out and in, respectively. The timing constraints at the end ensure successions going out of the decision step and coming into the merge step have exactly one value (HappensBefore link) for each time those steps happen, identified by the library features outgoingHBLink and incomingHBLink of DecisionPerformance and MergePerformance, respectively, which are required to have exactly one value for each performance.

```java
behavior Manufacture {
  /* Before decision. */
  step admit : Admit [1];
  succession a_before_i first admit [1] then inspect [1];

  /* Decision. */
  step inspect : DecisionPerformance [*];

  /* Two decision branches. */
  succession i_before_f first inspect [1] then finish [0..1];
  step finish : Touchup [*];
  succession i_before_r first inspect [1] then recycle [0..1];
  step recycle : MarkForRecycling [*];

  /* Two merge branches. */
  succession f_before_ms first finish [0..1] then mShip [1];
  succession r_before_ms first recycle [0..1] then mShip [1];

  /* Merge */
  step mShip : MergePerformance [*];

  /* After merge */
  succession ms_before_s first mShip [1] then ship [1];
  step ship : Ship [*];

  /* Decision and merge timing constraints. */
  feature inspectOutgoingHBLinks : HappensBefore [*] unions i_before_f, i_before_r;
  connector bindIOHBL : SelfLink
    from inspectOutgoingHBLinks [1] to inspect.outgoingHBLink [1];
  feature mShipIncomingHBLinks : HappensBefore [*] unions f_before_ms, r_before_ms;
  connector bindmSIHBL : SelfLink
    from mShipIncomingHBLinks [1] to mShip.incomingHBLink [1];
}
```
The instantiation procedure in A.3.3 is amended for decisions and merges:

5. For each connector above
   a. ... b., ..., c., ..., ...
   For succession connectors with decision steps as their source or merge steps as their target
      ° Create the same number of association atoms as there are values of all the connected features
         opposite the decision or merge step (1 for each in this example).
      ° Assign each connected feature value as participant in exactly one association atom.
         If all the connected features together opposite the decision or merge step has more or fewer
         values than the decision or merge step, create atoms for the type of the feature with fewer values
         up to the number in the other feature, and assign them as values of the first feature.

The instantiation steps above produce the following atoms, choosing in this execution to touchup, rather than mark
for recycling. Only the final result of execution is shown, at the end for brevity (MyManufacture), while the other
atoms appear in the order created.

    /* Before decision. */
    #atom
    behavior MyAdmit specializes Admit;

    /* Decision. */
    #atom
    behavior MyInspect specializes DecisionPerformance;
    #atom
    assoc MyAdmit_Before_Inspect_Link specializes HappensBefore { 
      end feature redefines earlierOccurrence : MyAdmit;
      end feature redefines laterOccurrence : MyInspect;
    }

    /* One decision branch taken. */
    #atom
    behavior MyTouchup specializes Touchup;
    #atom
    assoc MyInspect_Before_Touchup_Link specializes HappensBefore { 
      end feature redefines earlierOccurrence : MyInspect;
      end feature redefines laterOccurrence : MyTouchup;
    }

    /* One merge branch taken. Merge. */
    #atom
    behavior MyMergeToShip specializes MergePerformance;
    #atom
    assoc MyTouchup_Before_Merge_Link specializes HappensBefore { 
      end feature redefines earlierOccurrence : MyTouchup;
      end feature redefines laterOccurrence : MyMergeToShip;
    }

    /* After merge. */
    #atom
    behavior MyShip specializes Ship;
    #atom
    assoc MyMerge_Before_Ship_Link specializes HappensBefore { 
      end feature redefines earlierOccurrence : MyMergeToShip;
      end feature redefines laterOccurrence : Ship;
    }
**behavior** MyManufactureSteps **unions** MyAdmit, MyInspect, MyTouchup, MyMergeToShip, MyShip;

```mermaid
#atom
behavior MyManufacture specializes Manufacture {
  feature redefines timeEnclosedOccurrences : MyManufactureSteps [5];

  /* Before decision. */
  step redefines admit : MyAdmit [1];

  /* Decision. */
  step redefines inspect : MyInspect [1];
  succession redefines a_before_i : MyAdmit.Before_Inspect_Link [1]
    first admit then inspect;

  /* One decision branch taken. */
  step redefines finish : MyTouchup [1];
  succession redefines i_before_f : MyInspect.Before.Touchup_Link [1]
    first inspect then finish;

  /* One merge branch taken. */
  succession redefines f_before_ms : MyTouchup.Before_Merge_Link [1]
    first finish then mShip;

  /* Merge. */
  step redefines mShip: MyMergeToShip [1];

  /* After merge */
  step redefines ship : MyShip [1];
  succession redefines ms_before_s : MyMerge.Before.Ship_Link [1]
    first mShip then ship;

  /* Decision and merge timing constraints. */
  feature redefines inspectOutgoingHBLinks : MyInspect.Before.Touchup_Link;
  feature redefines mShipIncomingHBLinks : MyTouchup.Before_Merge_Link;
}
```

### A.3.8 Timing for behavior, Changing feature values

This covers changes in feature values of occurrences. Change execution requires creating additional atoms for the periods (time slices) when feature values are unchanged for each occurrence (life), and ordering the slices in time as feature values change. Time slice atoms are also occurrences, but represent the same thing as their life occurrence, just for a potentially smaller period of time, see 9.2.4.1.

