

Semantics of a Foundational Subset for Executable UML Models

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Preface

OMG

Founded in 1989, the Object Management Group, Inc. (OMG) is an open membership, not-for-profit computer industry standards consortium that produces and maintains computer industry specifications for interoperable, portable, and reusable enterprise applications in distributed, heterogeneous environments. Membership includes Information Technology vendors, end users, government agencies, and academia.

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- MOF
- XMI
- CWM
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- IDL/Language Mappings
- Specialized CORBA specifications
- CORBA Component Model (CCM)

Platform Specific Model and Interface Specifications

- CORBA services
- CORBA facilities

- OMG Domain specifications
- OMG Embedded Intelligence specifications
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Typographical Conventions

The type styles shown below are used in this document to distinguish programming statements from ordinary English. However, these conventions are not used in tables or section headings where no distinction is necessary.

Times/Times New Roman - 10 pt.: Standard body text

Helvetica/Arial - 10 pt. Bold: OMG Interface Definition Language (OMG IDL) and syntax elements.

Courier - 10 pt. Bold: Programming language elements.

Helvetica/Arial - 10 pt: Exceptions

NOTE: Terms that appear in italics are defined in the glossary. Italic text also represents the name of a document, specification, or other publication.

1 Scope

The scope of this specification is

- the selection of a subset of the UML 2 metamodel that provides a shared foundation for higher-level UML modeling concepts, as well as
- the precise definition of the execution semantics of that subset.

Given its fundamental nature, the subset assumes the most general type of system, including physically distributed and concurrent systems with no assumptions about global synchronization.

Many executable UMLs are conceivable, based on executing use cases, activities, workflow, methods, or state machines—and their combinations. This specification covers the capabilities described in the lower two layers described in Figure 6.1, Subclause 6.2.2 of the UML 2.2 Superstructure Specification. These layers encompass functionalities described as “structural foundations,” “intra-object behavior base,” “inter-object behavior base” and “actions,” and are covered primarily in Clause 7 and Clause 11 of the UML 2.2 Superstructure Specification.

The selected elements are translatable into an implementation such that a specified functional computation is independent of the control and data structures in which the elements reside. This translatability provides maximum flexibility to modify the organization of the data without affecting the definition of an algorithm. (The UML 1.5 action metamodel was designed in this manner for precisely this reason.)

It is not the intent of this specification to define the specification of every higher-level UML construct in terms of elements from the foundational subset; however, the specification does intend to encourage use of the broadest possible subset of UML constructs that can be reduced to a small set of elements.

In sum, the foundational subset defines a basic virtual machine for the Unified Modeling Language, and the specific abstractions supported thereon, enabling compliant models to be transformed into various executable forms for verification, integration, and deployment.

2 Conformance

This specification defines a subset of UML 2 and specifies foundational execution semantics for it. This subset will be referred to as Foundational UML or “fUML.” Conformance to this specification has two aspects:

1. *Syntactic Conformance.* A conforming model must be restricted to the abstract syntax subset defined for fUML.
2. *Semantic Conformance.* A conforming execution tool must provide execution semantics for a conforming model consistent with the semantics specified for fUML.

The fUML syntactic subset is defined by the abstract syntax metamodel given in Clause 7. The packages in this metamodel correspond to similarly named packages in the UML 2 Superstructure metamodel, which act as the basic language units for the purpose of syntactic conformance. The semantics for fUML is specified by the execution model given in Clause 8. The packaging structure of the execution model parallels the language unit packaging of the fUML abstract syntax exactly, except for one additional package called “Loci.”

As in the UML 2 Superstructure Specification, this specification defines a small number of *conformance levels*. Syntactically, each fUML level is a strict subset of the corresponding UML level, including a subset of the language unit packages placed at that level in the full UML 2 superstructure. Both syntactic and semantic conformance is relative to these levels.

The following subclauses define the fUML conformance levels and specify the meaning of conformance relative to those levels.

2.1 Conformance Levels

There are three conformance levels defined for fUML, corresponding to UML conformance levels L1, L2 and L3 (actually called “compliance levels” in the UML 2 Superstructure Specification). As in the UML 2 Superstructure, each conformance level is formally defined by merging the packages corresponding to the language units included at that level. However, for fUML, there are actually two sets of merges: one merge of the abstract syntax packages into a merged syntactic package for the level and a parallel merge of the corresponding execution model packages into a merged semantic package for the level. The merged syntactic package is a strict subset of the merged package for the corresponding UML 2 Superstructure level in the following sense: if the fUML syntactic L_n package is merged into the UML 2 Superstructure L_n package, the UML 2 Superstructure package is left unchanged.

The goal is to be able to syntactically interchange fUML models simply as UML 2 Superstructure models at the corresponding conformance level. Therefore, no new overall namespace is formally defined for fUML. The fUML abstract syntax is simply that portion of the UML 2 abstract syntax for which a corresponding semantic specification has been provided in this specification. To have a semantic meaning under this specification, a conforming fUML model must be constructed from the restricted portion of the UML abstract syntax defined for fUML, but it is otherwise interchanged as any other UML model.

Conformance Level 1 (L1) for fUML merges the following packages:

- Classes::Kernel
- CommonBehaviors::BasicBehaviors
- CommonBehaviors::Communications
- Loci (semantics only)

Note that there are separate merges for the syntactic (see Figure 1) and semantic packages (see Figure 2) with names as above (except for Loci, for which there is no syntactic package). The syntactic packages being merged are as they are defined for the fUML abstract syntax in Clause 7. The semantic packages being merged are as they are defined for the fUML execution model in Clause 8.

UML L1 also includes BasicActions and FundamentalActivities. But fUML does not have a separate package for FundamentalActivities, supporting execution semantics only at the level of IntermediateActivities (which is included at L2). Since BasicActions requires FundamentalActivities, that also cannot be included in fUML L1. As a result, actions and activities are not supported at all in fUML L1.

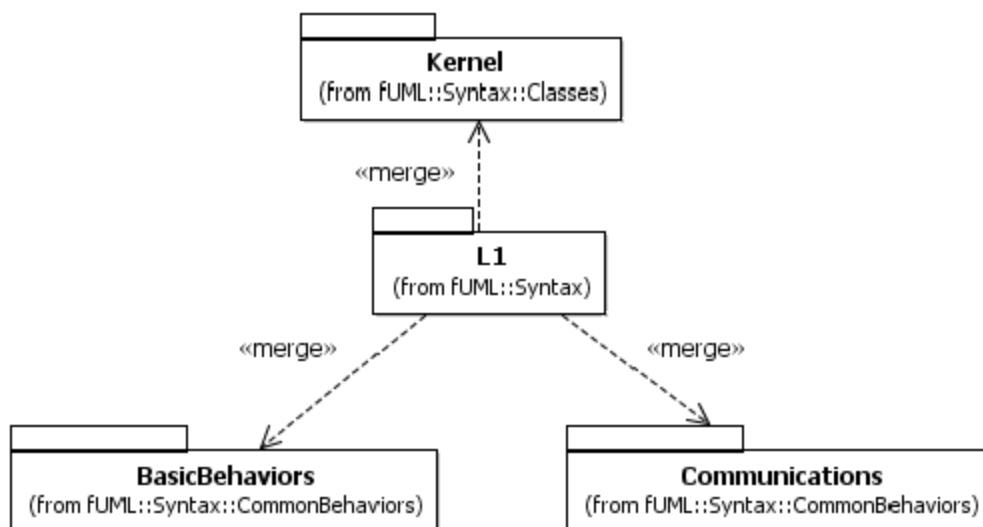


Figure 1 - fUML Syntax Level 1 Package Merges

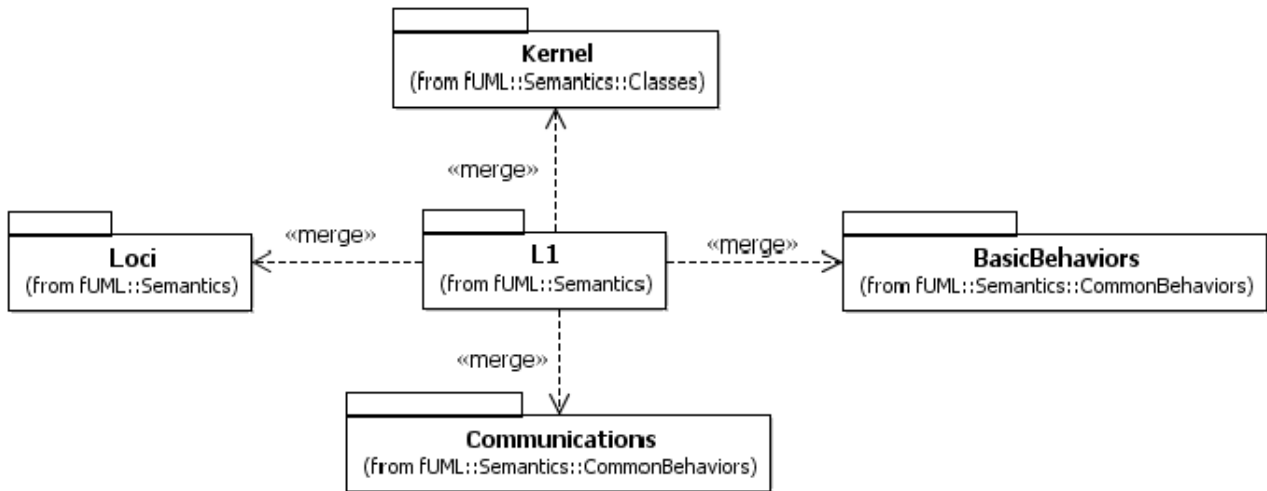


Figure 2 - fUML Semantics Level 1 Package Merges

Conformance Level 2 (L2) for fUML adds the following packages (as defined in Clauses 7 and 8) to L1 (see Figure 3 and Figure 4):

- Activities::IntermediateActivities
- Actions::BasicActions
- Actions::IntermediateActions

UML L2 also includes StructuredActivities. But fUML does not have a separate package for StructuredActivities, supporting execution semantics only at the level of CompleteStructuredActivities and ExtraStructuredActivities (which are included at L3).

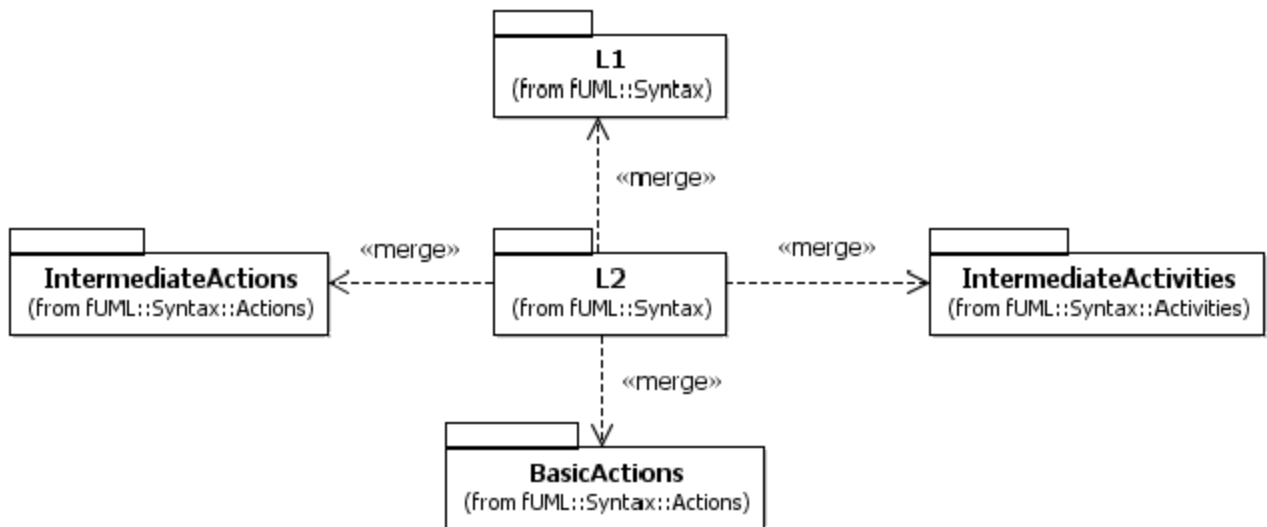


Figure 3 - fUML Syntax Level 2 Package Merges

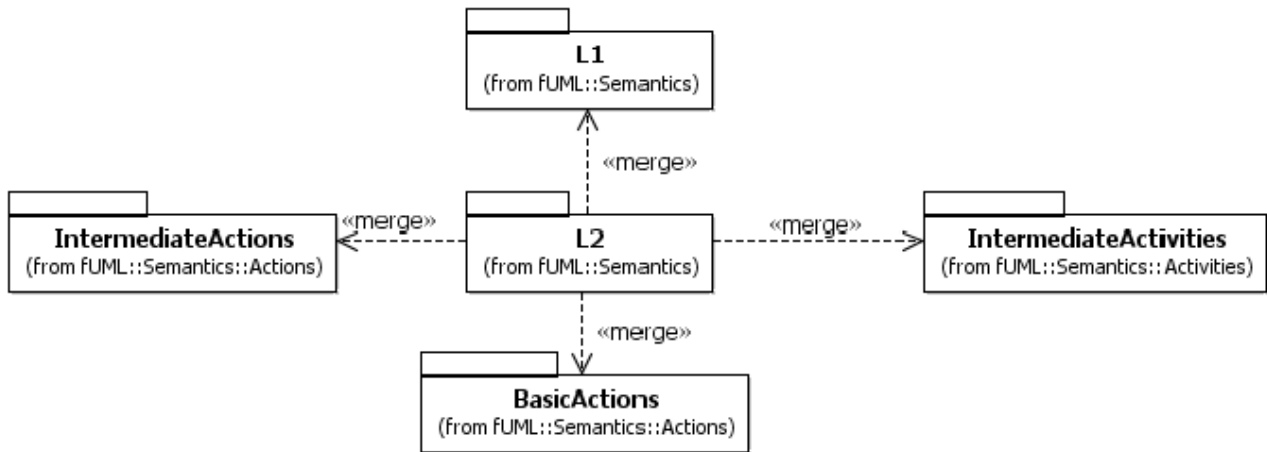


Figure 4 - fUML Semantics Level 2 Package Merges

Conformance Level 3 (L3) for fUML adds the following packages (as defined in Clauses 7 and 8) to L2 (see Figure 5 and Figure 6):

- Activities::CompleteStructuredActivities
- Activities::ExtraStructuredActivities
- Actions::CompleteActions

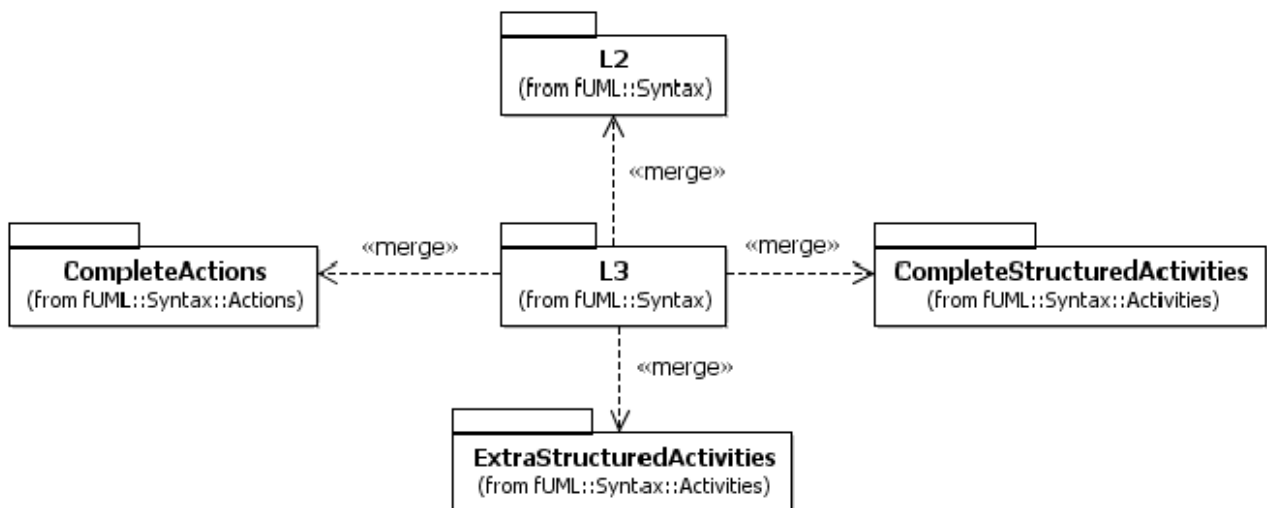


Figure 5 - fUML Syntax Level 3 Package Merges

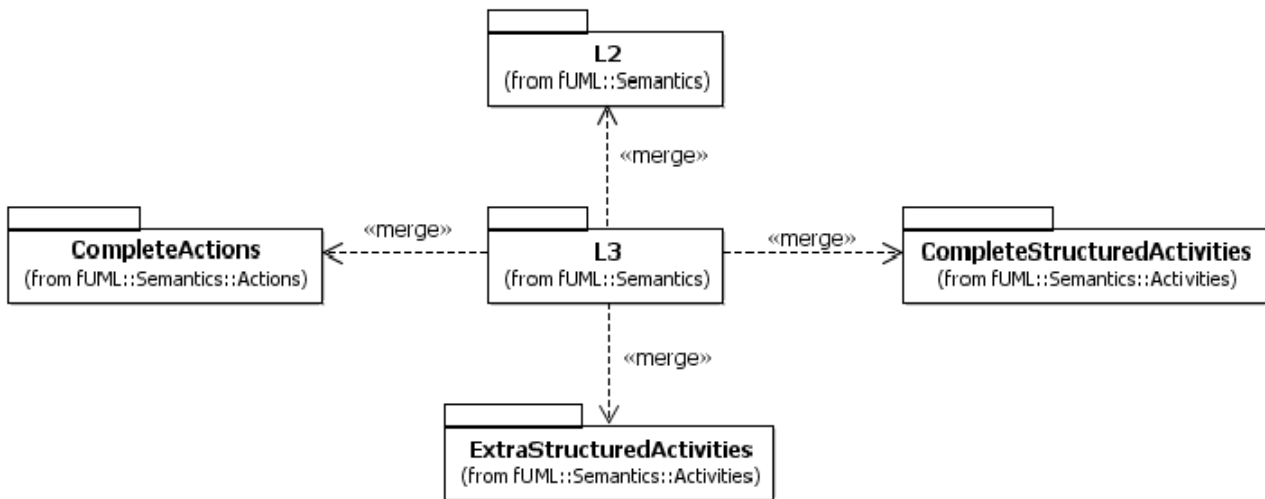


Figure 6 - fUML Semantics Level 3 Package Merges

2.2 Meaning and Types of Conformance

Conformance to a specific fUML conformance level entails both syntactic *and* semantic conformance. Syntactic conformance is defined in terms of a *conforming model*.

- *Abstract Syntax Conformance.* A UML model *conforms* to a specific fUML level if it is a well-formed model constructed from only syntactic elements that are included in the fUML abstract syntax metamodel for that level. A *well-formed* model is one that meets all constraints imposed on its syntactic elements by the UML 2 Superstructure abstract syntax metamodel *and* any additional constraints imposed on those elements by the fUML abstract syntax (given in Clause 7).
- *Model Library Conformance.* In addition, a conforming UML model at any level may make use of elements from the fUML model library (see Clause 9). An execution tool is not required to implement any of the model elements defined in Clause 9, but, if such elements are provided, they must conform to the behavior specified in that clause. An execution tool may, in addition, make available a tool-specific model library for use by conforming models accepted by the tool, so long as the execution behavior of elements of the models in that library may be entirely defined in fUML at the same conformance level as models accepted by the tool.

For a conforming model at a certain level, the fUML specification provides a precise definition of the execution semantics for the model at that level. Conformance to this semantics is defined in terms of a *conforming execution tool* (see Clause 4 for the definition of the term “execution tool” as used in this document). If a conforming execution tool is presented with a conforming model, then it must behave as further described below. On the other hand, if it is presented with a non-conforming model, then it may react in one of the following three ways.

1. *Rejection.* It may reject the model and refuse to process it further at all.
2. *Static Partial Acceptance.* If the tool is able to statically determine that the non-conforming parts of the model are all elements of abstract syntax packages that are not included in the fUML subset at all, and that the model elements from packages included in the fUML subset all conform to fUML, then the tool may accept the model. In this case, any elements that are not included in the fUML subset, and are not instances of metaclasses that are specializations, directly or indirectly, of metaclasses in the fUML subset, may be ignored by the tool. Any elements that are not

included in the fUML subset, but are instances of metaclasses that are specializations of metaclasses in the fUML subset, must be interpreted as if they are instances of the superclass that is in the fUML abstract syntax.

3. *Dynamic Partial Acceptance.* The tool may accept the model for execution and attempt to evaluate or execute any value specification or behavior from the model, interpreting any model elements as in the case of static partial acceptance. However, if the tool encounters any model element that is defined in an abstract syntax within the fUML subset, but does not conform to the additional constraints defined for the fUML subset, then the tool must terminate execution with an error.

A conforming execution tool need not use the same option above in all cases. However, it must be specified for any conforming tool in which cases each option is used.

To further claim conformance for an execution tool at a specific level, it must be possible to demonstrate the following.

- *Abstract Syntax Mapping.* An execution tool accepts a UML model for execution in some concrete form. It must be possible to bidirectionally map this concrete input form to a well-formed representation in terms of instances of the metaclasses in the fUML abstract syntax at the given conformance level. One standard way to do this is to use the XML Metadata Interchange (XMI) as the input form for the model, in which case the mapping to the UML abstract syntax is provided by the XMI standard (see Clause 3). However, it is not required that XMI be used as the input form. For example, a tool may provide for direct model input in terms of graphical and or textual notation, so long as this may be fully mapped to the fUML abstract syntax.
- *Semantic Value Mapping.* Runtime inputs and outputs are semantically specified by a model of *values* (see Subclause 8.3). During the execution of a behavioral model, the model execution will generally take values as inputs and produce values as outputs. The execution tool must provide a concrete implementation for all such values and demonstrate a mapping from this implementation to the model of values provided in Subclause 8.3. For this mapping, it is only required to demonstrate the effective implementation of the *properties* defined for the value classes, showing the corresponding implementation value for any value instance from the semantic model, and vice versa. It is *not* required to demonstrate the implementation of the operations specified for those classes in the execution model. Also, if the execution tool uses different internal and external forms for values, it is only required to provide a mapping for the external form, so long as this is sufficient to demonstrate semantic conformance, as described below.
- *Execution Environment Mapping.* The fUML execution model provides an abstraction of the *execution environment* for a model in terms of the concept of an execution *locus* (see Subclause 8.2). It must be possible to demonstrate how the actual execution environment provided by an execution tool corresponds to the locus concept. Specifically, this must include:
 - A definition of whether execution takes place at a single locus or may be distributed across multiple loci. If the latter, then the tool must provide a mechanism for allocating a model or a portion of a model to a specific locus.
 - A description of whether and how extensional values (see Subclauses 8.2 and 8.3) are persisted at a locus across behavior executions.
 - A specification of what objects are pre-instantiated at a locus in order to provide system services (such as input/output—see Subclause 9.3).

Note that, for an execution tool that, say, compiles a model to some target executable form, the execution environment for the purposes of this mapping will be the environment in which the target executable runs, rather than the environment of the tool itself.

- *Semantic Conformance.* Finally, a conforming execution tool must provide an implementation of the interface of the *Executor* class from the execution model (see Subclause 8.3). While it is not necessary that this be a strict implementation of the object-oriented operations provided by *Executor*, it must be possible to demonstrate the following:
 - *Evaluation.* Given a well-formed value specification from a conforming model, the tool must be able to produce a value conforming to the result of the *Executor::evaluate* operation on the value specification.
 - *Synchronous Execution.* Given a well-formed behavior from a conforming model and values for all input

parameters of the behavior, the tool must be able to execute the behavior in conformance to the effect and results of the `Executor::execute` operation.

- *Asynchronous Execution.* Given a behavior or an active class from a conforming model, the tool must be able to asynchronously start the given behavior in conformance to the effect and results of the `Executor::start` operation.

Note that, at a given conformance level, a conforming execution tool must semantically conform when presented with *any* conforming model at that level. That is, to conform at a certain level, an execution tool must implement *all* of the fUML abstract syntax at that level and provide conforming semantics for it.

The above definition of semantic conformance uses the concept of *conforming to an operation* of the `Executor` class from the execution model. This concept is further defined as follows.

- Inputs provided to the execution tool must correspond to the input parameters required for the operation.
- Using the abstract syntax and semantic value mappings for the tool, map the inputs to the execution tool from their implementation form to the corresponding representation in terms of instances of abstract syntax and semantic value classes.
- Using the execution environment mapping, map the intended target execution environment to a corresponding model in terms of execution loci and pre-instantiated extensional values.
- Using the specification of the given operation as part of the execution model (or the subset of that model that applies at a certain conformance level), determine the effect of invoking the operation on the given input values using an executor at a specific execution locus. This includes the generation of output values and any side effects that occur at and through the execution locus.
- Using the execution environment mapping, map any updates to loci to updates to the target execution environment.
- Using the semantic value mapping, map any output values to the corresponding implementation form for the tool.
- Conformance requires that the actual outputs and environmental changes produced by the execution tool be *consistent* with the outputs and changes determined in 5 and 6 above.

The conformance requirement here is one of *consistency* rather than *equivalence*, because, as a semantic specification, the execution model tightly *constrains*, but does not always fully determine, the exact results of an execution. This is particularly true in the presence of the high degree of concurrency possible with UML activity models, in which different conforming implementations may produce significantly different resulting executions of the same model due to timing issues.

This allowance for some flexibility in the conformance requirements is known as the *genericity* of the execution model, which is discussed in more detail in Subclause below. Nevertheless, it is still possible to formalize the conformance requirements even in the presence of such genericity.

- Clause 10 specifies the *base semantics* for the execution model. This specification effectively provides for an interpretation of the execution model as a set of first-order predicates, or *axioms*, over possible execution traces.
- A specific invocation of an operation in the execution model, as called for in the determination of conformance to the operation above, results in an execution trace. Any execution trace that satisfies the axioms of the base semantics is a legal execution trace.
- Conformance to the operation requires that the execution tool conform to the effect and results of *any* legal execution trace of the operation. The tool is allowed to conform to different execution traces for different invocations of the operation, even on identical inputs in an identical environment.

In essence, the base semantics provides an interpretation of the execution model as a set of constraints on the allowable execution of well-formed fUML models. A conforming execution tool must produce results that do not violate these constraints, but there is flexibility for allowing different implementations to provide somewhat different behavior for the execution of the same well-formed model, within the specified constraints. Ideally, conformance would be demonstrated by a formal proof that the execution tool implementation meets all the required constraints. In reality, it is expected that

conformance will be demonstrated by a sufficient suite of tests hand checked against the specification, as is the case for, say, conformance to most major programming language standards.

2.3 Genericity of the Execution Model

To support a variety of different execution paradigms and environments—including a number of widely used commercial and research variants of executable UML—the specification of the execution model incorporates a degree of *genericity*. This is achieved in two ways: (1) by leaving some key semantic elements unconstrained and (2) by defining explicit semantic variation points. A particular execution tool can then realize specific semantics by suitably constraining the unconstrained semantic aspects and providing specifications for any desired variation at semantic variation points.

The semantic areas below are not explicitly constrained by the execution model.

- *The semantics of time.* The execution model is agnostic about the semantics of time. This allows for a wide variety of time models to be supported, including discrete time (such as synchronous time models) and continuous (dense) time. Furthermore, it does not make any assumptions about the sources of time information and the related mechanisms, allowing both centralized and distributed time models.
- *The semantics of concurrency.* The execution model includes an implicit concept of concurrent threading of execution (see the discussion in Subclause 8.5.1). However, it does not require that a conforming execution tool actually execute such concurrent threads in a physically parallel fashion and it is agnostic about the actual scheduling of execution of concurrent threads that are not physically executed in parallel. So long as the execution tool respects the various creation, termination and synchronization constraints placed on such threads by the execution model, any sequentially ordered, or partial or totally parallel, execution of concurrent threads conforms to a legal execution trace.
- *The semantics of inter-object communications mechanisms.* This refers specifically to communication properties of the medium through which signals and messages are passed between objects. The execution model is written as if all communications were perfectly reliable and deterministic. However, this is not realistic for all execution tool implementations. Therefore, despite the restrictions that would be imposed by a strict interpretation of the execution model, conformance of an execution tool to the semantics of inter-object communication is not predicated on any assumptions about whether or not such communication is reliable (i.e., that signals and messages are never lost or duplicated), preserves ordering, happens with deterministic or non-deterministic delays, and so on.

Different execution tools may semantically vary in the above areas in executing the same model, while still being conformant to the semantics specified by the execution model for fUML. Additional semantic specifications or constraints may be provided for a specific execution tool in these areas, so long as it remains, overall, conformant to the execution model. For instance, a particular tool may be limited to a single centralized time source such that all time measurements can be fully ordered.

In contrast to the above areas, the items below are explicit *semantic variation points*. That is, the execution model as given in this specification by default fully specifies the semantics of these items. However, it is allowable for a conforming execution tool to define alternate semantics for them, so long as this alternative is fully specified as part of the conformance statement for the tool.

- *Event dispatch scheduling.* As described in Subclause 8.4.3, signal instances received by an active object are placed into an *event pool*. The instances in the pool are then asynchronously dispatched as occurrences of signal events, potentially triggering waiting accepters of such events. By default, events are dispatched from the pool using a first-in first-out (FIFO) rule. However, a conforming execution tool may define an alternative rule for how this dispatching is scheduled by providing a specialization of the `GetNextEventStrategy` class that redefines the `dispatchNextEvent` operation to specify the desired rule.
- *Polymorphic operation dispatching.* Operations in UML are potentially polymorphic—that is, there may be multiple methods for any one operation. The determination of which method to use for a given invocation of the operation depends on the context and target of the invocation. The specification for this determination is provided in the execution model by the *dispatch* operation of the `Object` class, as specified in Subclause 8.4.2 (the semantics of operation dispatching is further discussed in relation to the call operation action in Subclause 8.6.2).

By default, the method used for an operation must be associated with a (possibly inherited) member operation of a type of the target object of the operation invocation that is either the invoked operation or a redefinition (“override”) of it. However, a conforming execution tool may define an alternative rule for how this dispatching is to take place by providing a specialization of the *DispatchStrategy* class that redefines the *dispatch* operation to specify the desired rule.

If a conforming execution tool wishes to implement a semantic variation in one of the above areas, then a specification must be provided for this variation via a specialization of the appropriate execution model class as identified above. This specification must be provided as a fUML model in the “base UML” subset interpretable by the base semantics of Clause 10. Further, it must be defined in what cases the variation is used and, if different variants may be used in different cases, when each variant applies and/or how what variant to use is to be specified in a conforming model accepted by the execution tool.

2.4 Conformance Statement

The conformance of an execution tool to the fUML specification may be summarized in a *conformance statement* for the tool. Such a statement should include the following items.

- *Conformance Level.* The conformance level for models accepted by the tool.
- *Model Library.* An identification of what elements of the standard fUML model library are implemented by the tool. A specification of any additional tool-specific model library elements.
- Abstract Syntax Mapping
- Abstract Syntax Mapping
- Semantic Value Mapping
- Execution Environment Mapping
- *Semantic Conformance.* A demonstration of semantic conformance in terms of the above mappings.
- *Semantic Constraints.* A specification of any additional semantic constraints on semantic areas left unconstrained by the execution model.
- *Semantic Variation.* For each semantic variation point, a specification of any variation from the default semantics.

3 Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this specification. The following OMG standards provided the source for the foundational subset.

UML 2.2 RTF report (ptc/08-05-03)

UML 2.2 Infrastructure convenience document (ptc/08-05-04)

UML 2.2 Superstructure convenience document (ptc/08-05-05)

OCL 2.0 Specification (formal/06-05-01)

MOF 2.0 Core Specification (formal/06-01-01)

XML Metadata Interchange (XMI) provides a syntactic interchange mechanism for models. It is expected that models conforming to this specification will be interchanged using XMI.

MOF 2.0 XMI Mapping Specification (formal/07-12-01)

XML Metadata Interchange Specification (formal/05-05-06)

4 Terms and Definitions

For the purposes of this specification, the following terms and definitions apply.

Base Semantics

A definition of the execution semantics of those UML constructs used in the execution model, using some formalism *other than* the execution model itself. Since the execution model is a UML model, the base semantics are necessary in order to provide non-circular grounding for the execution semantics defined by the execution model. The base semantics provide the “meaning” for the execution of just those UML constructs used in the execution model. The execution model then defines the “meaning” of executing any UML model based on the full foundational subset. Any execution tool that executes the execution model should reproduce the execution behavior specified for it by the base semantics.

Behavioral Semantics

The denotational mapping of appropriate language elements to a specification of a dynamic behavior resulting in changes over time to instances in the semantic domain about which the language is making statements.

Compact Subset

For the purposes of this specification, a compact subset of UML is one that includes as small a subset of UML concepts as is practicable to achieve computational completeness.

Computationally Complete

A computationally complete subset of UML is one that is sufficiently expressive to allow definition of models that can be automatically executed on a computer by an execution tool.

Execution Model

A model that provides a complete, abstract specification to which a valid execution tool must conform. Such a model defines the required behavior of a valid execution tool in carrying out its function of executing a UML model and therefore provides a definition of the semantics of such execution.

Execution Semantics

For the purposes of this specification, the behavioral semantics of UML constructs that specify operational action over time, describing or constraining allowable behavior in the domain being modeled.

Execution Tool

Any tool that is capable of executing any valid UML model that is based on the foundational subset and expressed as an instantiation of the UML 2 abstract syntax metamodel. This may involve direct interpretation of UML models and/or generation of equivalent computer programs from the models through some kind of automated transformations. Such a tool may also itself be concurrent and distributed.

Foundational Subset

The subset of UML to which execution semantics are given in order to provide a foundation for ultimately defining the execution semantics of the rest of UML.

Static Semantics

Possible context sensitive constraints that statements of a language must satisfy, beyond their base syntax, in order to be well formed.

Structural Semantics

The denotational mapping of appropriate language elements to instances in the semantic domain about which the language makes statements.

Syntax

The rules for how to construct well-formed statements in a language or, equivalently, for validating that a proposed statement is actually well-formed.

5 Symbols

There are no symbols or abbreviated terms necessary for the understanding of this specification.

6 Additional Information

6.1 Changes to Adopted OMG Specifications

The Foundational Subset for Executable UML Models specification does not change any adopted OMG specifications. The semantics defined in this specification are generally a precise definition of a subset of the UML semantics given in the UML 2 Superstructure Specification. For this subset, the foundational execution semantics are intended to be consistent with, though sometimes more restrictive than, the less precise textual semantic specification given in the UML 2 Superstructure Specification. Cases where the foundational execution semantics restrict some semantic variability allowed in the UML 2 Superstructure Specification are noted in the overview discussions in the subclauses of Clause 8, Execution Semantics.

However, there are a few cases in which the semantic interpretation provided by fUML must be considered to be not entirely consistent with the semantics as stated in the UML 2 Superstructure Specification. In these cases, the fUML specification does *not* change the UML specification, since this would likely require addressing semantic implications beyond the fUML subset. Instead, an inconsistency simply remains at this time, which may be addressed in future versions of the full UML specification. Execution tools conforming to fUML are required to provide the semantics as specified in the Foundational Subset for Executable UML Models standard.

The following areas have been identified as semantic inconsistencies at this time.

- Null tokens are not passed to the output pins of an invoking action when the corresponding parameter nodes of an invoked activity are empty and the activity is terminated (see Subclause 8.5.2).
- Rather than receiving a full collection on a single token, expansion nodes use the set of all tokens they are holding as the “collection” referenced by their expansion region (see Subclause 8.5.4).

- Test identity actions apply to inputs that are data values, as well as objects, testing data values for equality by value rather than identity of reference (see Subclause 8.6.3).

NOTE: The foundational subset is based on UML 2.2. Particular changes made in UML 2.2 over the previous UML 2.1.2 version that are incorporated into the foundational subset include changes to decisions nodes and write structural feature actions and the addition of the start object behavior action.

6.2 On the Semantics of Languages and Models

In a general sense, a *language* is a symbolic means for communication. The language provides rules for constructing *statements* that communicate some specific meaning. In a natural language, these rules evolve neurologically and socially over time. For a formal language, on the other hand, the rules are constructed artificially in order to create a means of communication that, for some intended purpose, is in some way more precise than natural language.

A formal language only attaches meaning to statements that are correctly constructed or *well formed*. The *syntax* of the language provides the rules for how to construct well-formed statements or, equivalently, for validating that a proposed statement is actually well-formed. The *semantics* of the language then provides the specification of the meaning of well-formed statements.

It is usually possible to completely specify the syntax of a formal language. This is because syntax has specifically to do with the form and structure of statements in the language. Semantics is more problematical because it is inherently extrinsic to the form of the statements themselves. Meaning can only be assigned to a formal statement in relation to entities in some *semantic domain* about which the statement is intended to communicate.

An *interpretation* of a statement is a mapping of syntactic elements of the language to elements of the semantic domain such that the truth-value of the statement can be determined, to some level of accuracy. Colloquially, an interpretation of a model can be said to give it “meaning” relative to the semantic domain. If this mapping can be inverted, so that elements of the semantic domain can be mapped to syntactic language elements, then a statement can also be constructed as a *representation* of some part of the semantic domain, such that the statement is true under the interpretation mapping.

As a somewhat stylized example from natural language, consider the simple statement “Jack owns that house.” This is a syntactically correct statement in the English language. We can interpret the statement in terms of the “real world” as the semantic domain.

The word “Jack” is a syntactic element that *denotes* some person in the real world under this interpretation. Similarly, the phrase “that house” denotes a specific structure in the real world. Finally, the word “owns” denotes a legal relationship that may hold between a person and property. If this legal relationship does exist between the previously identified person and structure, then we can say that the statement “Jack owns that house” is true under this interpretation. Otherwise it is false.

Conversely, suppose we know it to be true that a person named “Jack” has legal ownership of a specific house being pointed to. Then we can say that the statement “Jack owns that house” is a truthful representation of this situation.

One of the most useful aspects of a formal language is that it can be used to make concrete statements about potentially abstract elements of the semantic domain. Essentially syntactic manipulations of these statements can then be used to make deductions about the semantic elements represented by the statements.

A *theory* is structured set of rules for *deducing* new statements in a language from existing statements. A theory is considered *correct* under a certain interpretation if any statements deduced from true statements under the interpretation are themselves always true. In this way, the syntactic deduction rules of the theory may be used to make corresponding actual deductions in the semantic domain.

A *model* is a set of statements in a *modeling language* about some domain under study, which provides the semantic domain for the model. The meaning of statements in the model is then assigned by an interpretation that maps model elements to elements of that semantic domain.

A model may be used to *describe* a domain. In this case, the model is considered *correct* (under some interpretation) if all statements made in the model are true for the domain. Similarly, a theory is considered correct for this domain if all statements deduced using the theory from statements in the model are also true.

Alternatively, a model may be used as a *specification* for a domain (or for some system within a domain). In this case, a specific domain is considered *valid* relative to this specification if no statement in the model is false for the domain. Similarly, a valid domain *conforms* to a specific theory if, in addition, no statements deducible using the theory from the model are false. That is, all statements deducible from the model also effectively become part of the specification.

UML is, of course, a modeling language. “Statements” in UML are constructed using a combination of (syntactic) modeling elements, both graphical and textual. The statements made by a UML model can then be interpreted against the domain being modeled.

For example, consider the simple instance model shown in Figure 7. As a model of the “real world”, this can be interpreted as making the set of statements: “There is a person whose name is Jack. There is a house. The person is the owner of the house.”



Figure 7 - Simple UML Instance Model

Note that it is an *instance* model that is interpreted here as making direct statements about the real world. These statements are what logicians call *first order* propositions. However, it is more common in UML to model (at least initially) at the level of classes. A class model makes *second order* statements about what kind of first order propositions are valid for the domain under study.

Consider the class model in Figure 8. Structurally, this model *requires* that each instance of the class Person have the properties “name” and “houses”. Further, it *requires* that the name of an instance of Person have a String value and it *allows* the instance to have zero or more houses associated with it.



Figure 8 - Simple UML Class Model

Under this interpretation, the relationship between the instance model of Figure 7 and the class model of Figure 8 is basically one of consistency. The instance *p* in Figure 7 is declared to have the class Person as its type. It is therefore required to have a *name* attribute. It would certainly be possible to construct a UML model of an instance of Person that does not have a name. However, this would be *inconsistent* with the class model given in Figure 8.

Of course, it is also possible to give a direct interpretation of a class model in terms of the domain under study. For example, we could take the class Person to denote the set of all people and the class House to denote the set of all houses, while the association Ownership denotes a relationship between people and houses. The class model of Figure 8 then makes statements about the “real world” such as “Every person has a name.” and “Some people own houses” (where the latter statement reflects the “zero or more” multiplicity of the “houses” association end).

There is also another common, but very different, interpretation that may be given to the same class model shown in Figure 8. In this interpretation the domain under study is that of computer programs written, say, in the Java programming language. That is, the class model is interpreted as a model *of* a Java program in this domain. Each class in the model is taken to denote a corresponding Java class with each property in the model denoting a corresponding field in the Java class. If the class model is taken as a specification, then the model will actually exist before the program is written—the model becomes the design for constructing a valid Java program.

This example points out the fact that the same model may have different “meanings” under different interpretations. In fact, it may even be useful to have multiple interpretations for a model at the same time. Indeed, under the usual tenets of object-oriented design, the design model of program should *also* be interpretable as a model (in a somewhat restricted sense) of the portion of the real world relevant to the program (the so-called “problem domain”).

6.3 On the Semantics of Metamodels

A *metamodel* is often rather loosely defined as “a model of a model.” For our purposes here, however, a more precise definition is “a model of a modeling *language*.” Thus, the UML metamodel is a model with the domain under study being UML, the language.

Another way to look at this is to consider the metamodel to be a specification model for a *class* of “systems” in the semantic domain, where each system in the class is itself a valid model expressed in a certain modeling language. The metamodel therefore makes statements about what can be expressed in the valid models of the modeling language. Since a metamodel is a specification, a model in the modeling language is *valid* only if none of these statements are false.

If the interpretation mapping for a metamodel is invertible, one can also uniquely map elements of the modeling language back to elements of the metamodeling language. In this case, given any model, we can invert the interpretation mapping to create a *metamodel representation* of the model—that is, a set of true statements about the model expressed in the metamodeling language.

A *theory of a metamodel* is a way to deduce new statements about a modeling language from the statements already in a metamodel of the modeling language. Since a metamodel is a specification, a valid model in the modeling language must not violate any statement deducible using the theory from the explicit metamodel statements.

One way to look at this is to consider the statements of the metamodel as *axioms* about the modeling language. Then, given the metamodel representation of a model, we can *deduce*, using the theory, whether the representation of the model is *consistent* with the metamodel. If it is consistent then the model is valid, otherwise it is not.

The UML Specification document provides a metamodel of UML. That is, it includes a set of statements about UML models that must not be violated by any valid UML model. Note that, in its entirety, this metamodel can be considered to include all of the concrete graphical notation, abstract syntax and semantics for UML. However, as defined in the Specification document, the only part of this metamodel that is *formal* is the abstract syntax model.

The UML abstract syntax is formalized as a UML class model. It is thus an example of a *reflexive* metamodel. That is, it is expressed in the same modeling language that it is defining. This, of course, introduces an inherent circularity.

Since a reflexive metamodel is expressed in the same modeling language as it is describing, its interpretation provides a mapping of the modeling language onto itself. Generally, this mapping will be from the entire modeling language to a subset of it. One can then iterate this mapping, each time producing a smaller subset, until one reaches the *minimal* reflexive metamodel that maps completely onto itself, rather than a subset. This minimal metamodel contains the smallest set of modeling elements required in order to specify the modeling language in question.

An interpretation of a *minimal* reflexive metamodel maps the metamodel onto itself. This means that any statement in the minimal reflexive metamodel can be represented in terms of elements of the minimal reflexive metamodel. However, the interpretation of this representation is itself expressed reflexively as a mapping to yet another representation in terms of the minimal reflexive metamodel. This circularity means that, for a minimal reflexive metamodel, the interpretation mapping really provides no useful expression of the “meaning” of the metamodel itself. To break this circularity, the minimal reflexive metamodel must be given a *base* semantics that is independent of its circular interpretation in terms of itself.

In the case of UML, the “minimal” reflexive abstract syntax metamodel is the UML Infrastructure (for pragmatic reasons the Infrastructure is not actually absolutely “minimal,” but it is still just a small subset of the full UML Superstructure). The Meta-Object Facility (MOF) specification defines a standard meta-metamodel based on the UML Infrastructure that provides the basic elements required to construct the abstract syntax metamodel for any modeling language.

The MOF specification also attempts to provide an “Abstract Semantics” for the MOF meta-metamodel. However, this semantics is still defined in terms of a semantic domain that is specified using a UML class model. Thus, the circularity is

not really broken. The only interpretations of the MOF meta-metamodel that are effectively non-circular are those provided by the standard mappings of the meta-metamodel to other technologies, such as XML Metadata Interchange (XMI) and Java Metadata Interface (JMI).

It is one of the goals of the Foundational Subset for Executable UML Models specification to provide a true abstract base semantics for the foundation of UML.

6.4 Alignment with the OMG Four Layer Metamodeling Architecture

OMG modeling language specifications are developed within the framework of a four layer metamodeling architecture.

- M0—The domain under study (the “objects” of the model)
- M1—The user specification (the model)
- M2—The modeling language specification (the metamodel)
- M3—The reflexive metamodeling language specification (the meta-metamodel)

In terms of the OMG metamodeling layers, interpretation can generally be said to “cross meta-layers.” For example, the interpretation mapping for UML maps from model elements, considered to be “at layer M1,” to elements of the domain under study, considered to be “at layer M0.” Similarly, there are interpretation mappings from metamodel elements “at layer M2” to model elements “at layer M1” and from meta-metamodel elements “at layer M3” to metamodel elements “at layer M2.”

On the other hand, a theory is “within a single meta-layer.” For example, a theory of UML allows some models to be deduced from other models (e.g., instance models from class models), entirely at layer M1. Similarly, a theory of the UML abstract syntax allows the validity of a UML model to be determined entirely at level M2, after mapping the model to its metamodel representation.

Note that this view of the meta-layers does *not* consider elements in one layer to necessarily be “instances of” elements in the layer above it. For example, consider the particularly simple case of the domain at level M0 being Java programs (as previously discussed in Section 6.2). Typically, the relationship of the model of a class at level M1 to level M0 is considered to be something of the sort given in Figure 9.

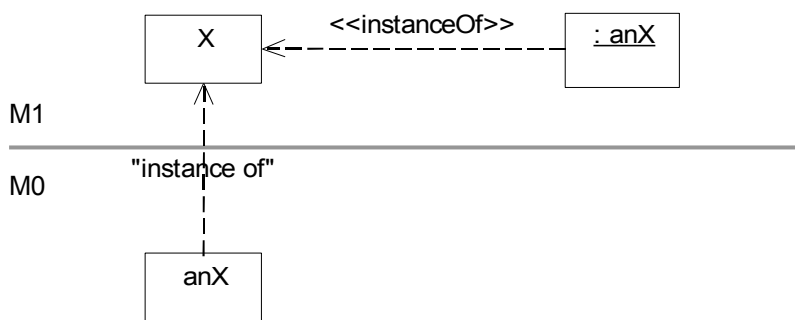


Figure 9 - Instance Relationship across Meta-Layers M1 and M0

The view taken here is that the concept of interpretation provides the general relationship between one meta-layer and the next. Thus, the above situation would be considered as in Figure 10. (Despite the concrete example of a Java class used

here at M0, the argument applies equally well to other more abstract domains, such as workers and the conceptual classes of their positions in a company.)

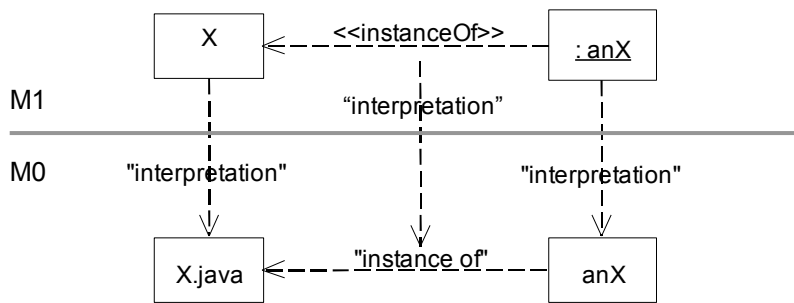


Figure 10 Interpretation across Meta-Layers M1 and M0

If we now add level M2 to this diagram, the interpretation mapping is between instances of metaclasses at M2 and the model elements at M1. This is shown in Figure 11.

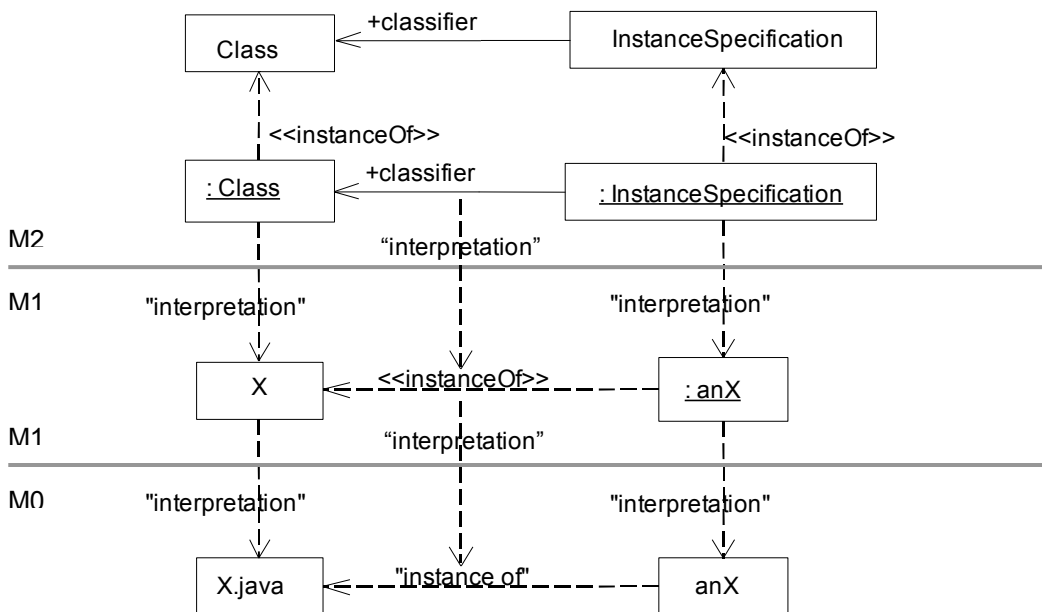


Figure 11 - Interpretation across Meta-Layers M1 and M0

The MOF takes the UML Infrastructure subset from layer M2 and places it in layer M3. The relationship between M2 and M3 is thus essentially the same as between M1 and M2. For example, the Class and InstanceSpecification metaclasses in layer M2 are represented as instances of the meta-metaclass Class in layer M3.

Now, it is common mental shorthand to identify a model element directly with its metamodel representation (e.g., the class X with its representation as an instance of the metaclass Class) and loosely refer to the model element as being directly “an instance of” the metaclass (e.g., class X “is an instance of” the metaclass Class). However, strictly speaking, the concept of “instance of” only has meaning within the theory of the metamodeling language. The fact that this concept

is in the metamodeling language at all is merely consequence of the use in OMG of an object-oriented modeling language for metamodeling, which is not the only possible approach, and is not really fundamental to the relationship between the meta-layers.

6.5 Acknowledgements

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NASA Jet Propulsion Laboratory
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7 Abstract Syntax

This clause defines the subset of UML for which foundational semantics are specified in Clause 8. This subset is called Foundational UML or fUML. It is a computationally complete language for executable models.

7.1 Overview

A fundamental purpose of fUML is to serve as an intermediary between “surface subsets” of UML used for modeling and computational platform languages used as the target for model execution. As shown in Figure 12, this generally requires the ability to translate from the surface subset to fUML and from fUML to the target platform language.

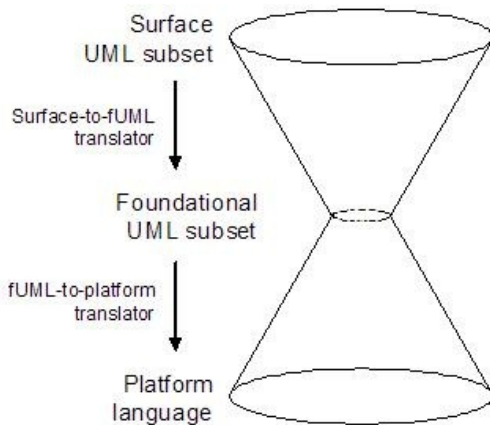


Figure 12 - Translation to and from the foundational UML subset

In this context, the contents of the fUML subset has been largely determined by three criteria.

- *Compactness.* The subset should be small to facilitate definition of a clear semantics and implementation of execution tools.
- *Ease of translation.* The subset should enable straightforward translation from common surface subsets of UML to fUML and from fUML to common computational platform languages.
- *Action functionality.* This specification only specifies how to execute the UML actions as they are currently defined with primitive functionality. Therefore, the fUML subset should not include UML functionality requiring coordinated sets of UML actions to reproduce.

There is, of course, some tension between these criteria.

Suppose that there is a surface feature of UML (say, polymorphic operation dispatching) that also happens to have a corresponding analog in a certain platform language (say, an object-oriented programming language such as Java), but which is excluded from fUML (though, in this case, it actually isn't). It is clearly desirable that the surface UML feature be translated, ultimately, into the corresponding feature of the platform language. However, if the feature is excluded from fUML, it is necessary for the surface-to-fUML translator to generate a coordinated set of fUML elements that has the same effect as that feature. But then the fUML-to-platform translator would need to recognize the pattern generated by the surface-to-fUML generator, in order to map this back into the desired feature of the target language. Compactness can therefore conflict with ease of translation.

Unfortunately, in practice, such overlaps between desired features in the surface subset of UML used for modeling and the available features of the target platform language can be significant, especially within a single domain of application. Further, the specific pattern of elements that might be generated by a surface-to-fUML translator for any given surface feature is not standardized—and such a standard is not in the scope of this specification. Therefore, a general fUML-to-platform translator cannot be optimized to specially handle a standard set of expected patterns.

On the other hand, if a feature of UML is included in fUML to reduce the translation problems described above, it increases the complexity of the semantics of fUML and the implementation of execution tools conforming to those semantics. This might not be so bad for any individual feature, but an accumulation of many such features will eventually defeat the purpose of having a compact subset.

The subset specified in this clause resolves the choice between compactness and ease of translation based on judgments about which functionalities in common between UML and computational platforms are more widely used than others. These judgments have the hazard of making broad generalizations about highly segmented modeling and platform markets, but once made, they help determine the contents of the foundational subset as follows.