Changes to occurrence feature values is modeled using the library behavior `FeatureWritePerformance` as a step, specifying when the change is to happen, see 9.2.8.1. Time slices are created each time it is performed.

The example below adds to the example in A.3.6.

- A class with changeable features (MyProduct with `isPainted`, `isDry`, `isShipped`).
- Features of behaviors to identify the above (`objectToFinish`).
- `FeatureWritePerformance` steps specifying when and how to change its feature values (in Paint, Dry, and Ship).

`FeatureWritePerformances` ensure when they finish that the occurrence has a time slice starting right then with the feature values specified, though the values might change immediately afterwards. Execution must define time slice atoms that prevent feature values from changing between `FeatureWritePerformances`, see below.
behavior Manufacture {
    feature objectToFinish : Product [1];
    step paint : Paint [1] {
        redefines objectToPaint = objectToFinish;
    }
    step dry : Dry [*] {
        redefines objectToDry = objectToFinish;
    }
    succession p_before_d first paint [1] then dry [1];
    step ship : Ship [*] {
        redefines objectToShip = objectToFinish;
    }
    succession d_before_s first dry [1] then ship [1];
}

struct Product {
    feature isPainted : Boolean [1] := false;
    feature isDry : Boolean [1] := true;
    feature isShipped : Boolean [1] := false;
}

behavior Paint {
    feature objectToPaint : Product [1];
    step painting : FeatureWritePerformance [1] {
        in redefines onOccurrence : Product = objectToPaint {
            redefines startingAt : Product {
                redefines accessedFeature : Boolean [1] subsets isDry; } }
        in redefines replacementValues = false;
    }
    succession p_before_p first painting [1] then painted [1];
    step painted : FeatureWritePerformance [*] {
        in redefines onOccurrence : Product = objectToPaint {
            redefines startingAt : Product {
                redefines accessedFeature : Boolean [1] subsets isPainted; } }
        in redefines replacementValues = true;
    }
}

behavior Dry {
    feature objectToDry : Product [1];
    step dried : FeatureWritePerformance [1] {
        in redefines onOccurrence : Product = objectToDry {
            redefines startingAt : Product {
                redefines accessedFeature : Boolean [1] subsets isDry; } }
        in redefines replacementValues = true;
    }
}

behavior Ship {
    feature objectToShip : Product [1];
    step shipped : FeatureWritePerformance [1] {
        in redefines onOccurrence : Product = objectToShip {
            redefines startingAt : Product {
                redefines accessedFeature : Boolean [1] subsets isShipped; } }
        in redefines replacementValues = true;
    }
}
The instantiation procedure is amended with

6. For behaviors with FeatureWritePerformances
   a. Create classes for time slices (ProductTimeSlice) specializing the kinds of things they are slicing (Product), and redefining the features being modified as readonly (isPainted, isDry, isShipped).
   b. Add time slice features to atoms of the kinds of things being modified (MyProduct):
      i. Before the first FeatureWritePerformance (beforePaint),
      ii. Between each successive FeatureWritePerformance (whilePainting, afterPaint, afterDry),
      iii. After the last FeatureWritePerformance (afterShip)
   c. In the behavior atom using FeatureWritePerformance (MyManufacture), create atoms for the above time slice features in order, assigning values to all the features, even if they were not modified, and specify that
      i. The first time slice above (i)
         ▪ Starts (startShot) at the same time (timeCoincidentOccurrences) as the behavior.
         ▪ Ends just before (immediateSuccessors) the first FeatureWritePerformance does (paint.painting.endShot).
      ii. The middle time slices (ii)
         ▪ Start at the same time a FeatureWritePerformance ends.
         ▪ End just before the next one does.
      iii. The last time slice (iii)
         ▪ Starts at the same time the last FeatureWritePerformance ends (ship.shipped.endShot).
         ▪ Ends at the same times as the behavior.

The instantiation steps above produce the following atoms, adding to (or modifying) those created in A.3.3. Step 6.a produces

```kernel
#atom
struct MyProduct specializes Product;
#atom
behavior MyManufacture specializes Manufacture;

struct ProductTimeSlice specializes Product {
    readonly feature redefines isPainted;
    readonly feature redefines isDry;
    readonly feature redefines isShipped;
}
```