- Widely used functionality in common between UML and platforms should have the simplest translation into and out of the fUML subset, namely, one-to-one translations. This functionality is included in the foundational subset. For example, classes with properties and operations are widely used elements of object oriented models and control and object flows are widely used in activity modeling.
- Moderately used functionality in common between UML and platforms should have a straightforward translation into and out of the foundational subset. This translation is not one-to-one, so this functionality is not included in the fUML subset, but the elements needed to enable straightforward mappings are included. For example, composite structure and simple state machines are considered moderately used.
- Less used functionality in common between UML and platforms may have a complicated translation into the fUML subset and is not included in the foundational subset. Little consideration is given to including functionality to simplify the translation. For example, association qualifiers and interruptible activity regions are considered less used.

Further, certain modeling features of UML are not directly supported by UML action functionality. For example, the UML semantics of default attribute values is that the default values are assigned to attributes when the object is created. However, the UML semantics for create object actions require that objects be created without attribute values being set. Therefore, making the semantics of UML default values explicit requires coordinated actions for creating objects and assigning structural feature values, with activity control and object flows between them. Consequently, default attribute values are not included in the foundational subset. In cases such as this, it is expected that the transformational approach above will be used to generate the set of actions corresponding to desired surface UML semantics. (Note, for example, that this is particularly important for embedded systems, where the execution of default actions for initialization purposes must carefully coordinated with other initialization activities.)

Finally, the fUML subset also contains some UML elements that have no execution semantics. Examples of this are comments and packages from Kernel and modeling declarations such as `isDeterminate` and `isAssured` on conditional nodes. These reduce compactness of the subset but not in a way that affects the specification of semantics, the implementation of execution tools or translator construction.

Clause Organization

The following subclauses define the abstract syntax of the fUML subset as a subset of the abstract syntax of the UML 2 Superstructure. The package structure parallels the package structure of the UML 2 Superstructure abstract syntax model. Packages in the UML 2 model that have no corresponding package here are excluded in their entirety. For packages that are included, some further elements from the UML package may be excluded in the corresponding fUML package. In this case, the model presented for the fUML version of the abstract syntax package shows those elements that are specifically in fUML and the class descriptions within the subclause specify additional constraints on the class that, via package merge, which will be combined with constraints already specified in the UML 2 Superstructure for the same class.

Also, the fUML abstract syntax model does not use package merge between abstract syntax packages the way the UML 2 Superstructure model does. Instead, each class in the fUML abstract syntax model already has effectively merged into it all the corresponding merge increments from the subset of the UML 2 Superstructure relevant to fUML. This greatly simplifies the overall structure of the fUML abstract syntax model, particularly in relation to the semantic model of Clause 8, by providing a single model element with the full specification of each syntactic metaclass.

However, as a result of this restructuring, the package merge relationships in the UML 2 Superstructure are generally reflected as package imports in the fUML abstract syntax. Further, the effective merging in the fUML model occasionally requires import relationships between packages that are not related in the UML 2 model.

For example, in the fUML abstract syntax, the `CommonBehaviors::Communications::Class` merge increment in the UML 2 abstract syntax has already been merged into `Classes::Kernel::Class`. This results in `Classes::Kernel::Class` becoming a specialization of `CommonBehaviors::BasicBehaviors::BehavioredClassifier`, leading to a package import relationship between the Kernel and BasicBehaviors package in fUML. Cases such as this are further noted in the appropriate subclauses below.

Note that, as discussed in Clause 2, package merge is still used in the fUML abstract syntax model to construct the conformance level packages L1, L2 and L3. Despite the elimination of the use of package merge otherwise in the fUML abstract syntax model, once the merges are performed for L1, L2 and L3, the resulting merged models at each level are, in fact, strict subsets of the fully merged UML 2 abstract syntax models at each corresponding level.

7.2 Classes

7.2.1 Overview

The fUML Classes package includes only the single sub-package Kernel. Figure 13 shows the package dependencies of the fUML Kernel package.

Note that, in the fUML model, the Kernel package imports the BasicBehaviors package from CommonBehaviors. This is because, in fUML, `Classes::Kernel::Class` includes the merge increment `CommonBehaviors::Communications::Class`, which results in `Classes::Kernel::Class` being a specialization of `CommonBehaviors::BasicBehaviors::BehavioredClassifier`.

The fUML Kernel package is thus dependent on the fUML BasicBehaviors package, as reflected in the package import shown in Figure 13.

The following packages from the UML 2 Superstructure are excluded from the fUML abstract syntax.

- *AssociationClasses*. Association classes, as a modeling construct, add significant semantic complexity and their effect can be equivalently modeled using regular classes and associations, albeit at the expense of some modeling convenience. They are therefore not considered fundamental for the fUML subset.
- *Dependencies*. Dependencies either declare a design intent or express a model-level relationship without significant execution semantics.
- *Interfaces*. Within the fUML subset, the effect of interfaces can be achieved using abstract classes with entirely abstract operations. (Note that fUML does *not* include UML 2 structured classes and ports, which depend specifically on the use of interfaces.)
- *PowerTypes*. Power types and generalization sets add significant complexity to the semantics of generalization, particularly as it relates to typing and polymorphic operation dispatching. Further, the effect of a generalization set can be equivalently modeled using regular classes and generalizations, albeit at the expense of some modeling convenience. Power types and generalization sets are therefore not considered fundamental for the fUML subset.

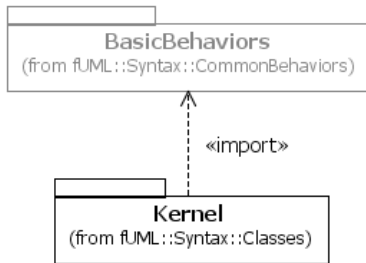


Figure 13 - Classes Syntax Packages

7.2.2 Kernel

7.2.2.1 Overview

The classes shown in Figure 14 to Figure 24 are those included in the fUML Classes::Kernel package. The diagrams correspond to similar diagrams in the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams.

From Root (see Figure 14):

- *Relationship and Directed Relationship*. These abstract classes are excluded from fUML because their properties are all derived and are not needed for model execution.

From Multiplicities (see Figure 15): No exclusions.

From Namespaces (see Figure 16): No exclusions.

From Expressions (see Figure 17):

- *Expression*. Expressions are excluded from fUML because, in UML, this construct simply captures the parse tree of an expression whose symbols are otherwise only informally represented as strings and thus cannot be properly executed.
- *OpaqueExpression*. Opaque expressions are excluded from fUML because, as defined in the UML Kernel, their body is not further defined within UML and, thus, not executable. In the UML BasicBehaviors package, *OpaqueExpression* is extended to allow for an optional association with a UML behavior. However, this was considered to be redundant with the ability to directly call behaviors within the context of UML activities, the primary form of behavior modeling supported in fUML.

From Constraints (no corresponding fUML diagram):

- *Constraint*. Constraints are excluded from fUML, because they are considered to be design-time annotations that should already be satisfied by a well-formed model. Otherwise, the general semantics of the run time checking of constraints is not currently well specified in UML 2, particularly when constraints should be evaluated and what should happen if they should fail. Further elaboration of the semantics of constraint checking in UML was judged to be outside the scope of the fUML specification.

From Instances (see Figure 18):

- *InstanceSpecification::specification*. Instance specifications in fUML are only used as part of the value specification of a structured instance value (see Figure 17), which is specified using slots, or as an enumeration literal (see Figure 23). Therefore, it is unnecessary provide a separate specification for its value.

From Classifiers (see Figure 19):

- *Classifier::redefinedClassifier*. Classifier redefinition is excluded from fUML because it was judged to add significant complexity to resolve during execution, without a fundamental need in the majority of cases.

From Features (see Figure 20):

- *BehavioralFeature::raisedException*. This is excluded because exceptions are not included in fUML.

From Operations (see Figure 21):

- *Operation::raisedException*. This is excluded because exceptions are not included in fUML.

From Classes (see Figure 22):

- *Property::defaultValue*. Setting defaults requires coordination of multiple UML actions, since the create object action is specified to create objects without default values. Setting defaults in fUML must be modeled explicitly by using the appropriate structural feature actions after object creation.
- *Property::qualifier*. Association qualifiers are excluded from fUML because their effect can be effectively achieved in models using unqualified associations and so are not considered fundamental. Further, they were judged not widely used enough to otherwise require inclusion in fUML for ease of implementation of execution tools and translators.
- *Property::subttedProperty*. Subsetting is excluded from fUML because subsetting is generally used in static models and there is no consensus on the execution semantics for this mechanism. (See Subclause 8.1 for further discussion of conventions related to the handling of subsetting in fUML execution semantics.)
- *Property::redefinedProperty*. Property redefinition is excluded from fUML because it was judged to add significant complexity to the resolution of structural features at runtime, without a fundamental need. (Note, on the other hand, that operation redefinition *is* included in fUML, as shown in Figure 21, because it is necessary for the default fUML semantics for polymorphic operation dispatching, as discussed in Subclause 8.3.2.1. Also see Subclause 8.1 for further discussion of conventions related to the handling of redefinition in fUML execution semantics.)

From Data Types (see Figure 23):

- *DataType::ownedOperation*. Data types cannot have operations in fUML because they are not behaviored classifiers and so cannot own behaviors. This means that there is no way to provide executable methods for the operations of a data type.

From Packages (see Figure 24):

- *PackageMerge*. Package merge is excluded from fUML because it is not considered to be a runtime construct. All package merges are assumed to have been already carried out before a model is submitted for execution.

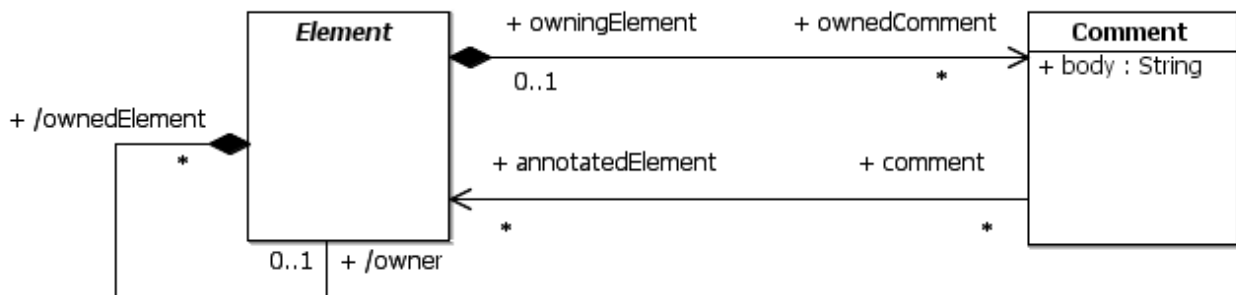


Figure 14 - Root

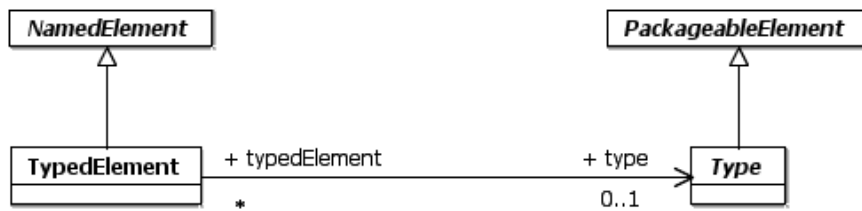
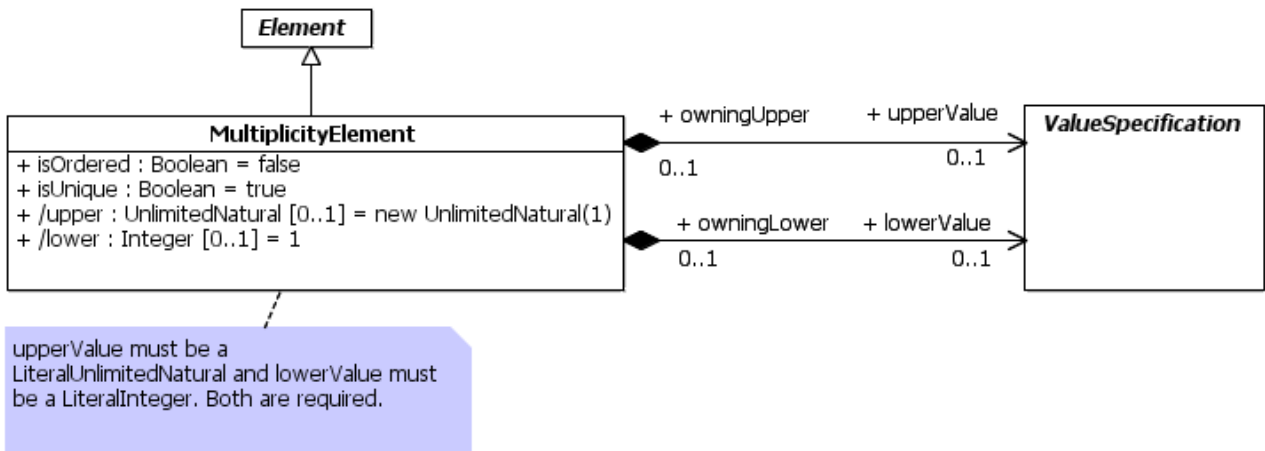


Figure 15 - Multiplicities

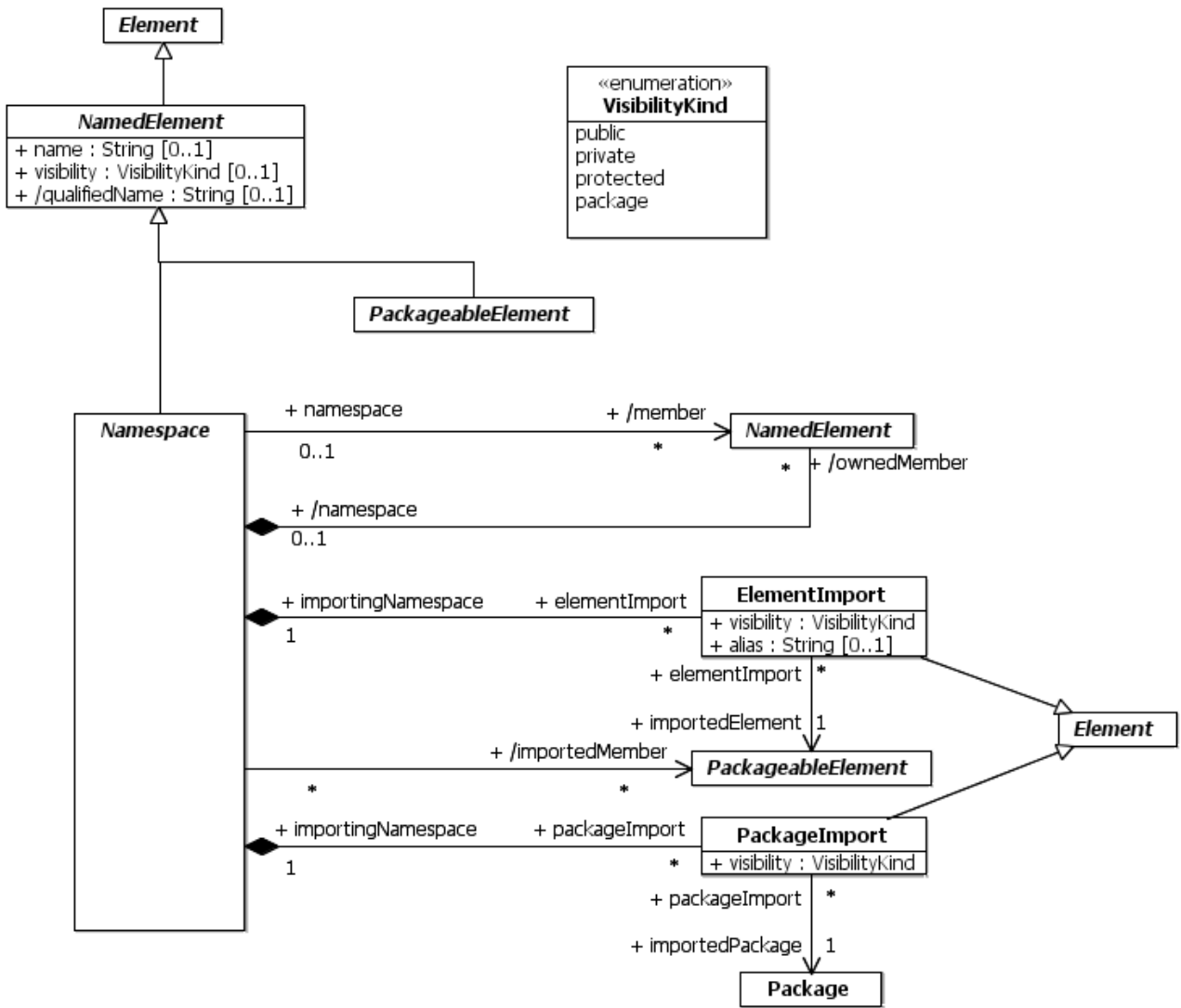


Figure 16 - Namespaces

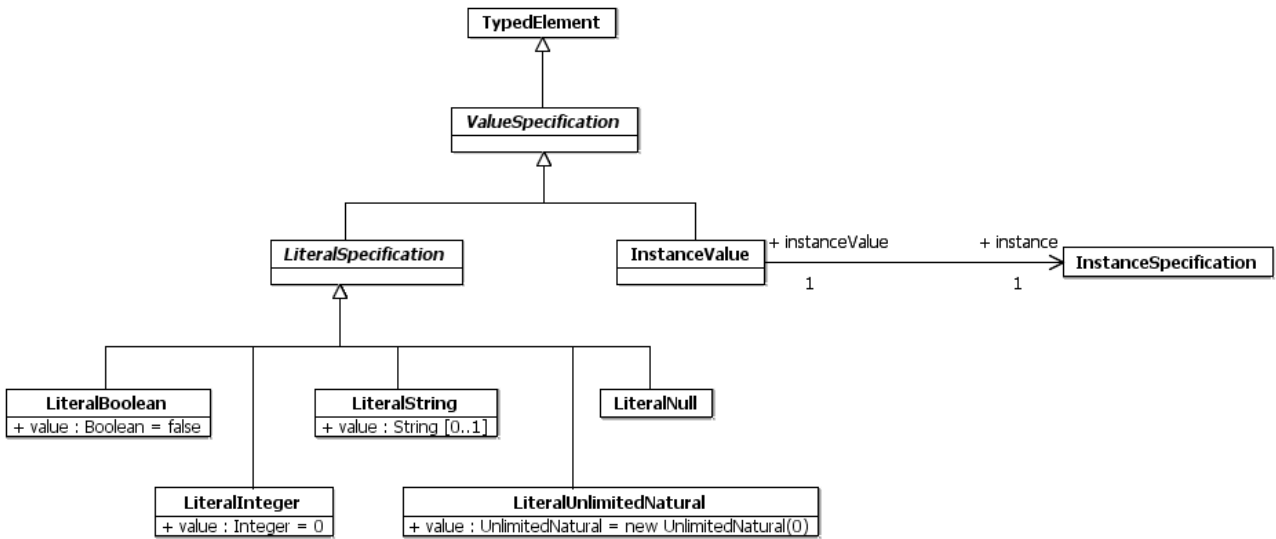


Figure 17 - Expressions

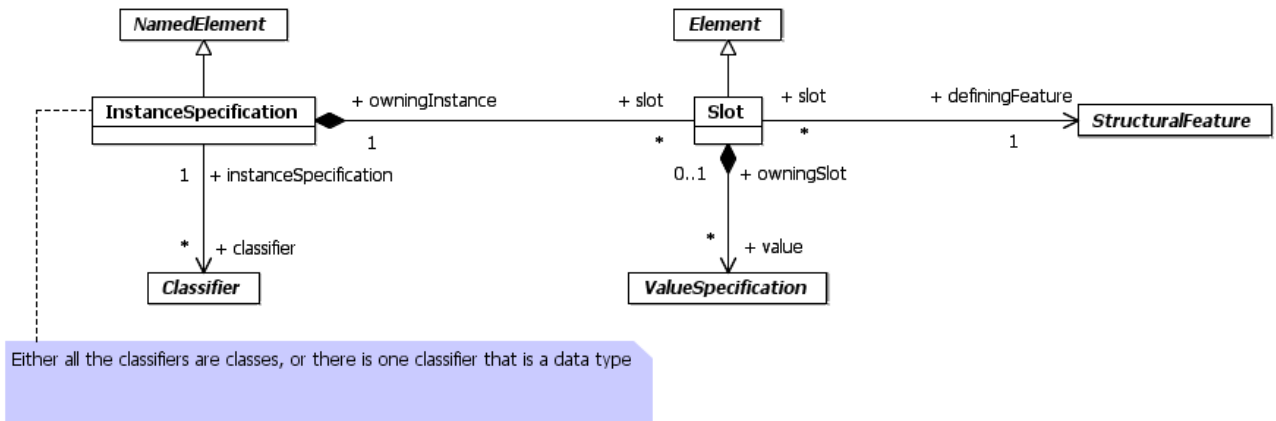


Figure 18 - Instances

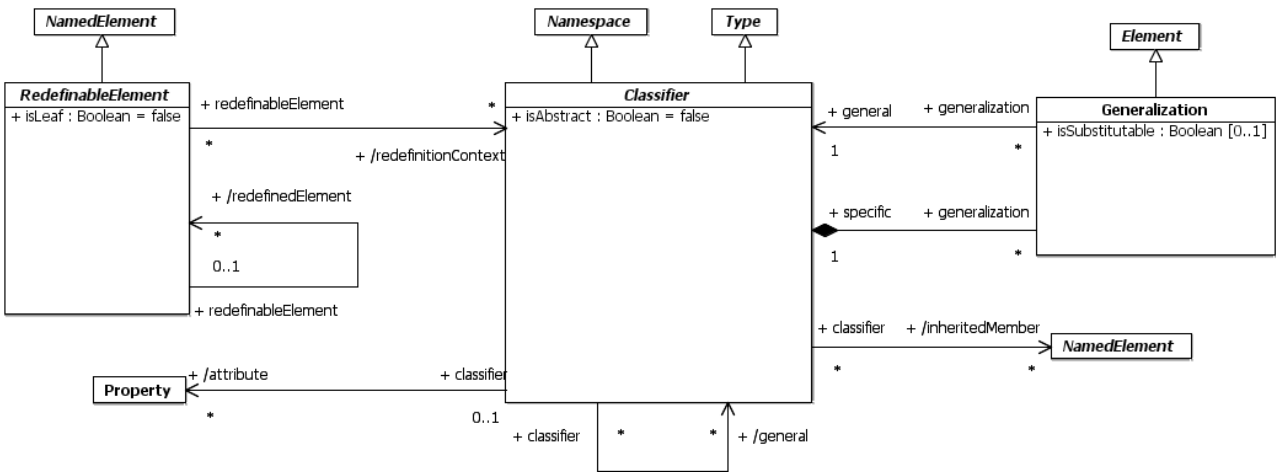


Figure 19 - Classifiers

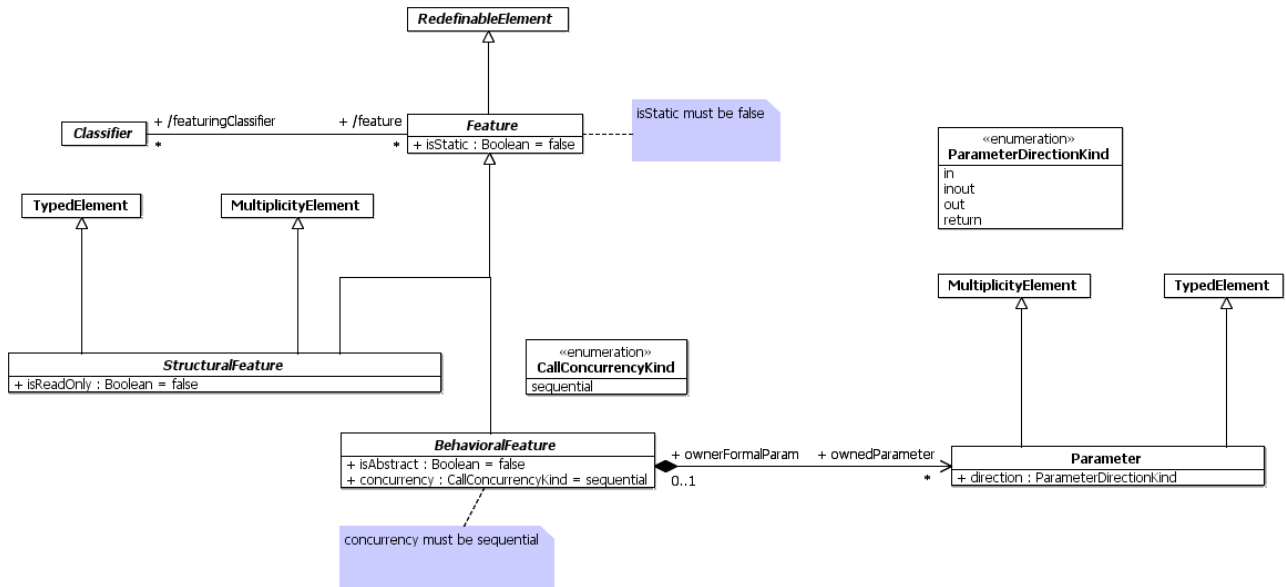


Figure 20 - Features

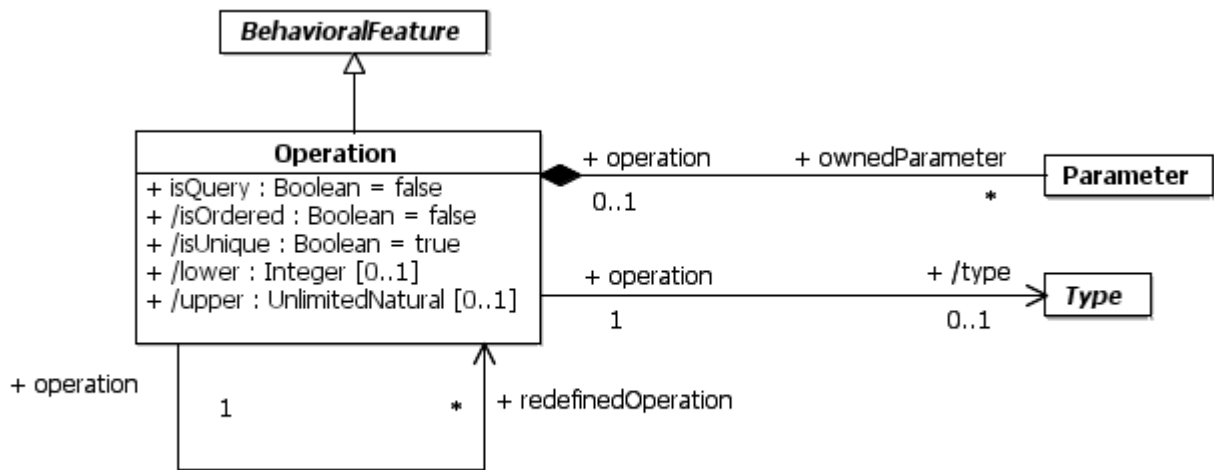


Figure 21 - Operations

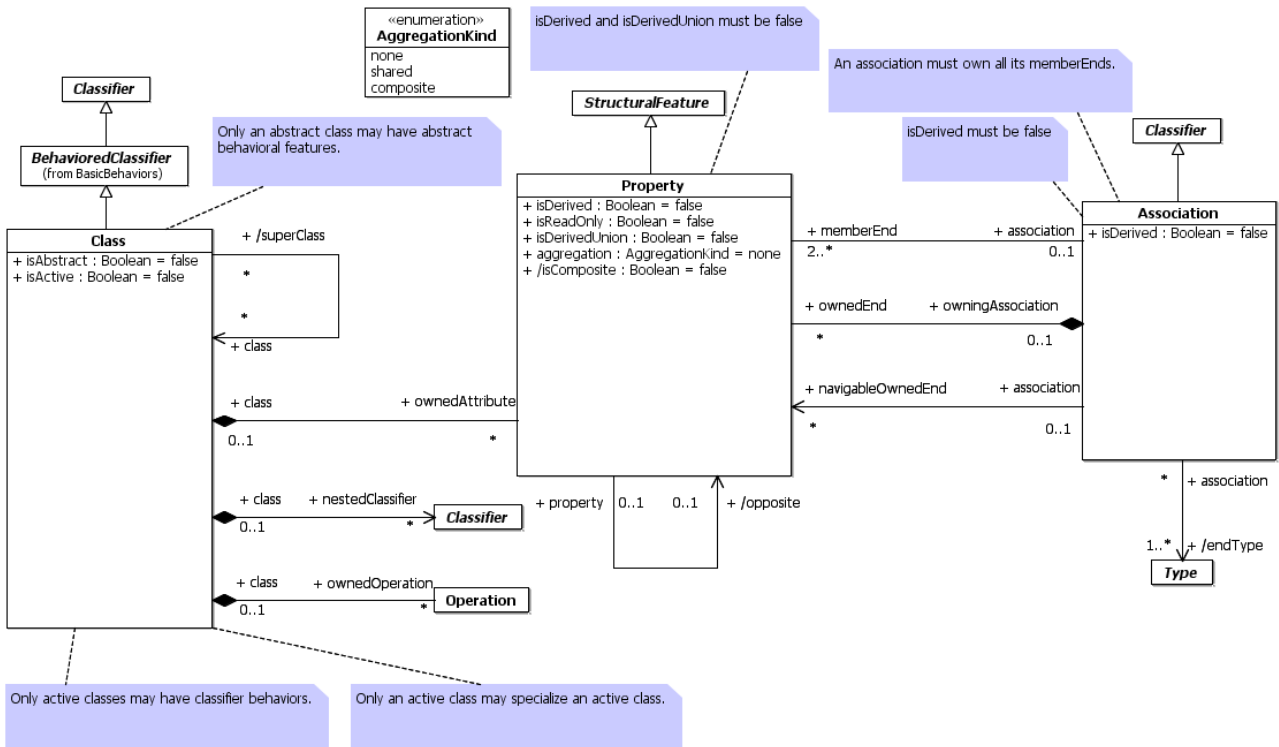


Figure 22 - Classes

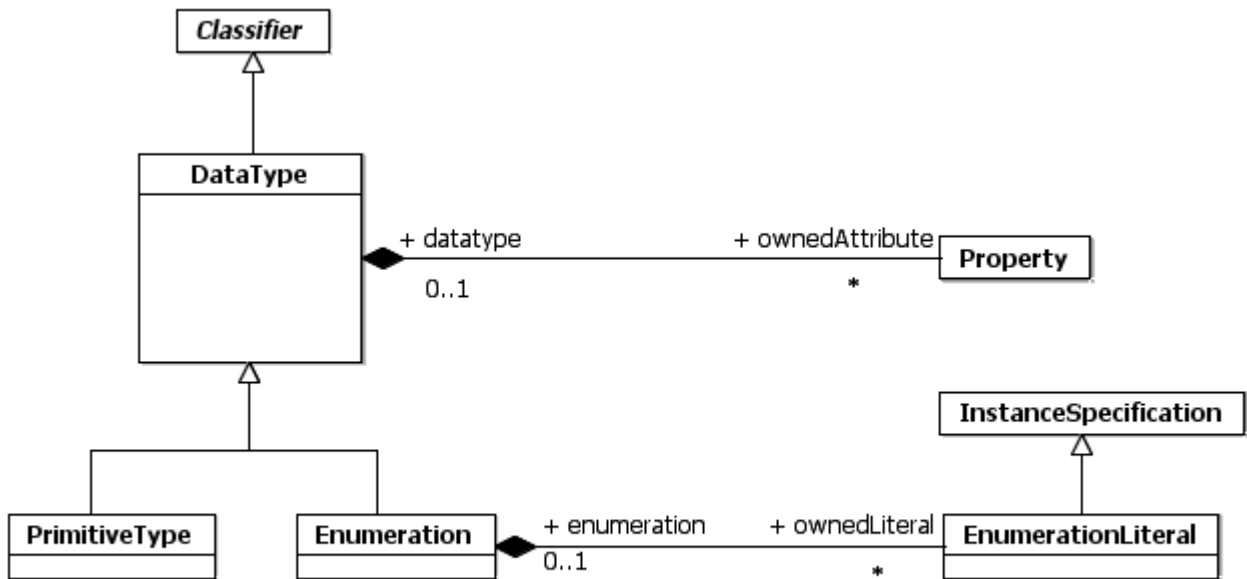


Figure 23 - Data Types

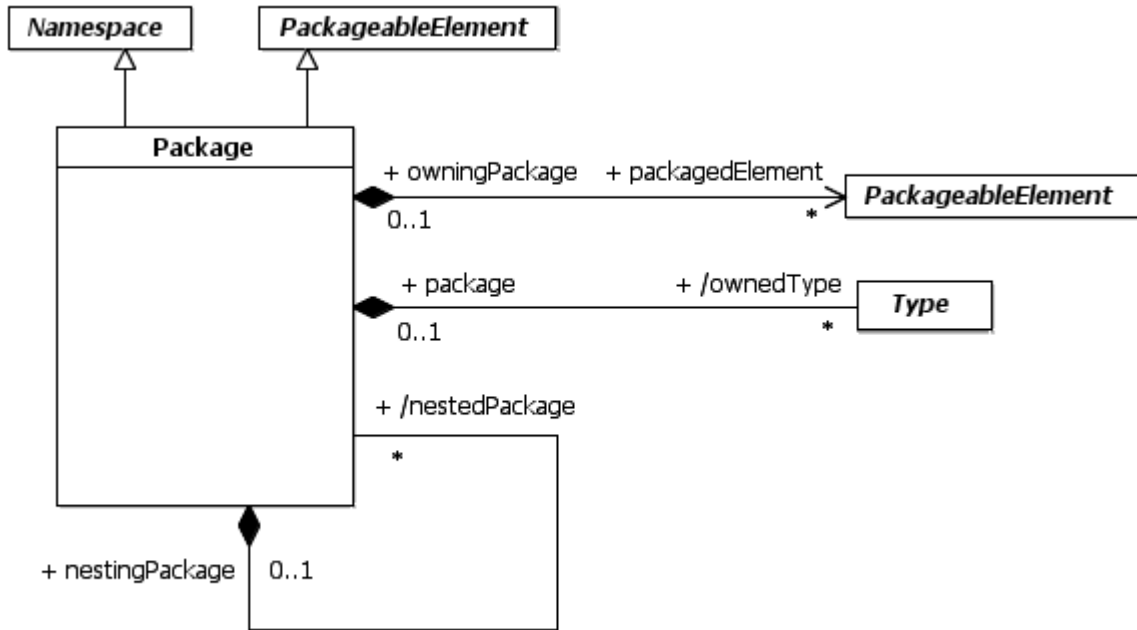


Figure 24 - Packages

7.2.2.2 Class Descriptions

7.2.2.2.1 Association

Generalizations

- [Classifier](#)

Attributes

- isDerived : Boolean = false

Associations

- endType : Type [1..*]
- memberEnd : Property [2..*]
- navigableOwnedEnd : Property [0..*]
- ownedEnd : Property [0..*]

Additional Constraints

[1] owns_memberEnds

An association must own all its memberEnds.

```
self.memberEnd->symmetricDifference(self.ownedEnd)->isEmpty()
```

[2] no_derivation

isDerived must be false

```
not self.isDerived
```

7.2.2.2.2 BehavioralFeature

Generalizations

- [Feature](#)

Attributes

- concurrency : CallConcurrencyKind = sequential
- isAbstract : Boolean = false

Associations

- method : Behavior [0..*]
- ownedParameter : Parameter [0..*]

Additional Constraints

[1] sequentiality

concurrency must be sequential

self.concurrency = CallConcurrencyKind::sequential

7.2.2.2.3 Class

Generalizations

- [BehavioedClassifier](#)

Attributes

- isAbstract : Boolean = false
- isActive : Boolean = false

Associations

- nestedClassifier : Classifier [0..*]
- ownedAttribute : Property [0..*]
- ownedOperation : Operation [0..*]
- ownedReception : Reception [0..*]
- superClass : Class [0..*]

Additional Constraints

[1] active_class_classifier_behavior

Only active classes may have classifier behaviors.

self.classifierBehavior->notEmpty() implies self.isActive

[2] active_class_specialization

Only an active class may specialize an active class.

self.parents()->exist(isActive) implies self.isActive

[3] abstract_class

Only an abstract class may have abstract behavioral features.

self.member->select(oclIsKindOf(BehavioralFeature))->exists(isAbstract) implies self.isAbstract

7.2.2.2.4 Classifier

Generalizations

- [Namespace](#)
- [Type](#)

Attributes

- isAbstract : Boolean = false

Associations

- attribute : Property [0..*]
- feature : Feature [0..*]
- general : Classifier [0..*]
- generalization : Generalization [0..*]
- inheritedMember : NamedElement [0..*]

Additional Constraints

None

7.2.2.2.5 Comment

Generalizations

None

Attributes

- body : String

Associations

- annotatedElement : Element [0..*]

Additional Constraints

None

7.2.2.2.6 DataType

Generalizations

- [Classifier](#)

Attributes

None

Associations

- ownedAttribute : Property [0..*]

Additional Constraints

None

7.2.2.2.7 Element

Generalizations

None

Attributes

None

Associations

- ownedComment : Comment [0..*]
- ownedElement : Element [0..*]
- owner : Element [0..1]

Additional Constraints

None

7.2.2.2.8 ElementImport

Generalizations

- [Element](#)

Attributes

- alias : String [0..1]
- visibility : VisibilityKind

Associations

- importedElement : PackageableElement
- importingNamespace : Namespace

Additional Constraints

None

7.2.2.2.9 Enumeration

Generalizations

- [DataType](#)

Attributes

None

Associations

- ownedLiteral : EnumerationLiteral [0..*]

Additional Constraints

None

7.2.2.2.10 EnumerationLiteral

Generalizations

- [InstanceSpecification](#)

Attributes

None

Associations

- enumeration : Enumeration [0..1]

Additional Constraints

None

7.2.2.2.11 Feature

Generalizations

- [RedefinableElement](#)

Attributes

- isStatic : Boolean = false

Associations

- featuringClassifier : Classifier [0..*]

Additional Constraints

[1] non_static

isStatic must be false

not self.isStatic

7.2.2.2.12 Generalization

Generalizations

- [Element](#)

Attributes

- isSubstitutable : Boolean [0..1]

Associations

- general : Classifier
- specific : Classifier

Additional Constraints

None

7.2.2.2.13 InstanceSpecification

Generalizations

- [NamedElement](#)

Attributes

None

Associations

- classifier : Classifier [0..*]
- slot : Slot [0..*]

Additional Constraints

[1] possible_classifiers

Either all the classifiers are classes, or there is one classifier that is a data type

self.classifier->forAll(oclsKindOf(Class)) or

self.classifier->size() = 1 and self.classifier->forAll(oclsKindOf(DataType))

7.2.2.2.14 InstanceValue

Generalizations

- [ValueSpecification](#)

Attributes

None

Associations

- instance : InstanceSpecification

Additional Constraints

None.

7.2.2.2.15 LiteralBoolean

Generalizations

- [LiteralSpecification](#)

Attributes

- value : Boolean = false

Associations

None

Additional Constraints

None

7.2.2.2.16 LiteralInteger

Generalizations

- [LiteralSpecification](#)

Attributes

- value : Integer = 0

Associations

None

Additional Constraints

None

7.2.2.2.17 LiteralNull

Generalizations

- [LiteralSpecification](#)

Attributes

None

Associations

None

Additional Constraints

None

7.2.2.2.18 LiteralSpecification

Generalizations

- [ValueSpecification](#)

Attributes

None

Associations

None

Additional Constraints

None

7.2.2.2.19 LiteralString

Generalizations

- [LiteralSpecification](#)

Attributes

- value : String [0..1]

Associations

None

Additional Constraints

None

7.2.2.2.20 LiteralUnlimitedNatural

Generalizations

- [LiteralSpecification](#)

Attributes

- value : UnlimitedNatural = 0

Associations

None

Additional Constraints

None

7.2.2.2.21 MultiplicityElement

Generalizations

- [Element](#)

Attributes

- isOrdered : Boolean = false
- isUnique : Boolean = true
- lower : Integer [0..1] = 1
- upper : UnlimitedNatural [0..1] = 1

Associations

- lowerValue : ValueSpecification [0..1]
- upperValue : ValueSpecification [0..1]

Additional Constraints

[1] required_lower_and_upper_for_fUML

upperValue must be a LiteralUnlimitedNatural and lowerValue must be a LiteralInteger. Both are required.

self.upperValue->notEmpty() and

self.upperValue->asSequence()->first().oclIsKindOf(LiteralUnlimitedNatural) and

self.lowerValue->notEmpty() and
self.lowerValue->asSequence()->first().oclIsKindOf(LiteralInteger)

7.2.2.2.22 NamedElement

Generalizations

- [Element](#)

Attributes

- name : String [0..1]
- qualifiedName : String [0..1]
- visibility : VisibilityKind [0..1]

Associations

- namespace : Namespace [0..1]

Additional Constraints

None

7.2.2.2.23 Namespace

Generalizations

- [NamedElement](#)

Attributes

None

Associations

- elementImport : ElementImport [0..*]
- importedMember : PackageableElement [0..*]
- member : NamedElement [0..*]
- ownedMember : NamedElement [0..*]
- packageImport : PackageImport [0..*]

Additional Constraints

None

7.2.2.2.24 Operation

Generalizations

- [BehavioralFeature](#)

Attributes

- isOrdered : Boolean = false
- isQuery : Boolean = false
- isUnique : Boolean = true
- lower : Integer [0..1]
- upper : UnlimitedNatural [0..1]

Associations

- class : Class [0..1]
- ownedParameter : Parameter [0..*]
- redefinedOperation : Operation [0..*]
- type : Type [0..1]

Additional Constraints

[1] zero_or_one_method

If an operation is abstract it must have no method. Otherwise it must have exactly one method.

(self.isAbstract and self.method->isEmpty()) xor (not self.isAbstract and self.method->size() = 1)

7.2.2.2.25 Package

Generalizations

- [Namespace](#)
- [PackageableElement](#)

Attributes

None

Associations

- nestedPackage : Package [0..*]
- nestingPackage : Package [0..1]
- ownedType : Type [0..*]
- packagedElement : PackageableElement [0..*]

Additional Constraints

None

7.2.2.2.26 PackageableElement

Generalizations

- [NamedElement](#)

Attributes

None

Associations

None

Additional Constraints

None

7.2.2.2.27 PackageImport

Generalizations

- [Element](#)

Attributes

- visibility : VisibilityKind

Associations

- importedPackage : Package
- importingNamespace : Namespace

Additional Constraints

None

7.2.2.2.28 Parameter

Generalizations

- [MultiplicityElement](#)
- [TypedElement](#)

Attributes

- direction : ParameterDirectionKind

Associations

- operation : Operation [0..1]

Additional Constraints

None

7.2.2.2.29 PrimitiveType

Generalizations

- [DataType](#)

Attributes

None

Associations

None

Additional Constraints

None

7.2.2.2.30 Property

Generalizations

- [StructuralFeature](#)

Attributes

- aggregation : AggregationKind = none
- isComposite : Boolean = false
- isDerived : Boolean = false
- isDerivedUnion : Boolean = false
- isReadOnly : Boolean = false

Associations

- association : Association [0..1]
- class : Class [0..1]
- datatype : DataType [0..1]
- opposite : Property [0..1]
- owningAssociation : Association [0..1]

Additional Constraints

[1] no_derivation

isDerived and isDerivedUnion must be false

not self.isDerived and not self.isDerivedUnion

7.2.2.2.31 RedefinableElement

Generalizations

- [NamedElement](#)

Attributes

- isLeaf : Boolean = false

Associations

- redefinedElement : RedefinableElement [0..*]
- redefinitionContext : Classifier [0..*]

Additional Constraints

None

7.2.2.2.32 Slot

Generalizations

- [Element](#)

Attributes

None

Associations

- definingFeature : StructuralFeature
- owningInstance : InstanceSpecification
- value : ValueSpecification [0..*]

Additional Constraints

None

7.2.2.2.33 StructuralFeature

Generalizations

- [Feature](#)
- [MultiplicityElement](#)
- [TypedElement](#)

Attributes

- isReadOnly : Boolean = false

Associations

None

Additional Constraints

None

7.2.2.2.34 Type

Generalizations

- [PackageableElement](#)

Attributes

None

Associations

- package : Package [0..1]

Additional Constraints

None

7.2.2.2.35 TypedElement

Generalizations

- [NamedElement](#)

Attributes

None

Associations

- type : Type [0..1]

Additional Constraints

None

7.2.2.2.36 UnlimitedNatural

Generalizations

None

Attributes

- naturalValue : Integer

Associations

None

Additional Constraints

None

7.2.2.2.37 ValueSpecification

Generalizations

- [TypedElement](#)

Attributes

None

Associations

None

Additional Constraints

None

7.3 Common Behaviors

7.3.1 Overview

The fUML CommonBehaviors package includes the following sub-packages:

- BasicBehaviors

- Communications

Figure 25 shows the dependencies of these packages.

The UML 2 Superstructure package SimpleTime is excluded in its entirety from fUML because time events and constraints are not within the scope of fUML.

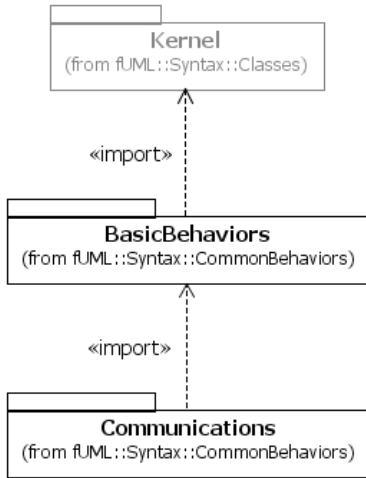


Figure 25 - Common Behaviors Syntax Packages

7.3.2 Basic Behaviors

7.3.2.1 Overview

The classes shown in Figure 26 are those included in the fUML `CommonBehaviors::BasicBehaviors` package. This diagram corresponds to similar diagrams in the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams.

From Common Behavior (see Figure 26):

- *Behavior::redefinedBehavior*. Behavior redefinition is excluded from fUML because opaque behaviors are only used for primitive behaviors in fUML, and the only other type of behavior provided is activities, the semantics of redefinition for which is not fully defined in UML 2.

From Expression (no fUML diagram):

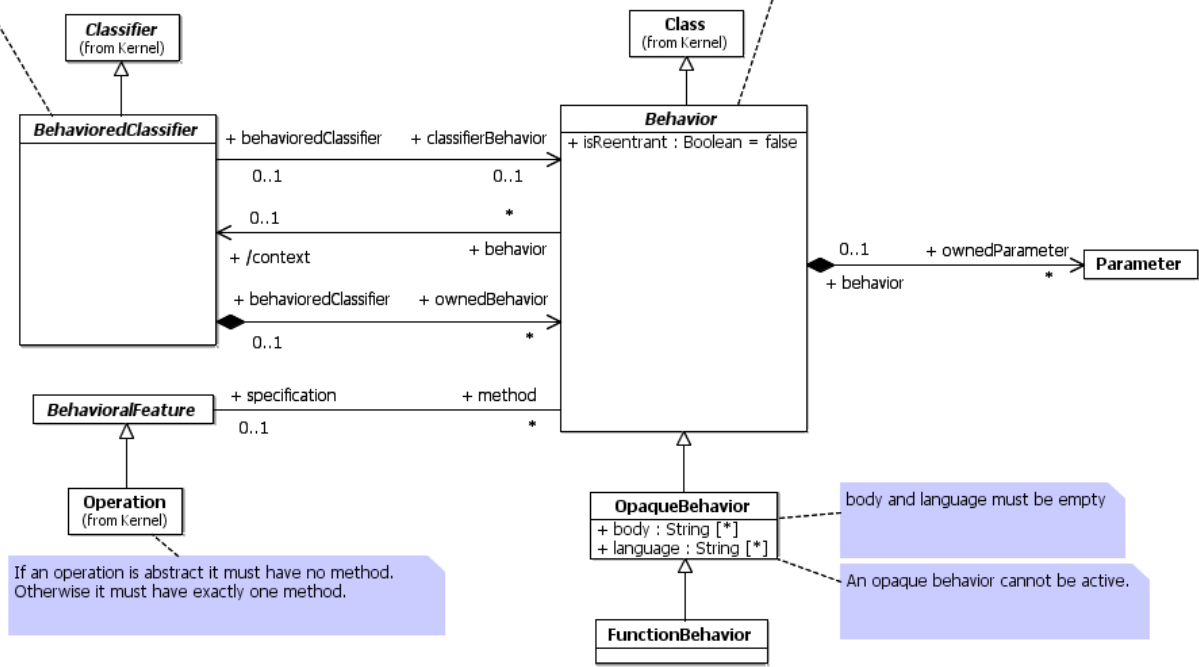
- *OpaqueExpression*. Opaque expressions are excluded in general from fUML (see Subclause 7.2.2.1).

From Precondition and Postcondition Constraints for Behavior (no fUML diagram):

- *Behavior::precondition* and *Behavior::postcondition*. Behavior preconditions and postconditions are excluded from fUML because constraints, in general, are excluded from fUML (see Subclause 7.2.2.1).

An owned behavior must be either the classifier behavior of or the method for an operation of its behaved classifier.

In this specification, an fUML instance model must have Behavior.isReentrant



If an operation is abstract it must have no method. Otherwise it must have exactly one method.

body and language must be empty
An opaque behavior cannot be active.

Figure 26 - Common Behavior

7.3.2.2 Class Descriptions

7.3.2.2.1 Behavior

Generalizations

- [Class](#)

Attributes

- isReentrant : Boolean = false

Associations

- context : BehavedClassifier [0..1]
- ownedParameter : Parameter [0..*]
- specification : BehavioralFeature [0..1]

Additional Constraints

[1] fUML_reentrant_behavior

In this specification, an fUML instance model must have Behavior.isReentrant

self.isReentrant

7.3.2.2.2 BehavedClassifier

Generalizations

- [Classifier](#)

Attributes

None

Associations

- classifierBehavior : Behavior [0..1]
- ownedBehavior : Behavior [0..*]

Additional Constraints

[1] fUML_allowed_owned_behaviors

An owned behavior must be either the classifier behavior of or the method for an operation of its behaved classifier.

self.ownedBehavior->forAll(b:Behavior | b = self.classifierBehavior xor self.allFeatures()->includes(b.specification))

7.3.2.2.3 FunctionBehavior**Generalizations**

- [OpaqueBehavior](#)

Attributes

None

Associations

None

Additional Constraints

None

7.3.2.2.4 OpaqueBehavior**Generalizations**

- [Behavior](#)

Attributes

None

Associations

- body : String [0..*]
- language : String [0..*]

Additional Constraints

[1] fUML_empty_body_and_language

body and language must be empty

self.language->isEmpty() and self.body->isEmpty()

[2] fUML_inactive

An opaque behavior cannot be active.

not self.isActive

7.3.3 Communications

7.3.3.1 Overview

The classes shown in Figure 27 to Figure 29 are those included in the fUML Common Behaviors::Communications package. The diagrams correspond to similar diagrams in the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams.

From Receptions (see Figure 27):

- *Interfaces*. Interfaces are excluded in general from fUML (see Subclause 7.2.2.1).

From Extensions to Behavioral Features (no fUML diagram):

- *BehavioralFeature::raisedException*. Exceptions are excluded in general in fUML (see Subclauses 7.5.1 and 7.2.2.1). (Note also that the UML CommonBehaviors::Communications::BehavioralFeature merge increment is already merged into Classes::Kernel::BehavioralFeature.)

From Triggers (see Figure 28):

- *BehavoredClassifier::ownedTriggers*. Triggers owned by behavored classifiers are excluded from fUML because triggers are only used in fUML in accept event actions, in which case they are owned by the action.

From Events (see Figure 29):

- *TimeEvent and ChangeEvent*. These events are excluded from fUML because they imply a background infrastructure, such as a model of time or a mechanism for monitoring for change. The execution semantics for this would be complicated to specify and more sophisticated than is necessary for computational completeness of the foundational subset.
- *CallEvent*. Call events are excluded from fUML because accept call actions are also excluded from fUML (see Subclause 7.5.4.1).
- *AnyReceiveEvent*. Any receive events are excluded because they are largely unnecessary. Only asynchronous signal events are allowed in fUML.

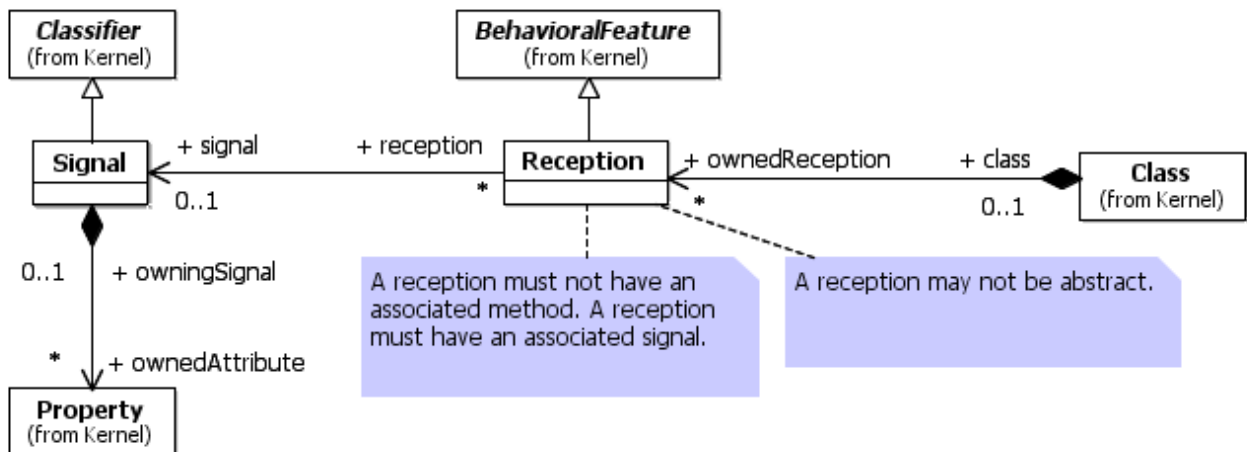


Figure 27 - Reception

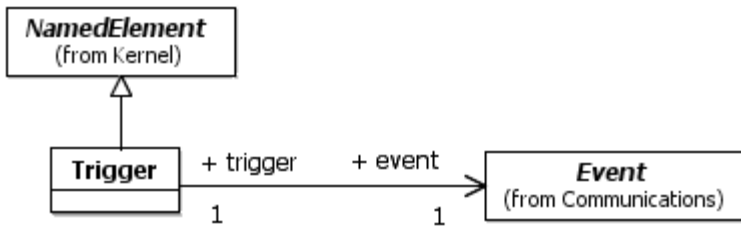


Figure 28 - Triggers

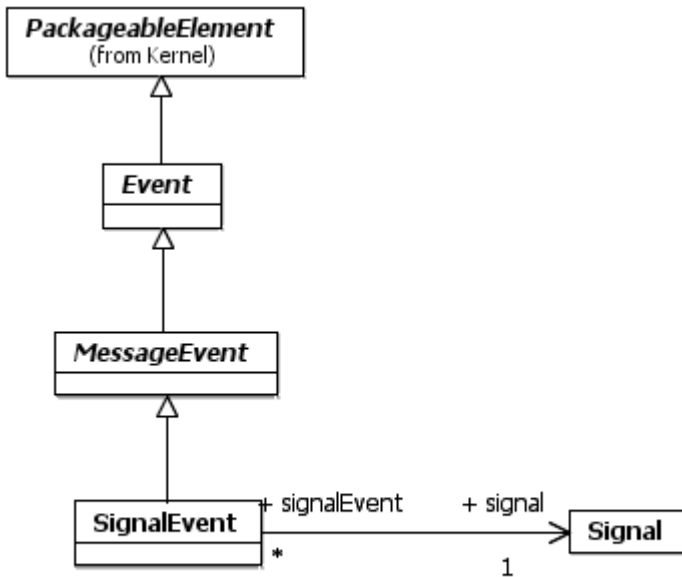


Figure 29 - Events

7.3.3.2 Class Descriptions

7.3.3.2.1 Event

Generalizations

- [PackageableElement](#)

Attributes

None

Associations

None

Additional Constraints

None

7.3.3.2.2 MessageEvent

Generalizations

- [Event](#)

Attributes

None

Associations

None

Additional Constraints

None

7.3.3.2.3 Reception

Generalizations

- [BehavioralFeature](#)

Attributes

None

Associations

- signal : Signal [0..1]

Additional Constraints

[1] a_signal_but_no_method

A reception must not have an associated method. A reception must have an associated signal.

self.method->isEmpty() and self.signal->notEmpty()

[2] not_abstract

A reception may not be abstract.

not self.isAbstract

7.3.3.2.4 Signal

Generalizations

- [Classifier](#)

Attributes

None

Associations

- ownedAttribute : Property [0..*]

Additional Constraints

None

7.3.3.2.5 SignalEvent

Generalizations

- [MessageEvent](#)

Attributes

None

Associations

- signal : Signal

Additional Constraints

None

7.3.3.2.6 Trigger**Generalizations**

- [NamedElement](#)

Attributes

None

Associations

- event : Event

Additional Constraints

None

7.4 Activities

7.4.1 Overview

The fUML Activities package includes the following sub-packages:

- IntermediateActivities
- CompleteStructuredActivities
- ExtraStructuredActivities

Figure 30 shows the dependencies of these packages.

The required capabilities from the UML 2 Superstructure packages FundamentalActivities and BasicActivities are already merged into the fUML IntermediateActivities, and the more basic packages are not separately supported in fUML. Similarly, the capabilities of the StructuredActivities package are already merged into the fUML CompleteStructuredActivities and Extra StructuredActivities packages and StructuredActivities is not separately supported in fUML.

In fUML, the IntermediateActivities package is not dependent on BasicActions. Rather, BasicAction imports IntermediateActions, so that Actions::BasicActions::Action can be a subclass of Activities::IntermediateActivities::ExecutableNode (see Subclause 7.5.1). BasicActions is then imported by CompleteStructuredActivities, since structured activity nodes are always actions in fUML.

The UML 2 Superstructure package CompleteActivities is excluded in its entirety from fUML because it provides advanced capabilities considered more appropriate for “higher level” process modeling and outside the scope of fUML.

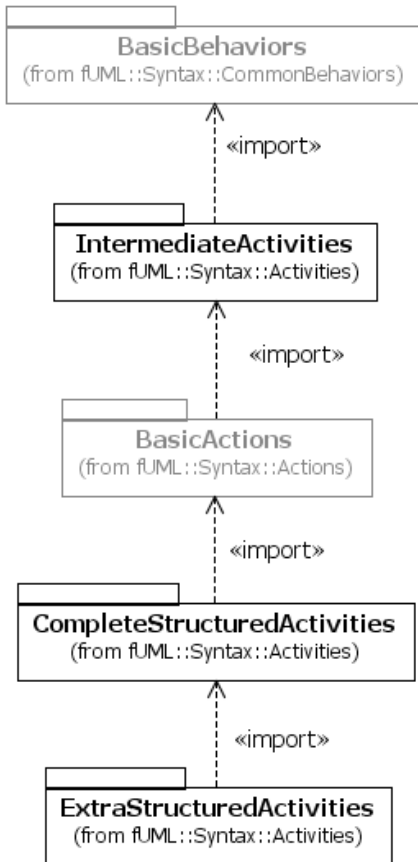


Figure 30 - Activities Syntax Packages

7.4.2 Intermediate Activities

7.4.2.1 Overview

The classes shown in Figure 31 to Figure 34 are those included in the fUML `Activities::IntermediateActivities` package. The diagrams correspond to similar diagrams in the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams.

From Nodes (see Figure 31): No exclusions (but note that the UML `Activities::FundamentalActivities::Action` merge increment is already merged into `Actions::BasicActions::Action` in fUML).

From Object Nodes (see Figure 32):

- *CentralBufferNode*. Central buffer nodes are excluded from fUML because they were judged to be unnecessary to for the computational completeness of fUML.

From Fundamental Groups in `FundamentalActivities` and Groups in `BasicActivities` (no fUML diagram):

- *ActivityGroup*. The abstract `ActivityGroup` class is excluded from fUML because the only kinds of activity group included in fUML are structured activity nodes, and the concrete properties of the abstract syntax classes representing structured nodes are sufficient.

From Control Nodes (see Figure 33):

- *FlowFinalNode*. Flow final nodes are not included in fUML because it is generally not necessary to explicitly terminate an individual flow in an activity. (Activity final nodes *are* included in fUML in order to terminate the entire activity.)

From Flows (see Figure 34):

- *ActivityEdge::redefinedEdge*. Activity edge redefinition is excluded from fUML because behavior redefinition is excluded from fUML (see Subclause 7.3.2).

From Partitions (no fUML diagram):

- *ActivityPartition*. Activity partitions are excluded from fUML because they are a very general modeling construct in UML activities and their precise execution semantics is unclear.

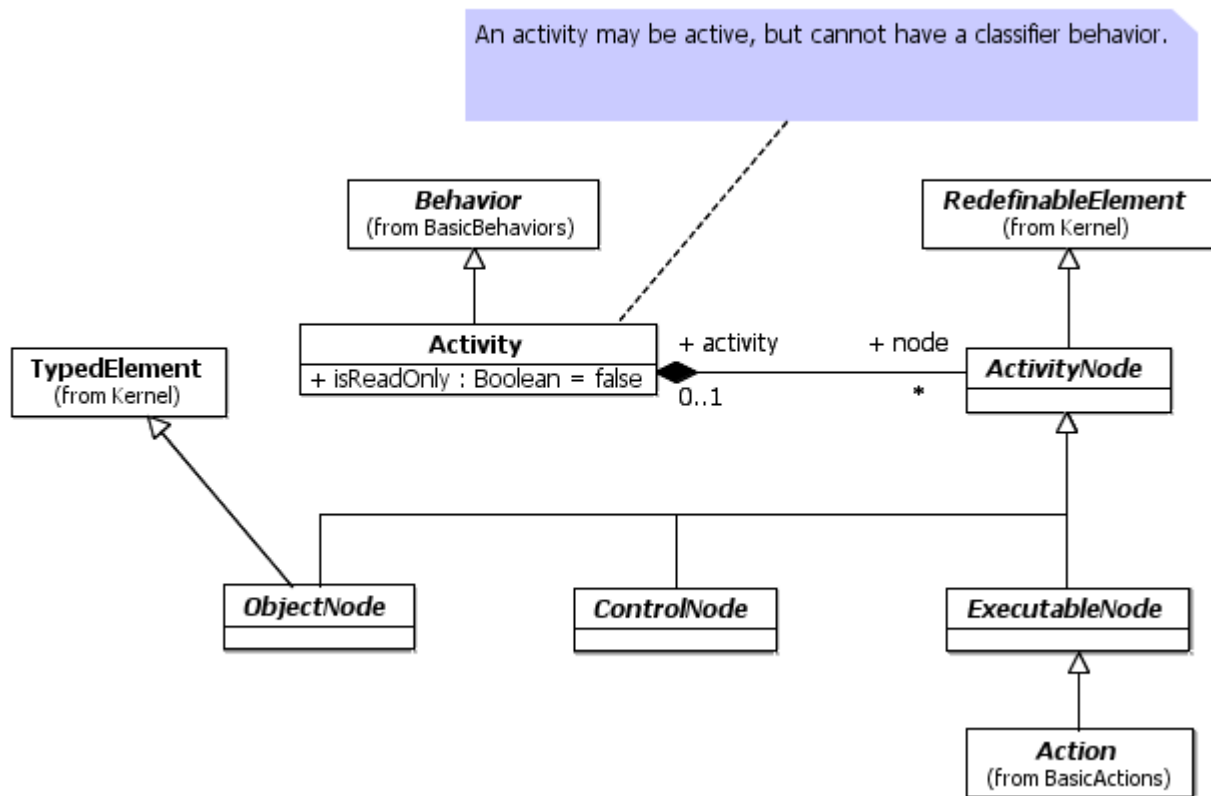


Figure 31 - Nodes

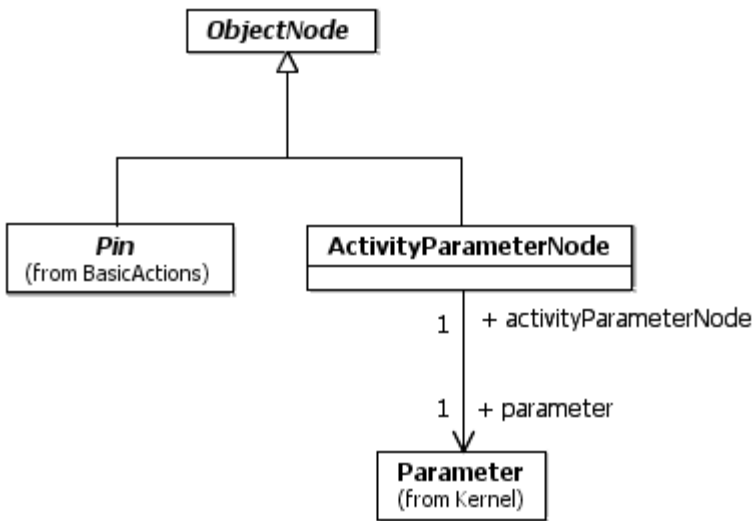


Figure 32 - Object Nodes

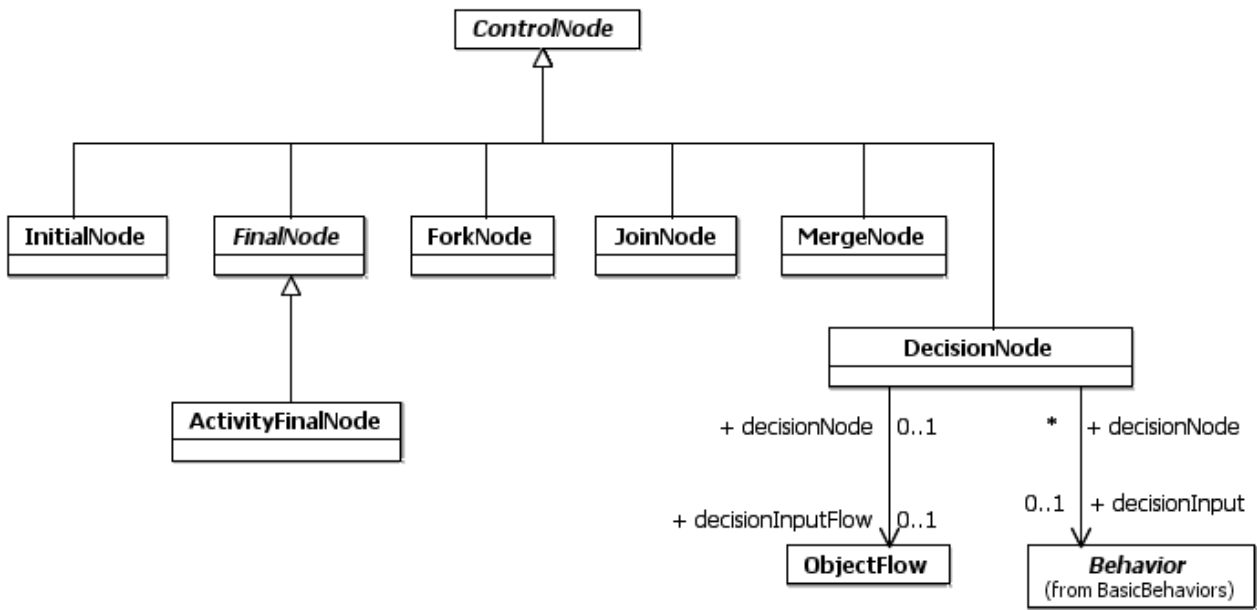


Figure 33 - Control Nodes

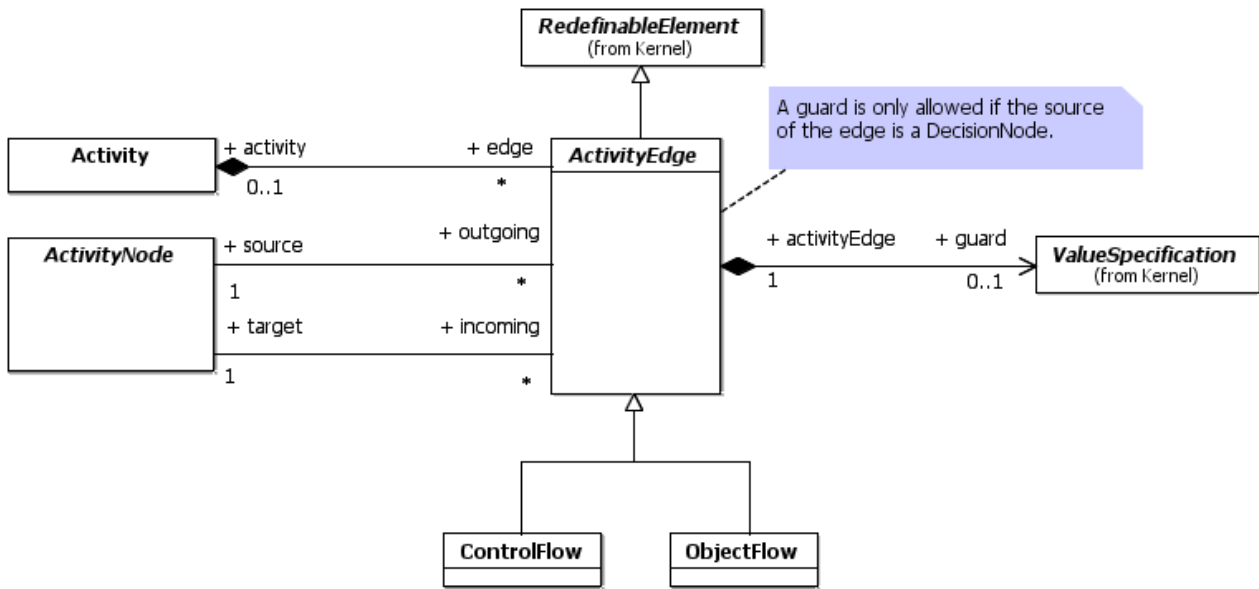


Figure 34 - Flows

7.4.2.2 Class Descriptions

7.4.2.2.1 Activity

Generalizations

- [Behavior](#)

Attributes

- `isReadOnly` : Boolean = false

Associations

- `edge` : ActivityEdge [0..*]
- `node` : ActivityNode [0..*]
- `structuredNode` : StructuredActivityNode [0..*]

Additional Constraints

[1] `fUML_no_classifier_behavior`

An activity may be active, but cannot have a classifier behavior.

```
self.classifierBehavior->isEmpty()
```

7.4.2.2.2 ActivityEdge

Generalizations

- [RedefinableElement](#)

Attributes

None

Associations

- `activity` : Activity [0..1]

- guard : ValueSpecification [0..1]
- inStructuredNode : StructuredActivityNode [0..1]
- source : ActivityNode
- target : ActivityNode

Additional Constraints

[1] fUML_allowed_guards

A guard is only allowed if the source of the edge is a DecisionNode.

self.guard->notEmpty() implies self.source.oclIsKindOf(DecisionNode)

7.4.2.2.3 ActivityFinalNode

Generalizations

- [FinalNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.4 ActivityNode

Generalizations

- [RedefinableElement](#)

Attributes

None

Associations

- activity : Activity [0..1]
- incoming : ActivityEdge [0..*]
- inStructuredNode : StructuredActivityNode [0..1]
- outgoing : ActivityEdge [0..*]

Additional Constraints

None

7.4.2.2.5 ActivityParameterNode

Generalizations

- [ObjectNode](#)

Attributes

None

Associations

- parameter : Parameter

Additional Constraints

None

7.4.2.2.6 ControlFlow

Generalizations

- [ActivityEdge](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.7 ControlNode

Generalizations

- [ActivityNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.8 DecisionNode

Generalizations

- [ControlNode](#)

Attributes

None

Associations

- decisionInput : Behavior [0..1]
- decisionInputFlow : ObjectFlow [0..1]

Additional Constraints

None

7.4.2.2.9 FinalNode

Generalizations

- [ControlNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.10 ForkNode

Generalizations

- [ControlNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.11 InitialNode

Generalizations

- [ControlNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.12 JoinNode

Generalizations

- [ControlNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.13 MergeNode

Generalizations

- [ControlNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.2.2.14 ObjectFlow

Generalizations

- [ActivityEdge](#)

Attributes

None

Associations

None

Additional Constraints

[None]

7.4.2.2.15 ObjectNode

Generalizations

- [ActivityNode](#)
- [TypedElement](#)

Attributes

None

Associations

None

Additional Constraints

[None]

7.4.3 Complete Structured Activities

7.4.3.1 Overview

The classes shown in Figure 35 are those included in the fUML `Activities::CompleteStructuredActivities` package. This diagram corresponds to similar diagrams in the `StructuredActivities` and `CompleteStructuredActivities` packages of the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams.

From Structured Nodes (see Figure 35):

- *Variable*. Variables are excluded from fUML because the passing of data between actions can be achieved using object flows.
- *SequenceNode*. Sequence nodes are excluded from fUML because the sequencing of actions can be expressed using control flows.

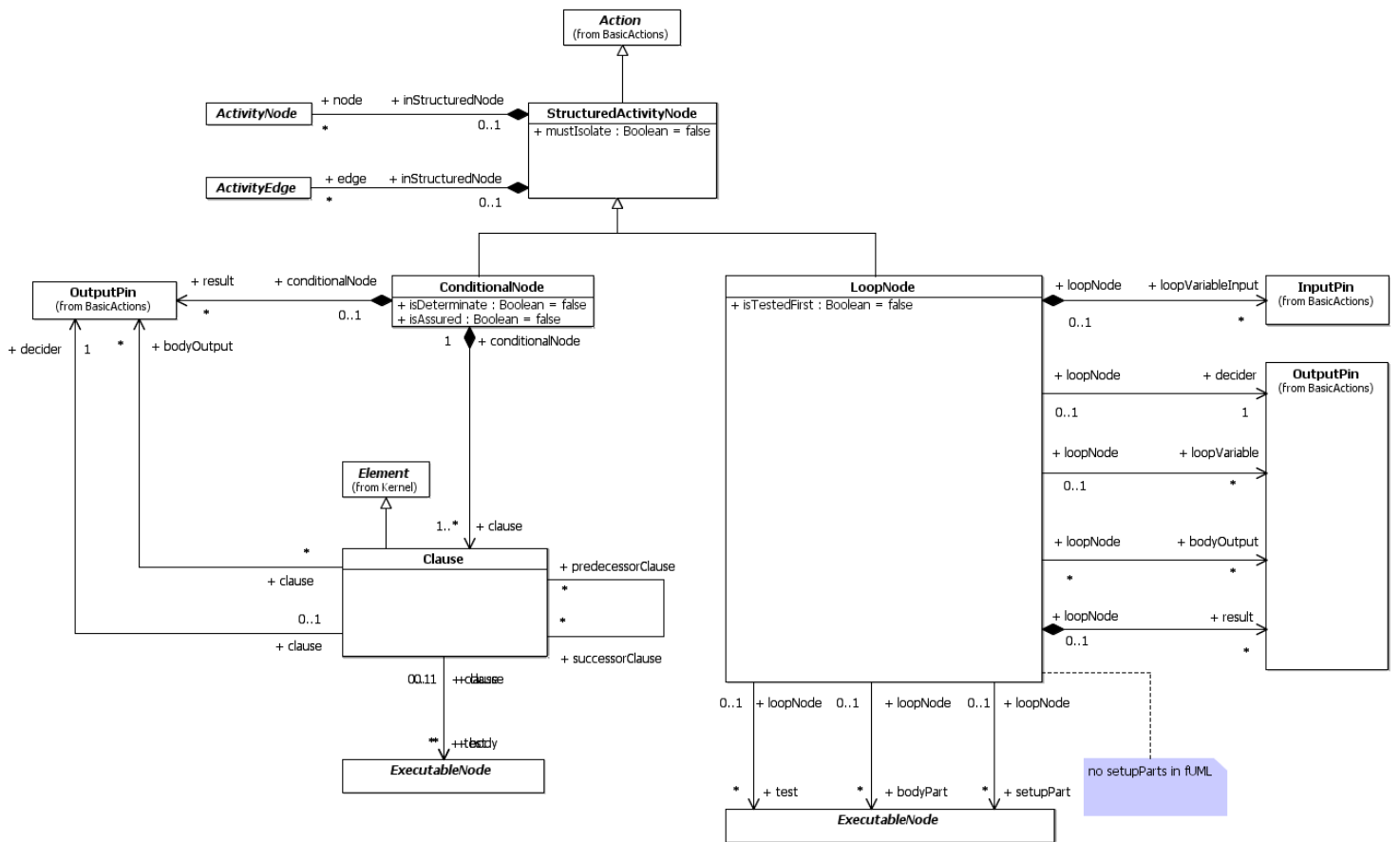


Figure 35 - Structured Nodes

7.4.3.2 Class Descriptions

7.4.3.2.1 Clause

Generalizations

- [Element](#)

Attributes

None

Associations

- body : ExecutableNode [0..*]
- bodyOutput : OutputPin [0..*]
- decider : OutputPin
- predecessorClause : Clause [0..*]
- successorClause : Clause [0..*]
- test : ExecutableNode [0..*]

Additional Constraints

None

7.4.3.2.2 ConditionalNode

Generalizations

- [StructuredActivityNode](#)

Attributes

- isAssured : Boolean = false
- isDeterminate : Boolean = false

Associations

- clause : Clause [1..*]
- result : OutputPin [0..*]

Additional Constraints

None

7.4.3.2.3 ExecutableNode

Generalizations

- [ActivityNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.4.3.2.4 LoopNode

Generalizations

- [StructuredActivityNode](#)

Attributes

- isTestedFirst : Boolean = false

Associations

- bodyOutput : OutputPin [0..*]
- bodyPart : ExecutableNode [0..*]
- decider : OutputPin
- loopVariable : OutputPin [0..*]
- loopVariableInput : InputPin [0..*]
- result : OutputPin [0..*]
- setupPart : ExecutableNode [0..*]
- test : ExecutableNode [0..*]

Additional Constraints

[1] noSetupParts_in_fUML
no setupParts in fUML

self.setupPart->isEmpty()

7.4.3.2.5 StructuredActivityNode

Generalizations

- [Action](#)

Attributes

- mustIsolate : Boolean = false

Associations

- activity : Activity [0..1]
- edge : ActivityEdge [0..*]
- node : ActivityNode [0..*]

Additional Constraints

None

7.4.4 Extra Structured Activities

7.4.4.1 Overview

The classes shown in Figure 36 are those included in the fUML Activities::ExtraStructuredActivities package. This diagrams corresponds to the similar diagram in the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams.

From Exceptions (no fUML diagram):

- *ExceptionHandler*. Exception handlers are not included in fUML because exceptions are not included in fUML (see Subclauses 7.2.2.1 and 7.5.1).

From Expansion Regions (see Figure 36): No exclusions.

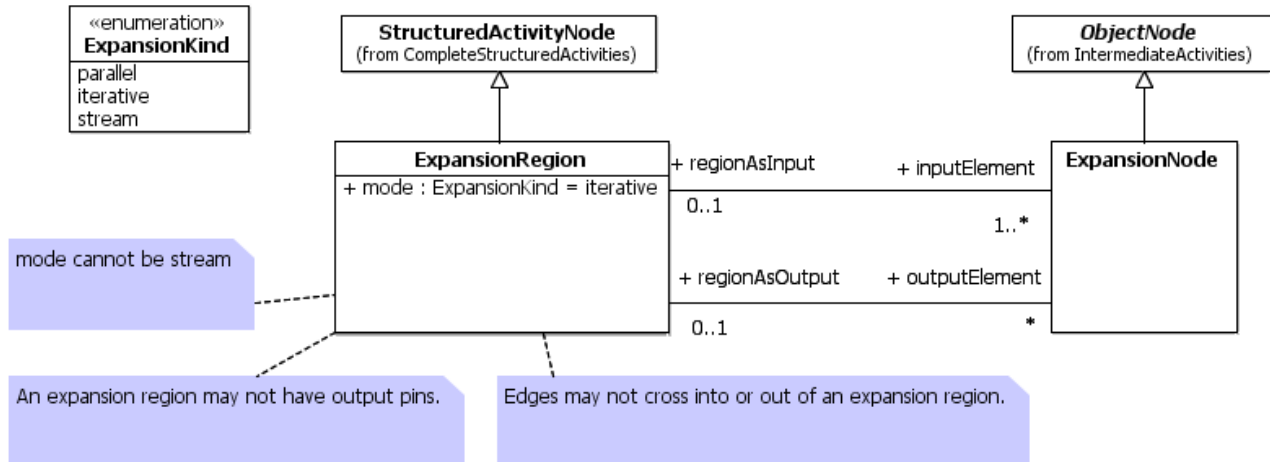


Figure 36 - Expansion Regions

7.4.4.2 Class Descriptions

7.4.4.2.1 ExpansionNode

Generalizations

- [ObjectNode](#)

Attributes

None

Associations

- regionAsInput : ExpansionRegion [0..1]
- regionAsOutput : ExpansionRegion [0..1]

Additional Constraints

None

7.4.4.2.2 ExpansionRegion

Generalizations

- [StructuredActivityNode](#)

Attributes

- mode : ExpansionKind = iterative

Associations

- inputElement : ExpansionNode [1..*]
- outputElement : ExpansionNode [0..*]

Additional Constraints

[1] fUML_no_crossing_edges

Edges may not cross into or out of an expansion region.

```
self.edge->forAll(self.node->includes(source) and self.node->includes(target))
```

[2] fUML_mode_cannot_be_stream

mode cannot be stream

```
self.mode != ExpansionKind::stream
```

[3] fUML_no_output_pins

An expansion region may not have output pins.

```
self.output->isEmpty()
```

7.5 Actions

7.5.1 Overview

The fUML Actions package includes the following sub-packages:

- BasicActions
- IntermediateActions
- CompleteActions

Figure 37 shows the dependencies of these packages.

Note that, in the fUML model, the BasicActions package imports the IntermediateActivities package from Activities.

This is because, in fUML, Actions::BasicActions::Actions includes the merge increment

Activities::StructuredActivities::Action, which results in Actions::BasicActions::Action being a specialization of

ExecutableNode. Since ExecutableNode is in Activities::IntermediateActivities in fUML, the fUML BasicActions

package is dependent on the fUML IntermediateActivities package, as reflected in the package import in Figure 37. Also,

in the fUML model, IntermediateActions imports BasicBehaviors (see Subclause 7.4.1) which imports Kernel (see Subclause 7.5.1), so Kernel does not need to be imported directly by BasicActions.

The StructuredActions package from the UML 2 Superstructure is excluded in its entirety from fUML, because variables, exceptions and action pins are not included in fUML. The fUML subset is based on a fully flow-based approach to activity modeling.

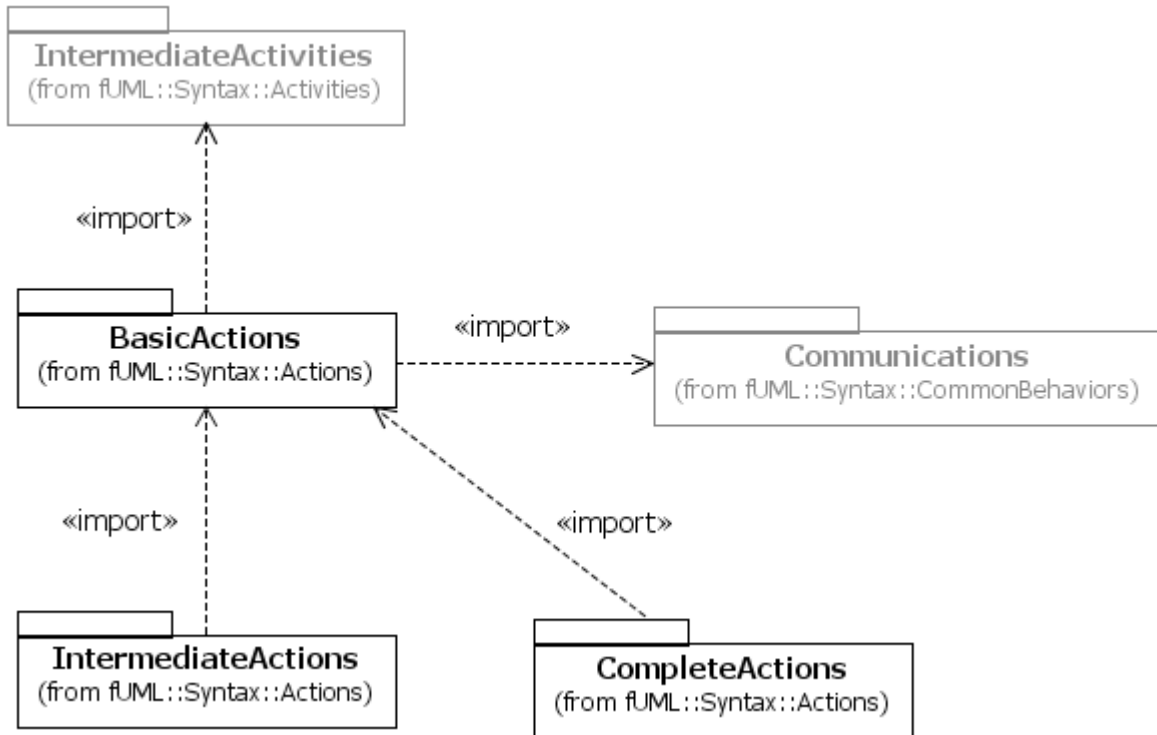


Figure 37 - Actions Syntax Packages

7.5.2 Basic Actions

7.5.2.1 Overview

The classes shown in Figure 38 to Figure 40 are those included in the fUML Actions::BasicActions package. The diagrams correspond to similar diagrams in the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams

From Basic Actions (see Figure 38):

- *OpaqueAction*. Opaque actions are excluded from fUML since, being opaque, they cannot be executed.

From Basic Pins (see Figure 39):

- *ValuePin*. Value pins are excluded from fUML because they are redundant with using value specifications to specify values.

From Basic Invocation Actions (see Figure 40): No exclusions.



Figure 38 - Basic Actions

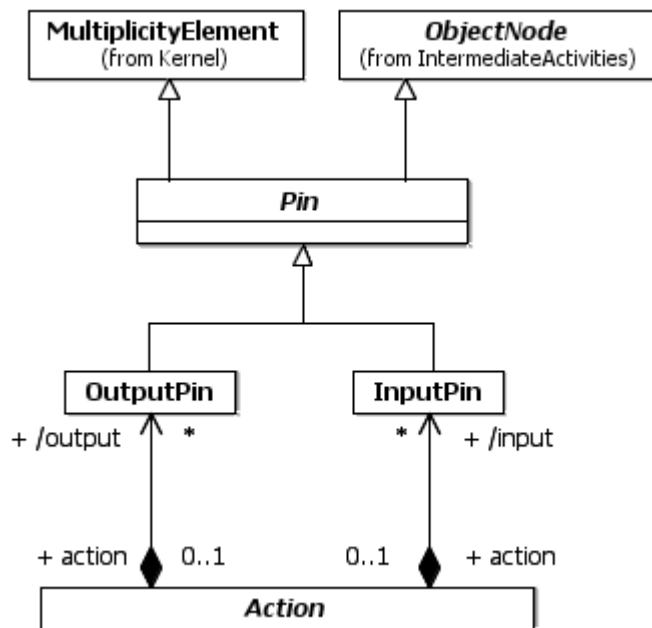


Figure 39 - Basic Pins

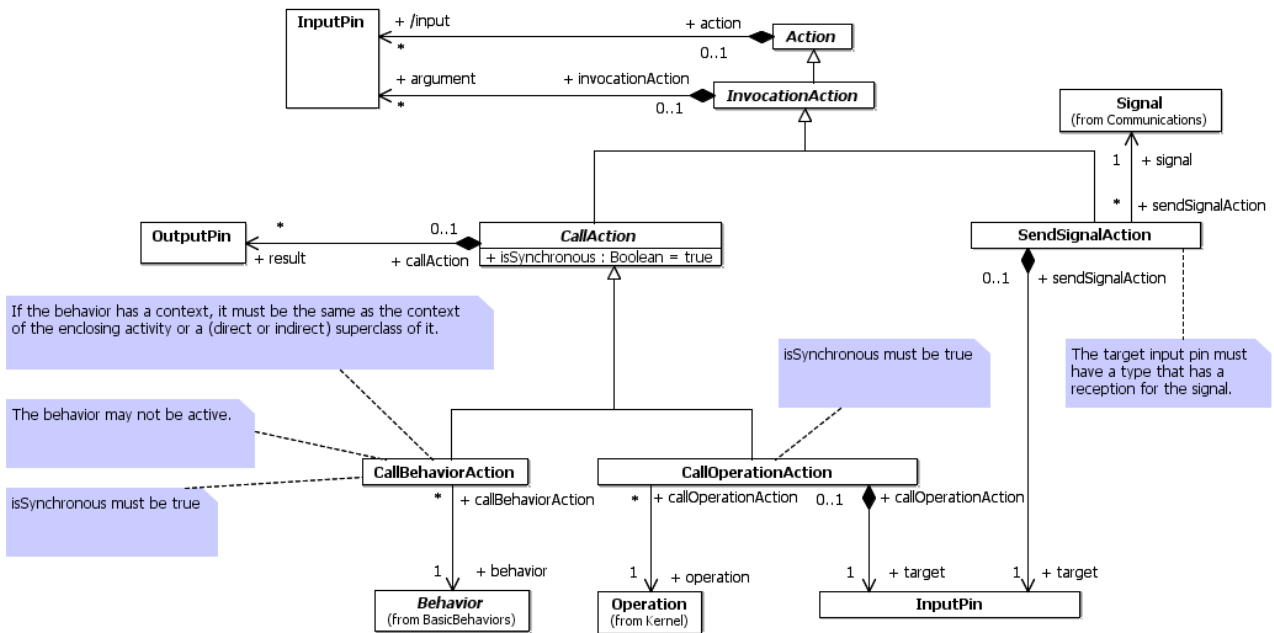


Figure 40 - Basic Invocation Actions

7.5.2.2 Class Descriptions

7.5.2.2.1 Action

Generalizations

- [ExecutableNode](#)

Attributes

None

Associations

- context : Classifier [0..1]
- input : InputPin [0..*]
- output : OutputPin [0..*]

Additional Constraints

None

7.5.2.2.2 CallAction

Generalizations

- [InvocationAction](#)

Attributes

- isSynchronous : Boolean = true

Associations

- result : OutputPin [0..*]

Additional Constraints

None

7.5.2.2.3 CallBehaviorAction

Generalizations

- [CallAction](#)

Attributes

None

Associations

- behavior : Behavior

Additional Constraints

[1] is_synchronous

isSynchronous must be true

self.isSynchronous

[2] inactive_behavior

The behavior may not be active.

not self.behavior.isActive

[3] proper_context

If the behavior has a context, it must be the same as the context of the enclosing activity or a (direct or indirect) superclass of it.

self.behavior.context->notEmpty() implies

union(self.context.allParents())->includes(self.behavior.context)

7.5.2.2.4 CallOperationAction

Generalizations

- [CallAction](#)

Attributes

None

Associations

- operation : Operation
- target : InputPin

Additional Constraints

[1] is_synchronous

isSynchronous must be true

self.isSynchronous

7.5.2.2.5 InputPin

Generalizations

- [Pin](#)

Attributes

None

Associations

None

Additional Constraints

None

7.5.2.2.6 InvocationAction

Generalizations

- [Action](#)

Attributes

None

Associations

- argument : InputPin [0..*]

Additional Constraints

None

7.5.2.2.7 OutputPin

Generalizations

- [Pin](#)

Attributes

None

Associations

None

Additional Constraints

None

7.5.2.2.8 Pin

Generalizations

- [MultiplicityElement](#)
- [ObjectNode](#)

Attributes

None

Associations

None

Additional Constraints

None

7.5.2.2.9 SendSignalAction

Generalizations

- [InvocationAction](#)

Attributes

None

Associations

- signal : Signal
- target : InputPin

Additional Constraints

[1] target_signal_reception

The target input pin must have a type that has a reception for the signal.

```
self.target.type.oclAsType(Classifier).allFeatures()->select(oclIsKindOf(Reception))->exists(f:Feature |
self.signal.conformsTo(f.oclAsType(Reception).signal))
```

7.5.3 Intermediate Actions

7.5.3.1 Overview

The classes shown in Figure 41 to Figure 45 are those included in the fUML Actions::IntermediateActions package. The diagrams correspond to similar diagrams in the UML 2 Superstructure Specification. The only exclusions from this package are BroadcastSignalAction and SendObjectAction. The sole mechanism for asynchronous invocation in fUML is via send signal action. This can be used to achieve the effect of broadcasting and sending objects.

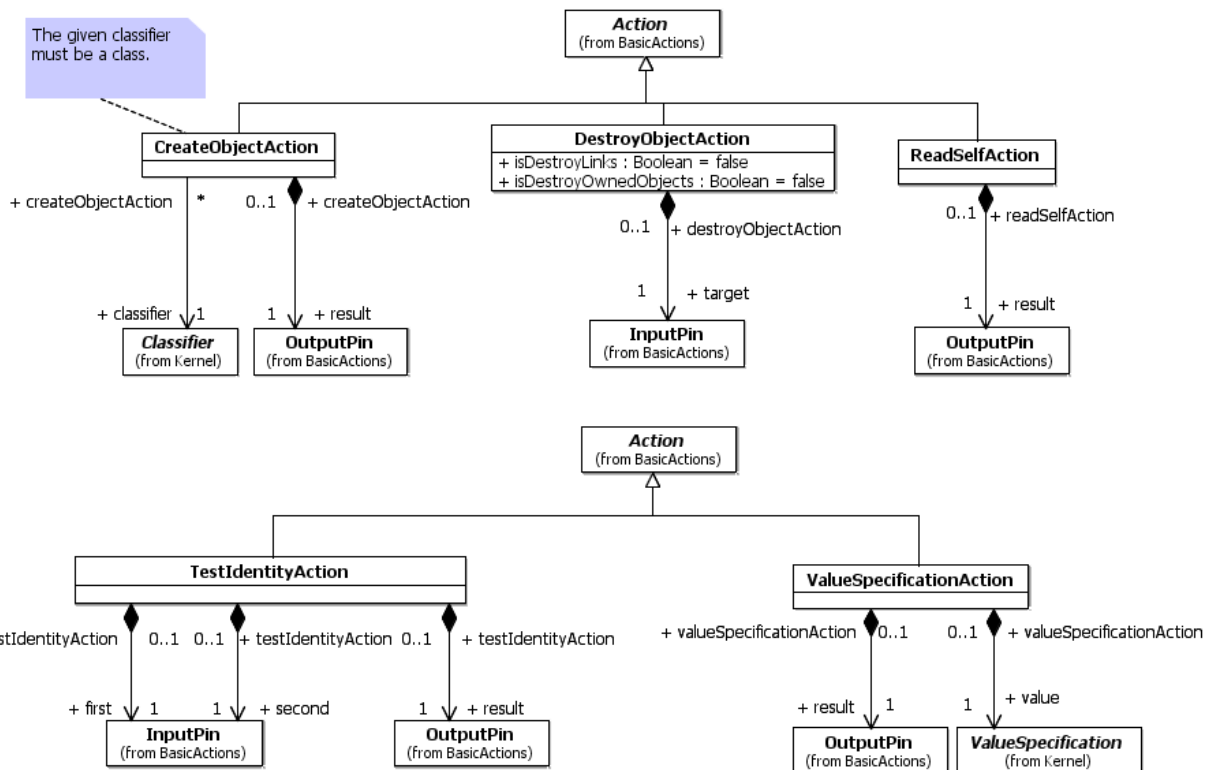


Figure 41 - Object Actions

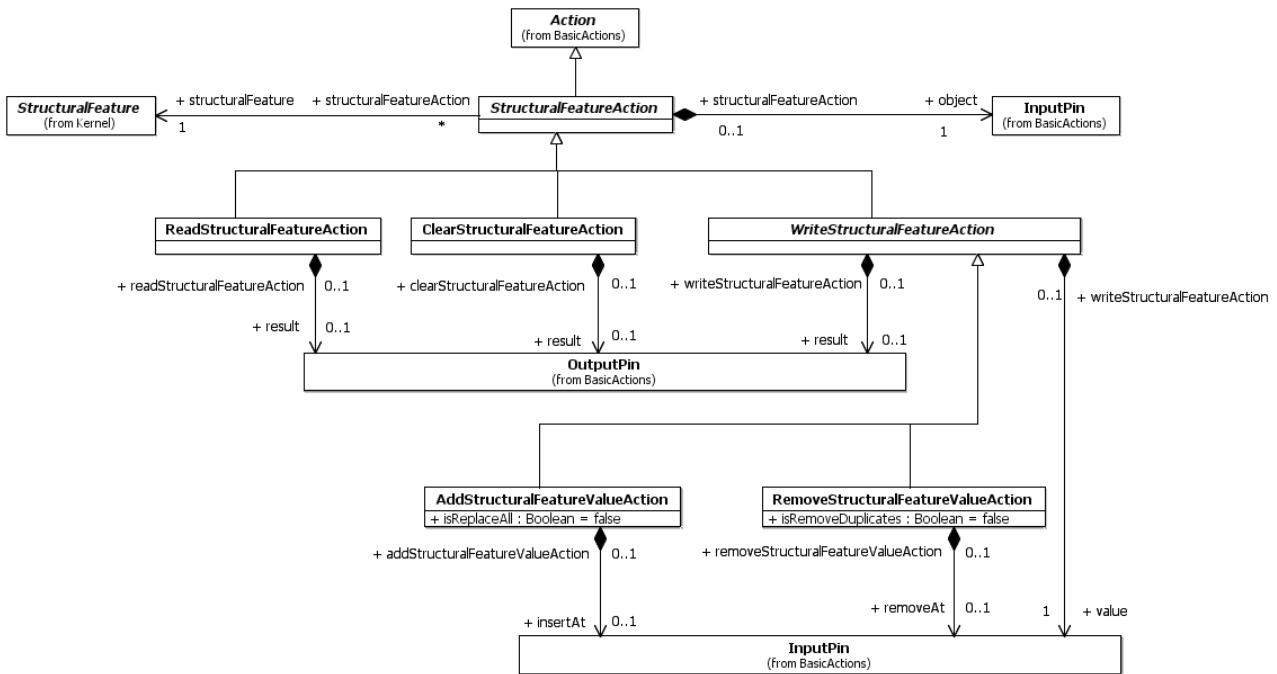


Figure 42 - Structural Feature Actions

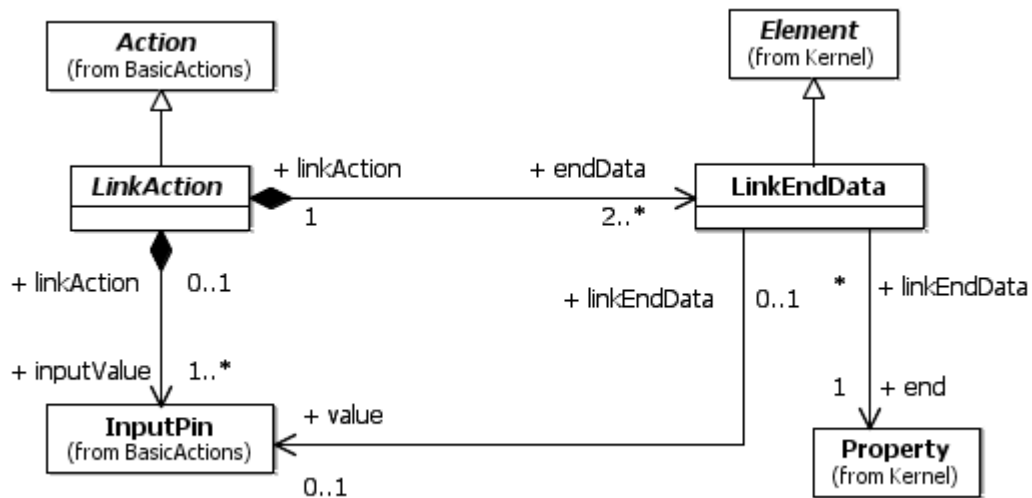


Figure 43 - Link Identification

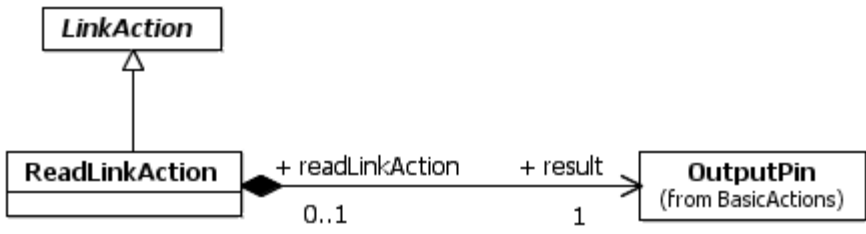


Figure 44 - Read Link Actions

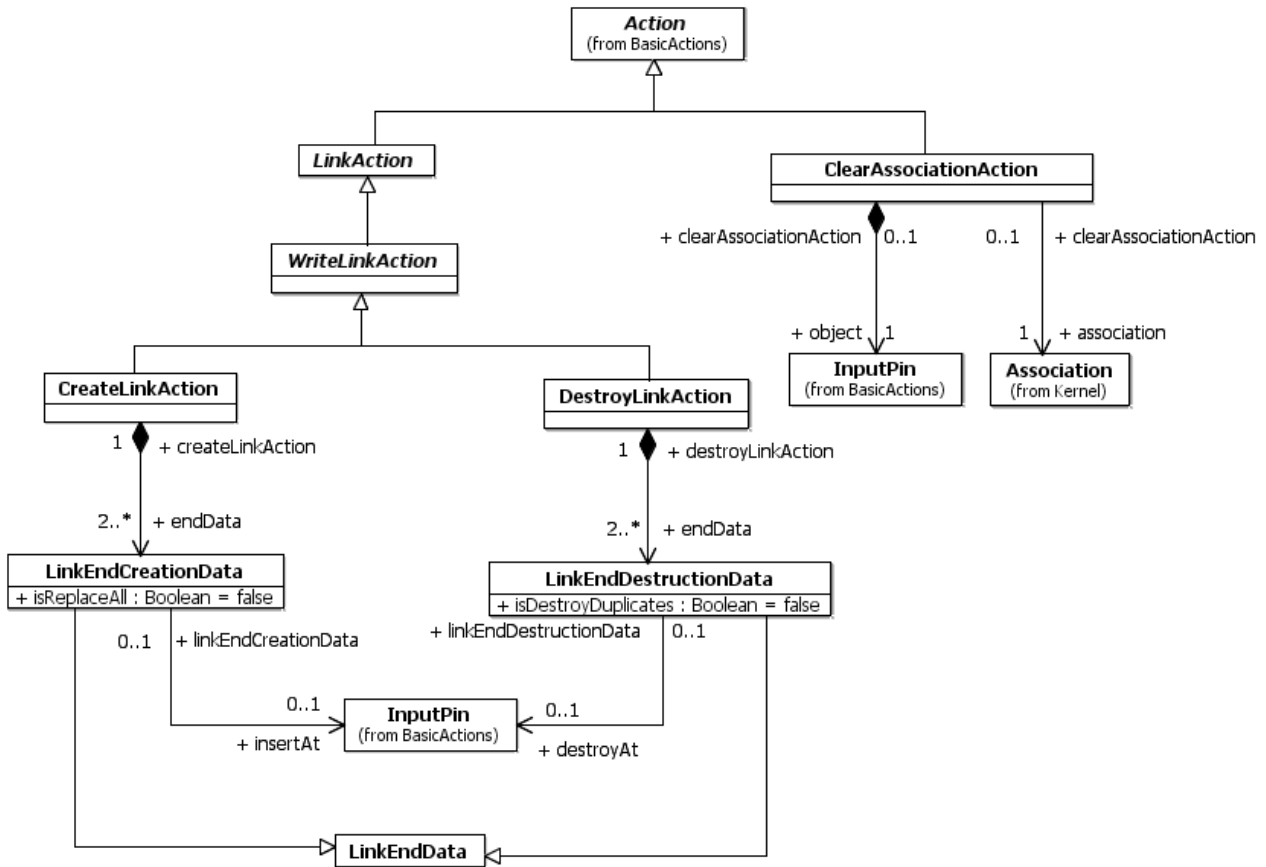


Figure 45 - Write Link Actions

7.5.3.2 Class Descriptions

7.5.3.2.1 AddStructuralFeatureValueAction

Generalizations

- [WriteStructuralFeatureAction](#)

Attributes

- isReplaceAll : Boolean = false

Associations

- insertAt : InputPin [0..1]

Additional Constraints

None

7.5.3.2.2 ClearAssociationAction**Generalizations**

- [Action](#)

Attributes

None

Associations

- association : Association
- object : InputPin

Additional Constraints

None

7.5.3.2.3 ClearStructuralFeatureAction**Generalizations**

- [StructuralFeatureAction](#)

Attributes

None

Associations

- result : OutputPin [0..1]

Additional Constraints

None

7.5.3.2.4 CreateLinkAction**Generalizations**

- [WriteLinkAction](#)

Attributes

None

Associations

- endData : LinkEndCreationData [2..*]

Additional Constraints

None

7.5.3.2.5 CreateObjectAction**Generalizations**

- [Action](#)

Attributes

None

Associations

- classifier : Classifier
- result : OutputPin

Additional Constraints

[1] fUML_is_class

The given classifier must be a class.

self.classifier.oclsIsKindOf(Class)

7.5.3.2.6 DestroyLinkAction

Generalizations

- [WriteLinkAction](#)

Attributes

None

Associations

- endData : LinkEndDestructionData [2..*]

Additional Constraints

None

7.5.3.2.7 DestroyObjectAction

Generalizations

- [Action](#)

Attributes

- isDestroyLinks : Boolean = false
- isDestroyOwnedObjects : Boolean = false

Associations

- target : InputPin

Additional Constraints

None

7.5.3.2.8 LinkAction

Generalizations

- [Action](#)

Attributes

None

Associations

- endData : LinkEndData [2..*]
- inputValue : InputPin [1..*]

Additional Constraints

None

7.5.3.2.9 LinkEndCreationData

Generalizations

- [LinkEndData](#)

Attributes

- isReplaceAll : Boolean = false

Associations

- insertAt : InputPin [0..1]

Additional Constraints

None

7.5.3.2.10 LinkEndData

Generalizations

- [Element](#)

Attributes

None

Associations

- end : Property
- value : InputPin [0..1]

Additional Constraints

None

7.5.3.2.11 LinkEndDestructionData

Generalizations

- [LinkEndData](#)

Attributes

- isDestroyDuplicates : Boolean = false

Associations

- destroyAt : InputPin [0..1]

Additional Constraints

None

7.5.3.2.12 ReadLinkAction

Generalizations

- [LinkAction](#)

Attributes

None

Associations

- result : OutputPin

Additional Constraints

None

7.5.3.2.13 ReadSelfAction

Generalizations

- [Action](#)

Attributes

None

Associations

- result : OutputPin

Additional Constraints

None

7.5.3.2.14 ReadStructuralFeatureAction

Generalizations

- [StructuralFeatureAction](#)

Attributes

None

Associations

- result : OutputPin [0..1]

Additional Constraints

None

7.5.3.2.15 RemoveStructuralFeatureValueAction

Generalizations

- [WriteStructuralFeatureAction](#)

Attributes

- isRemoveDuplicates : Boolean = false

Associations

- removeAt : InputPin [0..1]

Additional Constraints

None

7.5.3.2.16 StructuralFeatureAction

Generalizations

- [Action](#)

Attributes

None

Associations

- object : InputPin
- structuralFeature : StructuralFeature

Additional Constraints

None

7.5.3.2.17 TestIdentityAction

Generalizations

- [Action](#)

Attributes

None

Associations

- first : InputPin
- result : OutputPin
- second : InputPin

Additional Constraints

None

7.5.3.2.18 ValueSpecificationAction

Generalizations

- [Action](#)

Attributes

None

Associations

- result : OutputPin
- value : ValueSpecification

Additional Constraints

None

7.5.3.2.19 WriteLinkAction

Generalizations

- [LinkAction](#)

Attributes

None

Associations

None

Additional Constraints

None

7.5.3.2.20 WriteStructuralFeatureAction

Generalizations

- [StructuralFeatureAction](#)

Attributes

None

Associations

- result : OutputPin [0..1]
- value : InputPin

Additional Constraints

None

7.5.4 Complete Actions

7.5.4.1 Overview

The classes shown in Figure 46 to Figure 48 are those included in the fUML Actions::CompleteActions package. The diagrams correspond to similar diagrams in the UML 2 Superstructure Specification. The following features have been excluded from the fUML subset and are, therefore, not reflected in the fUML abstract syntax diagrams.

From Accept Event Actions (see Figure 46):

- *AcceptCallAction*. Accept call actions are excluded from fUML because only signal events are allowed in triggers in fUML. Operation calls in fUML are handled solely by the dispatching of operations to methods.
- *ReplyAction*. Reply actions are excluded from fUML because they are only used in conjunction with accept call actions for synchronous calls.
- *UnmarshallAction*. Unmarshall actions are excluded from fUML because it is redundant with unmarshalling a signal as received by an accept event action.

From Object Actions (see Figure 47): No exclusions.

From Link Identification Actions (no fUML diagram):

Table1 *QualifierValue*. Qualifier values are excluded from fUML because association qualifiers are excluded from fUML (see Subclause 7.2.2).

From Read Link Actions and Write Link Actions (no fUML diagrams):

Table1 *ReadLinkObjectEndAction*, *ReadLinkObjectEndQualifierAction* and *CreateLinkObjectAction*. These actions are excluded from fUML because association classes are excluded from fUML (see Subclause 7.2.1).

From Reduce Action (see Figure 48): No exclusions.