Instantiation step 6.b.i. the start of 6.c.i produces the first time slice (beforePaint) and starts it.

```kernel
#atom
struct MyProduct specializes Product {
}
#atom
behavior MyManufacture specializes Manufacture {
    feature redefines objectToFinish : MyProduct;
    feature redefines startShot
        subsets objectToFinish.beforePaint.startShot.timeCoincidentOccurrences;
    feature obPiP chains objectToFinish.beforePaint.isPainted = false;
    feature obPiD chains objectToFinish.beforePaint.isDry = true;
    feature obPiS chains objectToFinish.beforePaint.isShipped = false;
}
```
The first of instantiation step 6.b.ii and first start of 6.c.ii produces the second time slice (whilePainting), while the end of 6.c.i ends the first (beforePaint). The MyManufacture features above are omitted for brevity.

```
#atom
struct MyProduct specializes Product {
    feature whilePainting : ProductTimeSlice [1] subsets timeSlices;
}

behavior MyProductFeatureWrite specializes FeatureWritePerformance {
    in redefines onOccurrence : MyProduct;
}
#atom
behavior PaintingMyProductFeatureWrite specializes MyProductFeatureWrite;
#atom
behavior MyPaint specializes Paint {
    feature redefines objectToPaint : MyProduct;
    step redefines painting : PaintingMyProductFeatureWrite;
}
#atom
behavior MyManufacture specializes Manufacture {
    ...
    step redefines paint : MyPaint;
    feature subsets objectToFinish.beforePaint.immediateSuccessors,
    objectToFinish.whilePainting.startShot.timeCoincidentOccurrences
    chains painting.painting.endShot;
    feature owPiP chains objectToFinish.whilePainting.isPainted = false;
    feature owPiD chains objectToFinish.whilePainting.isDry = false;
    feature owPiS chains objectToFinish.whilePainting.isShipped = false;
}
```

The second of instantiation step 6.b.ii and second start of 6.c.ii produces the third time slice (afterPaint), while the end of the first 6.c.ii ends the second (whilePainting).

```
#atom
struct MyProduct specializes Product {
    feature whilePainting : ProductTimeSlice [1] subsets timeSlices;
}
#atom
behavior PaintedMyProductFeatureWrite specializes MyProductFeatureWrite;
#atom
assoc MyPaintingFW_Before_PaintFW_Link specializes HappensBefore {
    end feature redefines earlierOccurrence : PaintingMyProductFeatureWrite;
    end feature redefines laterOccurrence : PaintedMyProductFeatureWrite;
}
#atom
behavior MyPaint specializes Paint {
    feature redefines objectToPaint : MyProduct;
    step redefines painting : PaintingMyProductFeatureWrite;
    step redefines painted : PaintedMyProductFeatureWrite;
    succession redefines p_before_p : MyPaintingFW_Before_PaintFW_Link
    first painting then painted;
}
#atom
behavior MyManufacture specializes Manufacture {
    ...
    feature subsets objectToFinish.whilePainting.immediateSuccessors,
```
The third of instantiation step 6.b.ii and third start of 6.c.ii produces the fourth time slice (afterDry), while the end of the second 6.c.ii ends the third (afterPaint).

#atom
struct MyProduct specializes Product {
    feature whilePainting : ProductTimeSlice [1] subsets timeSlices;
    feature afterDry : ProductTimeSlice [1] subsets timeSlices;
}
#atom
behavior MyDry specializes Dry {
    feature redefines objectToDry : MyProduct;
    step redefines dried : MyProductFeatureWrite;
}
#atom
assoc MyPaint_Before_Dry_Link specializes HappensBefore {
    end feature redefines earlierOccurrence : MyPaint;
    end feature redefines laterOccurrence : MyDry;
}
behavior MyManufacture specializes Manufacture {
    ...
    step redefines dry : MyDry;
    succession redefines p_before_d : MyPaint_Before_Dry_Link [1] first paint then dry;
    feature subsets objectToFinish.afterPaint.immediateSuccessors,
    objectToFinish.afterDry.startShot.timeCoincidentOccurrences
    chains dry.dried.endShot;
    feature oaDiP chains objectToFinish.afterDry.isPainted = true;
    feature oaDiD chains objectToFinish.afterDry.isDry = true;
    feature oaDiS chains objectTo Finish.afterDry.isShipped = false;
}

Instantiation step 6.b.iii and 6.c.iii produce the fifth time slice (afterShip), while the end of the third 6.c.ii ends the fourth (afterDry).

#atom
struct MyProduct specializes Product {
    feature whilePainting : ProductTimeSlice [1] subsets timeSlices;
    feature afterDry : ProductTimeSlice [1] subsets timeSlices;
}
#atom
behavior MyShip specializes Ship {
    feature redefines objectToShip : MyProduct;
    step redefines shipped : MyProductFeatureWrite;
}
#atom
assoc MyDry_Before_Ship_Link specializes HappensBefore {
    end feature redefines earlierOccurrence : MyDry;
    end feature redefines laterOccurrence : MyShip;
}
behavior MyManufacture specializes Manufacture {
    ... 
    step redefines ship : MyShip;
    succession redefines d_before_s : MyDry_Before_Ship_Link [1] first dry then ship;
    feature subsets objectToFinish.afterDry.immediateSuccessors,
        objectToFinish.afterShip.startShot.timeCoincidentOccurrences
        chains ship.shipped.endShot;
    feature redefines endShot subsets objectToFinish.afterShip.timeCoincidentOccurrences;
    feature oaSiP chains objectToFinish.afterShip.isPainted = true;
    feature oaSiD chains objectToFinish.afterShip.isDry = true;
    feature oaSiS chains objectToFinish.afterShip.isShipped = true;
}