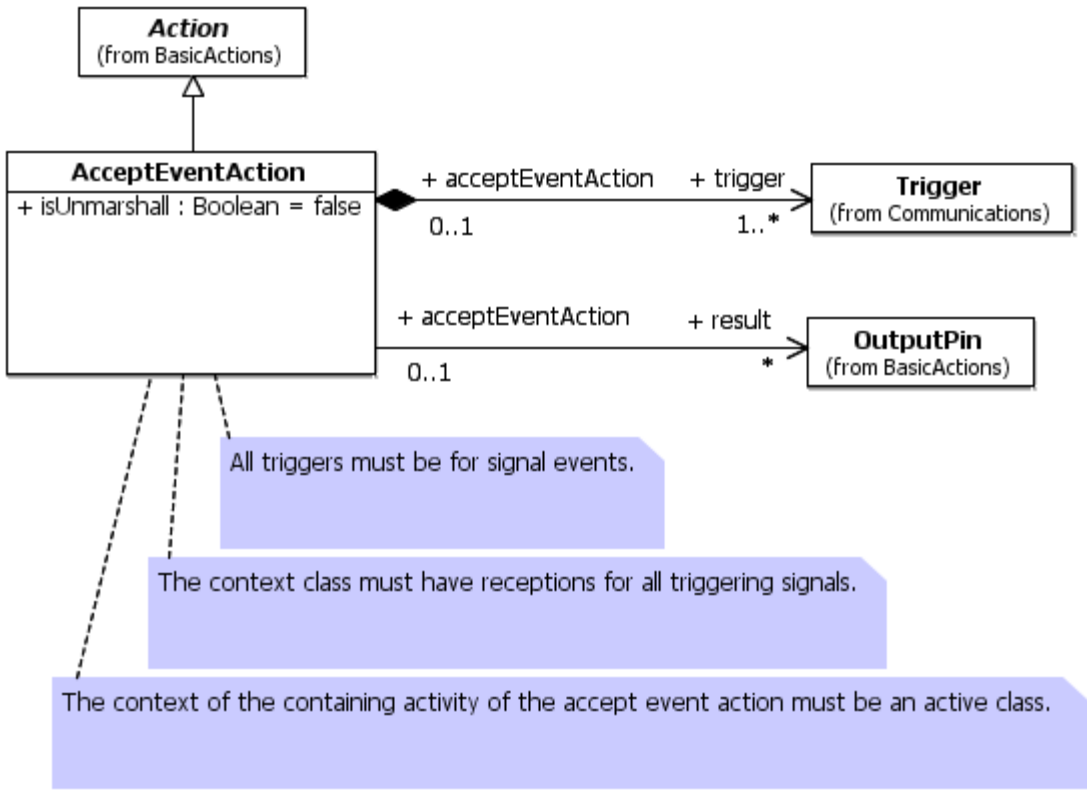


Figure 46 - Accept Event Actions

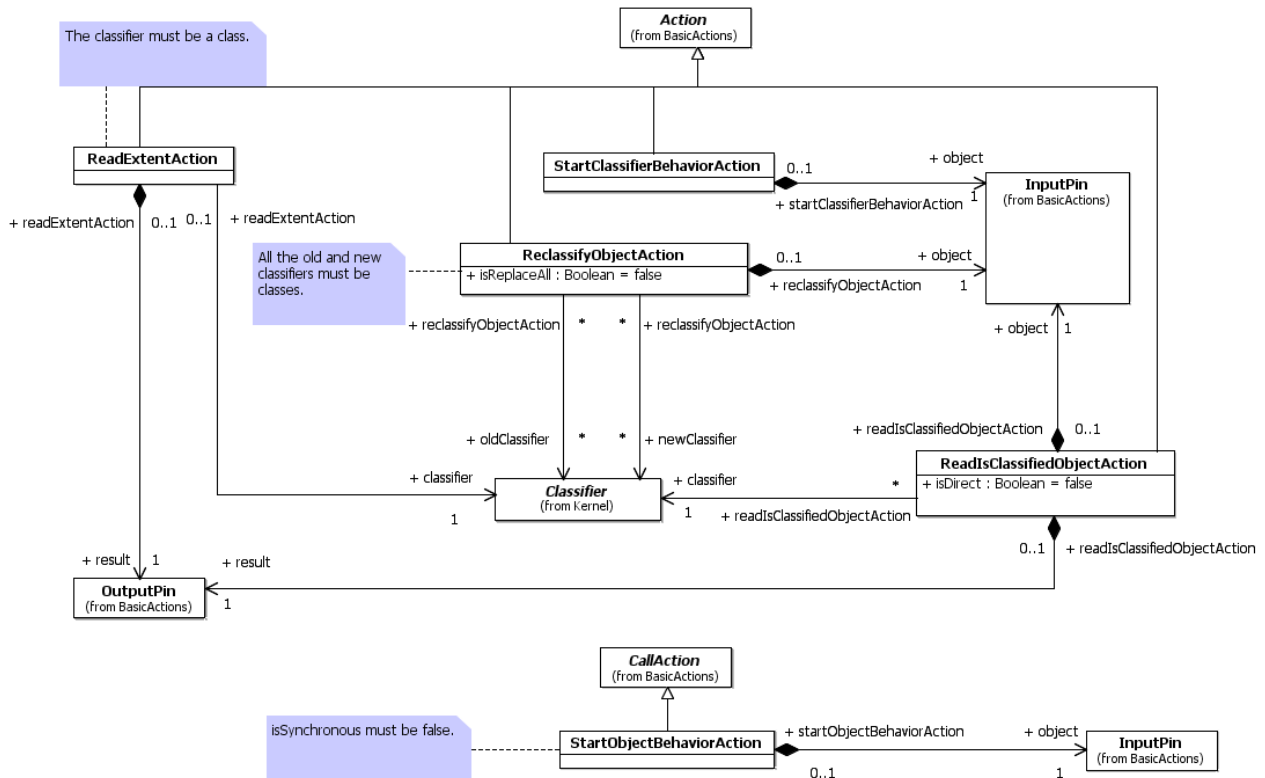


Figure 47 - Object Lifecycle Actions

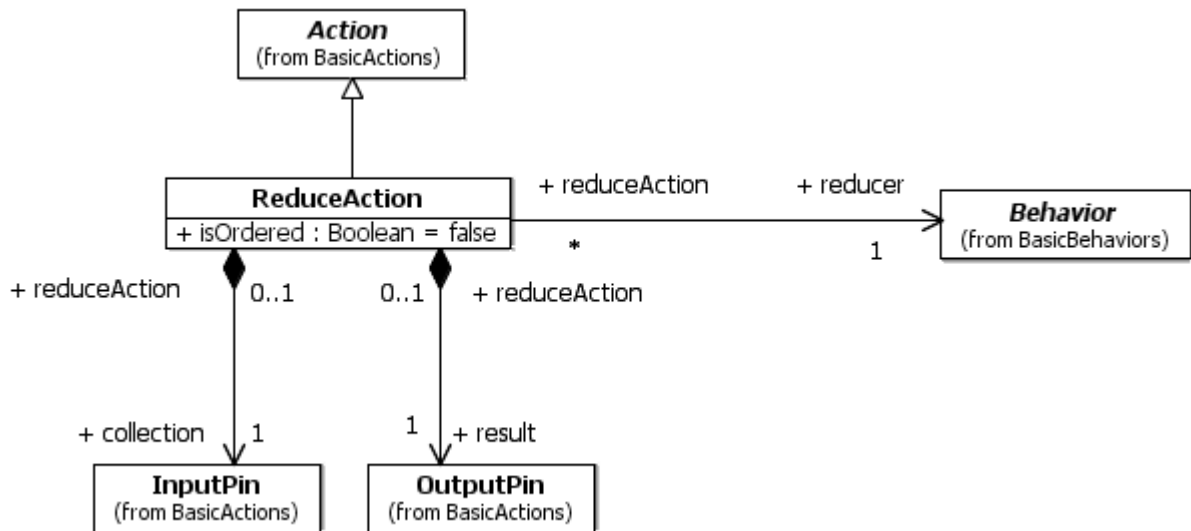


Figure 48 - Reduce Actions

7.5.4.2 Class Descriptions

7.5.4.2.1 AcceptEventAction

Generalizations

- [Action](#)

Attributes

- isUnmarshall : Boolean = false

Associations

- result : OutputPin [0..*]
- trigger : Trigger [1..*]

Additional Constraints

[1] fUML_active_context

The context of the containing activity of the accept event action must be an active class.

```
self.context.oclAsType(Class).isActive
```

[2] fUML_only_signal_event_triggers

All triggers must be for signal events.

```
self.trigger.event->forAll(oclIsKindOf(SignalEvent))
```

[3] fUML_receive_all_triggering_signals

The context class must have receptions for all triggering signals.

```
let cls:Class = self.context.oclAsType(Class) in
```

```
let classes:Bag(Class) = cls.allParents()->select(oclIsKindOf(Class))->collect(oclAsType(Class))->union(cls->asBag()) in  
classes.ownedReception.signal->includesAll(self.trigger.event->collect(oclAsType(SignalEvent)).signal)
```

7.5.4.2.2 ReadExtentAction

Generalizations

- [Action](#)

Attributes

None

Associations

- classifier : Classifier
- result : OutputPin

Additional Constraints

[1] fUML_is_class

The classifier must be a class.

```
self.classifier.oclIsKindOf(Class)
```

7.5.4.2.3 ReadsClassifiedObjectAction

Generalizations

- [Action](#)

Attributes

- isDirect : Boolean = false

Associations

- classifier : Classifier
- object : InputPin
- result : OutputPin

Additional Constraints

None

7.5.4.2.4 ReclassifyObjectAction**Generalizations**

- [Action](#)

Attributes

- isReplaceAll : Boolean = false

Associations

- newClassifier : Classifier [0..*]
- object : InputPin
- oldClassifier : Classifier [0..*]

Additional Constraints

[1] fUML_old_new_classes

All the old and new classifiers must be classes.

self.oldClassifier->forAll(oclsKindOf(Class)) and self.newClassifier->forAll(oclsKindOf(Class))

7.5.4.2.5 ReduceAction**Generalizations**

- [Action](#)

Attributes

- isOrdered : Boolean = false

Associations

- collection : InputPin
- reducer : Behavior
- result : OutputPin

Additional Constraints

None

7.5.4.2.6 StartClassifierBehaviorAction**Generalizations**

- [Action](#)

Attributes

None

Associations

- object : InputPin

Additional Constraints

None

7.5.4.2.7 StartObjectBehaviorAction

Generalizations

- [CallAction](#)

Attributes

None

Associations

- object : InputPin

Additional Constraints

[1] fUML_is_asynchronous
isSynchronous must be false.

not self.isSynchronous

8 Execution Model

8.1 Overview

This clause describes the *execution model* for fUML. The execution model is itself a model, written in fUML, that specifies how fUML models are to be executed. This circularity is broken by the separate specification of a base semantics for the subset of fUML actually used in the execution model (see Clause 10).

Static Semantics and Well Formedness

It is important to distinguish execution semantics from what is sometimes called “static semantics,” a term that comes from programming language compiler theory.

Typically, the syntax of a programming language is defined using a context-free grammar (e.g., using Backus-Naur Form productions). However, there are also typically aspects of the language that are context-sensitive, but can still be checked statically by the compiler. The most common example is static type checking, which requires matching expression types to declared variable types. The checking of such context-sensitive constraints is known as “static semantics.”

For UML, the abstract syntax is defined as a MOF metamodel. The UML specification also defines additional constraints that the metamodel representation of a valid UML model is required to meet. These constraints are the equivalent of the static semantics of UML.

However, since these constraints can all be checked statically, they are not part of the *execution semantics* of UML. Indeed, any model that violates one or more of these additional constraints is not actually well formed. Such an ill-formed model cannot really be assigned any meaning at all.

In this specification, static semantics are not considered to be part of the execution semantics to be specified. That is, any well-formed model is already presumed to have met all the constraints imposed on the abstract syntax as defined in the UML Specification. Semantic meaning will only be defined for models that are well formed in this sense.

Conventions on Derivation and Redefinition

In a number of cases in the UML abstract syntax metamodel, constraints express requirements for *derived properties* (including the implicit constraints involved in derived unions and subsetting). The values of such properties may be completely determined from the values of other, non-derived properties using the defining constraints. Thus, for example, the values of these properties do not need to be included in the interchange representation of the model.

On the other hand, the UML 2 Superstructure specification allows a derived property to be read using a read structural feature action, just like any other property. In principle, it should be possible to dynamically compute the value of the derived property in order to read it. However, the fUML subset does not include constraints (see Subclause 7.2.2.1 for the rationale for this exclusion) and, therefore, the defining constraints for derived properties are not available in an executing fUML model.

As a result, this specification adopts the convention that, when an object is instantiated, *explicit* values are provided for all derived properties and that these values are consistent with the defining constraints for the derivation. In the context of the abstract syntax metamodel, this means that all the implicit and explicit derivation constraints are treated as part of the conditions for a well-formed model. Consistent with the discussion of well-formedness above, the execution model therefore assumes that the abstract syntax representation of a model being executed has valid values set for all derived properties that may be read just like other properties (and that all derived properties keep the same value throughout an execution). That is, the distinction between derived and non-derived properties essentially disappears at runtime, so far as the execution model is concerned (since the execution model does not change the value of *any* properties in the abstract syntax representation of an input model).

For example, the UML abstract syntax metamodel defines the ownedAttribute property of Class to subset the derived union Namespace::ownedMember, which, in turn, subsets both Namespace::member and Element::ownedElement. The fUML execution model assumes that, in the abstract syntax representation of a well-formed model, every ownedAttribute of the representation of a class will also be explicitly included in the collection of values of the inherited ownedMember, member and ownedElement properties for that class.

Similarly, an object is considered to have values set for both any redefined property and the property redefinition of it. In this case, the implicit constraint is that the values must be the same, whether accessed via the redefined property or via the redefining property. However, the redefining property may also impose additional constraints (such as a narrowing of the allowed multiplicity, for example) that then effectively also apply to the value of the redefined property.

NOTE: A conforming execution tool is not necessarily required to handle the derived and redefined properties of the UML abstract syntax metamodel in this way. This is simply the convention for the execution model, which is written within the constraints of the fUML subset.

Behavioral Semantics

The execution model is a formal, *operational* specification of the execution semantics of fUML. That is, it defines the operational procedure for the dynamic changes required during the execution of a fUML model. This is in contrast to the *declarative* approach used for the base semantics (see Clause 10).

The execution model is itself an executable, object-oriented, fUML model of a fUML execution engine. To specify the behavioral semantics of fUML completely, the execution model must fully define its own behavior—that is, it must fully specify every operation method and classifier behavior in it. Since the only kind of user-defined behavior supported in fUML is the activity, each behavior in the execution model must be modeled as an activity.

Currently, the only UML notation provided for activity modeling is the graphical activity diagram. It would thus be possible to represent each of the activities in the execution model using such a diagram. For example, Figure 49 gives a sample activity diagram for just a part of the method specified for the execute operation of the ActivityExecution class in the execution model. Unfortunately, for significant activities, these diagrams quickly become large, intractable to draw and hard to comprehend.

Instead of using such cumbersome graphical notation, and rather than defining from scratch a new, non-normative textual notation for activities, most activities in this specification are written as equivalent code in the Java programming language. Informally, these code snippets can actually be understood as executable Java code, and the standard Java semantics for this code is consistent with the behavior to be specified for the activity. For example, Figure 50 shows the Java code equivalent to the activity model in Figure 49.

Formally, however, any Java code should be understood as just a surface notation for the true, underlying UML activity model. That is, the code in Figure 50 should be thought of as just another representation of the model given in Figure 49. Annex A provides the normative mapping from this Java surface notation to UML activity models, for the purposes of the fUML specification. The formal semantics of the constructs used in activity models mapped from the Java surface notation is then given by the base semantics in Clause 10.

Clause Organization

The remainder of this clause is organized according to the packaging structure of the execution model. The packaging of the execution model exactly parallels that of the fUML abstract syntax (see Clause 7), except for the addition of the *Loci* package. This package contains elements of the execution model that do not directly correspond to syntactic elements of fUML. Rather, the elements in this package provide a model of an *executor* for well-formed fUML models, which can be considered to be the abstract specification for actual fUML execution engines.

Subclause 8.2 describes the Loci package, which contains the Locus, Executor and ExecutionFactory classes that model a fUML execution engine and its environment.

Subclause 8.3 describes the Class package, which itself only contains the Kernel package (in the fUML subset). The semantic model for the Kernel package provides the *structural semantics* for fUML.

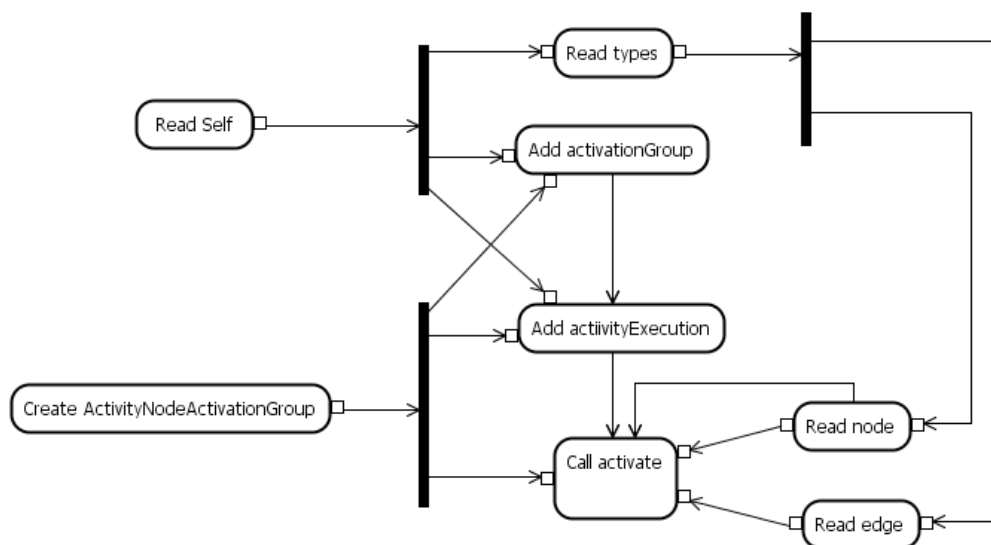


Figure 49 - Partial Activity Model for the ActivityExecution::execute Operation

```

Activity activity = (fUML.Syntax.Activity)(this.types.getValue(0));
ActivityNodeActivationGroup group = new ActivityNodeActivationGroup();
this.activationGroup = group;
group.activityExecution = this;
group.activate(activity.node, activity.edge);
  
```

Figure 50 - Java Surface Representation of the Activity Model in Figure 49

The remaining subclauses together define the *behavioral semantics* for fUML. Subclause 8.4 describes the Common Behavior package, including the fundamental models of active objects and behavior execution. Subclause 8.5 provides the semantic models for activities, the main form of behavior supported by fUML, and Subclause 8.6 provides the model for the execution of actions within an activity.

Throughout the following subclauses, the terminology of semantic interpretation introduced in Clause 6 will be freely used to relate the operational semantic specification provided by the execution model to the general semantics approach used in this specification.

8.2 Loci

8.2.1 Overview

The Loci package includes the model of the key concepts of an execution *locus* and of the *executor* that provides the abstract external interface of the execution model. Figure 51 shows the dependencies of this package on other packages.

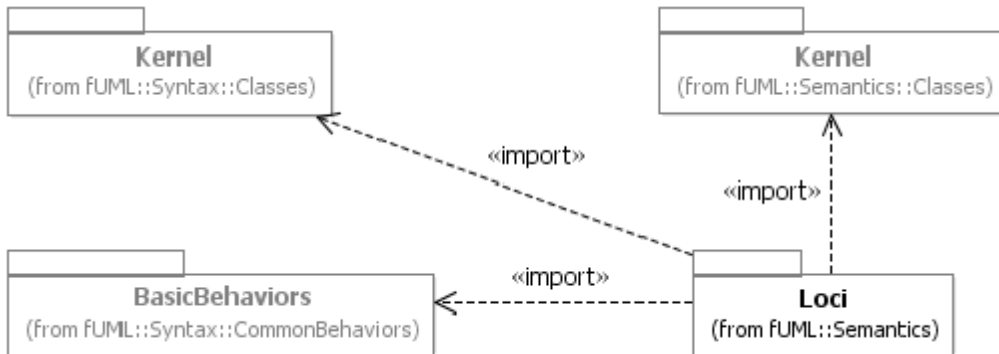


Figure 51 - Loci Semantics Packages

The Executor and the Execution Locus

The Executor class provides the root abstraction for executing a fUML model. As shown in Figure 52, it provides three operations:

- *Evaluate* – Evaluate a value specification, returning the specified value.
- *Execute* – Synchronously execute a behavior, given values for its input parameters and returning values for its output behaviors.
- *Start* – Asynchronously start the execution of a stand-alone or classifier behavior, returning a reference to the instance of the executing behavior or of the behaved classifier.

Every execution takes place at a specific *locus*. A locus is an abstraction of a physical or virtual computer capable of executing fUML models. It is a place at which *extensional values* (objects or links) can exist. The *extent* of a class or association is the set of objects or links of that type that exist *at a certain locus*. Note that this implies that an individual object is restricted to a single locus; i.e., it cannot span multiple loci (See Subclause 8.3.2.1 for further discussion of extensional values.)

All objects and links created during an execution are created at the locus of that execution. And, unless an object or link is explicitly destroyed, it will persist at the locus even after the execution has completed. This means that objects and links may already exist at a locus before a specific behavior execution begins, providing part of the *environment* in which the execution takes place. (The concept of an *execution environment* is discussed further at the end of this subclause.)

Indeed, an execution locus may provide a set of pre-existing objects as part of the environment of all behavior executions at that locus, as a means of providing external *services* to those executions. Given that the appropriate class is known, such service objects may be discovered using the read extent action (this is the mechanism used for accessing input/output services, for example – see Subclause 9.4). More sophisticated discovery services may also be provided but are not defined in this specification.

While the execution of any one behavior takes place at a single locus, an execution at one locus may invoke a behavior that executes at another locus. To do this, an execution must be able to instantiate, or otherwise obtain a reference to, an object on the remote locus on which the behavior is to be invoked (or which itself is a behavior instance). However, no normative mechanism is provided within fUML for an execution on one locus to obtain references to objects on another locus. Conformance execution tool implementations may optionally provide a service to discover objects on remote services or to allow references to be passed between loci using input/output channels (see Subclause 9.4). (With such extensions it should be possible to support the execution of models that span multiple loci.)

Visitor Classes and the Execution Factory

The model for evaluation and execution is based on the Visitor pattern¹. This pattern is used to add behavior to an already existing class hierarchy. In the case of the execution model, the existing class hierarchy is that of the fUML subset of the UML Abstract Syntax (see Clause 7). The intent of the execution model is to provide a specification for the execution of models represented in terms of instances of abstract syntax metaclasses, without making any change to those metaclasses as they are given in the UML Superstructure specification.

Using the Visitor Pattern, each abstract syntax metaclass for which behavior is to be added has a corresponding *visitor* class in the Execution Model. This visitor class has a unidirectional association to the corresponding abstract syntax metaclass and operations that effectively provide the behavioral specification of the semantics of model elements represented by that metaclass. All visitor classes in the execution model are descended, directly or indirectly from the root *SemanticVisitor* class (see Figure 52).

There are three types of visitor classes in the Execution Model. Two of them, *evaluations* and *executions*, are used by the Executor.

- *Evaluations* – An evaluation visitor is used to evaluate a specific kind of value specification; that is, to return an instance of the value denoted by the value specification. There is an evaluation visitor class corresponding to each concrete subclass of *ValueSpecification* included in the fUML subset (see Subclause 8.3.2). The name of the visitor class is the same as the name of the corresponding abstract syntax metaclass with the word “Evaluation” appended. For example, the evaluation visitor class for the abstract syntax metaclass *LiteralString* is called *LiteralStringEvaluation*. (See Subclause 8.3.2.1 for further discussion of evaluation classes.)
- *Executions* – An execution visitor is used to execute a specific kind of behavior. There is an execution visitor class corresponding to each concrete subclass of *Behavior* included in the fUML subset (see Subclauses 8.5 and 8.6). The name of the visitor class is the same as the name of the corresponding abstract syntax metaclass with the word “Execution” appended. The primary kind of UML behavior included in fUML is the activity with a corresponding visitor class called *ActivityExecution*. There are also *OpaqueBehaviorExecution* and *FunctionBehaviorExecution* visitor classes corresponding to *OpaqueBehavior* and *FunctionBehavior*. (See Subclause 8.4 for a general discussion of execution classes and Subclause 8.5 for specific discussion of activity execution.)

The behavior of the Executor evaluate and execute operations is to create an instance of the corresponding evaluation or execution visitor class and then use that visitor instance to carry out the required evaluation or execution. To create a corresponding visitor instance, the Executor uses an instance of the *ExecutionFactory* class located at the execution locus (see Figure 52). The *ExecutionFactory* class provides *createEvaluation* and *createExecution* operations that take, respectively, value specification and behavior abstract syntax instances and return, respectively, instances of the evaluation or execution class corresponding to the concrete class of the input abstract syntax object.

The third type of visitor class is an *activation*. An activation visitor is used to model the semantics of a specific kind of activity node within the execution of a containing activity. Such activation instances are created as part of the construction of the execution object for an activity. Therefore, they are further described in Subclause 8.5.2.1 as part of the discussion of activity execution.

Strategy Classes and Semantic Variation Points

There are two semantic variation points defined for fUML (see Subclause 2.3): *event dispatch scheduling* and *polymorphic operation dispatching*. In both of these cases, the execution model limits the semantic variability to the

¹ For a description of the Visitor pattern, see Gamma, E., Helm, R., Johnson, R., and Vlissides, J., *Design Patterns: Elements of Reusable Object-Oriented Software*, Addison-Wesley Publishing, 1994.

behavior of a single operation: `ObjectActivation::getNextEvent` (see Subclause 8.4.3.1) in the case of event dispatching and `Object::dispatch` in the case of operation dispatching (see Subclause 8.3.2.1). The execution model uses the Strategy pattern² in order to allow for possible variation in the behavior of these operations.

The Strategy pattern involves defining an abstract base *strategy class* for an operation whose behavior is to be allowed to vary. This base class defines an abstract operation corresponding to the original operation, to which the original operation is delegated. Different concrete subclasses of the base strategy class can then define different concrete behaviors for the operation, and selecting a specific behavior (or *strategy*) corresponds to using an instance of a specific concrete strategy class.

In the execution model, all strategy classes ultimately descend, directly or indirectly, from the class `SemanticStrategy` (see Figure 51). The `SemanticStrategy` class provides a common operation for getting the “name” of a strategy, which identifies to which semantic variation point a strategy instance applies. The standard strategy names used in the execution model correspond to the names of the operations whose behavior is being provided: “`getNextEvent`” and “`dispatch`”.

The strategy to be used for a semantic variation point is determined by the strategy instance that is *registered* with the execution factory (using the `setStrategy` operation) at a given locus under the corresponding strategy name. There must be exactly one strategy instance, of the appropriate subclass, registered for each semantic variation point. The execution factory `getStrategy` operation provides a lookup mechanism for retrieving a strategy instance to be used for a specific named semantic variation.

For further discussion of the strategy classes related to each semantic variation point, as well as the default strategies provided in the execution model, see Subclause 8.4.3.1 and Subclause 8.3.2.1.

NOTE: While there are currently only two semantic variation points defined for fUML, the strategy mechanism has intentionally been made general enough to accommodate the possible need for additional variation points in future extensions to the specification of the execution semantics for larger subsets of UML.

Specifying Nondeterministic Behavior

There are a number of cases in which the UML 2 Superstructure specification specifically indicates that the execution semantics in a certain area are *nondeterministic*—that is, the semantic specification does not prescribe which one of a number of possible choices is taken during an actual execution. A legal execution may take any one of the allowed choices. For example, if more than one clause of a conditional node has a successful test, then only one of the clause bodies will be executed, but it is nondeterministic which one is actually executed.

In order to model nondeterministic behavior in the execution model, a special case of the Strategy pattern is used. A *choice strategy* is one with the name “choice” that provides a single operation called *choose*. This operation takes a single integer argument *size* (which must be greater than zero) and returns an integer value from 1 to the given size.

The `ChoiceStrategy` class (see Figure 52) is the abstract base strategy class for all choice strategies. A single instance of a concrete subclass of `ChoiceStrategy` is registered with the execution factory at each locus. Whenever a behavior specification within the execution model is required to make a non-deterministic choice between some number of options, this choice is made by getting the registered choice strategy and using its `choose` operation.

The key point is that it a legal execution may use *any choice strategy at all*, so long as the `choose` operation always returns a selection from 1 to the required number of choices. Since any choice strategy is legal, no restriction is placed on a conforming execution tool as to how such choices are actually made in its specific implementation. In this way, the concept of nondeterminism is operationally interpreted in the execution model.

For completeness, the execution model includes a single concrete default choice strategy class, `FirstChoiceStrategy` (see Figure 52). The `choose` operation of this class always returns 1, which corresponds to always picking the first of a list of possible options. It is important to understand that, while this specific strategy is deterministic, the effective nondeterminism of allowed behavior comes about because *any* other choice strategy might also be used, whether it is some other simple algorithm, totally random or just based on what is most convenient for the internal implementation of some execution tool.

² For a description of the Strategy pattern, see Gamma et al., *ibid*.

NOTE: There is no requirement that a conforming execution tool provide a formal specification of what its effective choice strategy is, as this may be entirely implicit in the way the tool is implemented. On the other hand, a specific choice strategy *may* be formally specified by defining a new subclass of ChoiceStrategy. This may be useful, for example, if the implementation target is in a domain (such as life critical systems) in which fully determinable behavior is desirable or if it is desirable to be able to specify some sort of fair or parameterized distribution of how choices are made.

Primitive Behaviors and Primitive Types

The execution factory at each locus maintains the set of primitive behaviors available to be called by executions at a specific locus. In fUML, primitive behaviors are defined syntactically as instances of OpaqueBehavior. For each OpaqueBehavior instance representing a primitive behavior, the execution factory maintains a corresponding *prototype* instance of OpaqueBehaviorExecution. When an instance of OpaqueBehavior is passed to the execution factory createExecution operation, the corresponding prototype opaque behavior execution is looked up. A copy of this prototype execution instance is then returned as the result of the createExecution call.

Subclause 9.2 specifies the basic library of primitive behaviors that must be provided by any conforming execution tool. However, specific execution tools may also provide additional primitive behaviors. These are modeled as additional opaque behavior execution prototypes added to the standard list required to be maintained by any execution factory.

Finally, the execution factory also maintains a list of built-in primitive types for which there are corresponding literal value specifications. Note that this is a list of *instances* of the PrimitiveType metaclass—that is, representations of the M1-level types from the fUML model library (see Subclause 9.1). During the evaluation of a literal value specification, the appropriate evaluation class looks up by name the proper primitive type to attach to the resulting value (see Subclause 8.3). Since fUML includes literal value specifications for Boolean, Integer, String and UnlimitedNatural (see Subclause 7.2.2), the list of built-in types must include at least these types.

Configuring the Execution Environment at a Locus

While the Executor class provides the basic interface for evaluating value specifications and executing behaviors, the preceding discussion in this subclause indicates that more than just an instance of an executor is required in order to even begin to perform such evaluations and executions. Instead, it is necessary to instantiate a set of collaborating objects (largely from classes within the execution model) that provide the initial *execution environment*. The configuration of this initial environment in terms of the execution model is an abstraction of the capabilities that a conforming execution tool must actually provide in order to execute a fUML model.

The following items are *required* as part of the execution environment at a specific locus.

- A single instance of class Locus (see Subclause 8.2.2.5)
- A single instance of class Executor, linked to the locus (see Subclause 8.2.2.3)
- A single instance of class ExecutionFactory, also linked to the locus (see Subclause 8.2.2.2)
- Instances of PrimitiveType for each of the primitive types Boolean, Integer, String and UnlimitedNatural, as defined in the Foundational Model Library (see Subclause 9.1), registered with the execution factory as built-in types
- Single instances of concrete subclasses of ChoiceStrategy (see Subclause 8.2.2.1), DispatchStrategy (see Subclause 8.3.2.2.4) and GetNextEventStrategy (see Subclause 8.4.3.2.6), all registered with the execution factory

The following items are also *permitted* as part of the execution environment at a specific locus.

- Instances of concrete subclasses of OpaqueBehaviorExecution registered with the execution factory as primitive behavior prototypes (these may include some or all of the primitive behaviors from the Foundational Model Library—see Subclause 9.2)
- Instances of Object representing discoverable services, instantiated as existential values at the locus (these may include singleton instances of the basic input/output classes StandardInputChannel and StandardOutputChannel—see Subclause 9.4)

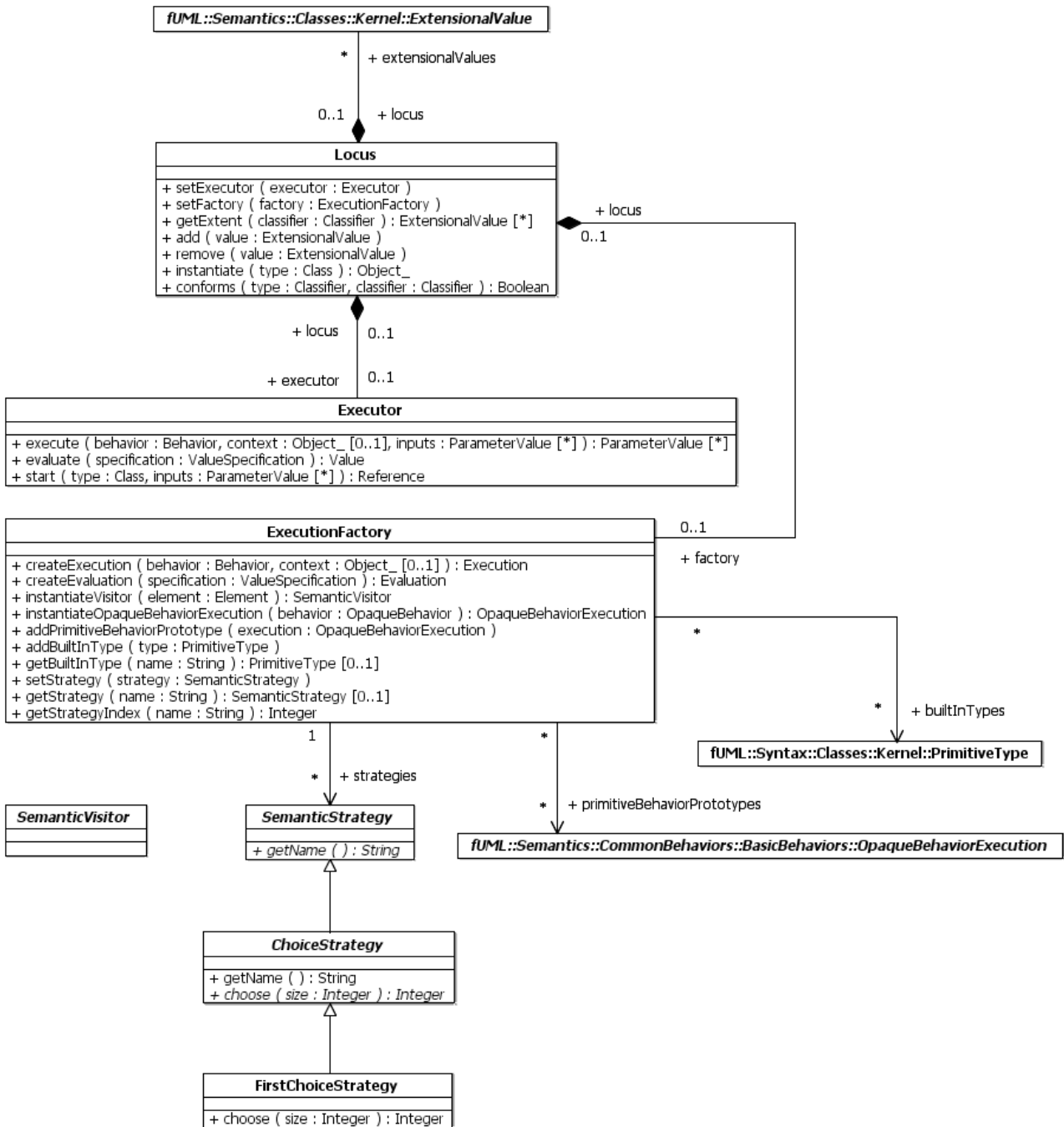


Figure 52 - Loci

8.2.2 Class Descriptions

8.2.2.1 ChoiceStrategy

A choice strategy is used to represent the behavior of making an arbitrary non-deterministic choice. A valid execution may use ANY choice strategy for choosing one element from a given set.

Generalizations

- [SemanticStrategy](#)

Attributes

None

Associations

None

Operations

[1] choose (in size : Integer) : Integer

Choose an integer from 1 to the given size.
[The size must be greater than 0.]

[2] getName () : String

```
// The name of a choice strategy is always "choice".  
return "choice";
```

8.2.2.2 ExecutionFactory

An execution factory is used to create objects that represent the execution of a behavior, the evaluation of a value specification or the activation of an activity node.

Generalizations

None

Attributes

None

Associations

- builtInTypes : PrimitiveType [0..*]
The set of primitive types that have corresponding literal value specifications.
Must include Integer, Boolean, String and UnlimitedNatural.
- locus : Locus [0..1]
The locus at which this factory resides.
- primitiveBehaviorPrototypes : OpaqueBehaviorExecution [0..*]
The set of opaque behavior executions to be used to execute the primitive behaviors known to the factory.
- strategies : SemanticStrategy [0..*]
The set of semantic strategies currently registered with this execution factory.

Operations

[1] addBuiltInType (in type : PrimitiveType)

```
// Add the given primitive type as a built-in type.  
// Precondition: No built-in type with the same name should already exist.  
  
this.builtInTypes.addValue(type);
```

[2] addPrimitiveBehaviorPrototype (in execution : OpaqueBehaviorExecution)

```
// Add an opaque behavior execution to use as a prototype for instantiating the
corresponding primitive opaque behavior.
// Precondition: No primitive behavior prototype for the type of the given execution
should already exist.
```

```
this.primitiveBehaviorPrototypes.addValue(execution);
```

[3] createEvaluation (in specification : ValueSpecification) : Evaluation

```
// Create an evaluation object for a given value specification.
// The evaluation will take place at the locus of the factory.
```

```
Evaluation evaluation = (Evaluation)(this.instantiateVisitor(specification,"Evaluation"));
```

```
evaluation.specification = specification;
evaluation.locus = this.locus;
```

```
return evaluation;
```

[4] createExecution (in behavior : Behavior, in context : Object [0..1]) : Execution

```
// Create an execution object for a given behavior.
// The execution will take place at the locus of the factory in the given context.
// If the context is empty, the execution is assumed to provide its own context.
```

```
Execution execution;
```

```
if (behavior instanceof OpaqueBehavior) {
    execution = this.instantiateOpaqueBehaviorExecution((OpaqueBehavior)behavior);
}
else {
    execution = (Execution)(this.instantiateVisitor(behavior,"Execution"));
    execution.types.addValue(behavior);
    execution.createFeatureValues();
}
```

```
this.locus.add(execution);
```

```
if (context == null) {
    execution.context = execution;
}
else {
    execution.context = context;
}
```

```
return execution;
```

[5] getBuiltInType (in name : String) : PrimitiveType [0..1]

```
// Return the built-in type with the given name.
```

```
PrimitiveType type = null;
```

```
int i = 1;
```

```
while (type == null & i <= this.builtInTypes.size()) {
    PrimitiveType primitiveType = this.builtInTypes.getValue(i-1);
    if (primitiveType.name.equals(name)) {
```

```

        type = primitiveType;
    }
    i = i + 1;
}

return type;

```

[6] getStrategy (in name : String) : SemanticStrategy [0..1]

```

// Get the strategy with the given name.

int i = this.getStrategyIndex(name);

SemanticStrategy strategy = null;
if (i <= this.strategies.size()) {
    strategy = this.strategies.getValue(i-1);
}

return strategy;

```

[7] getStrategyIndex (in name : String) : Integer

```

// Get the index of the strategy with the given name.
// If there is no such strategy, return the size of the strategies list.

SemanticStrategyList strategies = this.strategies;

int i = 1;
boolean unmatched = true;
while (unmatched & (i <= strategies.size())) {
    if (strategies.getValue(i-1).getName().equals(name)) {
        unmatched = false;
    } else {
        i = i + 1;
    }
}

return i;

```

[8] instantiateOpaqueBehaviorExecution (in behavior : OpaqueBehavior) : OpaqueBehaviorExecution

```

// Return a copy of the prototype for the primitive behavior execution of the given
opaque behavior.

OpaqueBehaviorExecution execution = null;
int i = 1;
while (execution == null & i <= this.primitiveBehaviorPrototypes.size()) {
    // Debug.println("[instantiateOpaqueExecution] Checking " +
this.primitiveBehaviorPrototypes.getValue(i).objectId() + "...");
    OpaqueBehaviorExecution prototype = this.primitiveBehaviorPrototypes.getValue(i-1);
    if (prototype.getBehavior() == behavior) {
        execution = (OpaqueBehaviorExecution) (prototype.copy());
    }
    i = i + 1;
}

if (execution == null) {

```

```

    Debug.println("[instantiateOpaqueExecution] No prototype execution found for " +
behavior.name + ".");
}

return execution;

```

[9] instantiateVisitor (in element : Element, in suffix : String) : SemanticVisitor

```

// Instantiate a visitor object for the given element, appending the given suffix to the
class name.

String elementClassName = element.getClass().getName();

// Strip off "fUML.Syntax."
int dotIndex = elementClassName.indexOf(".");
elementClassName = elementClassName.substring(dotIndex+1);
dotIndex = elementClassName.indexOf(".");
elementClassName = elementClassName.substring(dotIndex+1);

// Debug.println("[instantiateVisitor] Stripped name = " + elementClassName);

String visitorClassName = "fUML.Semantics." + elementClassName + suffix;

try {
    return (SemanticVisitor) (Class.forName(visitorClassName).newInstance());
} catch (Exception e) {
    Debug.println("[instantiateVisitor] Error: " + e);
    return null;
}

```

[10] setStrategy (in strategy : SemanticStrategy)

```

// Set the strategy for a semantic variation point. Any existing strategy for the same SVP
is replaced.

int i = this.getStrategyIndex(strategy.getName());

if (i <= this.strategies.size()) {
    this.strategies.removeValue(i-1);
}

this.strategies.addValue(strategy);

```

8.2.2.3 Executor

An executor is used to execute behaviors and evaluation value specifications.

Generalizations

None

Attributes

None

Associations

- locus : Locus [0..1]
The locus at which this executor resides.

Operations

[1] evaluate (in specification : ValueSpecification) : Value

```
// Evaluate the given value specification, returning the specified value.  
  
// Debug.println("[evaluate] Start...");  
return this.locus.factory.createEvaluation(specification).evaluate();
```

[2] execute (in behavior : Behavior, in context : Object [0..1], in inputs : ParameterValue [0..*]) : ParameterValue [0..*]

```
// Execute the given behavior with the given input values in the given context, producing  
the given output values.  
// There must be one input parameter value for each input (in or in-out) parameter of the  
behavior.  
// The returned values include one parameter value for each output (in-out, out or return)  
parameter of the behavior.  
// The execution instance is destroyed at completion.  
  
Execution execution = this.locus.factory.createExecution(behavior, context);  
  
for (int i = 0; i < inputs.size(); i++) {  
    execution.setParameterValue(inputs.getValue(i));  
}  
  
execution.execute();  
ParameterValueList outputValues = execution.getOutputParameterValues();  
execution.destroy();  
  
return outputValues;
```

[3] start (in type : Class, in inputs : ParameterValue [0..*]) : Reference

```
// Instantiate the given class and start any behavior of the resulting object.  
// (The behavior of an object includes any classifier behaviors for an active object or  
the class of the object itself, if that is a behavior.)  
  
Debug.println("[start] Starting " + type.name + "...");  
  
Object_ object = this.locus.instantiate(type);  
  
Debug.println("[start] Object = " + object);  
object.startBehavior(type, inputs);  
  
Reference reference = new Reference();  
reference.referent = object;  
  
return reference;
```

8.2.2.4 FirstChoiceStrategy

Generalizations

- [ChoiceStrategy](#)

Attributes

None

Associations

None

Operations

[1] choose (in size : Integer) : Integer

```
// Always choose one.
```

```
return 1;
```

8.2.2.5 Locus

A locus is a place at which extensional values (objects or links) can exist. The extent of a class or association is the set of objects or links of that type that exist at a certain locus.

A locus also has an executor and a factory associated with it, used to execute behaviors as a result of requests dispatched to objects at the locus.

Generalizations

None

Attributes

None

Associations

- executor : Executor [0..1]
The executor to be used at this locus.
- extensionalValues : ExtensionalValue [0..*]
The set of values that are members of classifier extents at this locus.
- factory : ExecutionFactory [0..1]
The factory to be used at this locus.

Operations

[1] add (in value : ExtensionalValue)

```
// Add the given extensional value to this locus
```

```
value.locus = this;
```

```
this.extensionalValues.addValue(value);
```

[2] conforms (in type : Classifier, in classifier : Classifier) : Boolean

```
// Test if a type conforms to a given classifier, that is, the type is equal to or a descendant of the classifier.
```

```
boolean doesConform = false;
```

```
if (type == classifier) {  
    doesConform = true;
```

```
} else {
```

```
    int i = 1;
```

```
    while (!doesConform & i <= type.general.size()) {
```

```
        doesConform = this.conforms(type.general.getValue(i-1), classifier);
```

```
        i = i + 1;
```



```

    }
}

return doesConform;

```

[3] `getExtent (in classifier : Classifier) : ExtensionalValue [0..*]`

// Return the set of extensional values at this locus which have the given classifier as a type.

```

ExtensionalValueList extent = new ExtensionalValueList();

ExtensionalValueList extensionalValues = this.extensionalValues;
for (int i = 0; i < extensionalValues.size(); i++) {
    ExtensionalValue value = extensionalValues.getValue(i);
    ClassifierList types = value.getTypes();

    boolean conforms = false;
    int j = 1;
    while (!conforms & j <= types.size()) {
        conforms = this.conforms(types.getValue(j-1), classifier);
        j = j + 1;
    }

    if (conforms) {
        extent.addValue(value);
    }
}

return extent;

```

[4] `instantiate (in type : Class) : Object`

```

// Instantiate the given class at this locus.

Object_ object = null;

if (type instanceof Behavior) {
    object = this.factory.createExecution((Behavior)type, null);
}
else {
    object = new Object_();

    object.types.addValue(type);
    object.createFeatureValues();
    this.add(object);
}

return object;

```

[5] `remove (in value : ExtensionalValue)`

```

// Remove the given extensional value from this locus.

value.locus = null;

boolean notFound = true;

```

```

int i = 1;
while (notFound & i <= this.extensionalValues.size()) {
    if (this.extensionalValues.getValue(i-1) == value) {
        this.extensionalValues.remove(i-1);
        notFound = false;
    }
    i = i + 1;
}

```

[6] setExecutor (in executor : Executor)

```
// Set the executor for this locus.
```

```
this.executor = executor;
this.executor.locus = this;
```

[7] setFactory (in factory : ExecutionFactory)

```
// Set the factory for this locus.
```

```
this.factory = factory;
this.factory.locus = this;
```

8.2.2.6 SemanticStrategy

The common base class for semantic strategy classes. A semantic strategy class specifies the behavior to be used at a specific semantic variatio point.

Generalizations

None

Attributes

None

Associations

None

Operations

[1] getName () : String

Return the name of this strategy, as defined for the semantic variation point to which the strategy applies.

8.2.2.7 SemanticVisitor

The common base class for semantic visitor classes.

Generalizations

None

Attributes

None

Associations

None

Operations

```
[1] _beginIsolation ()
```

```
Debug.println("[_beginIsolation] Begin isolation.");
```

```
[2] _endIsolation ()
```

```
Debug.println("[_endIsolation] End isolation.");
```

8.3 Classes

8.3.1 Overview

Within the Classes package, all the UML constructs included in fUML are from the Kernel package (see Subclause 7.2.2). Figure 52 shows the dependencies of the semantics Kernel packages on other packages.

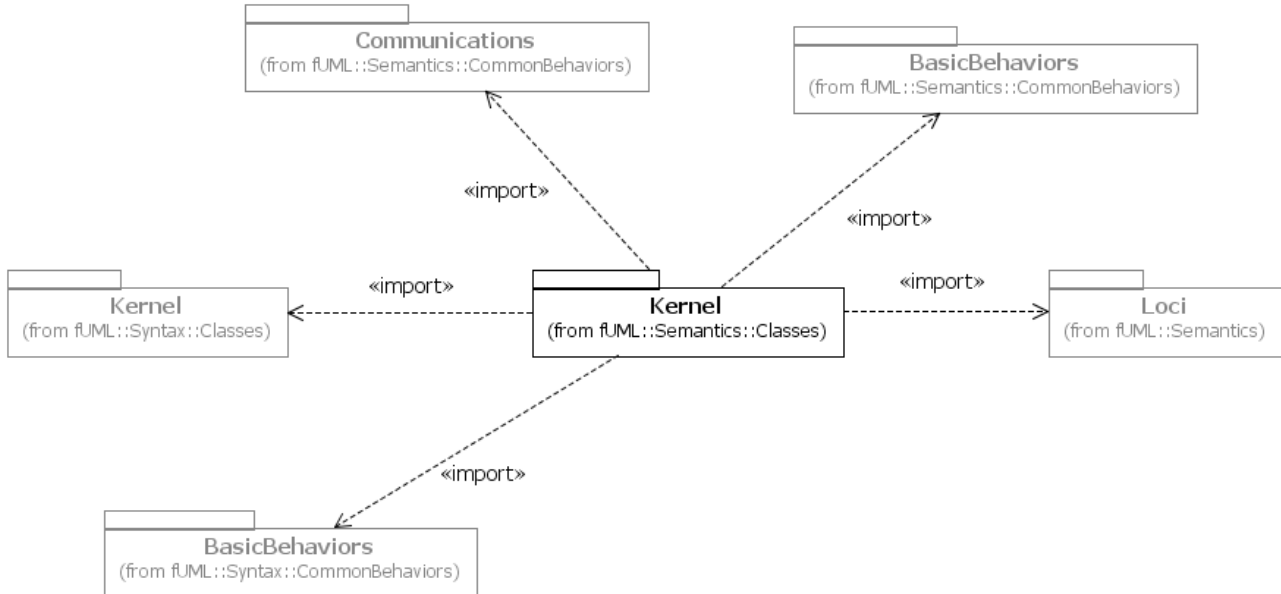


Figure 53 - Classes Semantics Packages

8.3.2 Kernel

8.3.2.1 Overview

Values

As discussed in Subclause 6.2, a model is interpreted to make statements about some *semantic domain*. First order statements are actually made on *instances* in the semantics domain. The *structural semantics* of UML provides the denotational mapping of appropriate UML model elements to such semantic instances.

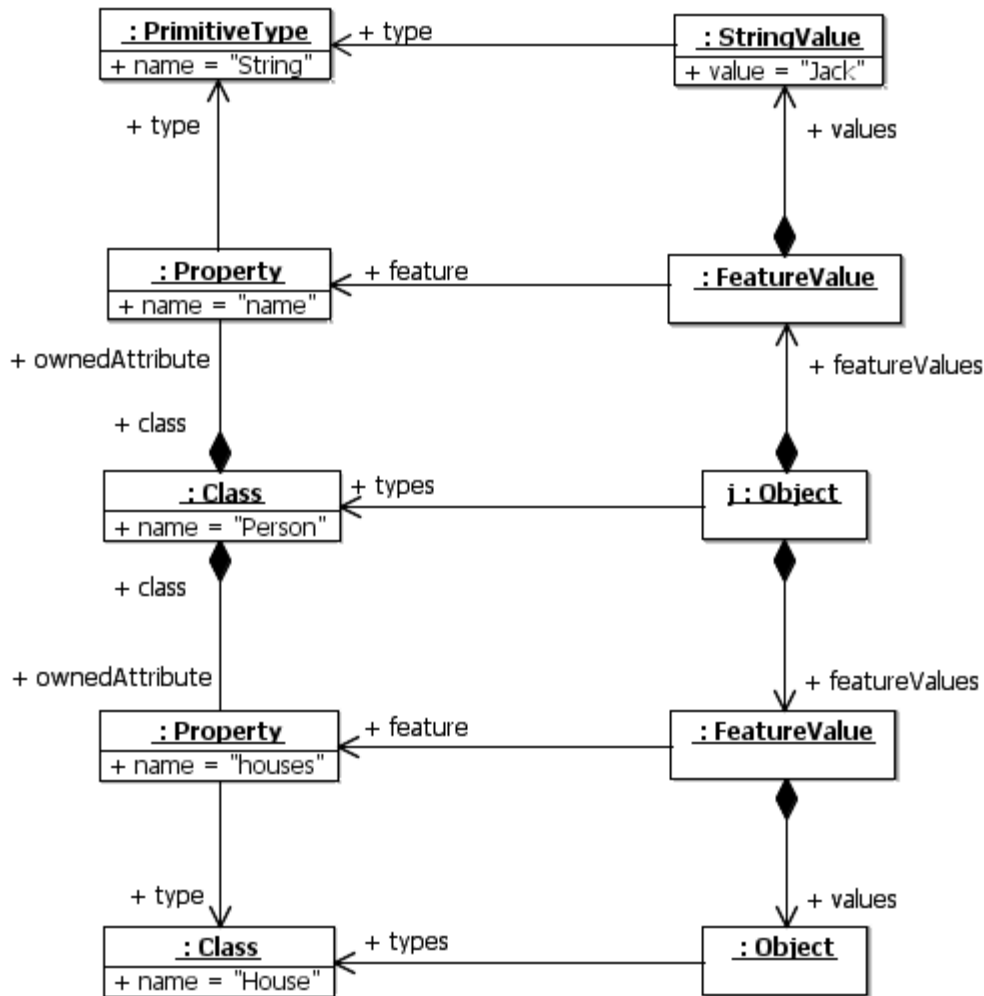


Figure 55 - Semantic Interpretation of a Simple Instance Model

Extensional values

Every classifier has an *intension*, that is, the set of all possible values that may have that classifier as a type. Other than for enumerations, for which this set is explicitly specified, the intension of a classifier is conceptually infinite (though, of course, actually finite in any real implementation). In fact, one semantic mapping for a classifier is to have it specifically *denote* its intension.

However, there is a fundamental difference between the intensions of data types and classes. The possible values of a data type are essentially fully determined by the definition of the type. For example, the intension of the primitive type Integer is the mathematical set of integers. While this set is infinite, it is completely specified by its mathematical definition. One cannot “create” a “new” instance of Integer that does not denote an integer value already in the set. In some sense, all the possible instances of Integer are considered to already exist, even though, of course, only a small finite subset of them will be denoted in any given model.

The UML syntax highlights this difference for primitive types by providing distinguished *literal* specifications to denote primitive values, rather than using *instance* specifications. However, the semantic difference also exists for structured

data types (that is a data type that is not a primitive or an enumeration, but which has structural features), even though the same UML syntax is used for denoting instances of structured data types and classes.

An instance value of a structured data type maps to a *data value*, as shown in Figure 57. A data value is a kind of structured value, which associates values with the attributes of the data type. The equality of two data values of the same type is determined by the equality of the values of their attributes. They have no identity separately from their value and are, therefore, semantically akin to non-structured data types.

An instance of a class, on the other hand, is an *object*. Unlike a data value, an object has an identity separate from the values of its attributes. Two objects can have the same values for their attributes, and still be distinct objects. Further, the values of the attributes of an object may change over time, independently of how the attribute values of any other object change.

Actually, an instance value of a class does not map directly to an object but, rather, to a *reference* to an object, as shown in Figure 57. This is because an object, once created, has an independent existence and there may be multiple references to that same object. Changes to the object made via one reference are visible via any other reference.

Objects are thus examples of *extensional values*, as are links, which are instances of associations. In addition to their intension, classes and associations have an *extension*, that is, the set of instances of the class or association that exist at any one point in time. This leads, however, to the issue of managing the scope of such extension sets.

This is particularly important for associations. There are actually no actions that return links as values. (Foundational UML does not contain association actions, so it does not provide semantics for link objects.) Rather, a read link action actually queries the current extension of the association for matching links.

But, pragmatically, how does one bound what is to be included in the actual extension set? Certainly links created during the execution of a model should be accessible later in the execution of that model. But what about other executions of the same model, perhaps widely physically distributed? What about other models that may reuse the same association?

In order to deal with this issue, the fUML semantic model introduces the concept of a *locus*, as shown in Figure 57 and described in Subclause 8.2. An existential value is created at a specific such locus and remains there during its life. The *extent* of a class or association is its extension *at a specific locus*.

For executions at a certain locus, the extension of a class or association is always limited to the extent at that locus. Therefore, a read link action will only query the specified association extent at the locus at which it is executing. Similarly, a read extent action will only return (references to) the set of currently extant objects in the specified class extent at the locus at which it is executing.

Evaluations

An evaluation is a kind of visitor class used to evaluate value specifications (see Subclause 8.2 for a general discussion of visitor classes). As shown in Figure 58, there is an evaluation class corresponding to each concrete subclass of the abstract syntax metaclass ValueSpecification.

To evaluate a value specification, the executor uses the execution factory to create an instance of the appropriate evaluation class (see Subclause 8.2), with a reference to the representation of the value specification to be evaluated. Evaluation is actually carried out by calling the evaluate method on the evaluation object, which then returns a value of the appropriate type.

An evaluation object is also created with a reference to the execution locus. This provides access to the execution factory at the locus in order to obtain the proper primitive type to use for the value resulting from a literal evaluation.

Polymorphic Operation Dispatching

Operations in UML are potentially polymorphic—that is, there may be multiple methods for any one operation. *Polymorphic operation dispatching* is the determination of which method to use for a given invocation of the operation, depending on the context and target of the invocation. The specification for this determination is provided in the execution model by the *dispatch* operation of the Object class, as shown in Figure 57 (the semantics of operation dispatching is further discussed in relation to the call operation action in Subclause 8.6.2).

However, the exact behavior to be specified for polymorphic operation dispatching is a semantic variation point in fUML. (See Clause 2.3 for a full discussion of semantic variation within fUML.) Following the general approach of using the Strategy Pattern to model semantic variation points (see Clause 8.2.1), the variability of operation dispatching is captured by using strategy classes for the `Object::dispatch` operation. `DispatchStrategy` provides the abstract base class for this type of strategy (see Figure 57). The default dispatching behavior is given by the concrete class `RedefinitionBasedDispatchStrategy`.

The default redefinition based dispatch strategy requires that every concrete fUML operation has an associated method. In order to override an operation inherited from a superclass, the subclass must declare the redefining operation as a redefinition of the inherited operation. This is interpreted as meaning that any calls made to the original superclass operation, for objects that are instances of the subclass or any of its descendants, will be dispatched to the method of the redefining operation, rather than to the method of the original operation.

A conforming execution tool may define an alternative rule for how this dispatching is to take place by defining a new `DispatchStrategy` subclass specifying whatever rule is desired. An instance of this alternate strategy must then be registered with the execution factory at a given locus, rather than the default strategy.

To simplify the specification of new concrete dispatch strategy subclasses, the abstract base `DispatchStrategy` class provides a generally applicable method for its dispatch operation using an abstract *getMethod* operation. The `getMethod` operation takes the same arguments as `dispatch` (the target object and the operation to be dispatched) and is required to return the operation method chosen to be executed for the operation by a specific dispatch strategy. The `dispatch` operation then creates an execution for the chosen method *at the locus of the target object on which the operation is being invoked* and returns that execution object.

The UML Superstructure allows data types to own operations, as well as classes. However, data types are not behavior classifiers, so they cannot own behaviors to be used as methods for their operations. Since fUML requires that every non-abstract operation have a method, it would thus only be possible to have abstract operations on data types, which would not be very useful. Therefore, data types are prohibited from having operations at all in fUML (see the constraint in Subclause 7.2.2.2.6).

It is thus not possible to use owned operations to define the primitive behaviors of a data type. Instead, the Foundational Model Library defines a set of primitive function behaviors that take values of primitive data types as their arguments. Rather than being operations of the primitive types, these primitive behaviors are grouped into library packages corresponding to the appropriate types (e.g., `IntegerFunctions` for type `Integer`, etc.). Implementations for these behaviors are then registered with the execution factory as part of the configuration of the execution environment (see Subclause 8.2.1).

Not being operations, such primitive behaviors are, of course, *not* polymorphic. They are called using call behavior actions, rather than call operation actions.

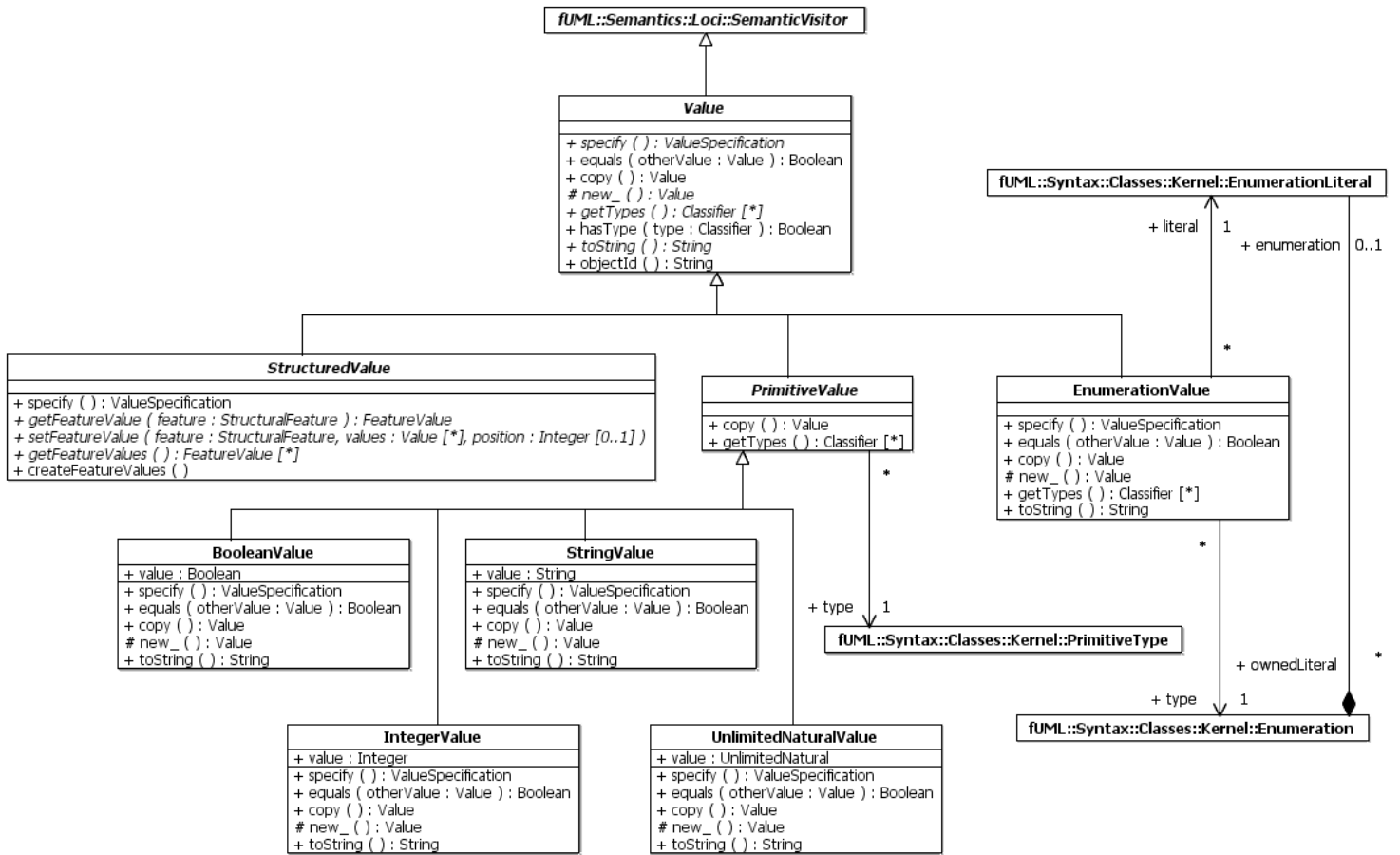


Figure 56 - Values

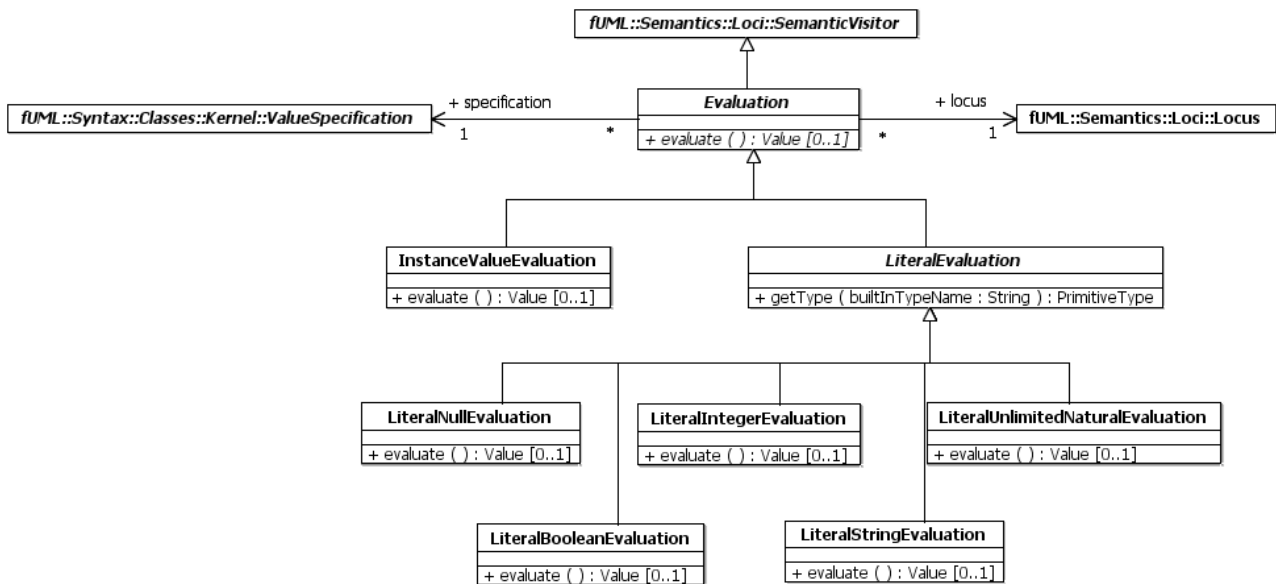


Figure 58 - Evaluations

8.3.2.2 Class Descriptions

8.3.2.2.1 BooleanValue

A boolean value is a primitive value whose type is Boolean.

Generalizations

- [PrimitiveValue](#)

Attributes

- value : Boolean
The actual Boolean value.

Associations

None

Operations

[1] copy () : Value

```

// Create a new boolean value with the same value as this boolean value.
BooleanValue newValue = (BooleanValue) (super.copy());
newValue.value = this.value;
return newValue;
  
```

[2] equals (in otherValue : Value) : Boolean

```

// Test if this boolean value is equal to the otherValue.
// To be equal, the otherValue must have the same value as this boolean value.
boolean isEqual = false;
  
```

```

if (otherValue instanceof BooleanValue) {
    isEqual = ((BooleanValue)otherValue).value == this.value;
}

return isEqual;

```

[3] new_(): Value

```

// Return a new boolean value with no value.

return new BooleanValue();

```

[4] specify(): ValueSpecification

```

// Return a literal boolean with the value of this boolean value.

LiteralBoolean literal = new LiteralBoolean();

literal.type = this.type;
literal.value = this.value;

return literal;

```

[5] toString(): String

```

String stringValue = "false";

if (this.value) {
    stringValue = "true";
}

return stringValue;

```

8.3.2.2.2 CompoundValue

A compound value is a structured value with by-value semantics. Values are associated with each structural feature specified by the type(s) of the compound value.

Generalizations

- [StructuredValue](#)

Attributes

None

Associations

- featureValues : FeatureValue [0..*]

Operations

[1] copy(): Value

```

// Create a new data value with the same featureValues as this data value.

```

```

CompoundValue newValue = (CompoundValue)(super.copy());

FeatureValueList featureValues = this.featureValues;
for (int i = 0; i < featureValues.size(); i++) {
    FeatureValue featureValue = featureValues.getValue(i);
    newValue.featureValues.addValue(featureValue.copy());
}

return newValue;

```

[2] equals (in otherValue : Value) : Boolean

```

// Test if this data value is equal to the otherValue.
// To be equal, the otherValue must also be a compound value with the same types and equal
values for each feature.

// Debug.println("[equals] othervalue instanceof CompoundValue = " + (otherValue
instanceof CompoundValue));
// Debug.println("[equals] super.equals(otherValue) = " + super.equals(otherValue));

boolean isEqual = otherValue instanceof CompoundValue;

if (isEqual) {

    CompoundValue otherCompoundValue = (CompoundValue)otherValue;
    // Debug.println("[equals] " + this.featureValues.size() + " feature(s).");

    isEqual = super.equals(otherValue) & otherCompoundValue.featureValues.size() ==
this.featureValues.size();

    int i = 1;
    while (isEqual & i <= this.featureValues.size()) {
        FeatureValue thisFeatureValue = this.featureValues.getValue(i-1);

        boolean matched = false;
        int j = 1;
        while (!matched & j <= otherCompoundValue.featureValues.size()) {
            FeatureValue otherFeatureValue = otherCompoundValue.featureValues.getValue(j-
1);

            if (thisFeatureValue.feature == otherFeatureValue.feature) {
                matched = thisFeatureValue.hasEqualValues(otherFeatureValue);
            }
            j = j + 1;
        }

        isEqual = matched;
        i = i + 1;
    }
}

return isEqual;

```

[3] getFeatureValue (in feature : StructuralFeature) : FeatureValue

```

// Get the value(s) of the member of featureValues for the given feature.

FeatureValue featureValue = null;
int i = 1;
while (featureValue == null & i <= this.featureValues.size()) {
    if (this.featureValues.getValue(i-1).feature == feature) {
        featureValue = this.featureValues.getValue(i-1);
    }
}

```

```

    i = i + 1;
}

return featureValue;

```

[4] getFeatureValues () : FeatureValue [0..*]

```

// Return the feature values for this compound value.

return this.featureValues;

```

[5] removeFeatureValues (in classifier : Classifier)

```

// Remove all feature values for features whose type is the given classifier.

int i = 1;
while (i <= this.featureValues.size()) {
    if (this.featureValues.getValue(i-1).feature.typedElement.type == classifier) {
        this.featureValues.remove(i-1);
    }
    else {
        i = i + 1;
    }
}

```

[6] setFeatureValue (in feature : StructuralFeature, in values : Value [0..*], in position : Integer [0..1])

```

// Set the value(s) of the member of featureValues for the given feature.

FeatureValue featureValue = this.getFeatureValue(feature);

if (featureValue == null) {
    featureValue = new FeatureValue();
    this.featureValues.addValue(featureValue);
}

featureValue.feature = feature;
featureValue.values = values;
featureValue.position = position;

```

[7] toString () : String

```

String buffer = "(" + this.objectId() + ":";

ClassifierList types = this.getTypes();

int i = 1;
while (i <= types.size()) {
    buffer = buffer + " " + types.getValue(i-1).name;
    i = i + 1;
}

int k = 1;
while (k <= this.featureValues.size()) {
    FeatureValue featureValue = this.featureValues.getValue(k-1);
    buffer = buffer + "\n\t\t" + featureValue.feature.name + "[" + featureValue.position

```

```

+ "]" =";

    int j = 1;
    while (j <= featureValue.values.size()) {
        buffer = buffer + " " + featureValue.values.getValue(j-1).toString();
        j = j + 1;
    }

    k = k + 1;
}

return buffer + " ";

```

8.3.2.2.3 DataValue

A data value is a compound value whose (single) type is a data type other than a primitive type or an enumeration.

Generalizations

- [CompoundValue](#)

Attributes

None

Associations

- type : DataType
The type of this data value. This must not be a primitive or an enumeration.

Operations

[1] copy () : Value

```

// Create a new data value with the same type and feature values as this data value.
DataValue newValue = (DataValue) (super.copy());
newValue.type = this.type;
return newValue;

```

[2] getTypes () : Classifier [0..*]

```

// Return the single type of this data value.
ClassifierList types = new ClassifierList();
types.addValue(this.type);

return types;

```

[3] new_ () : Value

```

// Create a new data value with no type or feature values.
return new DataValue();

```

8.3.2.2.4 DispatchStrategy

A dispatch strategy is a semantic strategy for the polymorphic dispatching of an operation to an execution of a method for that operation.

Generalizations

- [SemanticStrategy](#)

Attributes

None

Associations

None

Operations

[1] `dispatch (in object : Object, in operation : Operation) : Execution`

```
// Get the behavior for the given operation as determined by the type(s) of the given
object, compile the behavior at the locus of the object, and return the resulting
execution object.
```

```
return object.locus.factory.createExecution(this.getMethod(object,operation), object);
```

[2] `getMethod (in object : Object, in operation : Operation) : Behavior`

```
// Get the method that corresponds to the given operation for the given object.
```

[3] `getName () : String`

```
// Dispatch strategies are always named "dispatch".
```

```
return "dispatch";
```

8.3.2.2.5 EnumerationValue

An enumeration value is a value whose (single) type is an enumeration. Its literal must be an owned literal of its type.

Generalizations

- [Value](#)

Attributes

None

Associations

- `literal : EnumerationLiteral`
The literal value of this enumeration value.
- `type : Enumeration`

Operations

[1] copy () : Value

```
// Create a new enumeration value with the same literal as this enumeration value.
EnumerationValue newValue = (EnumerationValue) (super.copy());

newValue.type = this.type;
newValue.literal = this.literal;

return newValue;
```

[2] equals (in otherValue : Value) : Boolean

```
// Test if this enumeration value is equal to the otherValue.
// To be equal, the otherValue must also be an enumeration value with the same literal as
this enumeration value.

boolean isEqual = false;
if (otherValue instanceof EnumerationValue) {
    isEqual = ((EnumerationValue)otherValue).literal == this.literal;
}

return isEqual;
```

[3] getTypes () : Classifier [0..*]

```
// Return the single type of this enumeration value.

ClassifierList types = new ClassifierList();
types.addValue(this.type);

return types;
```

[4] new_ () : Value

```
// Create a new enumeration value with no literal.

return new EnumerationValue();
```

[5] specify () : ValueSpecification

```
// Return an instance value with literal as the instance.

InstanceValue instanceValue = new InstanceValue();
InstanceSpecification instance = new InstanceSpecification();

instanceValue.type = this.type;
instanceValue.instance = this.literal;

return instanceValue;
```

[6] toString () : String

```
return literal.name;
```


8.3.2.2.6 Evaluation

An evaluation is used to evaluate a value specification to produce a value.

Generalizations

- [SemanticVisitor](#)

Attributes

None

Associations

- locus : Locus
The locus at which this evaluation is taking place.
- specification : ValueSpecification
The value specification to be evaluated.

Operations

[1] evaluate () : Value [0..1]

Evaluate the specification, returning the resulting value.

8.3.2.2.7 ExtensionalValue

An extensional value is a data value that is part of the extent of some classifier at a specific locus.

Generalizations

- [CompoundValue](#)

Attributes

None

Associations

- locus : Locus [0..1]
The locus of the extent of which this value is a member. (If the value has been destroyed, it has no locus.)

Operations

[1] copy () : Value

```
// Create a new extensional value with the same feature values at the same locus as this one.
```

```
ExtensionalValue newValue = (ExtensionalValue) (super.copy());
```

```
if (this.locus != null) {  
    this.locus.add(newValue);  
}
```

```
return newValue;
```

[2] destroy ()

```
// Remove this value from its locus (if it has not already been destroyed).
```

```

if (this.locus != null) {
    this.locus.remove(this);
}

```

8.3.2.2.8 FeatureValue

A feature value gives the value(s) that a single structural feature has in a specific structured value.

Generalizations

None

Attributes

- position : Integer [0..1]
The position of this feature value in a set of ordered values for a feature of an association.
[This is only relevant if the feature value is for a link and the feature is ordered.]

Associations

- feature : StructuralFeature
The structural feature being given value(s).
- values : Value [0..*]
The values of for the feature. Zero or more values are possible, as constrained by the multiplicity of the feature.

Operations

[1] copy () : FeatureValue

```

// Create a copy of this feature value.
FeatureValue newValue = new FeatureValue();

newValue.feature = this.feature;
newValue.position = this.position;

ValueList values = this.values;
for (int i = 0; i < values.size(); i++) {
    Value value = values.getValue(i);
    newValue.values.addValue(value.copy());
}

return newValue;

```

[2] hasEqualValues (in other : FeatureValue) : Boolean

```

// Determine if this feature value has an equal set of values as another feature value.
// If the feature is ordered, then the values also have to be in the same order.

boolean equal = true;

if (this.values.size() != other.values.size()) {
    equal = false;
} else {

    // Debug.println("[hasEqualValues] feature = " + this.feature.name + ", " +
this.values.size() + " value(s).");

```

```

if (this.feature.multiplicityElement.isOrdered) {
    int i = 1;
    while (equal & i <= this.values.size()) {
        equal = this.values.getValue(i-1).equals(other.values.getValue(i-1));
        i = i + 1;
    }
} else {
    // Note: otherFeatureValues is used here solely as a holder for a copy of the list
of other values,
    // since the Java to UML mapping conventions do not allow "remove" on a local list
variable.
    FeatureValue otherFeatureValues = new FeatureValue();
    ValueList values = other.values;
    for (int i=0; i < values.size(); i++) {
        Value value = values.getValue(i);
        otherFeatureValues.values.addValue(value);
    }

    int i = 1;
    while (equal & i <= this.values.size()) {
        // Debug.println("[hasEqualValues] This value [" + (i-1) + "] = " +
this.values.getValue(i-1));

        boolean matched = false;
        int j = 1;
        while (!matched & j <= otherFeatureValues.values.size()) {
            if (this.values.getValue(i-
1).equals(otherFeatureValues.values.getValue(j-1))) {
                // Debug.println("[hasEqualValues] Other value [" + (j-1) + "] = " +
otherFeatureValues.values.getValue(j-1));
                matched = true;
                otherFeatureValues.values.remove(j-1);
            }
            j = j + 1;
        }

        equal = matched;
        i = i + 1;
    }
}
}

return equal;

```

8.3.2.2.9 InstanceValueEvaluation

An instance value evaluation is an evaluation whose specification is an instance value.

Generalizations

- [Evaluation](#)

Attributes

None

Associations

None

Operations

[1] evaluate () : Value [0..1]

```
// If the instance specification is for an enumeration, then return the identified
enumeration literal.
// If the instance specification is for a data type (but not a primitive value or an
enumeration), then create a data value of the given data type.
// If the instance specification is for an object, then create an object at the current
locus with the specified types.
// Set each feature of the created value to the result of evaluating the value
specifications for the specified slot for the feature.

// Debug.println("[evaluate] InstanceValueEvaluation...");

InstanceSpecification instance = ((InstanceValue)this.specification).instance;
ClassifierList types = instance.classifier;
Classifier myType = types.getValue(0);

Debug.println("[evaluate] type = " + myType.name);

Value value;
if (instance instanceof EnumerationLiteral) {
    // Debug.println("[evaluate] Type is an enumeration.");
    EnumerationValue enumerationValue = new EnumerationValue();
    enumerationValue.type = (Enumeration)myType;
    enumerationValue.literal = (EnumerationLiteral)instance;
    value = enumerationValue;
}
else {

    StructuredValue structuredValue = null;

    if (myType instanceof DataType) {
        // Debug.println("[evaluate] Type is a data type.");
        DataValue dataValue = new DataValue();
        dataValue.type = (DataType)myType;
        structuredValue = dataValue;
    }
    else {
        Object_ object = null;
        if (myType instanceof Behavior) {
            // Debug.println("[evaluate] Type is a behavior.");
            object = this.locus.factory.createExecution((Behavior)myType, null);
        }
        else {
            // Debug.println("[evaluate] Type is a class.");
            object = new Object_();
            for (int i = 0; i < types.size(); i++) {
                Classifier type = types.getValue(i);
                object.types.addValue((Class_)type);
            }
        }

        this.locus.add(object);

        Reference reference = new Reference();
        reference.referent = object;
        structuredValue = reference;
    }

    structuredValue.createFeatureValues();
}
```

```

// Debug.println("[evaluate] " + instance.slot.size() + " slot(s).");

SlotList instanceSlots = instance.slot;
for (int i = 0; i < instanceSlots.size(); i++) {
    Slot slot = instanceSlots.getValue(i);
    ValueList values = new ValueList();

    // Debug.println("[evaluate] feature = " + slot.definingFeature.name + ", " +
slot.value.size() + " value(s).");
    ValueSpecificationList slotValues = slot.value;
    for (int j = 0; j < slotValues.size(); j++) {
        ValueSpecification slotValue = slotValues.getValue(j);
        // Debug.println("[evaluate] Value = " + slotValue.getClass().getName());
        values.addValue(this.locus.executor.evaluate(slotValue));
    }
    structuredValue.setFeatureValue(slot.definingFeature, values, 0);
}

value = structuredValue;
}

return value;

```

8.3.2.2.10 IntegerValue

An integer value is a primitive value whose type is Integer.

Generalizations

- [PrimitiveValue](#)

Attributes

- value : Integer
The actual Integer value.

Associations

None

Operations

[1] copy () : Value

```

// Create a new integer value with the same value as this integer value.

IntegerValue newValue = (IntegerValue)(super.copy());

newValue.value = this.value;
return newValue;

```

[2] equals (in otherValue : Value) : Boolean

```

// Test if this integer value is equal to the otherValue.
// To be equal, the otherValue must have the same value as this integer value.

boolean isEqual = false;
if (otherValue instanceof IntegerValue) {
    isEqual = ((IntegerValue)otherValue).value == this.value;
}

```

```
return isEqual;
```

[3] new_(): Value

```
// Create a new integer value with no value.
```

```
return new IntegerValue();
```

[4] specify(): ValueSpecification

```
// Return a literal integer with the value of this integer value.
```

```
LiteralInteger literal = new LiteralInteger();
```

```
literal.type = this.type;  
literal.value = this.value;
```

```
return literal;
```

[5] toString(): String

```
String stringValue = "";
```

```
if (this.value == 0) {  
    stringValue = "0";  
} else {  
    int positiveValue = this.value;  
  
    if (positiveValue < 0) {  
        positiveValue = -positiveValue;  
    }  
  
    do {  
        int digit = positiveValue % 10;  
  
        if (digit == 0) {  
            stringValue = "0" + stringValue;  
        } else if (digit == 1) {  
            stringValue = "1" + stringValue;  
        } else if (digit == 2) {  
            stringValue = "2" + stringValue;  
        } else if (digit == 3) {  
            stringValue = "3" + stringValue;  
        } else if (digit == 4) {  
            stringValue = "4" + stringValue;  
        } else if (digit == 5) {  
            stringValue = "5" + stringValue;  
        } else if (digit == 6) {  
            stringValue = "6" + stringValue;  
        } else if (digit == 7) {  
            stringValue = "7" + stringValue;  
        } else if (digit == 8) {  
            stringValue = "8" + stringValue;  
        } else if (digit == 9) {  
            stringValue = "9" + stringValue;  
        }  
  
        positiveValue = positiveValue / 10;  
    } while (positiveValue > 0);  
  
    if (this.value < 0) {  
        stringValue = "-" + stringValue;  
    }  
}
```

```

    }
}
return stringValue;

```

8.3.2.2.11 Link

A link is an extensional value whose (single) type is an association. (However, if the link has been destroyed, then it has no type.)

A link must at have most one feature value for each structural feature owned by its type.

Generalizations

- [ExtensionalValue](#)

Attributes

None

Associations

- type : Association [0..1]
The type of this link.

Operations

[1] copy () : Value

```

// Create a new link with the same type, locus and feature values as this link.
Link newValue = (Link) (super.copy());
newValue.type = this.type;
return newValue;

```

[2] destroy ()

```

// Remove the type of this link and destroy it.
this.type = null;
super.destroy();

```

[3] getTypes () : Classifier [0..*]

```

// Return the single type of this link (if any).
ClassifierList types = null;

if (this.type == null) {
    types = new ClassifierList();
} else {
    types = new ClassifierList();
    types.addValue(this.type);
}

return types;

```

[4] new_ () : Value

```
// Create a new link with no type or properties.  
return new Link();
```

[5] setFeatureValue (in feature : StructuralFeature, in values : Value [0..*], in position : Integer [0..1])

```
// If a position is given, before setting the given feature value, adjust the position  
values of the ends of other links for this same feature.
```

```
if (position > 0) {  
    ExtensionalValueList extent = this.locus.getExtent(this.type);  
    for (int i = 0; i < extent.size(); i++) {  
        ExtensionalValue value = extent.getValue(i);  
        FeatureValue featureValue = value.getFeatureValue(feature);  
        if (featureValue.position >= position) {  
            featureValue.position = featureValue.position + 1;  
        }  
    }  
}  
super.setFeatureValue(feature, values, position);
```

8.3.2.2.12 LiteralBooleanEvaluation

A boolean evaluation is an evaluation whose specification is a literal boolean.

Generalizations

- [LiteralEvaluation](#)

Attributes

None

Associations

None

Operations

[1] evaluate () : Value [0..1]

```
// Evaluate a literal boolean, producing a boolean value.  
  
LiteralBoolean literal = (LiteralBoolean)specification;  
BooleanValue booleanValue = new BooleanValue();  
booleanValue.type = this.getType("Boolean");  
booleanValue.value = literal.value;  
  
return booleanValue;
```

8.3.2.2.13 LiteralEvaluation

A literal evaluation is an evaluation whose specification is a Literal Specification.

Generalizations

- [Evaluation](#)

Attributes

None

Associations

None

Operations

[1] `getType (in builtInTypeName : String) : PrimitiveType`

```
// Get the type of the specification. If that is null, then use the built-in type of the given name.
```

```
PrimitiveType type = (PrimitiveType)(this.specification.type);  
  
if (type == null) {  
    type = this.locus.factory.getBuiltInType(builtInTypeName);  
}  
  
return type;
```

8.3.2.2.14 LiteralIntegerEvaluation

A literal integer evaluation is an evaluation whose specification is a literal integer.

Generalizations

- [LiteralEvaluation](#)

Attributes

None

Associations

None

Operations

[1] `evaluate () : Value [0..1]`

```
// Evaluate a literal integer, producing an integer value.
```

```
LiteralInteger literal = (LiteralInteger)specification;  
IntegerValue integerValue = new IntegerValue();  
integerValue.type = this.getType("Integer");  
integerValue.value = literal.value;  
  
return integerValue;
```

8.3.2.2.15 LiteralNullEvaluation

A literal null evaluation is an evaluation whose specification is a literal null.

Generalizations

- [LiteralEvaluation](#)

Attributes

None

Associations

None

Operations

[1] evaluate () : Value [0..1]

```
// Evaluate a literal null, returning nothing (since a null represents an "absence of any value").
```

```
return null;
```

8.3.2.2.16 LiteralStringEvaluation

A literal string evaluation is an evaluation whose specification is a literal string.

Generalizations

- [LiteralEvaluation](#)

Attributes

None

Associations

None

Operations

[1] evaluate () : Value [0..1]

```
// Evaluate a literal string, producing a string value.
```

```
LiteralString literal = (LiteralString)specification;  
StringValue stringValue = new StringValue();  
stringValue.type = this.getType("String");  
stringValue.value = literal.value;
```

```
return stringValue;
```

8.3.2.2.17 LiteralUnlimitedNaturalEvaluation

A literal unlimited natural evaluation is an evaluation whose specification is a literal unlimited natural.

Generalizations

- [LiteralEvaluation](#)

Attributes

None

Associations

None

Operations

[1] evaluate () : Value [0..1]

```
// Evaluate a literal unlimited natural producing an unlimited natural value.

LiteralUnlimitedNatural literal = (LiteralUnlimitedNatural)specification;
UnlimitedNaturalValue unlimitedNaturalValue = new UnlimitedNaturalValue();
unlimitedNaturalValue.type = this.getType("UnlimitedNatural");
unlimitedNaturalValue.value = literal.value;

return unlimitedNaturalValue;
```

8.3.2.2.18 Object

An object is an extensional value that may have multiple types, all of which must be classes. (Note that a destroyed object has no types.)

An object has a unique identity. Usually, references to objects are manipulated, rather than the objects themselves, and there may be multiple references to the same object.

If an object is active, it has an object activation that handle the execution of its classifier behavior(s).

Generalizations

- [ExtensionalValue](#)

Attributes

None

Associations

- objectActivation : ObjectActivation
The object activation handling the active behavior of this object.
- types : Class
The classes under which this object is currently classified. (A destroyed object has no types.)

Operations

[1] copy () : Value

```
// Create a new object that is a copy of this object at the same locus as this object.
// However, the new object will NOT have any object activation (i.e, its classifier
behaviors will not be started).
```

```
Object_ newObject = (Object_)(super.copy());

Class_List types = this.types;
for (int i = 0; i < types.size(); i++) {
    Class_ type = types.getValue(i);
    newObject.types.addValue(type);
}

return newObject;
```

[2] destroy ()

```
// Stop the object activation (if any), clear all types and destroy the object as an
```

```

extensional value.

Debug.println("[destroy] object = " + this.objectId());

if (this.objectActivation != null) {
    this.objectActivation.stop();
    this.objectActivation = null;
}

this.types.clear();
super.destroy();

```

[3] dispatch (in operation : Operation) : Execution

```

// Dispatch the given operation to a method execution, using a dispatch strategy.

return ((DispatchStrategy)this.locus.factory.getStrategy("dispatch")).dispatch(this,
operation);

```

[4] getTypes () : Classifier [0..*]

```

// Return the types of this object.

ClassifierList types = new ClassifierList();
Class_List myTypes = this.types;
for (int i = 0; i < myTypes.size(); i++) {
    Class_type = myTypes.getValue(i);
    types.addValue(type);
}

return types;

```

[5] new_ () : Value

```

// Create a new object with no type, feature values or locus.

return new Object_();

```

[6] register (in acceptor : EventAcceptor)

```

// Register the given accept event acceptor to wait for a dispatched signal event.

if (this.objectActivation != null) {
    this.objectActivation.register(acceptor);
}

```

[7] send (in signalInstance : SignalInstance)

```

// If the object is active, add the given signal instance to the event pool and signal
that a new signal instance has arrived.

if (this.objectActivation != null) {
    this.objectActivation.send(signalInstance);
}

```

[8] startBehavior (in classifier : Class [0..1], in inputs : ParameterValue [0..*])

```
// Create an object activation for this object (if one does not already exist) and start its behavior(s).
```

```
// Debug.println("[startBehavior] On object...");
```

```
if (this.objectActivation == null) {
    this.objectActivation = new ObjectActivation();
    this.objectActivation.object = this;
}
```

```
// Debug.println("[startBehavior] objectActivation = " + objectActivation);
```

```
this.objectActivation.startBehavior(classifier, inputs);
```

[9] unregister (in acceptor : EventAcceptor)

```
// Remove the given event acceptor for the list of waiting event acceptors.
```

```
if (this.objectActivation != null) {
    this.objectActivation.unregister(acceptor);
}
```

8.3.2.2.19 PrimitiveValue

A primitive value is a value whose (single) type is a primitive type.

Generalizations

- [Value](#)

Attributes

None

Associations

- type : PrimitiveType

Operations

[1] copy () : Value

```
// Create a new value that is equal to this primitive value.
```

```
PrimitiveValue newValue = (PrimitiveValue)(super.copy());
```

```
newValue.type = this.type;
return newValue;
```

[2] getTypes () : Classifier [0..*]

```
// Return the single primitive type of this value.
```

```
ClassifierList types = new ClassifierList();
types.addValue(this.type);
return types;
```

8.3.2.2.20 RedefinitionBasedDispatchStrategy

A redefinition-based dispatch strategy is one that requires:

- each non-abstract operation to have exactly one method
- an overriding subclass operation to explicitly redefine the overridden superclass operation.

Generalizations

- [DispatchStrategy](#)

Attributes

None

Associations

None

Operations

[1] `getMethod (in object : Object, in operation : Operation) : Behavior`

```
// Get the method that corresponds to the given operation for the given object.  
// [If there is more than one type with a method for the operation, then the first one is  
arbitrarily chosen.]
```

```
Behavior method = null;  
int i = 1;  
while (method == null & i <= object.types.size()) {  
    Class_type = object.types.getValue(i-1);  
    NamedElementList members = type.member;  
    int j = 1;  
    while (method == null & j <= members.size()) {  
        NamedElement member = members.getValue(j-1);  
        if (member instanceof Operation) {  
            Operation memberOperation = (Operation)member;  
            if (this.operationsMatch(memberOperation, operation)) {  
                method = memberOperation.method.getValue(0);  
            }  
        }  
        j = j + 1;  
    }  
    i = i + 1;  
}  
  
return method;
```

[2] `operationsMatch (in ownedOperation : Operation, in baseOperation : Operation) : Boolean`

```
// Check if the owned operation is equal to or a redefinition (directly or indirectly) of  
the base operation.
```

```
boolean matches = false;  
if (ownedOperation == baseOperation) {  
    matches = true;  
} else {  
    int i = 1;  
    while (!matches & i <= ownedOperation.redefinedOperation.size()) {  
        matches = this.operationsMatch(ownedOperation.redefinedOperation.getValue(i-1),  
baseOperation);  
        i = i + 1;  
    }  
}
```

```
return matches;
```

8.3.2.2.21 Reference

A reference is an access path to a specific object. There may be multiple references to the same object. As a structured value, the reference acts just the same as its referent in terms of type, features, operations, etc.

Generalizations

- [StructuredValue](#)

Attributes

None

Associations

- referent : Object

Operations

[1] copy () : Value

```
// Create a new reference with the same referent as this reference.
Reference newValue = (Reference) (super.copy());
newValue.referent = this.referent;
return newValue;
```

[2] destroy ()

```
// Destroy the referent.
this.referent.destroy();
```

[3] dispatch (in operation : Operation) : Execution

```
// Dispatch the given operation to the referent object.
return this.referent.dispatch(operation);
```

[4] equals (in otherValue : Value) : Boolean

```
// Test if this reference is equal to the otherValue.
// To be equal, the otherValue must also be a reference, with the same referent as this
reference.

boolean isEqual = false;
if (otherValue instanceof Reference) {
    isEqual = (((Reference)otherValue).referent == this.referent);
}

return isEqual;
```

[5] `getFeatureValue (in feature : StructuralFeature) : FeatureValue`

```
// Get the feature value associated with the given feature in the referent object.  
return this.referent.getFeatureValue(feature);
```

[6] `getFeatureValues () : FeatureValue [0..*]`

```
// Return the feature values of the referent.  
return this.referent.getFeatureValues();
```

[7] `getTypes () : Classifier [0..*]`

```
// Get the types of the referent object.  
return this.referent.getTypes();
```

[8] `new_ () : Value`

```
// Create a new reference with no referent.  
return new Reference();
```

[9] `send (in signalInstance : SignalInstance)`

```
// Send the given signal instance to the referent object.  
this.referent.send(signalInstance);
```

[10] `setFeatureValue (in feature : StructuralFeature, in values : Value [0..*], in position : Integer [0..1])`

```
// Set the values associated with the given feature in the referent object.  
this.referent.setFeatureValue(feature, values, position);
```

[11] `startBehavior (in classifier : Class [0..1], in inputs : ParameterValue [0..*])`

```
// Asynchronously start the behavior of the given classifier for the referent object.  
this.referent.startBehavior(classifier, inputs);
```

[12] `toString () : String`

```
return "Reference to " + this.referent.toString();
```

8.3.2.2.22 StringValue

A string value is a primitive value whose type is String.

Generalizations

- [PrimitiveValue](#)

Attributes

- value : String

Associations

None

Operations

[1] copy () : Value

```
// Create a new string value with the same value as this string value.  
StringValue newValue = (StringValue)(super.copy());  
  
newValue.value = this.value;  
return newValue;
```

[2] equals (in otherValue : Value) : Boolean

```
// Test if this string value is equal to the otherValue.  
// To be equal, the otherValue must have the same value as this string value.  
  
boolean isEqual = false;  
if (otherValue instanceof StringValue) {  
    isEqual = ((StringValue)otherValue).value.equals(this.value);  
}  
  
return isEqual;
```

[3] new_ () : Value

```
// Create a new string value with no value.  
  
return new StringValue();
```

[4] specify () : ValueSpecification

```
// Return a literal string with the value of this string value.  
  
LiteralString literal = new LiteralString();  
  
literal.type = this.type;  
literal.value = this.value;  
  
return literal;
```

[5] toString () : String

```
return value;
```

8.3.2.2.23 StructuredValue

A structured value is a Value whose type has structural features: a data type (but not a primitive type or enumeration), a class or an association.

Generalizations

- [Value](#)

Attributes

None

Associations

None

Operations

[1] createFeatureValues ()

// Create empty feature values for all structural features, direct and inherited, of the types of this structured value.

```
ClassifierList types = this.getTypes();

for (int i = 0; i < types.size(); i++) {
    Classifier type = types.getValue(i);
    NamedElementList members = type.member;

    for (int j = 0; j < members.size(); j++) {
        NamedElement member = members.getValue(j);
        if (member instanceof StructuralFeature) {
            this.setFeatureValue((StructuralFeature)member, new ValueList(), 0);
        }
    }
}
```

[2] getFeatureValue (in feature : StructuralFeature) : FeatureValue

Get the feature value associated with the given feature.
The given feature must be a structural feature of the type of the structured value.

[3] getFeatureValues () : FeatureValue [0..*]

Return the feature values associated with this structural value.

[4] setFeatureValue (in feature : StructuralFeature, in values : Value [0..*], in position : Integer [0..1])

Set the value(s) and, optionally, the position index associated with the given feature.
The given feature must be a structural feature of the type of the structured value.

[5] specify () : ValueSpecification

// Return an instance value that specifies this structured value.

```
// Debug.println("[specify] StructuredValue...");
```

```
InstanceValue instanceValue = new InstanceValue();
InstanceSpecification instance = new InstanceSpecification();
```

```
instanceValue.type = null;
instanceValue.instance = instance;
```

```
instance.classifier = this.getTypes();
```

```

FeatureValueList featureValues = this.getFeatureValues();
// Debug.println("[specify] " + featureValues.size() + " feature(s).");

for (int i = 0; i < featureValues.size(); i++) {
    FeatureValue featureValue = featureValues.getValue(i);

    Slot slot = new Slot();
    slot.definingFeature = featureValue.feature;

    // Debug.println("[specify] feature = " + featureValue.feature.name + ", " +
featureValue.values.size() + " value(s).");

    ValueList values = featureValue.values;
    for (int j = 0; j < values.size(); j++) {
        Value value = values.getValue(j);
        // Debug.println("[specify] value = " + value);
        slot.value.addValue(value.specify());
    }

    instance.slot.addValue(slot);
}

return instanceValue;

```

8.3.2.2.24 UnlimitedNaturalValue

An unlimited natural value is a primitive value whose type is UnlimitedNatural.

Generalizations

- [PrimitiveValue](#)

Attributes

- value : UnlimitedNatural
The actual unlimited natural value.

Associations

None

Operations

[1] copy () : Value

```

// Create a new unlimited natural value with the same value as this value.
UnlimitedNaturalValue newValue = (UnlimitedNaturalValue) (super.copy());

newValue.value = this.value;
return newValue;

```

[2] equals (in otherValue : Value) : Boolean

```

// Test if this unlimited natural value is equal to the otherValue.
// To be equal, the otherValue must have the same value as this unlimited natural value.

boolean isEqual = false;
if (otherValue instanceof UnlimitedNaturalValue) {
    isEqual = ((UnlimitedNaturalValue)otherValue).value == this.value;
}

```

```
}  
return isEqual;
```

[3] new_ () : Value

```
// Create a new unlimited natural value with no value.  
return new UnlimitedNaturalValue();
```

[4] specify () : ValueSpecification

```
// Return a literal unlimited natural with the value of this unlimited natural value.  
  
LiteralUnlimitedNatural literal = new LiteralUnlimitedNatural();  
  
literal.type = this.type;  
literal.value = this.value;  
  
return literal;
```

[5] toString () : String

```
String stringValue = "*";  
  
if (this.value.naturalValue >= 0) {  
    IntegerValue integerValue = new IntegerValue();  
    integerValue.value = this.value.naturalValue;  
    stringValue = integerValue.toString();  
}  
  
return stringValue;
```

8.3.2.2.25 Value

A value is an instance of one or more classifiers, which are its types. A value is always representable using a value specification.

[Note: Value specializes SemanticVisitor to allow the Execution subclass to be a semantic visitor, without requiring multiple generalization of Execution.]

Generalizations

- [SemanticVisitor](#)

Attributes

None

Associations

None

Operations

[1] copy () : Value

```
// Create a new value that is equal to this value.
```

```
// By default, this operation simply creates a new value with empty properties.
// It must be overridden in each Value subclass to do the superclass copy and then
appropriately set properties defined in the subclass.
```

```
return this.new_();
```

[2] equals (in otherValue : Value) : Boolean

```
// Test if this value is equal to otherValue. To be equal, this value must have the same
type as otherValue.
// This operation must be overridden in Value subclasses to check for equality of
properties defined in those subclasses.
```

```
ClassifierList myTypes = this.getTypes();
ClassifierList otherTypes = otherValue.getTypes();

boolean isEqual = true;

// Debug.println("[equals] Value...");
// Debug.println("[equals] this has " + myTypes.size() + "types, other has " +
otherTypes.size() + ".");
if (myTypes.size() != otherTypes.size()) {
    isEqual = false;
} else {
    // Debug.println("[equals] " + myTypes.size() + " type(s).");

    int i = 1;
    while (isEqual & i <= myTypes.size()) {

        // Debug.println("[equals] this type = " + myTypes.getValue(i-1).name);

        boolean matched = false;
        int j = 1;
        while (!matched & j <= otherTypes.size()) {
            // Debug.println("[equals] other type = " + otherTypes.getValue(j-1).name);
            matched = (otherTypes.getValue(j-1) == myTypes.getValue(i-1));
            j = j + 1;
        }

        isEqual = matched;
        i = i + 1;
    }
}

return isEqual;
```

[3] getTypes () : Classifier [0..*]

Gets all the classifiers under which this value is currently classifier.

[4] hasType (in type : Classifier) : Boolean

```
// Check if this object has the given classifier as a type.
```

```
ClassifierList types = this.getTypes();

boolean found = false;
int i = 1;
while (!found & i <= types.size()) {
```

```
        found = (types.getValue(i-1) == type);
        i = i + 1;
    }

    return found;
```

[5] new_() : Value

Create a new value of the same Value subclass as this value, with all properties empty (even if this violates multiplicity constraints). This operation must be defined in each concrete Value subclass to create an instance of that subclass.

[6] objectId() : String

```
// Return an identifier for this object.
// [Non-normative.]

return super.toString();
```

[7] specify() : ValueSpecification

Return a value specification whose evaluation gives a value equal to this value.

[8] toString() : String

Return a string representation of this value.

8.4 Common Behaviors

8.4.1 Overview

As discussed in Subclause 8.3, the structural semantics of UML provide an interpretation for the structural models of instances. Behavioral semantics, on the other hand, provide an interpretation for models of behavior, that is, specifications of how instances change over time. The foundation for the behavioral semantics of fUML is the semantic specification for the CommonBehaviors classes.

The CommonBehavior package is divided into sub-packages in a way that parallels the package structure of the corresponding syntactic CommonBehavior packages. Figure 59 shows the dependencies of these sub-packages.

Subclause 8.4.2 describes the basic model for behavioral execution in fUML. This model is then further elaborated in Subclause 8.5, Activities, and Subclause 8.6, Actions. Subclause 8.4.3 describes the semantic model for active objects and how asynchronous communications between such objects are dispatched to behaviors attached to them.

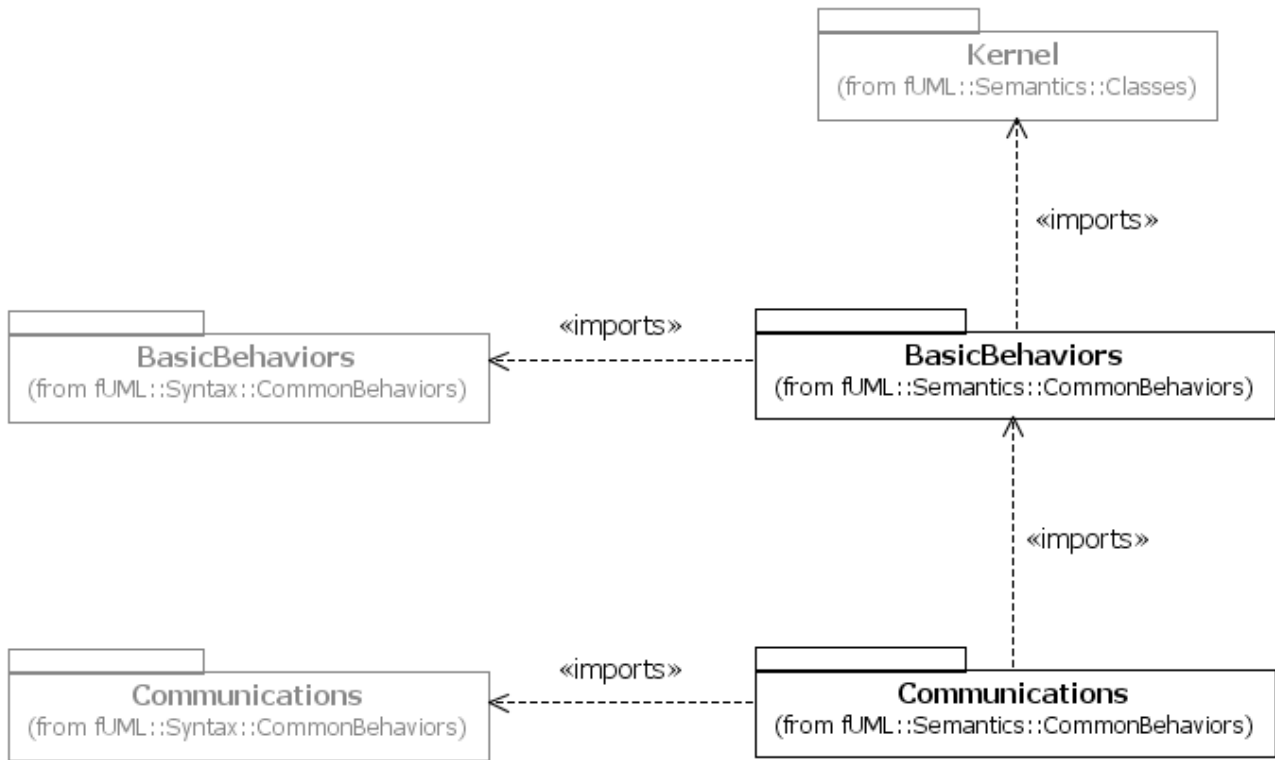


Figure 59 - Common Behaviors Semantics Packages

8.4.2 Basic Behaviors

8.4.2.1 Overview

In UML, a behavior is actually a kind of class, and it may, therefore, have instances. An instance of a behavior is called an execution, as shown in Figure 60. An instance value with a behavior type thus evaluates to an execution object.

The abstract Execution class has two concrete subclasses: OpaqueBehaviorExecution (shown in Figure 60) and ActivityExecution (see Subclause 8.5). These subclasses act as visitor classes for OpaqueBehavior and Activity, respectively (see Subclause 8.2 for a general discussion of visitor classes). (Since function behaviors are basically just opaque behaviors with certain additional restrictions, OpaqueBehaviorExecution also acts as the visitor class for FunctionBehavior.)

To execute a behavior, the executor uses the execution factory to create an instance of the appropriate execution class (see Subclause 8.2). The behavior to be executed becomes the type of the instantiated execution object. The executor then sets the parameter values for the input parameters (i.e., those with direction in and in-out) of the behavior (if any) and calls the execute operation on the execution object.

The Execution::execute operation provides the fundamental specification of behavior in fUML. It acts on the initial set of input parameter values and creates parameter values for any output parameters (i.e., those with direction in-out and out), as specified by the behavior. The execute operation is actually defined as an abstract operation on the Execution class, since its detailed specification depends on the kind of behavior being executed. See Subclause 8.5 for a specific discussion of the execution of activities, which provide the means for user modeling of behavior in fUML.

Note that, as a kind of object itself, an execution is an extensional value. As discussed in Subclause 8.3, this means that any execution effectively takes place at a specific locus. Thus, an object created during an execution will exist at the

locus of the execution. Unless this new object is explicitly destroyed later in the execution, it will continue to exist in the extent of its class at the execution locus, even after the behavior that created it has completed its execution.

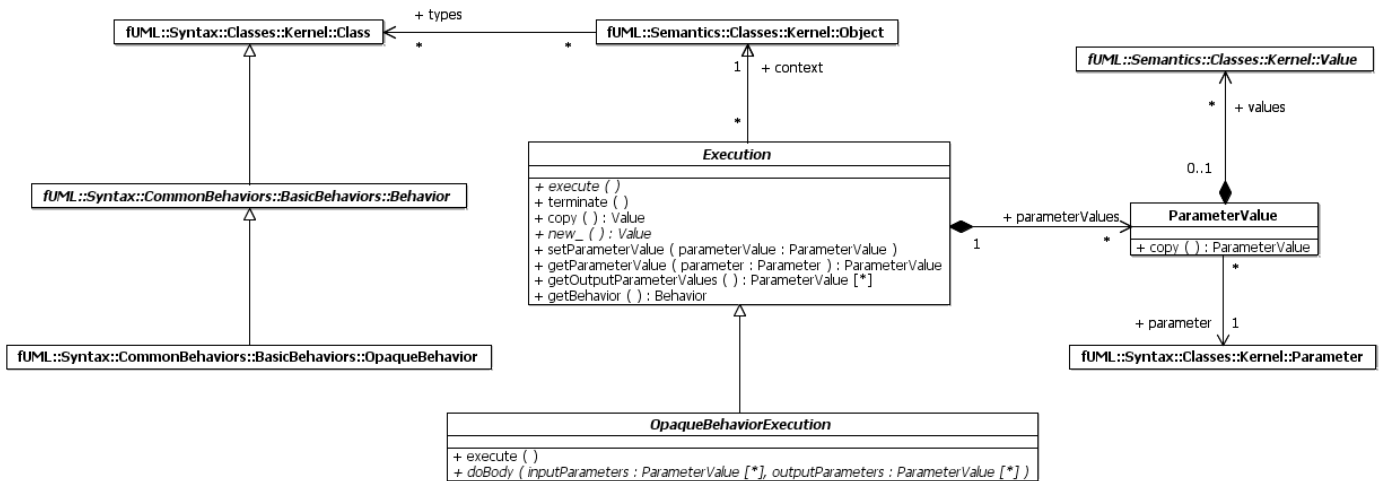


Figure 60 - Executions

8.4.2.2 Class Descriptions

8.4.2.2.1 Execution

An execution is used to execute a specific behavior. Since a behavior is a kind of class, an execution is an object with the behavior as its type.

Generalizations

- [Object](#)

Attributes

None

Associations

- context : Object
The object that provides the context for this execution.
The type of the context of the execution must be the type (behavior) of the execution.
- parameterValues : ParameterValue [0..*]
The parameterValues for this execution. All parameterValues must have a parameter that is a parameter of the type of this execution.
The values of all input (in and in-out) parameters must be set before the execution is executed.

Operations

[1] copy () : Value

```
// Create a new execution that has the same behavior and parameterValues as this execution.
```

```
// Debug.println("[Copy] execution = " + this);
```



```

Execution newValue = (Execution) (super.copy());

newValue.context = this.context;

ParameterValueList parameterValues = this.parameterValues;
for (int i = 0; i < parameterValues.size(); i++) {
    ParameterValue parameterValue = parameterValues.getValue(i);
    newValue.parameterValues.addValue(parameterValue.copy());
}

// Debug.println("[Copy] Done.");

return newValue;

```

[2] execute ()

Execute the behavior given by the type of this execution.
The parameterValues for any input (in or in-out) parameters of the behavior should be set before the execution.
The parameterValues for any output (in-out, out or return) parameters of the behavior will be set by the execution.

[3] getBehavior () : Behavior

```

// Get the behavior that is the type of this execution.

return (Behavior) (this.getTypes().getValue(0));

```

[4] getOutputParameterValues () : ParameterValue [0..*]

```

// Return the parameter values for output (in-out, out and return) parameters.

ParameterValueList outputs = new ParameterValueList();
ParameterValueList parameterValues = this.parameterValues;
for (int i = 0; i < parameterValues.size(); i++) {
    ParameterValue parameterValue = parameterValues.getValue(i);
    Parameter parameter = parameterValue.parameter;
    if ((parameter.direction == ParameterDirectionKind.inout) |
        (parameter.direction == ParameterDirectionKind.out) |
        (parameter.direction == ParameterDirectionKind.return_)) {
        outputs.addValue(parameterValue);
    }
}

return outputs;

```

[5] getParameterValue (in parameter : Parameter) : ParameterValue

```

// Get the parameter value of this execution corresponding to the given parameter (if any).

ParameterValue parameterValue = null;
int i = 1;
while (parameterValue == null & i <= this.parameterValues.size()) {
    if (this.parameterValues.getValue(i-1).parameter == parameter) {
        parameterValue = this.parameterValues.getValue(i-1);
    }
    i = i + 1;
}

```

```
}  
return parameterValue;
```

[6] new_ () : Value

Create a new execution with no behavior or parameterValues.

[7] setParameterValue (in parameterValue : ParameterValue)

```
// Set the given parameter value for this execution.  
// If a parameter value already existed for the parameter of the given parameter value,  
// then replace its value.  
  
// Debug.println("[setParameterValue] parameter = " + parameterValue.parameter.name + "  
with " + parameterValue.values.size() + " values");  
  
ParameterValue existingParameterValue = this.getParameterValue(parameterValue.parameter);  
  
if (existingParameterValue == null) {  
    this.parameterValues.addValue(parameterValue);  
}  
else {  
    existingParameterValue.values = parameterValue.values;  
}
```

[8] terminate ()

```
// Terminate an ongoing execution. By default, do nothing.  
return;
```

8.4.2.2.2 OpaqueBehaviorExecution

An opaque execution is an execution for an opaque behavior.

Opaque behaviors are used to define primitive behaviors.

The actual definition of the primitive behavior should be given in a concrete subclass of OpaqueBehaviorExecution.

Generalizations

- [Execution](#)

Attributes

None

Associations

None

Operations

[1] doBody (in inputParameters : ParameterValue [0..*], in outputParameters : ParameterValue [0..*])

The actual definition of the behavior of an Opaque Behavior should be given in a concrete

subclass that defines this operation.
The values of the inputParameters are set when the operation is called.
The values of the outputParameters should be set during the execution of the operation.

[2] execute ()

```
// Execute the body of the opaque behavior.

Debug.println("[execute] Opaque behavior " + this.getBehavior().name + "...");

ParameterList parameters = this.getBehavior().ownedParameter;

ParameterValueList inputs = new ParameterValueList();
ParameterValueList outputs = new ParameterValueList();

for (int i = 0; i < parameters.size(); i++) {
    Parameter parameter = parameters.getValue(i);

    if ((parameter.direction == ParameterDirectionKind.in) |
        (parameter.direction == ParameterDirectionKind.inout)) {
        inputs.addValue(this.getParameterValue(parameter));
    }

    if ((parameter.direction == ParameterDirectionKind.inout) |
        (parameter.direction == ParameterDirectionKind.out) |
        (parameter.direction == ParameterDirectionKind.return_)) {
        ParameterValue parameterValue = new ParameterValue();
        parameterValue.parameter = parameter;
        this.setParameterValue(parameterValue);
        outputs.addValue(parameterValue);
    }
}

this.doBody(inputs, outputs);
```

8.4.2.2.3 ParameterValue

A parameter value gives the value(s) for a specific parameter.

Generalizations

None

Attributes

None

Associations

- parameter : Parameter
- values : Value [0..*]
The values of for the parameter. Zero or more values are possible, as constrained by the multiplicity of the parameter.

Operations

[1] copy () : ParameterValue

```
// Create a new parameter value for the same parameter as this parameter value, but with
copies of the values of this parameter value.
```

```

ParameterValue newValue = new ParameterValue();

newValue.parameter = this.parameter;

ValueList values = this.values;
for (int i = 0; i < values.size(); i++) {
    Value value = values.getValue(i);
    newValue.values.addValue(value.copy());
}

return newValue;

```

8.4.3 Communications

8.4.3.1 Overview

Active Objects

An *active object* is one that has one or more classifiers that are *active classes*—that is, they are classes with a *classifier behavior*. (In fUML, an active class must either be a behavior or have a classifier behavior and only active classes may be behaviored classifiers – see Subclause 7.3.2). After an active object is instantiated, a start object behavior action (see Subclause 7.5.4.2.7) is used to start one or more of its classifier behaviors. Note that an object may also *become* active if it has an active class added to it using a reclassify object action (see Subclause 7.5.4.2.4). In this case, a start object behavior action must still be used to start the classifier behavior of the newly added class.

Once started, classifier behaviors then run asynchronously from whatever behavior executed the start object behavior action. This allows the active object to autonomously send communications to and react to communications from other objects. The points at which an active object responds to asynchronous communications from other objects is determined solely by the behavior of the active object.

Active objects in fUML communicate asynchronously via *signals*. A signal is a kind of classifier (see Subclause 7.3.3). Therefore, an instance of a signal is a value. Since a signal may have attributes, a signal instance is a kind of compound value (see Figure 61). This is an extension to the basic value model described in Subclause 8.3.

The semantic model for an active object itself is also an extension to the basic value model for objects. An active object still has the same structural semantics as a passive object, but it adds the behavioral semantics of the execution of classifier behaviors and the handling of asynchronous communication.

When the active behavior of an active object is started, an *object activation* is created for that object. The object activation further maintains a *classifier behavior execution* for each executing classifier behavior. Despite its name, the ClassifierBehaviorExecution class is not actually a subclass of Execution. Rather, it provides an association between a specific active class and the execution object for the classifier behavior of that class in the context of the active object whose activation is being modeled.

Note also that ClassifierBehaviorExecution is itself an active class. Thus, each classifier behavior execution instance runs “in its own thread,” modeling the autonomous execution of the classifier behaviors of an active object. Within the execution model, the concurrent execution semantics for such active objects are given by the base semantics (see Clause 10).

Event Dispatching

An object activation also handles the dispatching of asynchronous communications received by its active object. A signal instance is sent to an active object using a send signal action (see Subclause 7.5.2.2.9). The delivery of this signal to the active object is modeled in the Execution Model by the send operation on Object. This operation accepts a signal instance and passes it to the object activation for the active object, which places it in the *event pool* of received signal instances waiting to be dispatched. At this point, the delivery of the signal is complete and the signal sender may continue execution asynchronously to the eventual dispatching (or not) of the signal by the receiving active object.

In order to decouple the reception of a signal from its dispatching, `ObjectActivation` is also an active class. The classifier behavior for `ObjectActivation` (see Figure 62) is a simple dispatch loop. When a signal instance arrives, `ObjectActivation` sends an `ArrivalSignal` to itself after the received signal instance is placed in the event pool. The dispatch loop waits for a signal arrival and, when this happens, calls the `dispatchNextEvent` operation. This operation dispatches a single signal instance from the event pool. Once this is complete (“run to completion semantics” for dispatched events), the dispatch loop returns to waiting for another signal to arrive.

It is important to carefully note the two semantic levels in the above description. At the level of the execution of a user model, the execution model is modeling the reception of a signal instance (of a signal defined in the user model) and the dispatching of that signal instance to an executing classifier behavior (which is also defined in the user model). However, this semantic model *itself* also uses active classes (i.e., `ObjectActivation` and `ClassifierBehaviorExecution`) and signals (e.g., `ArrivalSignal`). The semantics for active classes and signals, as used in the execution model, are given by the base semantics for those model constructs (see Clause 10; also see Clause 6 for a general discussion of fUML execution semantics versus base semantics).

Now, while an event is being dispatched, it is possible that the active object will receive additional signal instances. In this case, these instances will be concurrently placed into the event pool for the active object and an `ArrivalSignal` will be generated for each arriving event. When the dispatch loop is ready to accept another event, it will accept *exactly one* pending `ArrivalSignal`, causing another event to be dispatched. The dispatch loop will continue to dispatch events, one at a time, until there are no more pending `ArrivalSignals` (or until the active object is destroyed).

Which event is actually dispatched out of the event pool is not determined by the `ArrivalSignal` but, rather, by the `dispatchNextEvent` operation. However, the exact behavior to be specified for this operation is a semantic variation point in fUML. (See Clause 2.3 for a full discussion of semantic variation within fUML.)

Following the general approach of using the Strategy Pattern to model semantic variation points (see Clause 8.2.1), the variability of event dispatching is captured by using strategy classes for the `ObjectActivation::getNextEvent` operation. `GetNextEventStrategy` provides the abstract base class for this type of strategy. The default dispatching behavior is given by the concrete `FIFOGetNextEventStrategy`, which dispatches events on a first-in first-out (FIFO queue) basis. Any variant behavior must be fully specified by overriding the behavioral specification of the `dispatchNextEvent` operation.

A conforming execution tool may define an alternative rule for how this dispatching is to take place by defining a new `GetNextEventStrategy` subclass specifying whatever rule is desired. An instance of this alternate strategy must then be registered with the execution factory at a given locus, rather than the default strategy.

Once an event is selected for dispatch, it is matched against the list of waiting *event accepters* for the active object. If a match is found, the signal instance is passed to the event accepter using its `accept` operation. If no matching event acceptor is found, the signal instance is not returned to the event pool and is lost. (Note that deferred events are not included in the fUML subset.)

The event accepters for an active object are points within the executing classifier behaviors of the object that are waiting for certain (signal reception) events. An executing classifier behavior may *register* an event accepter for itself using the `Object::registerForEvent` operation. The event accepter is then added to the list of waiting event accepters for the object and any matching signal instance is passed back to the executing classifier behavior via the `accept` operation of the event accepter. (Currently in fUML, event accepters are defined only for accept event actions—see Subclause 8.6.4.)

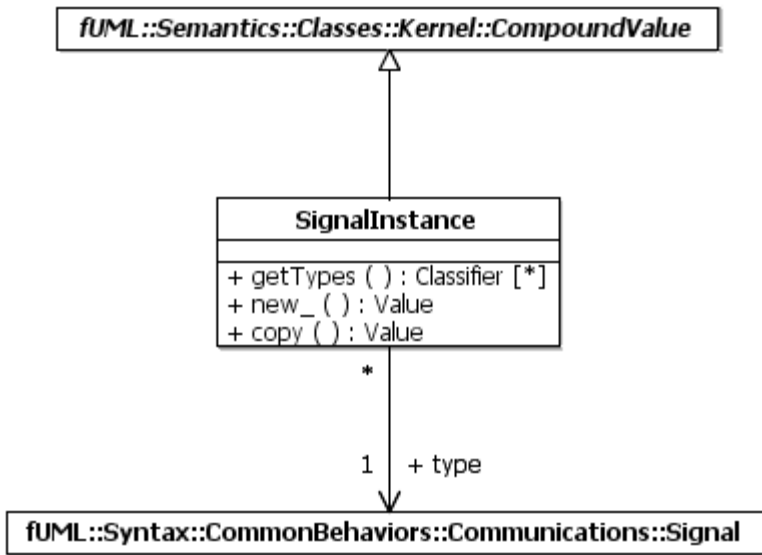


Figure 61 - Signal Instances

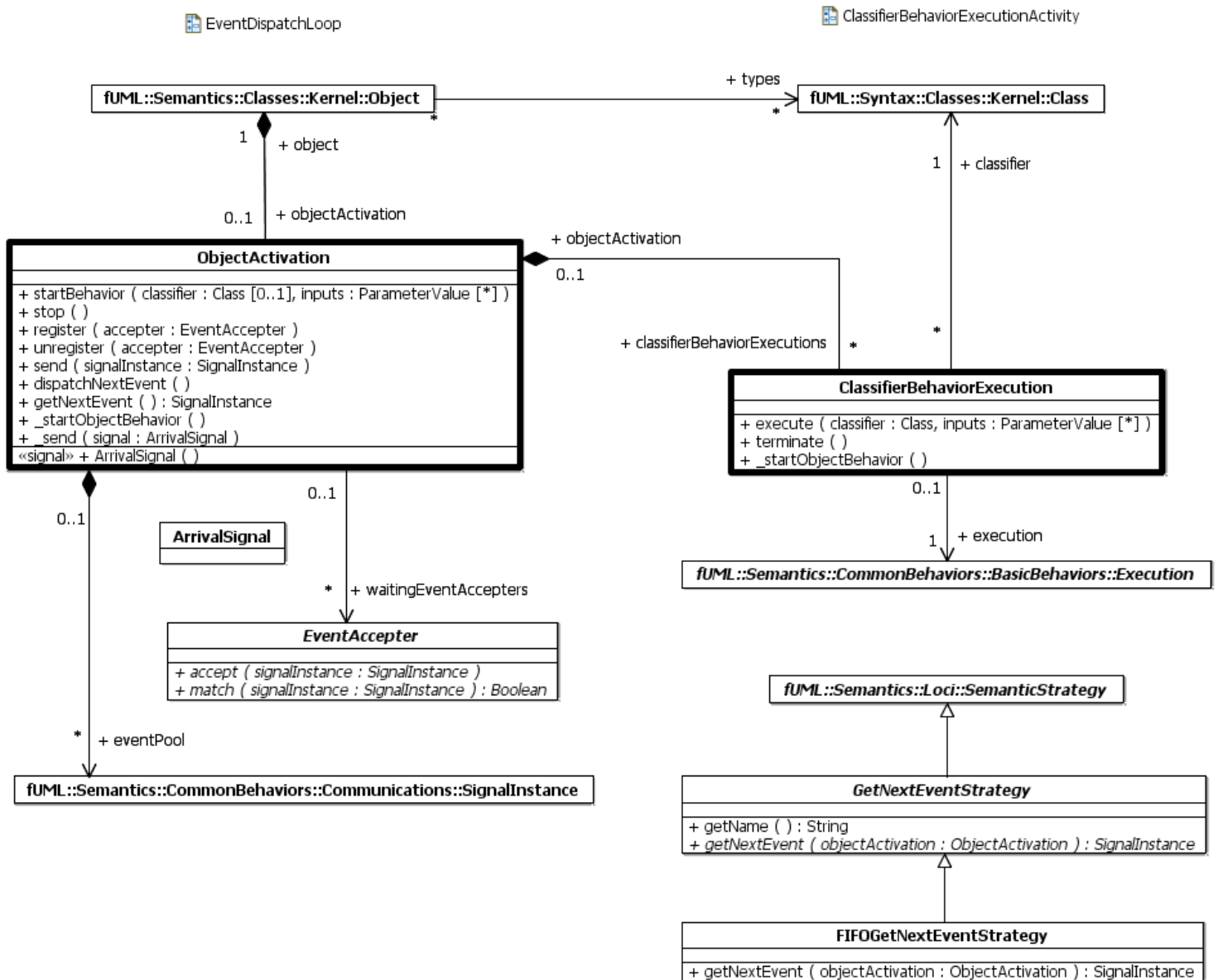


Figure 62 - Active Objects

8.4.3.2 Class Descriptions

8.4.3.2.1 ClassifierBehaviorExecution

A classifier behavior execution executes the classifier behavior from a specific active class.

Generalizations

None

Attributes

None

Associations

- classifier : Class
The classifier whose behavior is being executed. (This must be an active class.)
- execution : Execution
The execution of the associated classifier behavior for a certain object.
- objectActivation : ObjectActivation [0..1]
The object activation that owns this classifier behavior execution.

Operations

[1] execute (in classifier : Class, in inputs : ParameterValue [0..*])

```
// Set the classifier for this classifier behavior execution to the given class.
// If the given class is a behavior, set the execution to be the object of the object
activation of the classifier behavior execution.
// Otherwise the class must be an active class, so get an execution object for the
classifier behavior for the class.
// Set the input parameters for the execution to the given values.
// Then start the active behavior of this ClassifierBehaviorExecution object, which will
execute the execution object on a separate thread of control.

// Debug.println("[execute] Executing behavior for " + classifier.name + "...");

this.classifier = classifier;
Object_ object = this.objectActivation.object;

if (classifier instanceof Behavior) {
    this.execution = (Execution)object;
} else {
    this.execution = object.locus.factory.createExecution(classifier.classifierBehavior,
object);
}

if (inputs != null) {
    for (int i = 0; i < inputs.size(); i++) {
        ParameterValue input = inputs.getValue(i);
        this.execution.setParameterValue(input);
    }
}

_startObjectBehavior();
```

[2] terminate ()

```
// Terminate the associated execution.
// If the execution is not itself the object of the object activation, then destroy it.

//Debug.println("[terminate] Terminating behavior for " + classifier.name + "...");

this.execution.terminate();

if (this.execution != this.objectActivation.object) {
    this.execution.destroy();
}
```

[3] _startObjectBehavior ()


```
// *** This should start the asynchronous ClassifierBehaviorExecutionActivity to do the
following. ***
this.execution.execute();
```

8.4.3.2.2 EventAcceptor

An event accepter handles signal reception events.

This is an abstract class intended to provide a common interface for different kinds of event accepters.

Generalizations

None

Attributes

None

Associations

None

Operations

[1] accept (in signalInstance : SignalInstance)

Accept a signal occurrence for the given signal instance.

[2] match (in signalInstance : SignalInstance) : Boolean

Determine if the given signal instance matches a trigger of this event accepter.

8.4.3.2.3 FIFOGetNextEventStrategy

A FIFO get next event strategy gets events in first-in first-out order.

Generalizations

- [GetNextEventStrategy](#)

Attributes

None

Associations

None

Operations

[1] getNextEvent (in objectActivation : ObjectActivation) : SignalInstance

```
// Get the first event from the given event pool. The event is removed from the pool.
```

```
SignalInstance signalInstance = objectActivation.eventPool.getValue(0);
objectActivation.eventPool.removeValue(0);
return signalInstance;
```

8.4.3.2.4 GetNextEventStrategy

A get next event strategy is a semantic strategy that determines the order in which signal instances are retrieved from the event pool of an object activation.

Generalizations

- [SemanticStrategy](#)

Attributes

None

Associations

None

Operations

[1] getName () : String

```
// Get next event strategies are always named "getNextEvent".
```

```
return "getNextEvent";
```

[2] getNextEvent (in objectActivation : ObjectActivation) : SignalInstance

Get the next event from the event pool of the given object activation. The event is removed from the pool.

8.4.3.2.5 ObjectActivation

An object activation handles the active behavior of an active object.

Generalizations

None

Attributes

None

Associations

- classifierBehaviorExecutions : ClassifierBehaviorExecution [0..*]
The executing classifier behaviors for this object activation.
- eventPool : SignalInstance [0..*]
The pool of signals sent to the object of this object activation, pending dispatching as events.
(All the data values in the pool must be signal instances -- that is, they must have a single type that is a signal.)
- object : Object
The object whose active behavior is being handled by this active object.
- waitingEventAccepters : EventAcceptor [0..*]
The set of event accepters waiting for signals to be received by the object of this object activation.

Operations

[1] dispatchNextEvent ()

```
// Get the next signal instance out of the event pool.
```

```
// If there is one or more waiting event accepters with triggers that match the signal instance, then dispatch it to exactly one of those waiting accepters.
```

```
if (this.eventPool.size() > 0) {
```

```

SignalInstance signalInstance = this.getNextEvent();

Debug.println("[dispatchNextEvent] signalInstance = " + signalInstance);

intList matchingEventAcceptorIndexes = new intList();
EventAcceptorList waitingEventAccepters = this.waitingEventAccepters;
for (int i = 0; i < waitingEventAccepters.size(); i++) {
    EventAcceptor eventAcceptor = waitingEventAccepters.getValue(i);
    if (eventAcceptor.match(signalInstance)) {
        matchingEventAcceptorIndexes.addValue(i);
    }
}

if (matchingEventAcceptorIndexes.size() > 0) {
    // *** Choose one matching event acceptor non-deterministically. ***
    int j =
((ChoiceStrategy) this.object.locus.factory.getStrategy("choice")).choose(matchingEventAcceptorIndexes.size());
    EventAcceptor selectedEventAcceptor = this.waitingEventAccepters.getValue(j-1);
    this.waitingEventAccepters.removeValue(j-1);
    selectedEventAcceptor.accept(signalInstance);
}
}

```

[2] getNextEvent() : SignalInstance

```

// Get the next event from the event pool, using a get next event strategy.

return
((GetNextEventStrategy) this.object.locus.factory.getStrategy("getNextEvent")).getNextEvent(this);

```

[3] register (in acceptor : EventAcceptor)

```

// Register the given event acceptor to wait for a dispatched signal event.

Debug.println("[register] object = " + this.object);
Debug.println("[register] acceptor = " + acceptor);

this.waitingEventAccepters.addValue(acceptor);

```

[4] send (in signalInstance : SignalInstance)

```

// Add the given signal instance to the event pool and signal that a new signal instance
has arrived.

this.eventPool.addValue((SignalInstance) (signalInstance.copy()));
_send(new ArrivalSignal());

```

[5] startBehavior (in classifier : Class [0..1], in inputs : ParameterValue [0..*])

```

// Start the event dispatch loop for this object activation (if it has not already been
started).
// If a classifier is given that is a type of the object of this object activation and
there is not already a classifier behavior execution for it,
// then create a classifier behavior execution for it.

```

```

// Otherwise, create a classifier behavior execution for each of the types of the object
// of this object activation which has a classifier behavior or which is a behavior itself
// and for which there is not currently a classifier behavior execution.

// Start EventDispatchLoop
_startObjectBehavior();

if (classifier == null) {
    Debug.println("[startBehavior] Starting behavior for all classifiers...");
    // *** Start all classifier behaviors concurrently. ***
    Class_List types = this.object.types;
    for (Iterator i = types.iterator(); i.hasNext();) {
        Class_type = (Class_)i.next();
        if (type instanceof Behavior | type.classifierBehavior != null) {
            this.startBehavior(type, new ParameterValueList());
        }
    }
}
else {
    Debug.println("[startBehavior] Starting behavior for " + classifier.name + "...");

    boolean notYetStarted = true;
    int i = 1;
    while (notYetStarted & i <= this.classifierBehaviorExecutions.size()) {
        notYetStarted = (this.classifierBehaviorExecutions.getValue(i-1).classifier !=
classifier);
        i = i + 1;
    }

    if (notYetStarted) {
        ClassifierBehaviorExecution newExecution = new ClassifierBehaviorExecution();
        newExecution.objectActivation = this;
        this.classifierBehaviorExecutions.addValue(newExecution);
        newExecution.execute(classifier, inputs);
    }
}
}

```

[6] stop ()

```

// Stop this object activation by terminating all classifier behavior executions.

ClassifierBehaviorExecutionList classifierBehaviorExecutions =
this.classifierBehaviorExecutions;
for (int i = 0; i < classifierBehaviorExecutions.size(); i++) {
    ClassifierBehaviorExecution classifierBehaviorExecution =
classifierBehaviorExecutions.getValue(i);
    classifierBehaviorExecution.terminate();
}
}

```

[7] unregister (in acceptor : EventAcceptor)

```

// Remove the given event acceptor for the list of waiting event accepters.

Debug.println("[unregister] object = " + this.object);
Debug.println("[unregister] acceptor = " + acceptor);

boolean notFound = true;
int i = 1;
while (notFound & i <= this.waitingEventAccepters.size()) {
    if (this.waitingEventAccepters.getValue(i-1) == acceptor) {

```

```

        this.waitingEventAccepters.remove(i-1);
        notFound = false;
    }
    i = i + 1;
}

```

[8] `_send (in signal : ArrivalSignal)`

```

// Signal the arrival of a new signal instance in the event pool.
// *** This should send an ArrivalSignal to the EventDispatchLoop to do the following
asynchronously. ***
this.dispatchNextEvent();

```

[9] `_startObjectBehavior ()`

```

// *** This should start the EventDispatchLoop ***
return;

```

8.4.3.2.6 SignalInstance

Generalizations

- [CompoundValue](#)

Attributes

None

Associations

- type : Signal

Operations

[1] `copy () : Value`

```

// Create a new signal instance with the same type and feature values as this signal
instance.

```

```

SignalInstance newValue = (SignalInstance) (super.copy());

```

```

newValue.type = this.type;

```

```

return newValue;

```

[2] `getTypes () : Classifier [0..*]`

```

// Return the single type of this signal instance.

```

```

ClassifierList types = new ClassifierList();

```

```

types.addValue(this.type);

```

```

return types;

```

```
[3] new_() : Value
```

```
// Create a new signal instance with no type or feature values.
```

```
return new SignalInstance();
```

8.5 Activities

8.5.1 Overview

Activities are the only concrete sort of user behavior model included in fUML. (Opaque behaviors are also included in fUML, but only for specifying primitive behaviors.) The package structure for the semantic Activities sub-packages parallels that of the syntactic Activities sub-packages (see Subclause 7.3.1). Figure 63 shows the dependencies of these sub-packages.

Subclause 7.4.2 includes the top level diagrams of the abstract syntax for activities. The elements of this syntax are that activities are composed of *activity nodes* with control flow and object flow *activity edges* connecting the nodes.

Subclause 8.5.2 describes the basic semantics of activity execution in terms of *activations* of the activity nodes in the activity. Subclause 8.5.3 then provides the further semantics of structured activity nodes and Subclause 8.5.4 covers expansion regions. The semantics for actions, which are a kind of activity node, are given in Subclause 8.6.

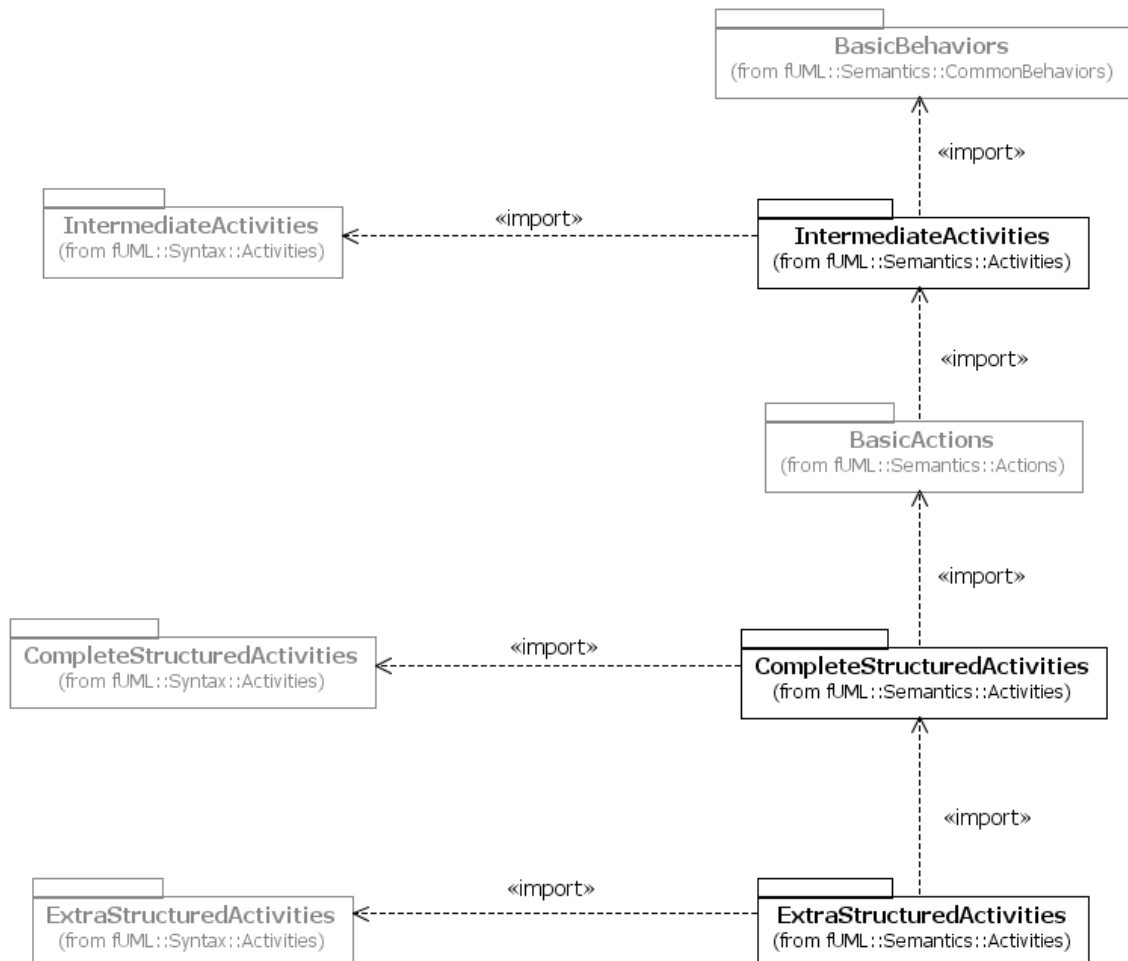


Figure 63 - Activities Semantics Packages

8.5.2 Intermediate Activities

8.5.2.1 Overview

Activity Node Activation

As shown in Figure 68, the activity execution model is an extension of the general behavior execution model from Subclause 8.4.2. In addition to activity executions themselves, the model includes activity node *activations* that specify the behavior of activity nodes during a specific activity execution. These node activations are then interconnected by activity edge *instances* corresponding to the activity edges in the activity.

Activity node activations are *semantic visitor* classes, like evaluations and executions (see Subclause 8.2.1 for a discussion of semantic visitor classes in general). There is an activation visitor class corresponding to each concrete subclass of ActivityNode. The name of the visitor class is the same as the name of the corresponding abstract syntax metaclass with the word “Activation” appended. For example, the activation visitor class for the abstract syntax metaclass JoinNode is called JoinNodeActivation. Note that actions are activity nodes, so that the semantics of actions are specified using activation visitor classes (see Subclause 8.6).

Activity node activations are always created within an *activity node activation group*. This concept is introduced in the execution model to handle nested groups within an activity. The activity itself is considered to implicitly be the top-level group.

Token and Offer Flow

Note that, consistent with the overall use of the Visitor Pattern (see Subclause 8.2.1), the activity execution model intentionally has a largely parallel structure to the abstract syntax model from Subclause 7.4. However, there are concepts introduced in the semantic model for which there is no explicit syntax in UML. In this case, the most important such concepts are those of *token* and *offer*.

Consider the simple activity model shown in Figure 64. Figure 65 shows the abstract syntax representation of this model, which may then be given the semantic interpretation shown in Figure 66.

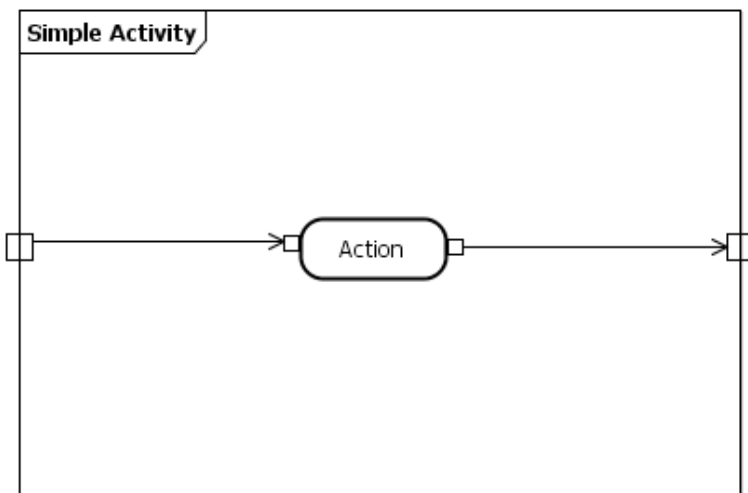


Figure 64 - A Simple Activity Model

The execution semantics for activities in UML places no restriction on the concurrent activation of activity nodes within an activity, other than that imposed by the semantics of token and offer flow across the activity edges connecting the nodes. The execution model captures this concurrent execution semantics through an implicit concept of *threading*.

When an activity node activation produces tokens and is ready to offer them to downstream activations, it calls the *sendOffer* operation on outgoing activity edge instances. The edge instance *sendOffer* operation, in turn, signals to the target activity node activation that an offer is available by calling the *receiveOffer* operation. The target activity node activation then checks if its execution prerequisites are satisfied (encoded in the method of the *isReady* operation for each kind of activity node activation) and, if so, it accepts the pending offers made to it using its *takeOfferedTokens* operation and then calls its *fire* operation.

Note that, in the execution model, the self-calls to the *isReady* operation and, if the activation is ready, to the *takeOfferedTokens* operation happen within a single isolated region—that is, a structured activity node with *mustIsolate* = true. This ensures that, if the *takeOfferedTokens* operation is invoked, then any offers checked by the *isReady* operation cannot be accepted by any other activity node activation before the *takeOfferedTokens* operation completes. The invocation of the *fire* operation, however, does *not* occur within this isolated region, in order to not block continued concurrency with other activity node activations. (See Subclause 8.5.3.1 for a discussion of the semantics of structured activity nodes with *mustIsolate* = true.)

The method of the *fire* operation for an activity node activation captures the execution behavior of the corresponding activity node, which may then cause new offers to be sent further downstream. While there is no explicit class for it in the Execution Model, an extended chain of *sendOffer*–*receiveOffer*–*fire*–*sendOffer* calls can be considered to be a single *thread* of execution through an activity.

When an activity begins execution, a control token is implicitly placed on each *enabled* node. Enabled nodes include initial nodes, input activity parameter nodes and actions with no incoming control nodes or input pins. If such an enabled node is immediately ready to fire, then it begins an execution thread within the activity execution. If there is more than one enabled node that fires, then each one begins a *concurrent* thread within the activity execution.

NOTE: The UML 2 Superstructure Specification (Subclause 12.3.31) states that “In addition [to initial nodes], when an activity starts, a control token is placed at each action...that has no incoming edges...” However, if an action has input pins, at least one of which has a multiplicity lower bound greater than zero, then the action will still not be able to fire until it is offered the appropriate number of object tokens. On the other hand, if the action has input pins, but they all have multiplicity lower bounds of zero, then placing a control token on the action will cause it to fire immediately. However, this is likely not to be the expected behavior, since, having input pins, the presumption is that the modeler expected the action to have at least *some* input. Therefore, fUML requires that an action with input pins have an offer on at least one of the pins before it fires, even if all the input bins have zero multiplicity lower bound.

It is also possible for a thread to *split*. This occurs whenever the same offer is made to multiple outgoing edges, such as when there are multiple edges leaving an output pin, fork node or action. Again, each outgoing thread executes *concurrently*—which is modeled by requiring that the *sendOffer* calls on outgoing edges are all made concurrently.

NOTE: This model of execution concurrency does not require the implementation of actual *parallelism* in a conforming execution tool. It simply means that such parallelism is *allowed* and that the execution semantics provide no further restriction on the serialization of execution across concurrent threads.

A thread ends when a target activity node activation does not accept an offer passed to it along the thread. In this case, the *receiveOffer* operation on the target node activation returns without calling the *fire* operation, and the chain of calls making up the thread terminates. For example, the input pin of an action cannot accept an offer unless its action as a whole is ready to execute (see Subclause 8.6.2.1). Therefore, if an action has several input pins with non-zero multiplicity lower bound, then offers need to be delivered to every input pin before the action can execute. Thus, all the threads delivering these offers, except the last one, will terminate at the action input pin activations. Only the thread delivering the final offer (assuming all the other offered tokens are still available) will result in the action firing, with the action execution continuing on that thread.

The execution of an activity terminates when all threads within it have ended. Such termination may happen naturally when, for example, all tokens are consumed by nodes that do not produce any new offers, or it may be forced by an activity final node. When an activity final node fires, it causes its enclosing activity execution to call the *terminate*

operation on all activity node activations within it. Once a node activation is terminated, it will no longer accept any offers and, as a result, all executing threads will eventually end, resulting in the termination of the activity execution.

NOTE: The UML 2 Superstructure Specification (Subclause 12.3.6) states that, when an activity is terminated by an activity final node, “The content of output activity parameter nodes are passed out of the containing activity, using the null token for object nodes that have nothing in them.” This applies when the activity has been invoked by a synchronous call behavior or call operation action with output pins corresponding to the output parameters of the activity. However, in general, fUML does not provide for the creation of null tokens. Therefore, the execution model does not actually generate null tokens in this case, and the empty output parameter at the end of activity execution simply results in no tokens at all being placed on the corresponding output pin of the calling action. Unlike having at least a null token, having no tokens on the output pin means that it makes no offers that might trigger subsequent actions.

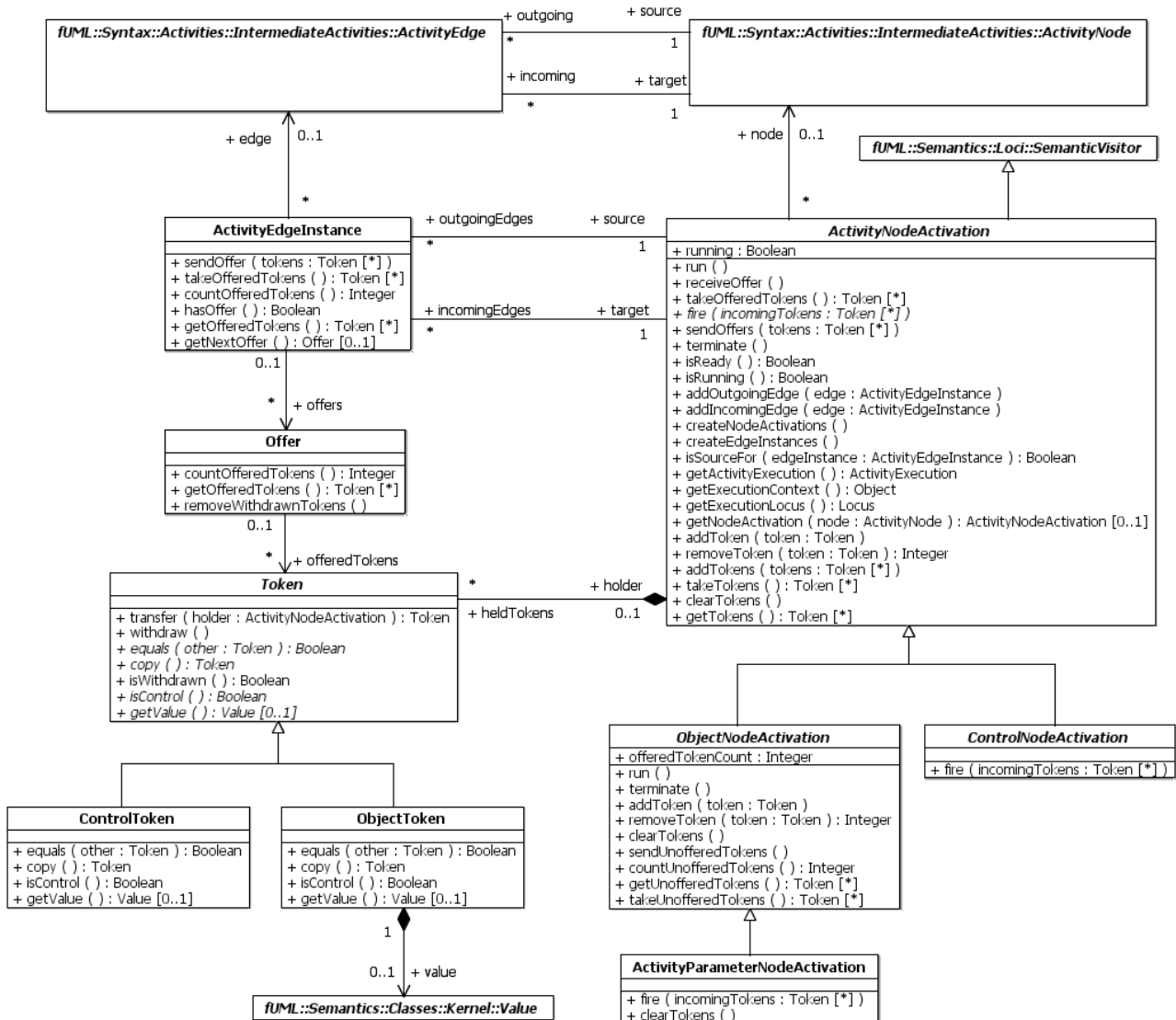


Figure 68 - Activity Executions

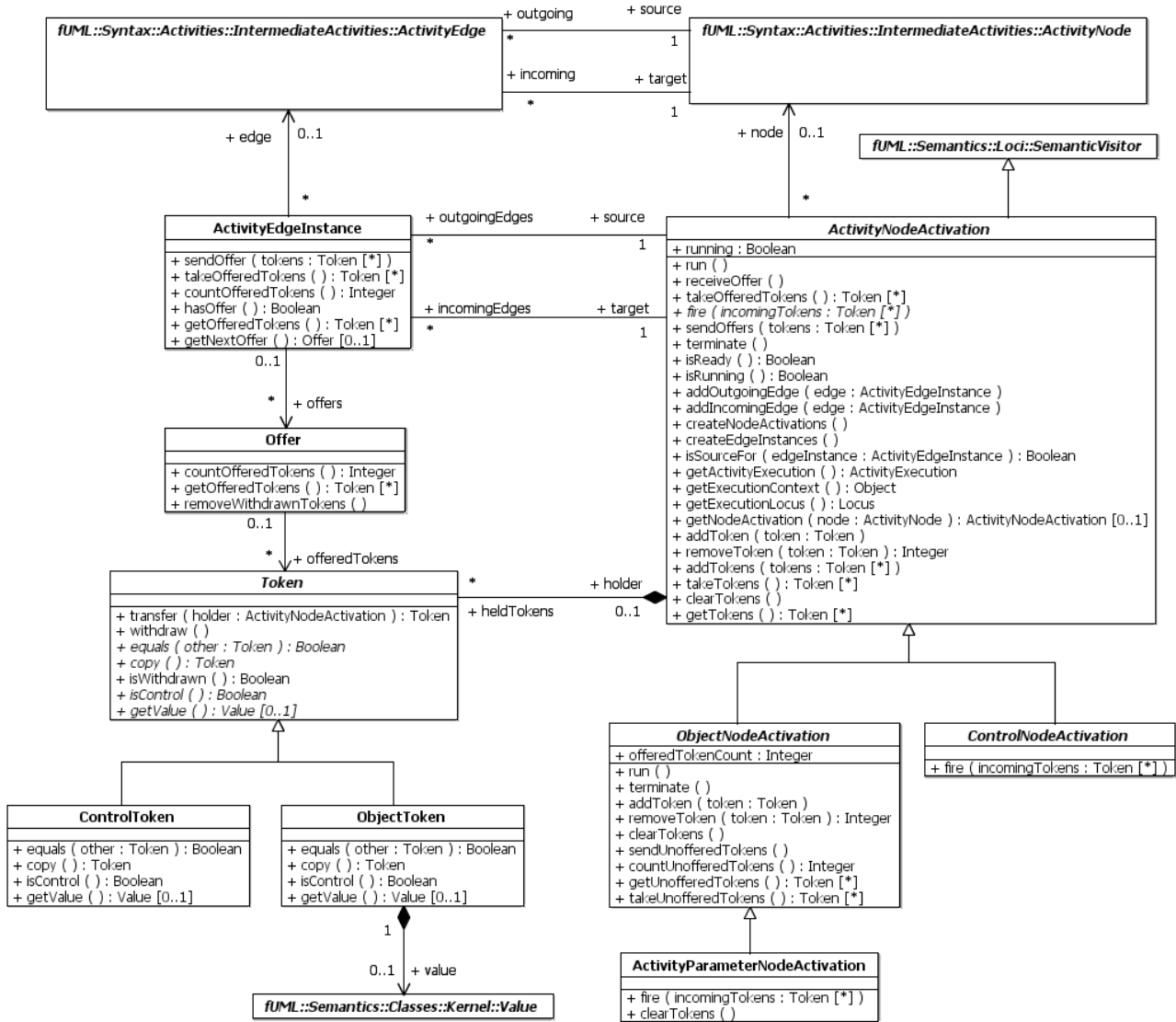


Figure 69 - Node Activations

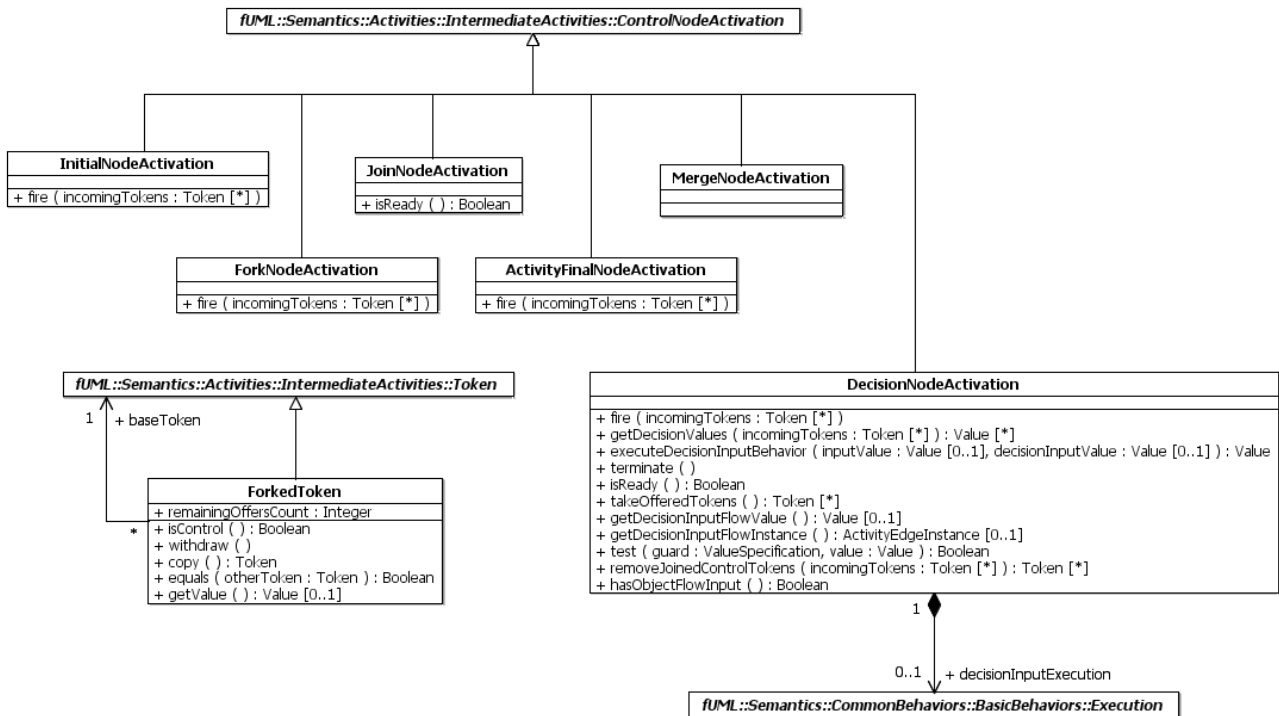


Figure 70 - Control Node Activations

8.5.2.2 Class Descriptions

8.5.2.2.1 ActivityEdgeInstance

An activity edge instance is a connection between activity node activations corresponding to an edge between the corresponding nodes of those activations

Generalizations

None

Attributes

None

Associations

- edge : ActivityEdge [0..1]
The activity edge of which this is an instance.
[This is optional to allow for an implicit fork node execution to be connected to its action execution by an edge instance which does not have a corresponding node in the model.]
- group : ActivityNodeActivationGroup
The activity group that contains this activity edge instance.
- offers : Offer [0..*]
- source : ActivityNodeActivation
The source of this activity edge instance.
The node of the source must be the same as the source of the edge of this edge instance.
- target : ActivityNodeActivation

The target of this activity edge instance.

The node of the target must be the same as the target of the edge of this edge instance.

Operations

[1] `countOfferedTokens () : Integer`

```
// Return the number of tokens being offered.
// Remove any tokens that have already been consumed and don't include them in the count.

Offer offer = this.getNextOffer();

int count = 0;
if (offer != null) {
    count = offer.countOfferedTokens();
}

return count;
```

[2] `getNextOffer () : Offer [0..1]`

```
// Return the next offer on this edge instance that still has tokens that are not
withdrawn.
// Remove any empty offers before the one returned.

Offer nextOffer = null;
while (nextOffer == null & this.offers.size() > 0) {
    Offer offer = this.offers.getValue(0);
    offer.removeWithdrawnTokens();
    if (offer.countOfferedTokens() == 0) {
        this.offers.remove(0);
    } else {
        nextOffer = offer;
    }
}

return nextOffer;
```

[3] `getOfferedTokens () : Token [0..*]`

```
// Get the offered tokens (after which the tokens will still be offered).

Offer nextOffer = this.getNextOffer();

TokenList offeredTokens = new TokenList();
if (nextOffer != null) {
    offeredTokens = nextOffer.getOfferedTokens();
}

return offeredTokens;
```

[4] `hasOffer () : Boolean`

```
// Return true if there are any pending offers.

return this.getNextOffer() != null;
```

[5] `sendOffer (in tokens : Token [0..*])`

```

// Send an offer from the source to the target.
// Keep the offered tokens until taken by the target.
// (Note that any one edge should only be handling either all object tokens or all control
tokens.)

Offer offer = new Offer();

for (int i = 0; i < tokens.size(); i++) {
    Token token = tokens.getValue(i);
    // Debug.println("[sendOffer] token value = " + token.getValue());
    offer.offeredTokens.addValue(token);
}

this.offers.addValue(offer);

this.target.receiveOffer();

```

[6] takeOfferedTokens () : Token [0..*]

```

// Take all the offered tokens and return them.

TokenList tokens = this.getOfferedTokens();

if (this.hasOffer()) {
    this.offers.removeValue(0);
}

return tokens;

```

8.5.2.2.2 ActivityExecution

An activity execution is used to execute a specific activity. The type of the activity execution must be an activity. When executed, the activity execution creates activity edge instances for all activity edges, activity node activations for all activity nodes and makes offers to all nodes with no incoming edges. Execution terminates when either all node activations are complete, or an activity final node is executed.

Generalizations

- [Execution](#)

Attributes

None

Associations

- activationGroup : ActivityNodeActivationGroup
The group of activations of the activity nodes of the activity.

Operations

[1] copy () : Value

```

// Create a new activity execution that is a copy of this execution.
// [Note: This currently just returns a non-executing execution for the same activity as
this execution.]

return super.copy();

```


[2] execute ()

```
// Execute the activity for this execution by creating an activity node activation group
and activating all the activity nodes in the activity.
// When this is complete, copy the values on the tokens offered by output parameter nodes
to the corresponding output parameters.

Activity activity = (Activity) (this.getTypes().getValue(0));

Debug.println("[execute] Activity " + activity.name + "...");
// Debug.println("[execute] context = " + this.context.objectId());

this.activationGroup = new ActivityNodeActivationGroup();
this.activationGroup.activityExecution = this;
this.activationGroup.activate(activity.node, activity.edge);

// Debug.println("[execute] Getting output parameter node activations...");

ActivityParameterNodeActivationList outputActivations =
this.activationGroup.getOutputParameterNodeActivations();

// Debug.println("[execute] There are " + outputActivations.size() + " output parameter
node activations.");

for (int i = 0; i < outputActivations.size(); i++) {
    ActivityParameterNodeActivation outputActivation = outputActivations.getValue(i);

    ParameterValue parameterValue = new ParameterValue();
    parameterValue.parameter = ((ActivityParameterNode) (outputActivation.node)).parameter;

    TokenList tokens = outputActivation.getTokens();
    for (int j = 0; j < tokens.size(); j++) {
        Token token = tokens.getValue(j);
        Value value = ((ObjectToken) token).value;
        if (value != null) {
            parameterValue.values.addValue(value);
        }
    }

    this.setParameterValue(parameterValue);
}

Debug.println("[execute] Activity " + activity.name + " completed.");
```

[3] new_(): Value

```
// Create a new activity execution with empty properties.

return new ActivityExecution();
```

[4] terminate ()

```
// Terminate all node activations (which will ultimately result in the activity execution
completing).

this.activationGroup.terminateAll();
```

8.5.2.2.3 ActivityFinalNodeActivation

An activity final node activation is a control node activation for a node that is an activity final node.

Generalizations

- [ControlNodeActivation](#)

Attributes

None

Associations

None

Operations

```
[1] fire ( in incomingTokens : Token [0..*] )
```

```
// Terminate the group containing this activation.
```

```
Debug.println("[fire] Activity final node " + this.node.name + "...");
```

```
this.group.terminateAll();
```

8.5.2.2.4 ActivityNodeActivation

An activity node activation is used to define the behavior of an activity node in the context of a containing activity or structured activity node.

Generalizations

- [SemanticVisitor](#)

Attributes

- running : Boolean
If true, this node activation is enabled for execution once all its other prerequisites are satisfied.

Associations

- group : ActivityNodeActivationGroup
The group that contains this activity node activation.
- heldTokens : Token [0..*]
- incomingEdges : ActivityEdgeInstance [0..*]
The set of activity edge instances for the incoming edges of the node.
- node : ActivityNode [0..1]
The activity node being activated by this activity node activation. The node must be owned by the activity (type) of the activity execution of this node activation.
[This is optional, to allow for fork node edge queues and implicit fork and join node activations for actions to not have nodes in the model.]
- outgoingEdges : ActivityEdgeInstance [0..*]
The set of activity edge instances for the outgoing edges of the node.

Operations

[1] addIncomingEdge (in edge : ActivityEdgeInstance)

```
// Add an activity edge instance as an incoming edge of this activity node activation.  
edge.target = this;  
this.incomingEdges.addValue(edge);
```

[2] addOutgoingEdge (in edge : ActivityEdgeInstance)

```
// Add an activity edge instance as an outgoing edge of this activity node activation.  
edge.source = this;  
this.outgoingEdges.addValue(edge);
```

[3] addToken (in token : Token)

```
// Transfer the given token to be held by this node.  
  
if (this.node == null) {  
    Debug.println("[addToken] ...");  
} else {  
    Debug.println("[addToken] node = " + this.node.name);  
}  
  
Token transferredToken = token.transfer(this);  
// Debug.println("[addToken] Adding token with value = " + transferredToken.getValue());  
this.heldTokens.addValue(transferredToken);
```

[4] addTokens (in tokens : Token [0..*])

```
// Transfer the given tokens to be the held tokens for this node.  
  
// if (this.node == null) {  
//     Debug.println("[addTokens] ...");  
// } else {  
//     Debug.println("[addTokens] node = " + this.node.name);  
// }  
  
for (int i = 0; i < tokens.size(); i++) {  
    Token token = tokens.getValue(i);  
    this.addToken(token);  
}
```

[5] clearTokens ()

```
// Remove all held tokens.  
  
while (this.heldTokens.size() > 0) {  
    this.heldTokens.getValue(0).withdraw();  
}
```

[6] createEdgeInstances ()

```
// Create edge instances for any edge instances owned by the node for this activation.
```

```
// For most kinds of nodes, this does nothing.
```

```
return;
```

[7] createNodeActivations ()

```
// Create node activations for any subnodes of the node for this activation.
```

```
// For most kinds of nodes, this does nothing.
```

```
return;
```

[8] fire (in incomingTokens : Token [0..*])

Carry out the main behavior of this activity node.

[9] getActivityExecution () : ActivityExecution

```
// Return the activity execution that contains this activity node activation, directly or indirectly.
```

```
return this.group.getActivityExecution();
```

[10] getExecutionContext () : Object

```
// Get the context object for the containing activity execution.
```

```
return this.getActivityExecution().context;
```

[11] getExecutionLocus () : Locus

```
// Get the locus of the containing activity execution.
```

```
return this.getActivityExecution().locus;
```

[12] getNodeActivation (in node : ActivityNode) : ActivityNodeActivation [0..1]

```
// Get the activity node activation corresponding to the given activity node, in the context of this activity node activation.
```

```
// By default, return this activity node activation, if it is for the given node, otherwise return nothing.
```

```
ActivityNodeActivation activation = null;
```

```
if (node == this.node) {
```

```
    activation = this;
```

```
}
```

```
return activation;
```

[13] getTokens () : Token [0..*]

```
// Get the tokens held by this node activation.
```

```
// Debug.println("[getTokens] node = " + this.node.name);
```

```

TokenList tokens = new TokenList();
TokenList heldTokens = this.heldTokens;
for (int i = 0; i < heldTokens.size(); i++) {
    Token heldToken = heldTokens.getValue(i);
    // Debug.println("[getTokens] token value = " + heldTokens.getValue());
    tokens.addValue(heldToken);
}

return tokens;

```

[14] isReady(): Boolean

```

// Check if all the prerequisites for this node have been satisfied.
// By default, check that this node is running.

return this.isRunning();

```

[15] isRunning(): Boolean

```

// Test whether this node activation is running.

return this.running;

```

[16] isSourceFor (in edgeInstance : ActivityEdgeInstance) : Boolean

```

// Check if this node activation is the effective source for the given edge instance.

return edgeInstance.source == this;

```

[17] receiveOffer()

```

// Receive an offer from an incoming edge.
// Check if all prerequisites have been satisfied. If so, fire.

if (this.node != null) {
    Debug.println("[receiveOffer] node = " + this.node.name);
}

_beginIsolation();

    boolean ready = this.isReady();

    TokenList tokens = new TokenList();
    if (ready) {
        Debug.println("[receiveOffer] Firing.");
        tokens = this.takeOfferedTokens();
    }

_endIsolation();

if (ready) {
    this.fire(tokens);
}

```

[18] removeToken (in token : Token) : Integer

```
// Remove the given token, if it is held by this node activation.
// Return the position (counting from 1) of the removed token (0 if there is none
removed).

boolean notFound = true;
int i = 1;
while (notFound & i <= this.heldTokens.size()) {
    if (this.heldTokens.getValue(i-1) == token) {
        if (this.node == null) {
            Debug.println("[removeToken] ...");
        } else {
            Debug.println("[removeToken] node = " + this.node.name);
        }
        this.heldTokens.remove(i-1);
        notFound = false;
    }
    i = i + 1;
}

if (notFound) {
    i = 0;
} else {
    i = i - 1;
}

return i ;
```

[19] run ()

```
// Run the activation of this node.

if (this.node != null) {
    Debug.println("[run] node = " + this.node.name);
} else {
    Debug.println("[run] Anonymous activation of type " + this.getClass().getName());
}

this.running = true;
```

[20] sendOffers (in tokens : Token [0..*])

```
// Send offers for the given set of tokens over all outgoing edges (if there are any
tokens actually being offered).

if (tokens.size()>0) {

    // *** Send all outgoing offers concurrently. ***
    ActivityEdgeInstanceList outgoingEdges = this.outgoingEdges;
    for (Iterator i = outgoingEdges.iterator(); i.hasNext();) {
        ActivityEdgeInstance outgoingEdge = (ActivityEdgeInstance)i.next();
        // Debug.println("[sendOffers] Sending offer to " + outgoingEdge.target.node.name
+ ".");
        outgoingEdge.sendOffer(tokens);
    }
}
```

[21] takeOfferedTokens () : Token [0..*]

```
// Get tokens from all incoming edges.

TokenList allTokens = new TokenList();
ActivityEdgeInstanceList incomingEdges = this.incomingEdges;
for (int i = 0; i < incomingEdges.size(); i++) {
    ActivityEdgeInstance incomingEdge = incomingEdges.getValue(i);
    TokenList tokens = incomingEdge.takeOfferedTokens();
    for (int j = 0; j < tokens.size(); j++) {
        Token token = tokens.getValue(j);
        allTokens.addValue(token);
    }
}

return allTokens;
```

[22] takeTokens () : Token [0..*]

```
// Take the tokens held by this node activation.

TokenList tokens = this.getTokens();
this.clearTokens();

return tokens;
```

[23] terminate ()

```
// Terminate the activation of this node.

if (this.running) {
    if (this.node != null) {
        Debug.println("[terminate] node = " + this.node.name);
    } else {
        Debug.println("[terminate] Anonymous activation of type " +
this.getClass().getName());
    }
}

this.running = false;
```

8.5.2.2.5 ActivityNodeActivationGroup

An activity node group is a group of nodes that are activated together, either directly in the context of an activity execution, or in the context of

Generalizations

None

Attributes

None

Associations

- activityExecution : ActivityExecution [0..1]
The activity execution to which this group belongs.
(This will be empty if the group is for a structured activity node activation.)
- containingNodeActivation : StructuredActivityNodeActivation [0..1]

The structured activity node activation to which this group belongs.
(This will be empty if the group is for an activity execution.)

- `edgeInstances` : `ActivityEdgeInstance` [0..*]
The set of activity edge instances for this group.
- `nodeActivations` : `ActivityNodeActivation` [0..*]
The set of activity node executions for this group.

Operations

[1] `activate (in nodes : ActivityNode [0..*], in edges : ActivityEdge [0..*])`

```
// Activate and run the given set of nodes with the given set of edges, within this activation group.
```

```
this.createNodeActivations(nodes);  
this.createEdgeInstances(edges);  
this.run(this.nodeActivations);
```

```
// Debug.println("[activate] Exiting.");
```

[2] `addEdgeInstance (in instance : ActivityEdgeInstance)`

```
// Add the given edge instance to this group.
```

```
instance.group = this;  
this.edgeInstances.addValue(instance);
```

[3] `addNodeActivation (in activation : ActivityNodeActivation)`

```
// Add the given node activation to this group.
```

```
activation.group = this;  
this.nodeActivations.addValue(activation);
```

[4] `createEdgeInstances (in edges : ActivityEdge [0..*])`

```
// Create instance edges for the given activity edges, as well as for edge instances within any nodes activated in this group.
```

```
for (int i = 0; i < edges.size(); i++) {  
    ActivityEdge edge = edges.getValue(i);
```

```
    Debug.println("[createEdgeInstances] Creating an edge instance from " +  
edge.source.name + " to " + edge.target.name + ".");
```

```
    ActivityEdgeInstance edgeInstance = new ActivityEdgeInstance();  
    edgeInstance.edge = edge;
```

```
    this.addEdgeInstance(edgeInstance);  
    this.getNodeActivation(edge.source).addOutgoingEdge(edgeInstance);  
    this.getNodeActivation(edge.target).addIncomingEdge(edgeInstance);
```

```
    // Debug.println("[createEdgeInstances] Edge instance created...");  
}
```

```
ActivityNodeActivationList nodeActivations = this.nodeActivations;  
for (int i = 0; i < nodeActivations.size(); i++) {
```



```

        ActivityNodeActivation nodeActivation = nodeActivations.getValue(i);
        nodeActivation.createEdgeInstances();
    }

    // Debug.println("[createEdgeInstances] Done creating edge instances.");

```

[5] createNodeActivation (in node : ActivityNode) : ActivityNodeActivation

```

// Create an activity node activation for a given activity node in this activity node
activation group.

```

```

ActivityNodeActivation activation = (ActivityNodeActivation)
(this.getActivityExecution().locus.factory.instantiateVisitor(node, "Activation"));
activation.node = node;
activation.running = false;

this.addNodeActivation(activation);

activation.createNodeActivations();

return activation;

```

[6] createNodeActivations (in nodes : ActivityNode [0..*])

```

// Add activity node activations for the given set of nodes to this group and create edge
instances between them.

```

```

for (int i = 0; i < nodes.size(); i++) {
    ActivityNode node = nodes.getValue(i);

    Debug.println("[createNodeActivations] Creating a node activation for " + node.name +
"...");
    this.createNodeActivation(node);
}

```

[7] getActivityExecution () : ActivityExecution

```

// Return the activity execution to which this group belongs, directly or indirectly.

```

```

ActivityExecution activityExecution = this.activityExecution;
if (activityExecution == null) {
    activityExecution = this.containingNodeActivation.group.getActivityExecution();
}

// Debug.println("[getActivityExecution] activityExecution = " + activityExecution);

return activityExecution;

```

[8] getNodeActivation (in node : ActivityNode) : ActivityNodeActivation [0..1]

```

// Return the node activation (if any) in this group, or any nested group, corresponding
to the given activity node.

```

```

ActivityNodeActivation activation = null;
int i = 1;
while (activation == null & i <= this.nodeActivations.size()) {

```

```

        activation = this.nodeActivations.getValue(i-1).getNodeActivation(node);
        i = i + 1;
    }

    return activation;

```

[9] `getOutputParameterNodeActivations () : ActivityParameterNodeActivation [0..*]`

// Return the set of all activations in this group of activity parameter nodes for output (inout, out and return) parameters.

```

ActivityParameterNodeActivationList parameterNodeActivations = new
ActivityParameterNodeActivationList();
ActivityNodeActivationList nodeActivations = this.nodeActivations;
for (int i = 0; i < nodeActivations.size(); i++) {
    ActivityNodeActivation activation = nodeActivations.getValue(i);
    if (activation instanceof ActivityParameterNodeActivation) {
        ParameterDirectionKind direction = ((ActivityParameterNode)
(activation.node)).parameter.direction;
        if ((direction.equals(ParameterDirectionKind.inout)) |
            (direction.equals(ParameterDirectionKind.out)) |
            (direction.equals(ParameterDirectionKind.return_))) {
            parameterNodeActivations.addValue((ActivityParameterNodeActivation) activation)
;
        }
    }
}

return parameterNodeActivations;

```

[10] `run (in activations : ActivityNodeActivation [0..*])`

// Run the given node activations and then (concurrently) send an offer to all activations for nodes with no incoming edges within the given set.

```

for (int i = 0; i < activations.size(); i++) {
    ActivityNodeActivation activation = activations.getValue(i);
    activation.run();
}

Debug.println("[run] Checking for enabled nodes...");

ActivityNodeActivationList enabledActivations = new ActivityNodeActivationList();

for (int i = 0; i < activations.size(); i++) {
    ActivityNodeActivation activation = activations.getValue(i);
    ActivityEdgeInstanceList incomingEdges = activation.incomingEdges;

    Debug.println("[run] Checking node " + activation.node.name + "...");

    boolean isEnabled;
    if (activation instanceof ActionActivation) {
        isEnabled = ((Action)activation.node).input.size() == 0;
    } else {
        isEnabled = (activation instanceof ControlNodeActivation) | (activation instanceof
ActivityParameterNodeActivation);
    }

    int j = 1;
    while (j <= incomingEdges.size() & isEnabled) {
        int k = 1;

```

```

        while (k <= activations.size() & isEnabled) {
            if (activations.getValue(k-1).isSourceFor(incomingEdges.getValue(j-1))) {
                isEnabled = false;
            }
            k = k + 1;
        }
        j = j + 1;
    }

    if (isEnabled) {
        Debug.println("[run] Node " + activation.node.name + " is enabled.");
        enabledActivations.addValue(activation);
    }
}

// Debug.println("[run] " + enabledActivations.size() + " node(s) are enabled.");

// *** Send offers to all enabled nodes concurrently. ***
for (Iterator i = enabledActivations.iterator(); i.hasNext();) {
    ActivityNodeActivation activation = (ActivityNodeActivation)i.next();
    Debug.println("[run] Sending offer to node " + activation.node.name + ".");
    activation.receiveOffer();
}

```

[11] runNodes (in nodes : ActivityNode [0..*])

// Run the node activations associated with the given nodes in this activation group.

```

ActivityNodeActivationList nodeActivations = new ActivityNodeActivationList();

for (int i = 0; i < nodes.size(); i++) {
    ActivityNode node = nodes.getValue(i);
    ActivityNodeActivation nodeActivation = this.getNodeActivation(node);
    if (nodeActivation != null) {
        nodeActivations.addValue(nodeActivation);
    }
}

this.run(nodeActivations);

```

[12] terminateAll ()

```

// Terminate all node activations in the group.

Debug.println("[terminateAll] Terminating activation group for " +
    (this.activityExecution != null? "activity " +
this.activityExecution.getTypes().getValue(0).name: "node " +
this.containingNodeActivation.node.name) +
    ".");

ActivityNodeActivationList nodeActivations = this.nodeActivations;
for (int i = 0; i < nodeActivations.size(); i++) {
    ActivityNodeActivation nodeActivation = nodeActivations.getValue(i);
    nodeActivation.terminate();
}

```

8.5.2.2.6 ActivityParameterNodeActivation

An activity parameter node activation is an object node activation for a node that is an activity parameter node.

Generalizations

- [ObjectNodeActivation](#)

Attributes

None

Associations

None

Operations

[1] clearTokens ()

```
// Clear all held tokens only if this is an input parameter node.
```

```
if (this.node.incoming.size() == 0) {
    super.clearTokens();
}
```

[2] fire (in incomingTokens : Token [0..*])

```
// If there are no incoming edges, this is an activation of an input activity parameter node.
```

```
// Get the values from the input parameter indicated by the activity parameter node and offer those values as object tokens.
```

```
if (this.node.incoming.size() == 0) {
    Debug.println("[fire] Input activity parameter node " + this.node.name + "...");
    Parameter parameter = ((ActivityParameterNode) (this.node)).parameter;
    ParameterValue parameterValue =
this.getActivityExecution().getParameterValue(parameter);
    // Debug.println("[fire] parameter = " + parameter.name);
    if (parameterValue != null) {
        Debug.println("[fire] Parameter has " + parameterValue.values.size() + "
value(s).");
        TokenList tokens = new TokenList();
        ValueList values = parameterValue.values;
        for (int i = 0; i < values.size(); i++) {
            Value value = values.getValue(i);
            ObjectToken token = new ObjectToken();
            token.value = value;
            this.addToken(token);
        }
        this.sendUnofferedTokens();
    }
}
```

```
// If there are one or more incoming edges, this is an activation of an output activity parameter node.
```

```
// Take the tokens offered on incoming edges and add them to the set of tokens being offered.
```

```
// [Note that an output activity parameter node may fire multiple times, accumulating tokens offered to it.]
```

```
else {
    Debug.println("[fire] Output activity parameter node " + this.node.name + "...");
    this.addTokens(incomingTokens);
}
```

8.5.2.2.7 ControlNodeActivation

A control node activation is an activity node activation for a node that is a control node.

Generalizations

- [ActivityNodeActivation](#)

Attributes

None

Associations

None

Operations

[1] fire (in incomingTokens : Token [0..*])

```
// By default, offer all tokens on all outgoing edges.
```

```
if (this.node != null) {  
    Debug.println("[fire] Control node " + this.node.name + "...");  
}
```

```
this.sendOffers(incomingTokens);
```

8.5.2.2.8 ControlToken

A control token represents the passing of control along a control flow edge.

Generalizations

- [Token](#)

Attributes

None

Associations

None

Operations

[1] copy () : Token

```
// Return a new control token.
```

```
return new ControlToken();
```

[2] equals (in other : Token) : Boolean

```
// Return true if the other token is a control token, because control tokens are  
interchangeable.
```

```
return other instanceof ControlToken;
```

[3] getValue () : Value [0..1]

```
// Control tokens do not have values.
return null;
```

[4] isControl(): Boolean

```
// Return true for a control token.
return true;
```

8.5.2.2.9 DecisionNodeActivation

Generalizations

- [ControlNodeActivation](#)

Attributes

None

Associations

- decisionInputExecution : Execution [0..1]
The current execution of the decision input behavior (if any).

Operations

[1] executeDecisionInputBehavior (in inputValue : Value [0..1], in decisionInputValue : Value [0..1]) : Value

```
// Create the decision input execution from the decision input behavior.
// If the behavior has input parameter(s), set the input parameter(s) of the execution to
the given value(s).
// Execute the decision input execution and then remove it.
// Return the value of the output parameter of the execution.
// If there is no decision input behavior, the decision input value is returned, if one is
given, otherwise the input value is used as the decision value.

Debug.println("[executeDecisionBehavior] inputValue = " + inputValue);

Behavior decisionInputBehavior = ((DecisionNode)(this.node)).decisionInput;

Value decisionInputResult = null;

if (decisionInputBehavior == null) {

    if (decisionInputValue != null) {
        decisionInputResult = decisionInputValue;
    } else {
        decisionInputResult = inputValue;
    }

} else {

    this.decisionInputExecution =
this.getExecutionLocus().factory.createExecution(decisionInputBehavior,
this.getExecutionContext());

    int i = 1;
    int j = 0;
    while ((j == 0 | (j == 1 & decisionInputValue != null)) & i <=
decisionInputBehavior.ownedParameter.size()) {
```

```

Parameter parameter = decisionInputBehavior.ownedParameter.getValue(i-1);
if (parameter.direction.equals(ParameterDirectionKind.in) |
    parameter.direction.equals(ParameterDirectionKind.inout)) {
    ParameterValue inputParameterValue = new ParameterValue();
    inputParameterValue.parameter = parameter;

    j = j + 1;
    if (j == 1 && inputValue != null) {
        inputParameterValue.values.addValue(inputValue);
    } else {
        inputParameterValue.values.addValue(decisionInputValue);
    }

    this.decisionInputExecution.setParameterValue(inputParameterValue);
}
i = i + 1;
}

this.decisionInputExecution.execute();

ParameterValueList outputParameterValues =
this.decisionInputExecution.getOutputParameterValues();
decisionInputExecution.destroy();

decisionInputResult = outputParameterValues.getValue(0).values.getValue(0);
}

return decisionInputResult;

```

[2] fire (in incomingTokens : Token [0..*])

```

// Get the decision values and test them on each guard.
// Forward the offer over the edges for which the test succeeds.

Debug.println("[fire] Decision node " + this.node.name + "...");

//TokenList incomingTokens = this.takeOfferedTokens();
TokenList removedControlTokens = this.removeJoinedControlTokens(incomingTokens);
ValueList decisionValues = this.getDecisionValues(incomingTokens);

ActivityEdgeInstanceList outgoingEdges = this.outgoingEdges;
for (int i = 0; i < outgoingEdges.size(); i++) {
    ActivityEdgeInstance edgeInstance = outgoingEdges.getValue(i);
    ValueSpecification guard = edgeInstance.edge.guard;

    TokenList offeredTokens = new TokenList();
    for (int j = 0; j < incomingTokens.size(); j++) {
        Token incomingToken = incomingTokens.getValue(j);
        Value decisionValue = decisionValues.getValue(j);
        if (this.test(guard, decisionValue)) {
            offeredTokens.addValue(incomingToken);
        }
    }

    if (offeredTokens.size() > 0) {
        for (int j = 0; j < removedControlTokens.size(); j++) {
            Token removedControlToken = removedControlTokens.getValue(j);
            offeredTokens.addValue(removedControlToken);
        }
        edgeInstance.sendOffer(offeredTokens);
    }
}

```

```
}
```

[3] `getDecisionInputFlowInstance () : ActivityEdgeInstance [0..1]`

```
// Get the activity edge instance for the decision input flow, if any.
ActivityEdge decisionInputFlow = ((DecisionNode)(this.node)).decisionInputFlow;

ActivityEdgeInstance edgeInstance = null;
if (decisionInputFlow != null) {
    int i = 1;
    while (edgeInstance == null & i <= this.incomingEdges.size()) {
        ActivityEdgeInstance incomingEdge = this.incomingEdges.getValue(i-1);
        if (incomingEdge.edge == decisionInputFlow) {
            edgeInstance = incomingEdge;
        }
        i = i + 1;
    }
}

return edgeInstance;
```

[4] `getDecisionInputFlowValue () : Value [0..1]`

```
// Take the next token available on the decision input flow, if any, and return its value.
ActivityEdgeInstance decisionInputFlowInstance = this.getDecisionInputFlowInstance();

Value value = null;
if (decisionInputFlowInstance != null) {
    TokenList tokens = decisionInputFlowInstance.takeOfferedTokens();
    if (tokens.size() > 0) {
        value = ((ObjectToken)(tokens.getValue(0))).value;
    }
}

return value;
```

[5] `getDecisionValues (in incomingTokens : Token [0..*]) : Value [0..*]`

```
// If there is neither a decision input flow nor a decision input behavior, then return
the set of values from the incoming tokens.
// [In this case, the single incoming edge must be an object flow.]
// If there is a decision input flow, but no decision input behavior, then return a list
of the decision input values equal in size to the number of incoming tokens.
// If there is both a decision input flow and a decision input behavior, then execute the
decision input behavior once for each incoming token and return the set of resulting
values.
// If the primary incoming edge is an object flow, then the value on each object token
is passed to the decision input behavior, along with the decision input flow value, if
any.
// If the primary incoming edge is a control flow, then the decision input behavior
only receives the decision input flow, if any.
```

```
Value decisionInputValue = this.getDecisionInputFlowValue();

ValueList decisionValues = new ValueList();
for (int i = 0; i < incomingTokens.size(); i++) {
```



```

    Token incomingToken = incomingTokens.getValue(i);
    Value value = this.executeDecisionInputBehavior(incomingToken.getValue(),
decisionInputValue);
    decisionValues.addValue(value);
}

// Debug.println("[getDecisionValues] " + decisionValues.size() + " decision value(s):");
for (int i = 0; i < decisionValues.size(); i++) {
    Value decisionValue = decisionValues.getValue(i);
    Debug.println("[getDecisionValues] decisionValues[" + i + "] = " + decisionValue);
}

return decisionValues;

```

[6] hasObjectFlowInput () : Boolean

```

// Check that the primary incoming edge is an object flow.

ActivityEdge decisionInputFlow = ((DecisionNode)(this.node)).decisionInputFlow;

boolean isObjectFlow = false;
int i = 1;
while (!isObjectFlow & i <= this.incomingEdges.size()) {
    ActivityEdge edge = this.incomingEdges.getValue(i-1).edge;
    isObjectFlow = edge != decisionInputFlow & edge instanceof ObjectFlow;
    i = i + 1;
}

return isObjectFlow;

```

[7] isReady () : Boolean

```

// Check that all incoming edges have sources that are offering tokens.
// [This should be at most two incoming edges, if there is a decision input flow.]

int i = 1;
boolean ready = true;
while (ready & i <= this.incomingEdges.size()) {
    ready = this.incomingEdges.getValue(i-1).hasOffer();
    i = i + 1;
}

return ready;

```

[8] removeJoinedControlTokens (in incomingTokens : Token [0..*]) : Token [0..*]

```

// If the primary incoming edge is an object flow, then remove any control tokens from the
incoming tokens and return them.
// [Control tokens may effectively be offered on an object flow outgoing from a join node
that has both control and object flows incoming.]

TokenList removedControlTokens = new TokenList();

if (this.hasObjectFlowInput()) {
    int i = 1;
    while (i <= incomingTokens.size()) {
        Token token = incomingTokens.getValue(i-1);
        if (token.isControl()) {
            removedControlTokens.addValue(token);
        }
    }
}

```

```

        incomingTokens.removeValue(i-1);
        i = i - 1;
    }
    i = i + 1;
}
}

```

```
return removedControlTokens;
```

[9] takeOfferedTokens () : Token [0..*]

```
// Get tokens from the incoming edge that is not the decision input flow.
```

```
ObjectFlow decisionInputFlow = ((DecisionNode)(this.node)).decisionInputFlow;
```

```
TokenList allTokens = new TokenList();
ActivityEdgeInstanceList incomingEdges = this.incomingEdges;
for (int i = 0; i < incomingEdges.size(); i++) {
    ActivityEdgeInstance edgeInstance = incomingEdges.getValue(i);
    if (edgeInstance.edge != decisionInputFlow) {
        TokenList tokens = edgeInstance.takeOfferedTokens();
        for (int j = 0; j < tokens.size(); j++) {
            allTokens.addValue(tokens.getValue(j));
        }
    }
}

```

```
return allTokens;
```

[10] terminate ()

```
// Terminate the decision input execution, if any, and then terminate this activation.
```

```
if (this.decisionInputExecution != null) {
    this.decisionInputExecution.terminate();
}

```

```
super.terminate();
```

[11] test (in guard : ValueSpecification, in value : Value) : Boolean

```
// Test if the given value matches the guard. If there is no guard, return true.
```

```
boolean guardResult = true;
if (guard != null) {
    Value guardValue = this.getExecutionLocus().executor.evaluate(guard);
    guardResult = guardValue.equals(value);
}

```

```
return guardResult;
```

8.5.2.2.10 ForkedToken

A forked token is a proxy for a token that has been offered through a fork node. If the token is accepted through the fork node, then the original token is withdrawn from its holder, but the forked token remains held by the fork node activation until all outstanding offers on all outgoing edges are accepted.

Generalizations

- [Token](#)

Attributes

- remainingOffersCount : Integer
The remaining number of outstanding offers for this token on outgoing edges of the fork node.

Associations

- baseToken : Token

Operations

[1] copy () : Token

```
// Return a copy of the base token.
return this.baseToken.copy();
```

[2] equals (in otherToken : Token) : Boolean

```
// Test if this token is equal to another token.
return this == otherToken;
```

[3] getValue () : Value [0..1]

```
// Return the value of the base token.
return this.baseToken.getValue();
```

[4] isControl () : Boolean

```
// Test if the base token is a control token.
return this.baseToken.isControl();
```

[5] withdraw ()

```
// If the base token is not withdrawn, then withdraw it.
// Decrement the remaining offers count.
// When the remaining number of offers is zero, then remove this token from its holder.
if (!this.baseToken.isWithdrawn()) {
    this.baseToken.withdraw();
}

if (this.remainingOffersCount > 0) {
    this.remainingOffersCount = this.remainingOffersCount - 1;
}

if (this.remainingOffersCount == 0) {
    super.withdraw();
}
```

8.5.2.2.11 ForkNodeActivation

A fork node activation is a control node activation for a node that is a fork node.

Generalizations

- [ControlNodeActivation](#)

Attributes

None

Associations

None

Operations

[1] fire (in incomingTokens : Token [0..*])

```
// Create forked tokens for all incoming tokens and offer them on all outgoing edges.
```

```
if (this.node == null) {
    Debug.println("[fire] Anonymous fork node.");
} else {
    Debug.println("[fire] Fork node " + this.node.name + "...");
}
```

```
ActivityEdgeInstanceList outgoingEdges = this.outgoingEdges;
int outgoingEdgeCount = outgoingEdges.size();
```

```
TokenList forkedTokens = new TokenList();
//TokenList tokens = this.takeOfferedTokens();
for (int i = 0; i < incomingTokens.size(); i++) {
    Token token = incomingTokens.getValue(i);
    ForkedToken forkedToken = new ForkedToken();
    forkedToken.baseToken = token;
    forkedToken.remainingOffersCount = outgoingEdgeCount;
    forkedTokens.addValue(forkedToken);
}
```

```
this.addTokens(forkedTokens);
```

```
this.sendOffers(forkedTokens);
```

8.5.2.2.12 InitialNodeActivation

An initial node activation is a control node activation for a node that is an initial node.

Generalizations

- [ControlNodeActivation](#)

Attributes

None

Associations

None

Operations

[1] fire (in incomingTokens : Token [0..*])

```
// Create a single token and send offers for it.

TokenList tokens = new TokenList();
tokens.addValue(new ControlToken());
this.addTokens(tokens);

this.sendOffers(tokens);
```

8.5.2.2.13 JoinNodeActivation

A join node activation is a control node activation for a node that is a join node.

Generalizations

- [ControlNodeActivation](#)

Attributes

None

Associations

None

Operations

[1] isReady(): Boolean

```
// Check that all incoming edges have sources that are offering tokens.

boolean ready = true;
int i = 1;
while (ready & i <=this.incomingEdges.size()) {
    ready = this.incomingEdges.getValue(i-1).hasOffer();
    i = i + 1;
}

return ready;
```

8.5.2.2.14 MergeNodeActivation

A merge node activation is a control node activation for a node that is a merge node.

Generalizations

- [ControlNodeActivation](#)

Attributes

None

Associations

None

Operations

None

8.5.2.2.15 ObjectNodeActivation

An object node activation is an activity node activation for a node that is an object node.

Generalizations

- [ActivityNodeActivation](#)

Attributes

- offeredTokenCount : Integer
The number of held tokens that have already been offered.

Associations

- unofferedTokens : ObjectToken [0..*]
Tokens held by this node activation that have not yet been offered.

Operations

[1] addToken (in token : Token)

```
// Transfer the given token to be held by this node only if it is an object token.  
// If it is a control token, consume it without holding it.
```

```
if (token.isControl()) {  
    token.withdraw();  
} else {  
    super.addToken(token);  
}
```

[2] clearTokens ()

```
// Remove all held tokens.  
  
super.clearTokens();  
this.offeredTokenCount = 0;
```

[3] countUnofferedTokens () : Integer

```
// Return the number of unoffered tokens that are to be offered next.  
// (By default, this is all unoffered tokens.)
```

```
if (this.heldTokens.size() == 0) {  
    this.offeredTokenCount = 0;  
}
```

```
return this.heldTokens.size() - this.offeredTokenCount;
```

[4] getUnofferedTokens () : Token [0..*]

```
// Get the next set of unoffered tokens to be offered and return it.  
// [Note: This effectively treats all object flows as if they have weight=*, rather than  
the weight=1 default in the current superstructure semantics.]
```

```
TokenList tokens = new TokenList();
```

```
int i = 1;  
while (i <= this.countUnofferedTokens()) {  
    tokens.addValue(this.heldTokens.getValue(this.offeredTokenCount + i - 1));  
    i = i + 1;  
}
```

```
return tokens;
```

[5] removeToken (in token : Token) : Integer

```
// Remove the given token, if it is held by this node activation.

int i = super.removeToken(token);
if (i > 0 & i <= this.offeredTokenCount) {
    this.offeredTokenCount = this.offeredTokenCount - 1;
}

return i;
```

[6] run ()

```
// Initialize the offered token count to zero.

super.run();
this.offeredTokenCount = 0;
```

[7] sendUnofferedTokens ()

```
// Send offers over all outgoing edges, if there are any tokens to be offered.

TokenList tokens = this.getUnofferedTokens();
this.offeredTokenCount = this.offeredTokenCount + tokens.size();

this.sendOffers(tokens);
```

[8] takeUnofferedTokens () : Token [0..*]

```
// Take the next set of unoffered tokens to be offered from this node activation and
return them.

TokenList tokens = this.getUnofferedTokens();
for (int i = 0; i < tokens.size(); i++) {
    Token token = tokens.getValue(i);
    token.withdraw();
}
return tokens;
```

[9] terminate ()

```
// Remove any offered tokens and terminate.

this.clearTokens();
super.terminate();
```

8.5.2.2.16 ObjectToken

An object token represents the passing of data along an object flow edge.

Generalizations

- [Token](#)

Attributes

None

Associations

- value : Value [0..1]

The value carried by this token. A token may have no value, in which case it is a "null token".

Operations

[1] copy () : Token

```
// Return a new object token with the same value as this token.  
// [Note: the holder of the copy is not set.]
```

```
ObjectToken copy = new ObjectToken();  
copy.value = this.value;
```

```
return copy;
```

[2] equals (in other : Token) : Boolean

```
// Test if this object token is the same as the other token.
```

```
return this == other;
```

[3] getValue () : Value [0..1]

```
// Return the value of this object token.
```

```
return this.value;
```

[4] isControl () : Boolean

```
// Return false for an object token.
```

```
return false;
```

8.5.2.2.17 Offer

Generalizations

None

Attributes

None

Associations

- offeredTokens : Token [0..*]

Operations

[1] countOfferedTokens () : Integer

```
// Return the number of tokens being offered.
```

```
return this.offeredTokens.size();
```


[2] `getOfferedTokens () : Token [0..*]`

```
// Get the offered tokens.  
  
TokenList tokens = new TokenList();  
TokenList offeredTokens = this.offeredTokens;  
for (int i = 0; i < this.offeredTokens.size() ; i++) {  
    Token offeredToken = offeredTokens.getValue(i);  
    // Debug.println("[getOfferedTokens] token value = " + offeredToken.getValue());  
    tokens.addValue(offeredToken);  
}  
  
return tokens;
```

[3] `removeWithdrawnTokens ()`

```
// Remove any tokens that have already been consumed.  
  
TokenList offeredTokens = this.offeredTokens;  
int i = 1;  
while (i <= this.offeredTokens.size()) {  
    if (this.offeredTokens.getValue(i-1).isWithdrawn()) {  
        this.offeredTokens.remove(i-1);  
        i = i - 1;  
    }  
    i = i + 1;  
}
```

8.5.2.2.18 Token

A token is an individual element of data or control that may flow across an activity edge.

Generalizations

None

Attributes

None

Associations

- holder : ActivityNodeActivation [0..1]

Operations

[1] `copy () : Token`

```
// Make a copy of this token.
```

[2] `equals (in other : Token) : Boolean`

Test if this token is equal to another token.

[3] `getValue () : Value [0..1]`

Get the value associated with this token (if any).

[4] `isControl ()` : Boolean

Test whether this is a control token.

[5] `isWithdrawn ()` : Boolean

```
// Test if this token has been withdrawn.
```

```
return this.holder == null;
```

[6] `transfer (in holder : ActivityNodeActivation)` : Token

```
// if this token does not have any holder, make the given holder its holder.  
// Otherwise, remove this token from its holder and return a copy of it transferred to a  
new holder.
```

```
Token token = this;  
if (this.holder != null) {  
    this.withdraw();  
    token = this.copy();  
}
```

```
token.holder = holder;  
return token;
```

[7] `withdraw ()`

```
// Remove this token from its holder, withdrawing any offers for it.
```

```
if (!this.isWithdrawn()) {  
    // Debug.println("[withdraw] Taking token with value = " + this.getValue());  
    this.holder.removeToken(this);  
    this.holder = null;  
}
```

8.5.3 Complete Structured Activities

8.5.3.1 Overview

The fUML subset includes base structured activity nodes and the specialized conditional and loop nodes (see Subclause 7.4.3). However, since fUML does not support variables and, therefore, requires the use of pins and object flows, only the full Complete Structured Activities abstract syntax is supported as a conformance level in fUML (see Clause 2). The basic Structured Activities syntax is not supported on its own.

Structured Activity Node Activation

In the Complete Structure Activities abstract syntax, structure activity nodes actually become kinds of actions. Therefore, as shown in Figure 71, their semantics are specified using action activations (see Subclause 8.6.2.1 for a general discussion of action activation semantics). However, unlike other kinds of nodes, structured activity nodes have nested activity nodes within them. The activation of the nested activity nodes is handled by an activity node activation group associated with the structured activity node activation (see Subclause 8.5.2 for the specification of `ActivityNodeActivationGroup`).

Note that all structured activity node activations have *exactly one* activation group which covers the activation of all nested activity nodes. However, how nested activity nodes are actually activated varies depending on the kind of structured activity node.

For the base structured activity node, which simply groups its nested activity nodes, execution proceeds much as in the case of an overall activity. All nested activity nodes are activated, and subsequent behavior is determined by the flow of offers and tokens between activations.

For a conditional node, however, the test part is activated first. Depending on the result of the test, additional nodes are activated depending on which conditional clause is selected.

For a loop node, the loop test and body parts are repeatedly activated (with the test coming before or after the body, depending on the `isTestedFirst` attribute of the loop node). The same activity node activation group is used for every iteration of the loop, but the group is cleared of node activations between iterations.

Isolation

If a structured activity node has the property `mustIsolate = true`, then its activity node activations run in *isolation* from activity node activation external to it. The UML Superstructure Specification (Subclause 12.3.48) defines this behavior as follows:

If the `mustIsolate` flag is true for an activity node, then any access to an object by an action within the node must not conflict with access to the object by an action outside the node. A conflict is defined as an attempt to write to the object by one or both of the actions. If such a conflict potentially exists, then no such access by an action outside the node may be interleaved with the execution of the node.

For the purposes of fUML, however, it is important to define this important optional behavior somewhat more completely.

The following definitions apply for the purposes of this discussion.

- An *execution trace* provides timing for all the events in the execution of a model.
- The *duration* of a firing of an action activation is the time interval from the event of the action activation firing to the event of the action activation offering tokens on outgoing control flows (even if there are no outgoing control flows, the duration ends at that point in time at which the firing of the action activation is “complete” and would offer control tokens if there were flows.) A *legal* execution trace is one that is permitted by the behavioral semantics specified for executing the model. Note that there can, and generally will, be multiple possible legal execution traces for any given model.
- Two action activation firings *overlap* if their durations are not disjoint.
- An action activation A is *serializable* with respect to another action activation B if, for any legal execution trace in which one or more of the firings of A and B overlap, there is another legal execution trace in which none of their firings overlap but for which the execution behavior of the firings of B are identical to that of the first trace. (Note that the behavior of A does *not* have to be preserved in the second trace. This means that A being serializable with respect to B does *not* necessarily imply that B is serializable with respect to A.)
- The *scope of control* of an activity execution or a structured activity node activation firing is defined to be the set of activity node activations covered by the following:
 1. For a structured activity node activation, that activation itself.
 2. All activations of nested activity nodes with the activity or structured activity node that are run as a result of that specific activity execution or structured activity node activation firing. (In the execution model, this is called the “activity node activation group”.)
 3. The scope of control of the firing of any nested structured activity node activations.
 4. The scope of control of any activity executions resulting from the firing of any nested call (behavior or operation) actions (which, in fUML, are always synchronous).

The rule for isolation can now be stated fairly simply: Let S be a structured activity node with `mustIsolate=true`. Then any action activation *not* in the scope of control of S must be serializable with respect to any action activation that is within the scope of control of S.

Basically, under this rule, any action behavior not under the control of S, even if it physically happens in parallel with an execution of S, has the same effect on S as if it occurred entirely before or entirely after the execution of S. In particular, any actions that write to objects read within S must either have their effect visible throughout the execution of S (“as if it occurred entirely before the execution of S”) or their effect must not be visible at all within the execution of S (“as if it occurred entirely after the execution of S”). (This is similar to the way that “isolation” is defined for database transactional semantics.)

Note that the asymmetric definition of “serializable” above means that, in general, an action activation not under the control of S *can* see into intermediate results produced by S (in database terminology, this is known as a “dirty read”), unless it, too, is part of some other structured activity node with `mustIsolate=true`. For two structured activity nodes to run in complete isolation with respect to each other, *both* must specify `mustIsolate=true`.

Note also that the above rule does *not* allow certain deadlock conditions that can occur due to specific implementation techniques, such as locking. For example, there is the archetypical case in which two concurrent threads are each holding locks which the other needs, and so neither can proceed. However, in most such cases, there *is* a legal execution trace in which these threads *could* have successfully executed (e.g., if they were run sequentially instead of concurrently). The intent is that the execution trace leading to deadlock would *not* be legal at all, since it is only the locking implementation that leads to the deadlock, not anything specified by the behavioral semantics. In particular, this means that, if an execution tool uses locking to implement isolation, then it also must provide some means to detect implementation-specific deadlock conditions and recover from them (again, this is typically what is done in database transaction implementations).

On the other hand, there are cases in which deadlock cannot be avoided. For example, suppose a structured activity node with `mustIsolate = true` contains just two read actions. The first read action has an outgoing control flow that crosses out of the structured activity node to a write action on the outside that writes to the object read by the read actions. If the write action then has an outgoing control flow that crosses back into the structured activity node to the second read action, it is impossible to satisfy both the control flow constraints and the isolation rule. Such a model has *no* legal control flows. Per the UML Superstructure Specification, it is actually ill-formed and has no execution semantics.

NOTE: The above semantics for `mustIsolate = true` are intended to allow the simple implementation of approach of serializing the execution of all structured activity nodes with `mustIsolate = true`—that is, running them sequentially, one at a time, with nothing else running at the same time. One subtlety here is the case when an execution of one or more of the isolated structured activity nodes does not terminate, due to, say, an infinite loop. In this case, there may not be any finite execution trace in which all isolated structured activity nodes can complete sequentially. However, since there are no particular requirements in the fUML semantics for liveness or fairness in concurrent execution, it is generally permissible in any case for an implementation to allow a concurrent thread that does not terminate to continue to use all resources and not allow any other threads to run. Therefore, the rule above for isolation is not meant to disallow a fully serialized implementation.

The above rule for isolation is part of the base semantics of the modeling subset used to write the execution model itself (see Subclause 10.4.5). Therefore, structured activity nodes with `mustIsolate = true` may be used within the execution model. For fUML user models being executed by the execution model, the effect of `mustIsolate = true` is achieved by activating the body of the fUML structured activity node within a structured activity node in the execution mode with `mustIsolate = true`. This results in the body of the structured activity node being run in isolation from other threads running within the executing fUML activity, resulting in the base isolation behavior being elevated to fUML.

In order to accommodate this optional isolation behavior, the class `StructuredActivityNodeActivation` provides a method for the operation `doAction` in terms of an operation called `doStructuredActivity`. The operation `StructuredActivityActivation::doAction` checks the `mustIsolate` flag for the structured activity node being executed. If it is true, then `doAction` calls `doStructuredActivity` within a structured activity node with `mustIsolate = true`. If `mustIsolate = false`, then `doAction` still calls `doStructuredActivity`, but not within an isolated structured activity node.

The classes `ConditionalNodeActivation` and `LoopNodeActivation` specialize `StructuredActivityNodeActivation` (see Figure 71)). They both override the operation `doStructuredActivity` to specify the behavior specific to conditional nodes

- conditionalNodeActivation : ConditionalNodeActivation

The activation of the conditional node that contains the clause for this clause activation.

Operations

[1] getDecision () : BooleanValue [0..1]

// Get the value (if any) on the decider pin of the clause for this clause activation.

```
ValueList deciderValues =
this.conditionalNodeActivation.getPinValues(this.clause.decider);
```

```
BooleanValue deciderValue = null;
if (deciderValues.size() > 0) {
    deciderValue = (BooleanValue)(deciderValues.getValue(0));
}
```

```
return deciderValue;
```

[2] getPredecessors () : ClauseActivation [0..*]

// Return the clause activations for the predecessors of the clause for this clause activation.

```
ClauseActivationList predecessors = new ClauseActivationList();
```

```
ClauseList predecessorClauses = this.clause.predecessorClause;
for (int i = 0; i < predecessorClauses.size(); i++) {
    Clause predecessorClause = predecessorClauses.getValue(i);
    predecessors.addValue(this.conditionalNodeActivation.getClauseActivation(predecessorClause));
}
```

```
return predecessors;
```

[3] getSuccessors () : ClauseActivation [0..*]

// Return the clause activations for the successors of the clause for this clause activation.

```
ClauseActivationList successors = new ClauseActivationList();
```

```
ClauseList successorClauses = this.clause.successorClause;
for (int i = 0; i < successorClauses.size(); i++) {
    Clause successorClause = successorClauses.getValue(i);
    successors.addValue(this.conditionalNodeActivation.getClauseActivation(successorClause));
}
```

```
return successors;
```

[4] isReady () : Boolean

// Test if all predecessors to this clause activation have failed.

```
ClauseActivationList predecessors = this.getPredecessors();
```

```

boolean decision = true;
int i = 1;
while (decision & i <= predecessors.size()) {
    ClauseActivation predecessor = predecessors.getValue(i-1);
    BooleanValue decisionValue = predecessor.getDecision();

    // Note that the decision will be null if the predecessor clause has not run yet.
    if (decisionValue == null) {
        decision = false;
    } else {
        decision = decisionValue.value;
    }

    i = i + 1;
}

return decision;

```

[5] receiveControl ()

```

// If all predecessors to the clause for this activation have run their tests and failed,
// then run the test for this clause.
// If the test succeeds, then terminate any other clauses that may be running and run the
// body of this clause.
// If the test fails, then pass control to successor clauses.

if (this.isReady()) {
    this.runTest();

    BooleanValue decision = this.getDecision();

    // Note that the decision may be null if the test was terminated before completion.
    if (decision != null) {
        if (decision.value == true) {
            this.selectBody();
        } else {
            ClauseActivationList successors = this.getSuccessors();

            // *** Give control to all successors concurrently. ***
            for (Iterator i = successors.iterator(); i.hasNext();) {
                ClauseActivation successor = (ClauseActivation)i.next();
                successor.receiveControl();
            }
        }
    }
}

```

[6] runTest ()

```

// Run the test of the clause for this clause activation.

this.conditionalNodeActivation.runTest(this.clause);

```

[7] selectBody ()

```

// Select the body of the clause for this clause activation.

```

```
this.conditionalNodeActivation.selectBody(this.clause);
```

8.5.3.2.2 ConditionalNodeActivation

A conditional node activation is a structured activity node activation for a node that is a conditional node.

Generalizations

- [StructuredActivityNodeActivation](#)

Attributes

None

Associations

- `clauseActivations` : `ClauseActivation` [0..*]
The activations for each clause in the conditional node for this node activation.
- `selectedClauses` : `Clause` [0..*]
The set of clauses which meet the conditions to have their bodies activated.

Operations

[1] `doStructuredActivity()`

```
// Activate all clauses in the conditional node and pass control to those that are ready
// (i.e., have no predecessors).
// If one or more clauses have succeeded in being selected, choose one non-
// deterministically and run its body, then copy the outputs of that clause to the output
// pins of the node.
```

```
ConditionalNode node = (ConditionalNode)(this.node);
this.clauseActivations.clear();
```

```
ClauseList clauses = node.clause;
for (int i = 0; i < clauses.size(); i++) {
    Clause clause = clauses.getValue(i);
    ClauseActivation clauseActivation = new ClauseActivation();
    clauseActivation.clause = clause;
    this.clauseActivations.addValue(clauseActivation);
}
```

```
this.selectedClauses.clear();
```

```
ClauseActivationList readyClauseActivations = new ClauseActivationList();
for (int i = 0; i < this.clauseActivations.size(); i++) {
    ClauseActivation clauseActivation = this.clauseActivations.getValue(i);
    if (clauseActivation.isReady()) {
        readyClauseActivations.addValue(clauseActivation);
    }
}
```

```
// *** Give control to all ready clauses concurrently. ***
for (Iterator i = readyClauseActivations.iterator(); i.hasNext(); ) {
    ClauseActivation clauseActivation = (ClauseActivation)i.next();
    clauseActivation.receiveControl();
}
```

```
this.activationGroup.terminateAll();
```

```
if (this.selectedClauses.size() > 0 & this.isRunning()) {
    // *** If multiple clauses are selected, choose one non-deterministically. ***
}
```



```

    int i =
    ((ChoiceStrategy) this.getExecutionLocus().factory.getStrategy("choice")).choose(this.selectedClauses.size());
    Clause selectedClause = this.selectedClauses.getValue(i-1);

    this.activationGroup.runNodes(this.makeActivityNodeList(selectedClause.body));

    OutputPinList resultPins = node.result;
    OutputPinList bodyOutputPins = selectedClause.bodyOutput;
    for (int k = 0; k < resultPins.size(); k++) {
        OutputPin resultPin = resultPins.getValue(k);
        OutputPin bodyOutputPin = bodyOutputPins.getValue(k);
        this.putTokens(resultPin, this.getPinValues(bodyOutputPin));
    }
}

```

[2] getClassActivation (in clause : Clause) : ClauseActivation

```

// Get the clause activation corresponding to the given clause.

ClauseActivation selectedClauseActivation = null;
int i = 1;
while ((selectedClauseActivation == null) & i <= this.clauseActivations.size()) {
    ClauseActivation clauseActivation = this.clauseActivations.getValue(i-1);
    if (clauseActivation.clause == clause) {
        selectedClauseActivation = clauseActivation;
    }
    i = i + 1;
}

return selectedClauseActivation;

```

[3] runTest (in clause : Clause)

```

// Run the test for the given clause.

if (this.isRunning()) {
    this.activationGroup.runNodes(this.makeActivityNodeList(clause.test));
}

```

[4] selectBody (in clause : Clause)

```

// Add the clause to the list of selected clauses.

this.selectedClauses.addValue(clause);

```

8.5.3.2.3 LoopNodeActivation

A loop node activation is a structured activity node activation for a node that is a loop node.

Generalizations

- [StructuredActivityNodeActivation](#)

Attributes

None

Associations

- bodyOutputLists : Values [0..*]

Operations

[1] createNodeActivations ()

```
// In addition to creating activations for contained nodes, create activations for any loop variables.
```

```
super.createNodeActivations();
this.activationGroup.createNodeActivations(this.makeLoopVariableList());
```

[2] doStructuredActivity ()

```
// Set the loop variables to the values of the loop variable input pins.
// If isTestedFirst is true, then repeatedly run the test part and the body part of the loop, copying values from the body outputs to the loop variables.
// If isTestedFirst is false, then repeatedly run the body part and the test part of the loop, copying values from the body outputs to the loop variables.
// When the test fails, copy the values of the loop variables to the loop outputs.
```

```
LoopNode loopNode = (LoopNode)(this.node);
```

```
this.runLoopVariables();
```

```
InputPinList loopVariableInputs = loopNode.loopVariableInput;
OutputPinList loopVariables = loopNode.loopVariable;
for (int i = 0; i < loopVariables.size(); i++) {
    OutputPin loopVariable = loopVariables.getValue(i);
    InputPin loopVariableInput = loopVariableInputs.getValue(i);
    this.putPinValues(loopVariable, this.takeTokens(loopVariableInput));
}
```

```
boolean continuing = true;
```

```
do {
    if (loopNode.isTestedFirst) {
        continuing = this.runTest();
        if (continuing) {
            this.runBody();
        }
    }
    else {
        this.runBody();
        continuing = this.runTest();
    }
}
```

```
if (continuing) {
```

```
    this.activationGroup.terminateAll();
```

```
    this.bodyOutputLists.clear();
```

```
    OutputPinList bodyOutputs = loopNode.bodyOutput;
    for (int i = 0; i < bodyOutputs.size(); i++) {
        OutputPin bodyOutput = bodyOutputs.getValue(i);
        Values bodyOutputList = new Values();
        bodyOutputList.values = this.getPinValues(bodyOutput);
        this.bodyOutputLists.addValue(bodyOutputList);
    }
}
```

```

        this.runLoopVariables();

        for (int i = 0; i < loopVariables.size(); i++) {
            OutputPin loopVariable = loopVariables.getValue(i);
            Values bodyOutputList = this.bodyOutputLists.getValue(i);
            ValueList values = bodyOutputList.values;
            this.putPinValues(loopVariable, values);
        }
    }

} while (continuing);

OutputPinList resultPins = loopNode.result;
for (int i = 0; i < loopVariables.size(); i++) {
    OutputPin loopVariable = loopVariables.getValue(i);
    OutputPin resultPin = resultPins.getValue(i);
    this.putTokens(resultPin, this.getPinValues(loopVariable));
}

```

[3] makeLoopVariableList () : ActivityNode [0..*]

// Return an activity node list containing the loop variable pins for the loop node of this activation.

```

LoopNode loopNode = (LoopNode) (this.node);
ActivityNodeList nodes = new ActivityNodeList();

OutputPinList loopVariables = loopNode.loopVariable;
for (int i = 0; i < loopVariables.size(); i++) {
    OutputPin loopVariable = loopVariables.getValue(i);
    nodes.addValue(loopVariable);
}

return nodes;

```

[4] runBody ()

// Run the body part of the loop node for this node activation.

```

this.activationGroup.runNodes(this.makeActivityNodeList(((LoopNode)
(this.node)).bodyPart));

```

[5] runLoopVariables ()

// Run the loop variable pins of the loop node for this node activation.

```

this.activationGroup.runNodes(this.makeLoopVariableList());

```

[6] runTest () : Boolean

// Run the test part of the loop node for this node activation.
// Return the value on the decider pin.

```

LoopNode loopNode = (LoopNode) (this.node);

```

```
this.activationGroup.runNodes(this.makeActivityNodeList(loopNode.test));  
return ((BooleanValue)(this.getPinValues(loopNode.decider).getValue(0))).value;
```

8.5.3.2.4 StructuredActivityNodeActivation

A structured activity node activation is an action activation for an action that is a structured activity node.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

- activationGroup : ActivityNodeActivationGroup
The group of activations of the activity nodes contained in the structured activity node.

Operations

[1] createEdgeInstances ()

```
// Create instances for all edges owned by this node.
```

```
this.activationGroup.createEdgeInstances(((StructuredActivityNode)(this.node)).edge);
```

[2] createNodeActivations ()

```
// Create an activation group and create node activations for all the nodes within the  
structured activity node.
```

```
this.activationGroup = new ActivityNodeActivationGroup();  
this.activationGroup.containingNodeActivation = this;  
this.activationGroup.createNodeActivations(((StructuredActivityNode)(this.node)).node);
```

[3] doAction ()

```
// If the structured activity node has mustIsolate=true, then carry out its behavior with  
isolation.
```

```
// Otherwise just activate it normally.
```

```
if (((StructuredActivityNode)(this.node)).mustIsolate) {  
    _beginIsolation();  
    this.doStructuredActivity();  
    _endIsolation();  
} else {  
    this.doStructuredActivity();  
}
```

[4] doStructuredActivity ()

```
// Run all activations of contained nodes. When this is complete, return.
```

```
// (This is the default behavior for a structured activity node used simply as a group. It
is overridden for the execution of conditional and loop nodes.)
```

```
this.activationGroup.run(this.activationGroup.nodeActivations);
```

[5] `getNodeActivation (in node : ActivityNode) : ActivityNodeActivation [0..1]`

```
// If this structured activity node activation is not for the given node, then check if
there is an activation for the node in the activation group.
```

```
ActivityNodeActivation thisActivation = super.getNodeActivation(node);
```

```
ActivityNodeActivation activation;
if (thisActivation != null) {
    activation = thisActivation;
} else {
    activation = this.activationGroup.getNodeActivation(node);
}
```

```
return activation;
```

[6] `getPinValues (in pin : OutputPin) : Value [0..*]`

```
// Return the values of the tokens on the pin activation corresponding to the given pin in
the internal activation group for this node activation.
```

```
PinActivation pinActivation = (PinActivation)
(this.activationGroup.getNodeActivation(pin));
TokenList tokens = pinActivation.getTokens();
```

```
ValueList values = new ValueList();
for (int i = 0; i < tokens.size(); i++) {
    Token token = tokens.getValue(i);
    Value value = ((ObjectToken)token).value;
    if (value != null) {
        values.addValue(value);
    }
}
```

```
return values;
```

[7] `makeActivityNodeList (in nodes : ExecutableNode [0..*]) : ActivityNode [0..*]`

```
// Return an activity node list containing the given list of executable nodes.
```

```
ActivityNodeList activityNodes = new ActivityNodeList();
```

```
for (int i = 0; i < nodes.size(); i++) {
    ActivityNode node = nodes.getValue(i);
    activityNodes.addValue((ActivityNode)node);
}
```

```
return activityNodes;
```

[8] `putPinValues (in pin : OutputPin, in values : Value [0..*])`

```
// Place tokens for the given values on the pin activation corresponding to the given
output pin on the internal activation group for this node activation.
```

```

PinActivation pinActivation = (PinActivation)
(this.activationGroup.getNodeActivation(pin));

for (int i = 0; i < values.size(); i++) {
    Value value = values.getValue(i);
    ObjectToken token = new ObjectToken();
    token.value = value;
    pinActivation.addToken(token);
}

```

[9] terminate ()

```

// Terminate the execution of all contained node activations (which completes the
performance of the structured activity node activation).

```

```

this.activationGroup.terminateAll();
super.terminate();

```

8.5.3.2.5 Values

Generalizations

None

Attributes

None

Associations

- values : Value [0..*]

Operations

None

8.5.4 Extra Structured Activities

8.5.4.1 Overview

Collections

The fUML subset includes only expansion regions from the Extra Structure Activities abstract syntax package (see Subclause 7.4.4).

The UML 2 Superstructure Specification (Subclause 12.3.27) defines the semantics of expansion regions in which “each input is a collection of values.” However, neither the fUML subset nor the Foundation Model Library provide a standard set of collection types. Instead, fUML relies on the use of properties with multiplicity upper bounds greater than zero to provide the ability to model collections.

Therefore, rather than an expansion node being expected to receive a single token with a collection value, in fUML the “collection” is made up of the values on a *set* of tokens accepted by the expansion node. An expansion region fires when its input expansion node accepts an offer for such a collection of tokens. If the region has more than one input expansion region, then all must accept the same number of tokens for the region to fire.

Similarly, the output expansion nodes of the region (if any) collect tokens generated during the iterations of the body of the region. When the expansion region completes, the tokens on its output expansion nodes are offered downstream in the normal fashion.

Expansion Region Activation

An expansion region is a kind of structured activity node and, therefore, a kind of action. However, because the semantics of expansion regions are rather different than those of other structured activity nodes, `ExpansionRegionActivation` does not specialize `StructuredActivityNodeActivation` but, rather, directly specializes `ActionActivation` (see Figure 72). There is also an `ExpansionNodeActivation` class to capture the specialized semantics of expansion nodes.

Unlike other structured activity nodes (as described in Subclause 8.5.3), an expansion region activation may have *multiple* activity node activation groups. This is to allow for the possible parallel activation of the body of the expansion region, if so specified for the expansion region. In addition, the activity node activation groups for an expansion region activation are all instances of the specialized `ExpansionActivationGroup`. This specialization handles the semantic relationship between the pins and expansion nodes of the expansion region and the nested activity nodes in the body of the expansion region.

Note, in particular, that an expansion activation group defines *output* pin activations corresponding to the *input* pins and expansion nodes of the expansion region. This is to allow these output pin activations to be connected to input pin activations within the expansion activation group. Tokens are placed on the output pin activations for input values to be sent into the group and they then flow to the appropriate input pins within the group via the normal token/offer semantics.

An expansion activation group also defines output pin activations on which the outputs of the group are placed, corresponding to the output expansion nodes of the expansion region. (An expansion region in fUML is not allowed to have output pins—see Subclause 7.4.4.)

Since an expansion region is syntactically a kind of structured activity node, it includes the option of running its body in isolation (i.e., with `mustIsolate = true`). However, since `ExpansionRegionActivation` does not specialize `StructuredActivityNodeActivation`, it does not automatically inherit the behavior defined in `StructuredActivityNodeActivation` for isolation (see Subclause 8.5.2.1). Nevertheless, the class `ExpansionRegionActivation` uses a similar pattern to `StructuredActivityActivation` to handle isolation. That is, `ExpansionRegionActivation::doAction` checks whether `mustIsolate = true` for the associated expansion region and, if so, it calls `ExpansionRegionActivation::doStructuredActivity` within a structured activity node with `mustIsolate = true`. Otherwise it calls `doStructuredActivity` with no isolation.

Attributes

None

Associations

- `groupInputs : OutputPinActivation [1..*]`
Output pin activations corresponding, in order, to the input expansion nodes of the expansion region of this activation group.
- `groupOutputs : OutputPinActivation [0..*]`
Output pin activations corresponding, in order, to the output expansion nodes of the expansion region of this activation group.
- `regionActivation : ExpansionRegionActivation`
- `regionInputs : OutputPinActivation [0..*]`
Output pin activations corresponding, in order, to the input pins of the expansion region of this activation group.

Operations

[1] `getNodeActivation (in node : ActivityNode) : ActivityNodeActivation`

```
// If the given node is an input pin of the expansion region, then return the
corresponding region-input output-pin activation.
// If the given node is an input expansion node of the expansion region, then return the
corresponding group-input output-pin activation.
// If the given node is an output expansion node of the expansion region, then return the
corresponding group-output output-pin activation.
// Otherwise return the node activation from the activation group, as usual.
```

```
ExpansionRegion region = (ExpansionRegion)(this.regionActivation.node);
```

```
InputPinList inputs = region.input;
ActivityNodeActivation activation = null;
```

```
int i = 1;
while (activation == null & i <= region.input.size()) {
    if (node == region.input.getValue(i-1)) {
        activation = this.regionInputs.getValue(i-1);
    }
    i = i + 1;
}
```

```
int j = 1;
while (activation == null & j <= region.inputElement.size()) {
    if (node == region.inputElement.getValue(j - 1)) {
        activation = this.groupInputs.getValue(j - 1);
    }
    j = j + 1;
}
```

```
int k = 1;
while (activation == null & k <= region.outputElement.size()) {
    if (node == region.outputElement.getValue(k - 1)) {
        activation = this.groupOutputs.getValue(k - 1);
    }
    k = k + 1;
}
```

```
if (activation == null) {
    activation = super.getNodeActivation(node);
}
```

```
}  
return activation;
```

8.5.4.2.2 ExpansionNodeActivation

Generalizations

- [ObjectNodeActivation](#)

Attributes

None

Associations

None

Operations

[1] countUnofferedTokens () : Integer

```
// Count the number of tokens being offered to the expansion node.  
  
int totalTokenCount = super.countUnofferedTokens();  
int i = 1;  
while (i <= this.incomingEdges.size()) {  
    totalTokenCount = totalTokenCount + this.incomingEdges.getValue(i-  
1).countOfferedTokens();  
    i = i + 1;  
}  
  
return totalTokenCount;
```

[2] fire (in incomingTokens : Token [0..*])

```
// Take tokens from all incoming edges.  
  
Debug.println("[fire] Expansion node " + this.node.name + "...");  
  
this.addTokens(incomingTokens);
```

[3] getExpansionRegionActivation () : ExpansionRegionActivation

```
// Return the expansion region activation corresponding to this expansion node, in the  
context of the activity node activation group this expansion node activation is in.  
  
ExpansionNode node = (ExpansionNode) (this.node);  
  
ExpansionRegion region = node.regionAsInput;  
if (region == null) {  
    region = node.regionAsOutput;  
}  
  
return (ExpansionRegionActivation) (this.group.getNodeActivation(region));
```

[4] isReady () : Boolean

```

// An expansion node is always fired by its expansion region.
return false;

[5] receiveOffer ()

// Forward the offer on to the expansion region.
this.getExpansionRegionActivation().receiveOffer();

```

8.5.4.2.3 ExpansionRegionActivation

An expansion region activation is an action activation for a node that is an expansion region.

[Note that even though an expansion region is a structured activity node, an expansion region activation is not a structured activity activation because of the special nature of expansion region behavior.]

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

- activationGroups : ExpansionActivationGroup [0..*]
- inputExpansionTokens : TokenSet [1..*]
- inputTokens : TokenSet [0..*]

Operations

[1] activateGroup (in activationGroup : ExpansionActivationGroup)

```

// Activate the given group (which must be one of the groups for this region activation)
and then fire the group outputs.

```

```

ExpansionRegion region = (ExpansionRegion)(this.node);
activationGroup.activate(region.node, region.edge);

```

```

OutputPinActivationList groupOutputs = activationGroup.groupOutputs;
for (int i = 0; i < groupOutputs.size(); i++) {
    OutputPinActivation groupOutput = groupOutputs.getValue(i);
    groupOutput.fire(groupOutput.takeOfferedTokens());
}

```

```

activationGroup.terminateAll();

```

[2] doAction ()

```

// If the expansion region has mustIsolate=true, then carry out its behavior with
isolation.
// Otherwise just activate it normally.

```

```

if (((StructuredActivityNode)(this.node)).mustIsolate) {

```

```

    _beginIsolation();
        this.doStructuredActivity();
    _endIsolation();
} else {
    this.doStructuredActivity();
}

```

[3] doStructuredActivity ()

```

// Activate the body of the region in each group, either iteratively or in parallel.
// Add the outputs of each activation group to the corresponding output expansion node
activations.

ExpansionRegion region = (ExpansionRegion)(this.node);
ExpansionActivationGroupList activationGroups = this.activationGroups;

if (region.mode == ExpansionKind.iterative) {
    for (int i = 0; i < activationGroups.size(); i++) {
        ExpansionActivationGroup activationGroup = activationGroups.getValue(i);
        this.activateGroup(activationGroup);
    }
}
else if (region.mode == ExpansionKind.parallel) {
    // *** Activate all groups concurrently. ***
    for (Iterator i = activationGroups.iterator(); i.hasNext();) {
        ExpansionActivationGroup activationGroup = (ExpansionActivationGroup)i.next();
        this.activateGroup(activationGroup);
    }
}

ExpansionNodeList outputElements = region.outputElement;

for (int i = 0; i < activationGroups.size(); i++) {
    ExpansionActivationGroup activationGroup = activationGroups.getValue(i);
    OutputPinActivationList groupOutputs = activationGroup.groupOutputs;
    for (int j = 0; j < groupOutputs.size(); j++) {
        OutputPinActivation groupOutput = groupOutputs.getValue(j);
        ExpansionNode outputElement = outputElements.getValue(j);
        this.getExpansionNodeActivation(outputElement).addTokens(groupOutput.takeTokens());
    }
}

```

[4] getExpansionNodeActivation (in node : ExpansionNode) : ExpansionNodeActivation

```

// Return the expansion node activation corresponding to the given expansion node, in the
context of the activity node activation group this expansion region activation is in.
// [Note: Expansion regions do not own their expansion nodes. Instead, they are own as
object nodes by the enclosing activity or group.
// Therefore, they will already be activated along with their expansion region.]

return (ExpansionNodeActivation)(this.group.getNodeActivation(node));

```

[5] isReady () : Boolean

```
// In addition to the usual ready checks for an action, check that all expansion nodes
have the same number of inputs (greater than zero).
```

```
ExpansionRegion region = (ExpansionRegion)(this.node);
```

```
boolean ready = false;
```

```
if (super.isReady()) {
```

```
    int n = this.numberOfValues(); // This gets the number of values on the first
expansion node.
```

```
    if (n < 1) {
```

```
        ready = false;
```

```
    }
```

```
    else {
```

```
        int i = 1;
```

```
        while (ready & i<= region.inputElement.size()) {
```

```
            ready = (this.getExpansionNodeActivation(region.inputElement.getValue(i-
1)).countUnofferedTokens() == n);
```

```
            i = i + 1;
```

```
        }
```

```
    }
```

```
}
```

```
return ready;
```

[6] numberOfValues () : Integer

```
// Return the number of values on the first input expansion node of the expansion region
of this activation.
```

```
// (The region is required to have at least one input expansion node.)
```

```
ExpansionRegion region = (ExpansionRegion)(this.node);
```

```
return
```

```
this.getExpansionNodeActivation(region.inputElement.getValue(0)).countUnofferedTokens();
```

[7] sendOffers ()

```
// Fire all output expansion nodes and send offers on all outgoing control flows.
```

```
ExpansionRegion region = (ExpansionRegion)(this.node);
```

```
// *** Send offers from all output expansion nodes concurrently. ***
```

```
ExpansionNodeList outputElements = region.outputElement;
```

```
for (Iterator i = outputElements.iterator(); i.hasNext();) {
```

```
    ExpansionNode outputElement = (ExpansionNode)i.next();
```

```
    this.getExpansionNodeActivation(outputElement).sendUnofferedTokens();
```

```
}
```

```
// Send offers on all outgoing control flows.
```

```
super.sendOffers();
```

[8] takeOfferedTokens () : Token [0..*]

```
// Create a number of expansion region activation groups equal to the number of values
```

expanded in the region, setting the region inputs and group inputs for each group.

```
ExpansionRegion region = (ExpansionRegion)(this.node);
InputPinList inputPins = region.input;
ExpansionNodeList inputElements = region.inputElement;

this.inputTokens.clear();
this.inputExpansionTokens.clear();

for (int i = 0; i < inputPins.size(); i++) {
    InputPin inputPin = inputPins.getValue(i);
    TokenSet tokenSet = new TokenSet();
    tokenSet.tokens = this.getPinActivation(inputPin).takeTokens();
    this.inputTokens.addValue(tokenSet);
}

for (int i = 0; i < inputElements.size(); i++) {
    ExpansionNode inputElement = inputElements.getValue(i);
    ExpansionNodeActivation expansionNodeActivation =
this.getExpansionNodeActivation(inputElement);
    expansionNodeActivation.fire(expansionNodeActivation.takeOfferedTokens());
    TokenSet tokenSet = new TokenSet();
    tokenSet.tokens = expansionNodeActivation.takeTokens();
    this.inputExpansionTokens.addValue(tokenSet);
}

int k = 1;
int n = this.numberOfValues();
while (k <= n) {
    ExpansionActivationGroup activationGroup = new ExpansionActivationGroup();
    activationGroup.regionActivation = this;
    this.activationGroups.addValue(activationGroup);

    TokenSetList inputTokens = this.inputTokens;
    for (int j = 0; j < inputTokens.size(); j++) {
        TokenSet tokenSet = inputTokens.getValue(j);
        OutputPinActivation regionInput = new OutputPinActivation();
        regionInput.addTokens(tokenSet.tokens);
        activationGroup.regionInputs.addValue(regionInput);
    }

    TokenSetList inputExpansionTokens = this.inputExpansionTokens;
    for (int j = 0; j < inputExpansionTokens.size(); j++) {
        TokenSet tokenSet = inputExpansionTokens.getValue(j);
        OutputPinActivation groupInput = new OutputPinActivation();
        groupInput.addToken(tokenSet.tokens.getValue(k));
        activationGroup.groupInputs.addValue(groupInput);
    }

    k = k + 1;
}

return new TokenList();
```

[9] terminate ()

// Terminate the execution of all contained node activations (which completes the performance of the expansion region activation).

```
ExpansionActivationGroupList activationGroups = this.activationGroups;
for (int i = 0; i < activationGroups.size(); i++) {
    ExpansionActivationGroup activationGroup = this.activationGroups.getValue(i);
```

```
    activationGroup.terminateAll();
}

super.terminate();
```

8.5.4.2.4 TokenSet

Generalizations

None

Attributes

None

Associations

- tokens : Token

Operations

None

8.6 Actions

8.6.1 Overview

This section describes the semantics of actions, which are the basic units out of which most non-trivial kinds of behavior are created in fUML. Actions are kinds of activity nodes, so they are always executed in the context of an activity, which is the overall behavioral construct (see Subclause 8.5 for the general semantics of activities).

The package structure for the semantic sub-packages for Actions parallel those of the syntactic Action package. Figure 73 shows the dependencies of the Action sub-packages.

Subclause 8.6.2 describes the semantics of Basic Actions (see Subclause 7.5.2). The semantic model for Basic Actions includes the fundamental activation semantics for actions and pins, as well as the specific semantics for basic invocation actions included in fUML.

Subclause 8.6.3 and 8.4.4 describe the semantics of Intermediate and Complete Actions (see Subclauses 7.3.3 and 7.3.4). This covers the semantics of most of the rest of the actions included in fUML, such as object actions, structural feature actions and link actions.

In fUML, structured activity nodes are also actions. However, the UML abstract syntax organizes the syntax of structured activity nodes into the Activities package. Therefore, the semantics for structured activity nodes are described with the semantics of actions (see Subclause 8.5.2).

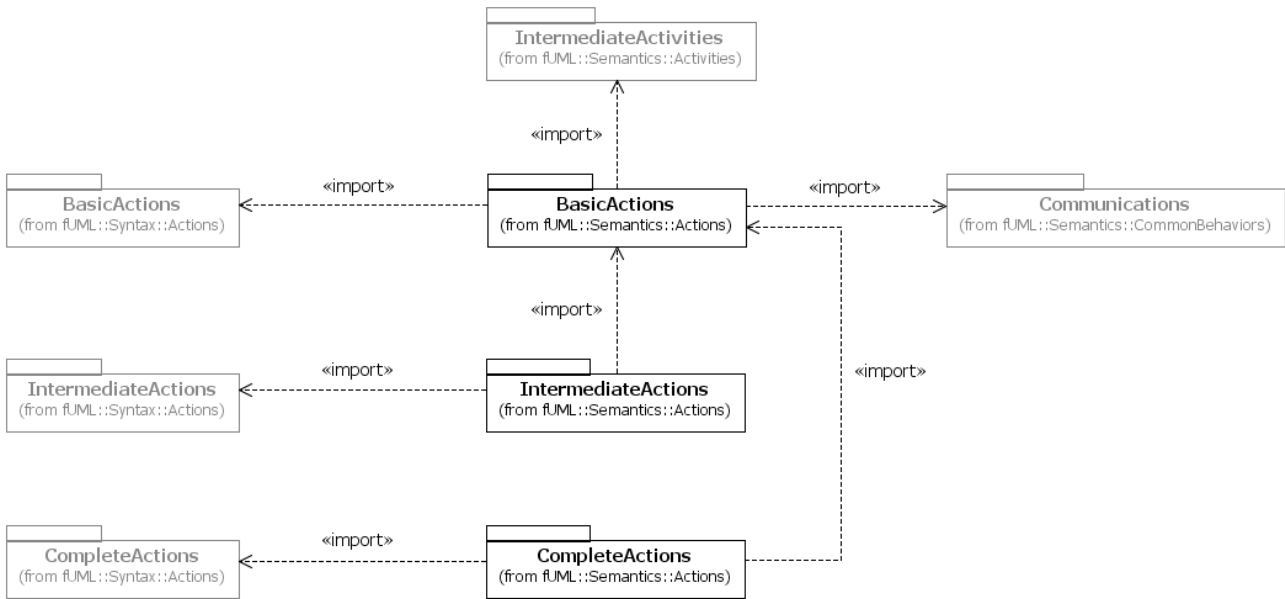


Figure 73 - Actions Semantics Packages

8.6.2 Basic Actions

8.6.2.1 Overview

Action Activation

Since actions are kinds of activity node, the semantic visitor classes for actions are kinds of activity node activations (see Subclause 8.5.2.1). In addition, the pins on actions are also kinds of activity nodes—specifically, object nodes—so there are also visitor classes for input and output pins that are kinds of object node activation. Pin activations are associated with an action activation in a parallel way to the association of the corresponding pins with their action (see Figure 74).

The `ActionActivation` class provides a method for the abstract *fire* operation inherited from `ActivityNodeActivation` and overrides the *takeOfferedTokens* operation. In general, the fire operation for an activity node activation is called whenever the prerequisites for execution of the node have been satisfied, as determined by the *isReady* operation, after accepted tokens are obtained using *takeOfferedTokens* (see Subclause 8.5.2.1). For an action activation, these operations are specialized to model the particular semantic requirements of action execution in terms of the offers received by the pins of the action.

When an input pin activation receives an offer, via a call to its *receiveOffer* operation, it passes the offer on by calling the *receiveOffer* operation of its action activation. The *isReady* operation of the action activation then checks whether *all* its input pin activations are ready. If so, then it fires *all* of the input pin activations at once, accepting all the offers that have been made to them and moving the accepted tokens to the input pins.

NOTE: The UML 2 Superstructure Specification (Subclause 12.3.2) states that “The object flow prerequisite is satisfied when all of the input pins are offered all necessary tokens and accept them all at once, precluding them from being consumed by any other actions.” In the execution model, the calls to the *isReady* and *takeOfferedTokens* operations from the `ActivityNodeActivation::receiveOffer` operation are made within an isolated region (see Subclause 8.5.2.1). This means that the source node activations of any offers to an action activation cannot be modified while the action activation is checking for, and possibly accepting, offers to its input pins. This prevents contention for the offers during this period, as required by the UML 2 semantics. (See Subclause 8.5.3 for more on the semantics of isolated regions—that is, structured activity nodes with `mustIsolate = true`.)

The above behavior is specified in the `takeOfferedTokens` method for `ActionActivation` and is generic to all action activations. The actual specific behavior of each kind of action is factored into the `doAction` operation. This operation is called from the `ActionActivation` fire operation after all the input pin activations have fired. Once the `doAction` operation is complete, all the output pin activations of the action are fired, which causes them to send offers on any outgoing edges (assuming they have tokens to offer), and a control token is offered on all control flows outgoing from the action.

The semantics of the offering of a token on control flows outgoing from an action are those of an “implicit fork” (see Subclause 12.3.2 of the UML 2 Superstructure Specification). Therefore, in order that the semantic model for control flows from an action be identical to those of a fork, if an action has outgoing control flows, an anonymous fork node activation is also created along with the action activation for the action. The action activation is then connected to the fork node activation, and the activity edge instances corresponding to the control flows outgoing the action are connected to the fork node activation. When the action activation completes its behavior, it creates a control token and offers it to the fork node activation which, per the semantics of fork nodes, in turn offers it on all outgoing activity edge instances.

Invocation Actions

The `BasicActions` abstract syntax package also includes basic invocation actions, including send signal, call operation and call behavior actions (see Subclause 7.5.2). The corresponding activation classes are specializations of `ActionActivation` (see Figure 74).

Of these, the behavior of a send signal action activation is the simplest. When it fires, it takes values from its argument input pin activations, constructs a signal instance with slots filled in with those values and sends the signal via the object reference obtained from its target input pin activation. The signal instance is actually sent by calling the `sendSignal` operation on the target object (see Subclause 8.4.3). This results in the signal instance being placed in the event pool for the target object, at which point the `sendSignal` call returns and the thread on which the send signal action is executing can continue (as appropriate). As discussed in Subclause 8.4.3, signal instances in the event pool are dispatched asynchronously by the event dispatching loop of the object activation for the target object.

In contrast to sending signals, call behavior and operation actions in fUML are always synchronous (see Subclause 7.5.2). This basic synchronous calling behavior is modeled in the `doAction` method of the `CallActionActivation` class. Associated with this class is an `Execution` object that represents the invocation of the called behavior. Other than for how this execution object is instantiated, the semantics of call behavior and call operation actions are the same: values of argument input pin activations are passed as input parameter values to the execution object, the execute operation is called on the execution and then any output parameter values are placed on result output pin activations. Once execution is complete, the execution object is destroyed.

NOTE: The fUML execution model interprets the semantics of called behaviors as requiring that the execution object instantiated by a synchronous call action be destroyed when the call returns. Otherwise, repeated calls would result in a potentially large number of anonymous, completed called executions accumulating at any execution locus.

Instantiating the execution object for a call behavior action is straightforward: an instance of the referenced behavior is simply instantiated at the execution locus of the call action. Instantiating the execution object for an operation call, on the other hand, requires that a potentially polymorphic operation be *dispatched* in order to determine which method should act as its behavior. This dispatching is carried by calling the `dispatch` operation on the target object. (See Subclause 8.3.2.1 for further discussion of polymorphic operation dispatching.)

Unlike the case of a call behavior action, the default behavior of polymorphic operation dispatching is for the execution object for the operation method to be instantiated at the locus *of the target object*, not the locus of the action execution. Thus, if an operation call is made on an object at a remote locus, then the operation will be executed on that locus. While fUML does not provide a normative means for passing object references between loci, a specific execution tool may implement such a means, in which case the semantics of operation calls across inter-locus references *is* specified normatively. (See Subclause 8.2.1 for a discussion of loci.)

NOTE: As described in Subclause 8.3.2.1, polymorphic operation dispatching is a semantic variation point. The default semantics for operation calls acts as described above for references to objects on other loci, and it would generally be expected that any alternative dispatching strategy would have a similar behavior. However, a conforming execution tool is allowed to define a dispatching strategy that would prescribe, for example, that *all* operation executions are performed on the local locus, regardless of where the target object resides.

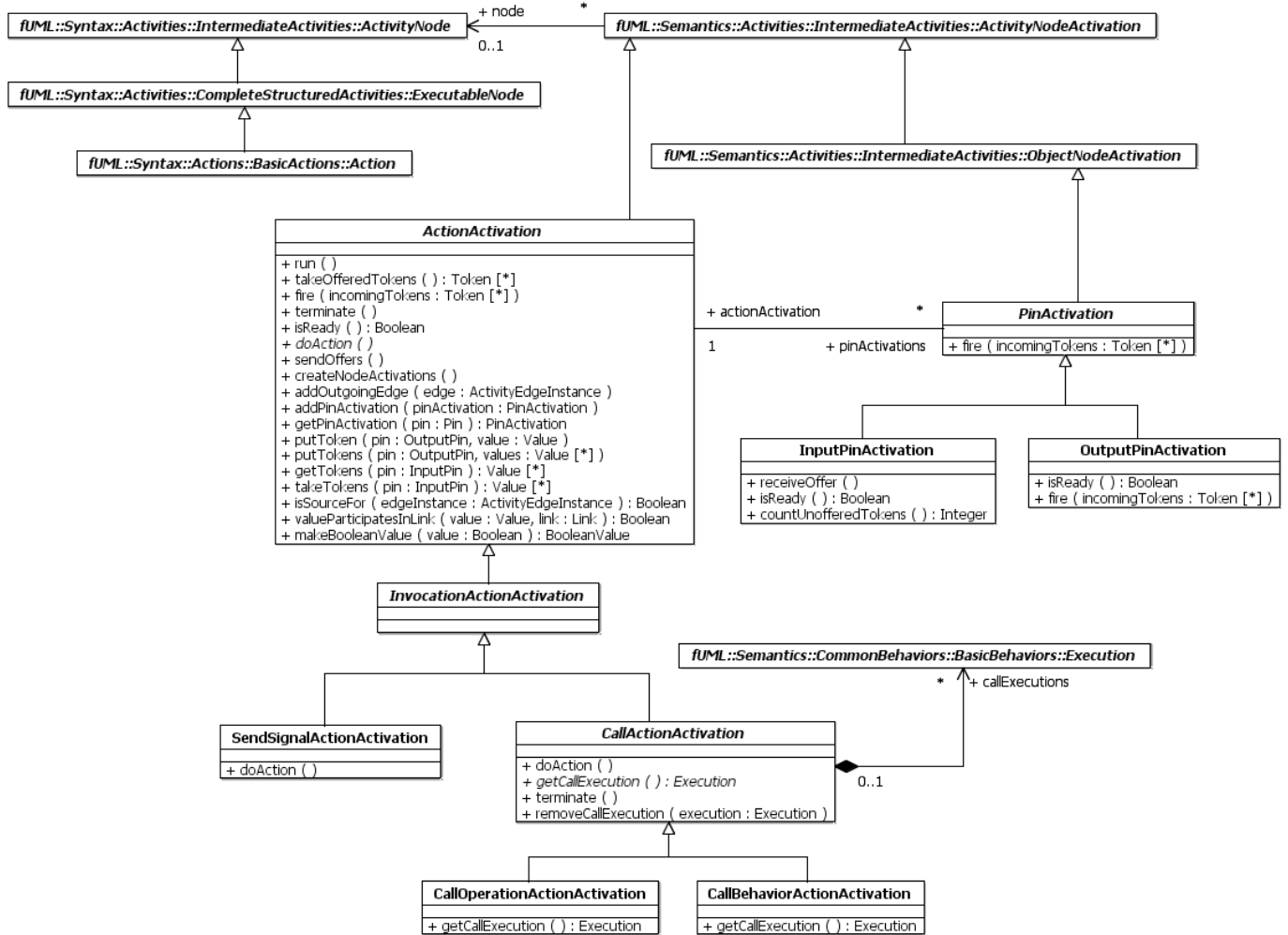


Figure 74 - Basic Action Activations

8.6.2.2 Class Descriptions

8.6.2.2.1 ActionActivation

An action activation is an activity node activation for a node that is an action.

Generalizations

- [ActivityNodeActivation](#)

Attributes

None

Associations

- pinActivations : PinActivation [0..*]
The activations of the pins owned by the action of this action activation.

Operations

[1] addOutgoingEdge (in edge : ActivityEdgeInstance)

```
// If there are no outgoing activity edge instances, create a single activity edge
instance with a fork node execution at the other end.
// Add the give edge to the fork node execution that is the target of the activity edge
instance out of this action execution.
// [This assumes that all edges directly outgoing from the action are control flows, with
an implicit fork for offers out of the action.]

ActivityNodeActivation forkNodeActivation;

if (this.outgoingEdges.size() == 0) {
    forkNodeActivation = new ForkNodeActivation();
    ActivityEdgeInstance newEdge = new ActivityEdgeInstance();
    super.addOutgoingEdge(newEdge);
    forkNodeActivation.addIncomingEdge(newEdge);
}
else {
    forkNodeActivation = this.outgoingEdges.getValue(0).target;
}

forkNodeActivation.addOutgoingEdge(edge);
```

[2] addPinActivation (in pinActivation : PinActivation)

```
// Add a pin activation to this action activation.

this.pinActivations.addValue(pinActivation);
pinActivation.actionActivation = this;
```

[3] createNodeActivations ()

```
// Create node activations for the input and output pins of the action for this
activation.
// [Note: Pins are owned by their actions, not by the enclosing activity (or group), so
they must be activated through the action activation.]

Action action = (Action)(this.node);

ActivityNodeList inputPinNodes = new ActivityNodeList();
InputPinList inputPins = action.input;
for (int i = 0; i < inputPins.size(); i++) {
    InputPin inputPin = inputPins.getValue(i);
    inputPinNodes.addValue(inputPin);
}

this.group.createNodeActivations(inputPinNodes);

for (int i = 0; i < inputPinNodes.size(); i++) {
    ActivityNode node = inputPinNodes.getValue(i);
    this.addPinActivation((PinActivation)(this.group.getNodeActivation(node)));
}

ActivityNodeList outputPinNodes = new ActivityNodeList();
OutputPinList outputPins = action.output;
for (int i = 0; i < outputPins.size(); i++) {
    OutputPin outputPin = outputPins.getValue(i);
    outputPinNodes.addValue(outputPin);
}
```

```

}

this.group.createNodeActivations(outputPinNodes);

for (int i = 0; i < outputPinNodes.size(); i++) {
    ActivityNode node = outputPinNodes.getValue(i);
    this.addPinActivation((PinActivation) (this.group.getNodeActivation(node)));
}

```

[4] doAction ()

Do the required action behavior.

[5] fire (in incomingTokens : Token [0..*])

```

// Do the main action behavior then oncurrently fire all output pin activations and offer
a single control token.

Debug.println("[fire] Action " + this.node.name + "...");

this.doAction();
this.sendOffers();

// Activate the action again, if tokens have been left on input pins and the action has no
incoming control flows.
Debug.println("[fire] Checking if " + this.node.name + " should fire again...");
if (((Action) (this.node)).input.size() > 0 & this.node.incoming.size() == 0) {

    boolean fireAgain = true;
    InputPinList inputPins = ((Action) (this.node)).input;
    int j = 1;
    while (fireAgain & j <= inputPins.size()) {
        PinActivation inputPinActivation = this.getPinActivation(inputPins.getValue(j-1));
        fireAgain = inputPinActivation.isReady() &
inputPinActivation.countUnofferedTokens() > 0;
        j = j + 1;
    }

    if (fireAgain) {
        this.fire(new TokenList());
    }
}

```

[6] getPinActivation (in pin : Pin) : PinActivation

```

// Precondition: The given pin is owned by the action of the action activation.
// Return the pin activation corresponding to the given pin.

PinActivation pinActivation = null;
int i = 1;
while (pinActivation == null & i <= this.pinActivations.size()) {
    PinActivation thisPinActivation = this.pinActivations.getValue(i-1);
    if (thisPinActivation.node == pin) {
        pinActivation = thisPinActivation;
    }
    i = i + 1;
}

```

```
return pinActivation;
```

[7] getTokens (in pin : InputPin) : Value [0..*]

```
// Precondition: The action execution has fired and the given pin is owned by the  
action of the action execution.
```

```
// Get any tokens held by the pin activation corresponding to the given input pin and  
return them  
// (but leave the tokens on the pin).
```

```
Debug.println("[getTokens] node = " + this.node.name + ", pin = " + pin.name);
```

```
PinActivation pinActivation = this.getPinActivation(pin);  
TokenList tokens = pinActivation.getUnofferedTokens();
```

```
ValueList values = new ValueList();  
for (int i = 0; i < tokens.size(); i++) {  
    Token token = tokens.getValue(i);  
    Value value = ((ObjectToken)token).value;  
    if (value != null) {  
        values.addValue(value);  
    }  
}
```

```
return values;
```

[8] isReady () : Boolean

```
// In addition to the default condition, check that the sources of all incoming edges  
(control flows) have offers and all input pin activations are ready.  
// [This assumes that all edges directly incoming to the action are control flows.]
```

```
boolean ready = super.isReady();
```

```
int i = 1;  
while (ready & i <= this.incomingEdges.size()) {  
    ready = this.incomingEdges.getValue(i-1).hasOffer();  
    i = i + 1;  
}
```

```
InputPinList inputPins = ((Action)(this.node)).input;  
int j = 1;  
while (ready & j <= inputPins.size()) {  
    ready = this.getPinActivation(inputPins.getValue(j-1)).isReady();  
    j = j + 1;  
}
```

```
return ready;
```

[9] isSourceFor (in edgeInstance : ActivityEdgeInstance) : Boolean

```
// If this action has an outgoing fork node, check that the fork node is the source of the  
given edge instance.
```

```
boolean isSource = false;  
if (this.outgoingEdges.size() > 0) {  
    isSource = this.outgoingEdges.getValue(0).target.isSourceFor(edgeInstance);  
}
```

```

}

return isSource;

```

[10] makeBooleanValue (in value : Boolean) : BooleanValue

```

// Make a Boolean value using the built-in Boolean primitive type.
// [This ensures that Boolean values created internally are the same as the default used
for evaluating Boolean literals.]

LiteralBoolean booleanLiteral = new LiteralBoolean();
booleanLiteral.value = value;
return (BooleanValue)(this.getExecutionLocus().executor.evaluate(booleanLiteral));

```

[11] putToken (in pin : OutputPin, in value : Value)

```

// Precondition: The action execution has fired and the given pin is owned by the action
of the action execution.
// Place a token for the given value on the pin activation corresponding to the given
output pin.

```

```

Debug.println("[putToken] node = " + this.node.name);

ObjectToken token = new ObjectToken();
token.value = value;

PinActivation pinActivation = this.getPinActivation(pin);
pinActivation.addToken(token);

```

```

// Precondition: The action execution has fired and the given pin is owned by the action
of the action execution.
// Place a token for the given value on the pin activation corresponding to the given
output pin.

```

```

Debug.println("[putToken] node = " + this.node.name);

ObjectToken token = new ObjectToken();
token.value = value;
PinActivation pinActivation = this.getPinActivation(pin);
pinActivation.addToken(token);

```

[12] putTokens (in pin : OutputPin, in values : Value [0..*])

```

// Precondition: The action execution has fired and the given pin is owned by the action
of the action execution.
// Place tokens for the given values on the pin activation corresponding to the given
output pin.

```

```

// Debug.println("[putTokens] node = " + this.node.name);

for (int i = 0; i < values.size(); i++) {
    Value value = values.getValue(i);
    this.putToken(pin, value);
}

```

[13] run ()

```
// Run this action activation and any outgoing fork node attached to it.
super.run();

if (this.outgoingEdges.size() > 0) {
    this.outgoingEdges.getValue(0).target.run();
}
```

[14] sendOffers ()

```
// Fire all output pins and send offers on all outgoing control flows.

Action action = (Action)(this.node);

// *** Fire all output pins concurrently. ***
OutputPinList outputPins = action.output;
for (Iterator i = outputPins.iterator(); i.hasNext();) {
    OutputPin outputPin = (OutputPin)i.next();
    PinActivation pinActivation = this.getPinActivation(outputPin);
    pinActivation.fire(pinActivation.takeOfferedTokens());
}

// Send offers on all outgoing control flows.
if (this.outgoingEdges.size() > 0) {
    TokenList tokens = new TokenList();
    tokens.addValue(new ControlToken());
    this.addTokens(tokens);
    this.outgoingEdges.getValue(0).sendOffer(tokens);
}
```

[15] takeOfferedTokens () : Token [0..*]

```
// Take any incoming offers of control tokens, then concurrently fire all input pin
activations.

ActivityEdgeInstanceList incomingEdges = this.incomingEdges;
for (int i = 0; i < incomingEdges.size(); i++) {
    ActivityEdgeInstance incomingEdge = incomingEdges.getValue(i);
    TokenList tokens = incomingEdge.takeOfferedTokens();
    for (int j = 0; j < tokens.size(); j++) {
        Token token = tokens.getValue(j);
        token.withdraw();
    }
}

Action action = (Action)(this.node);

// Debug.println("[fire] Firing pins...");

// *** Fire all input pins concurrently. ***
InputPinList inputPins = action.input;
for (Iterator i = inputPins.iterator(); i.hasNext();) {
    InputPin pin = (InputPin)(i.next());
    PinActivation pinActivation = this.getPinActivation(pin);
    pinActivation.fire(pinActivation.takeOfferedTokens());
}

return new TokenList();
```

[16] takeTokens (in pin : InputPin) : Value [0..*]

```
// Precondition: The action execution has fired and the given pin is owned by the action
of the action execution.
// Take any tokens held by the pin activation corresponding to the given input pin and
return them.
```

```
Debug.println("[takeTokens] node = " + this.node.name + ", pin = " + pin.name);
```

```
PinActivation pinActivation = this.getPinActivation(pin);
TokenList tokens = pinActivation.takeUnofferedTokens();
```

```
ValueList values = new ValueList();
for (int i = 0; i < tokens.size(); i++) {
    Token token = tokens.getValue(i);
    Value value = ((ObjectToken)token).value;
    if (value != null) {
        values.addValue(value);
    }
}
```

```
return values;
```

[17] terminate ()

```
// Terminate this action activation and any outgoing fork node attached to it.
```

```
super.terminate();
```

```
if (this.outgoingEdges.size() > 0) {
    this.outgoingEdges.getValue(0).target.terminate();
}
```

[18] valueParticipatesInLink (in value : Value, in link : Link) : Boolean

```
// Test if the given value participates in the given link.
```

```
FeatureValueList linkFeatureValues = link.getFeatureValues();
```

```
boolean participates = false;
int i = 1;
while (!participates & i <= linkFeatureValues.size()) {
    participates = linkFeatureValues.getValue(i-1).values.getValue(0).equals(value);
    i = i + 1;
}
```

```
return participates;
```

8.6.2.2.2 CallActionActivation

A call action activation is an invocation action activation for a call action.

Generalizations

- [InvocationActionActivation](#)

Attributes

None

Associations

- callExecutions : Execution [0..*]

The set of execution object for currently ongoing calls made through this call action activation.

Operations

[1] doAction ()

```
// Get the call execution object, set its input parameters from the argument pins and
execute it.
// Once execution completes, copy the values of the output parameters of the call
execution to the result pins of the call action execution, then destroy the execution.

Execution callExecution = this.getCallExecution();

if (callExecution != null) {
    this.callExecutions.addValue(callExecution);

    CallAction callAction = (CallAction)(this.node);
    InputPinList argumentPins = callAction.argument;
    OutputPinList resultPins = callAction.result;

    ParameterList parameters = callExecution.getBehavior().ownedParameter;

    int pinNumber = 1;
    int i = 1;
    while (i <= parameters.size()) {
        Parameter parameter = parameters.getValue(i-1);
        if (parameter.direction == ParameterDirectionKind.in |
            parameter.direction == ParameterDirectionKind.inout) {
            ParameterValue parameterValue = new ParameterValue();
            parameterValue.parameter = parameter;
            parameterValue.values = this.takeTokens(argumentPins.getValue(pinNumber-1));
            callExecution.setParameterValue(parameterValue);
            pinNumber = pinNumber + 1;
        }
        i = i + 1;
    }

    callExecution.execute();

    ParameterValueList outputParameterValues = callExecution.getOutputParameterValues();
    for (int j = 0; j < outputParameterValues.size(); j++) {
        ParameterValue outputParameterValue = outputParameterValues.getValue(j);
        OutputPin resultPin = resultPins.getValue(j);
        this.putTokens(resultPin, outputParameterValue.values);
    }

    callExecution.destroy();
    this.removeCallExecution(callExecution);
}
```

[2] getCallExecution () : Execution

Get the execution object for the called behavior.

[3] removeCallExecution (in execution : Execution)

```
// Remove the given execution from the current list of call executions.

boolean notFound = true;
```

```

int i = 1;
while (notFound & i <= this.callExecutions.size()) {
    if (this.callExecutions.getValue(i-1) == execution) {
        this.callExecutions.removeValue(i-1);
        notFound = false;
    }
}

```

[4] terminate ()

```

// Terminate all call executions (if any), then terminate the call action activation
(self).

for (int i = 0; i < this.callExecutions.size(); i++) {
    Execution execution = this.callExecutions.getValue(i);
    execution.terminate();
}

super.terminate();

```

8.6.2.2.3 CallBehaviorActionActivation

A call behavior action activation is a call action activation for a call behavior action.

Generalizations

- [CallActionActivation](#)

Attributes

None

Associations

None

Operations

[1] getCallExecution () : Execution

```

// Create and execution for the given behavior at the current locus and return the
resulting execution object.
// If the given behavior is in the context of a classifier, then pass the current context
object as the context for the call.
// Otherwise, use a null context.
// [Note that this requires the behavior context to be compatible with the type of the
current context object.]

Behavior behavior = ((CallBehaviorAction)(this.node)).behavior;

Object_ context;
if (behavior.context == null) {
    context = null;
} else {
    // Debug.println("[getCallExecution] behavior context = " + behavior.context.name);
    context = this.getExecutionContext();
}

// Debug.println("[getCallExecution] context = " + context);

return this.getExecutionLocus().factory.createExecution(behavior, context);

```

8.6.2.2.4 CallOperationActionActivation

A call operation action activation is a call action activation for a call operation action.

Generalizations

- [CallActionActivation](#)

Attributes

None

Associations

None

Operations

[1] getCallExecution () : Execution

```
// If the value on the target input pin is a reference, dispatch the operation to it and  
return the resulting execution object.
```

```
CallOperationAction action = (CallOperationAction) (this.node);  
Value target = this.takeTokens(action.target).getValue(0);  
  
Execution execution;  
if (target instanceof Reference) {  
    execution = ((Reference)target).dispatch(action.operation);  
}  
else {  
    execution = null;  
}  
  
return execution;
```

8.6.2.2.5 InputPinActivation

An input pin activation is a pin activation for an input pin.

Generalizations

- [PinActivation](#)

Attributes

None

Associations

None

Operations

[1] countUnofferedTokens () : Integer

```
// Limit the number of tokens to be offered to no more than the upper multiplicity of the  
pin.
```

```
int count = super.countUnofferedTokens();  
  
int upper = ((Pin) (this.node)).multiplicityElement.upper.naturalValue;
```

```

// Note that upper < 0 indicates an unbounded upper multiplicity.
int limitedCount = upper;
if (upper < 0 | count <= upper) {
    limitedCount = count;
}

return limitedCount;

```

[2] isReady () : Boolean

// Return true if the total number of tokens already being offered by this pin plus those being offered by the sources of incoming edges is at least equal to the minimum multiplicity of the pin.

```

boolean ready;
if (!super.isReady()) {
    ready = false;
} else {
    int totalTokenCount = this.countUnofferedTokens();
    int i = 1;
    while (i <= this.incomingEdges.size()) {
        totalTokenCount = totalTokenCount + this.incomingEdges.getValue(i-
1).countOfferedTokens();
        i = i + 1;
    }

    int minimum = ((Pin)(this.node)).multiplicityElement.lower;
    ready = totalTokenCount >= minimum;
}

return ready;

```

[3] receiveOffer ()

// Forward the offer to the action activation. [When all input pins are ready, the action will fire them.]

```
this.actionActivation.receiveOffer();
```

8.6.2.2.6 InvocationActionActivation

An invocation action activation is an action activation of an invocation action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

None

8.6.2.2.7 OutputPinActivation

An output pin activation is a pin activation for an output pin.

Generalizations

- [PinActivation](#)

Attributes

None

Associations

None

Operations

[1] fire (in incomingTokens : Token [0..*])

```
// Add incoming tokens and send offers on outgoing edges.
```

```
super.fire(incomingTokens);  
this.sendUnofferedTokens();
```

[2] isReady () : Boolean

```
// Always return false. [The pin will be fired by its associated action.]
```

```
return false;
```

8.6.2.2.8 PinActivation

A pin activation is an object node activation for a node that is a pin.

Generalizations

- [ObjectNodeActivation](#)

Attributes

None

Associations

- actionActivation : ActionActivation
The activation of the action that owns the pin for this pin activation.

Operations

[1] fire (in incomingTokens : Token [0..*])

```
// Add all incoming tokens to the pin.  
// [Note that a pin will consume all tokens offered to it, even if this is more than the  
multiplicity upper bound, but will only offer tokens up to that upper bound.]
```

```
Debug.println("[fire] Pin " + this.node.name + "...");
```

```
this.addTokens(incomingTokens);
```

8.6.2.2.9 SendSignalActionActivation

A send signal action activation is an invocation action activation for a send signal action.

Generalizations

- [InvocationActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the value from the target pin. If the value is not a reference, then do nothing.
// Otherwise, construct a signal using the values from the argument pins and send it to
the referent object.
```

```
SendSignalAction action = (SendSignalAction) (this.node);
Value target = this.takeTokens(action.target).getValue(0);

if (target instanceof Reference) {
    Signal signal = action.signal;

    SignalInstance signalInstance = new SignalInstance();
    signalInstance.type = signal;

    PropertyList attributes = signal.ownedAttribute;
    InputPinList argumentPins = action.argument;
    for (int i = 0; i < attributes.size(); i++) {
        Property attribute = attributes.getValue(i);
        InputPin argumentPin = argumentPins.getValue(i);
        ValueList values = this.takeTokens(argumentPin);
        signalInstance.setFeatureValue(attribute, values, 0);
    }

    ((Reference) target).send(signalInstance);
}
```

8.6.3 Intermediate Actions

8.6.3.1 Overview

Object Actions

At the intermediate level, fUML includes the following object actions (see Figure 75 for the corresponding activation model).

- *Create Object Action.* In fUML, the classifier specified by a create object action must be a class (see Subclause 7.5.3). Therefore, the instance created really is an object, as the action name indicates. The object becomes part of the extent of the specified class at the execution locus of the activity execution that contains the action activation. (See Subclauses 8.2 and 8.3 for more on loci and extents.)

- *Destroy Object Action.* This action accepts an object reference and destroys the referenced object. Destruction involves terminating the object activation (if any), removing all of the objects types and removing the object from the extent at the execution locus. Note that the fUML semantics do not preclude references continuing to exist to destroyed objects. However, since such objects do not have any types, they will have neither attributes nor behaviors. Note also that only objects can be destroyed in fUML—attempting to destroy a data value will have no effect.
- *Test Identity Action.* This action tests whether its two input values are “identical”. If the input values are both data values, then “identical” means that they are either the same primitive value or they have the same compound type, with identical values for all corresponding attributes. If the input values are both object references, then “identical” means that they reference the same object. That is, for data values equality is testing “by value”, while for objects it is tested “by reference.”

NOTE: The UML 2 Superstructure Specification (Subclause 11.3.49) describes the behavior of test identity actions as “This action returns true if the two input values are the same identity, false if they are not.” Typically, “same identity” would be interpreted as meaning “reference to the same object.” However, the fUML semantics for test identity actions goes beyond this, also providing for the comparison of data values for equality by value. This extends the action to provide a general equality test for all kinds of values.

- *Read Self Action.* This action reads the *context* object of the activity activation that contains the action activation. If the activity is associated with a class (as a method or a classifier behavior), then the context object will be an instance of that class. Otherwise, the context object will be the execution object of the activity itself.
- *Value Specification Action.* This action evaluates a given value specification and outputs the resulting value. The value specification is evaluated using the evaluate operation of the executor at the execution locus of the activity execution that contains the action activation (see Subclause 8.2).

Structural Feature Actions

fUML includes actions for accessing the structural features of both objects and data types (see Figure 76 for the corresponding activation model).

NOTE: In fUML, association ends are always owned by the association and never by the types of the ends (see Subclause 7.2.2). Therefore, it is not possible to navigate a link in fUML using a structural feature action. Nevertheless, a classifier may have a structural feature whose type is a class, in which case the value of that feature will be an object reference, and reading it will have much the same effect as navigating a binary association link. The semantics of the creation and destruction of links, though, is rather different in fUML than the semantics of setting such a referential structural feature (see below).

NOTE: For an ordered structural feature, the UML Superstructure Specification (Subclause 11.3.5) defines the effect of “insertAt” to be: “A positive integer less than or equal to the current number of values means to insert the new value at that position in the sequence of existing values, with the integer one meaning the new value will be first in the sequence. A value of unlimited for insertAt means to insert the new value at the end of the sequence.” For fUML, this behavior is assumed to mean that the new value is inserted into the required position without replacing any of the previously existing values in the structural feature, which retain the same relative ordering as before the insertion of the new value.

Link Actions

In fUML, a link is an extensional value that exists at a specific execution locus (see Subclause 8.3). Unlike objects, however, there are no explicit references to links. Rather, links may be thought of as tuples of values, one for each association end, and a link of a specific association can be identified by giving such a tuple. Note that this identification is *not* necessarily unique, though, unless all the ends of the association are specified as being unique.

fUML includes the following actions for manipulating links (see Figure 77 for the corresponding activation model).

- *Create Link Action.* Given a value for each association end, this action normally creates a link with those values. This link becomes a member of the extent of the association at the execution locus of the activity activation that contains the action activation. However, if a link already exists in the association extent with the same tuple of values, and all the ends of the association are specified as unique, then no new link is actually created (though

this is not an error). Since, in fUML, an association always owns its ends (see Subclause 7.2.2), each of the values for the link are represented as structural feature values for the link (see Subclause 8.3.2.1 for more on the representation of the structure of links). If an association end is ordered, then the link also maintains the position of its value for that association end relative to the value provided by other links in the extent of the association.

- *Destroy Link Action*. Given a value for each association end, this action destroys all links that match the link end destruction data in the extent of the given association at the execution locus of the activity activation that contains the action activation. Destroying a link means simply removing it from the extent of the association. Matching links are determined as follows.
 - For unique ends, or non-unique ends for which `isDestroyDuplicates` is true, match links with a matching value for that end.
 - For non-unique, ordered ends for which `isDestroyDuplicates` is false, match links with an end value at the given `destroyAt` position.
 - For non-unique, non-ordered ends for which `isDestroyDuplicates` is false, pick one matching link (if any) nondeterministically.

NOTE: The behavior in this third class when there is more than one matching link is not explicitly stated in the UML 2 Superstructure specification (Subclause 11.3.17). fUML provides an interpretation of nondeterministic choice in this case.

- *Read Link Action*. This action provides a means for querying the extent of an association at the execution locus of the activity activation that contains the action activation. The action specifies values for all ends of the association but one—the *open* end (see Subclause 7.5.3). This link end data identifies a subset of matching links from the association extent that have the specified end values. The action outputs the set of values on the open ends of these matching links.
- *Clear Association Action*. This action destroys all the links in the extent of the given association (at the execution locus of the activity activation that contains the action activation) that has the input value of the action as an end value.

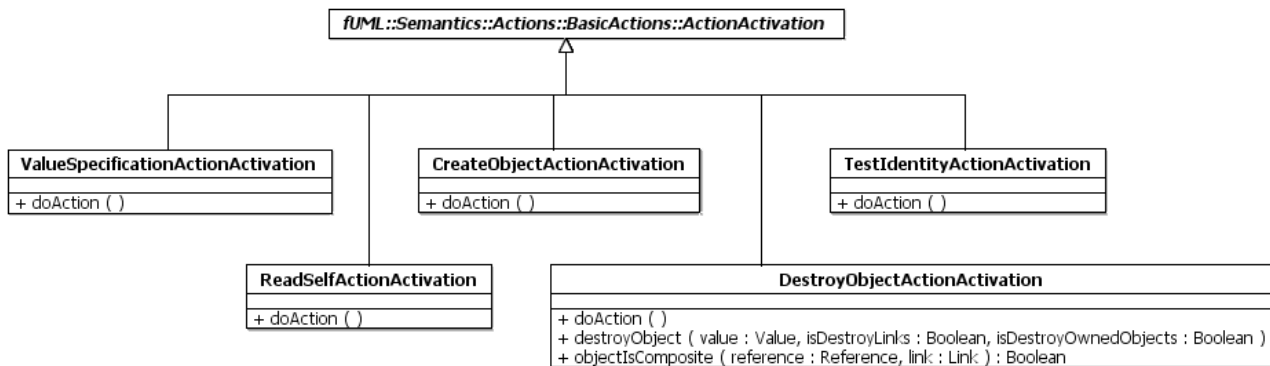


Figure 75 - Object Action Activations

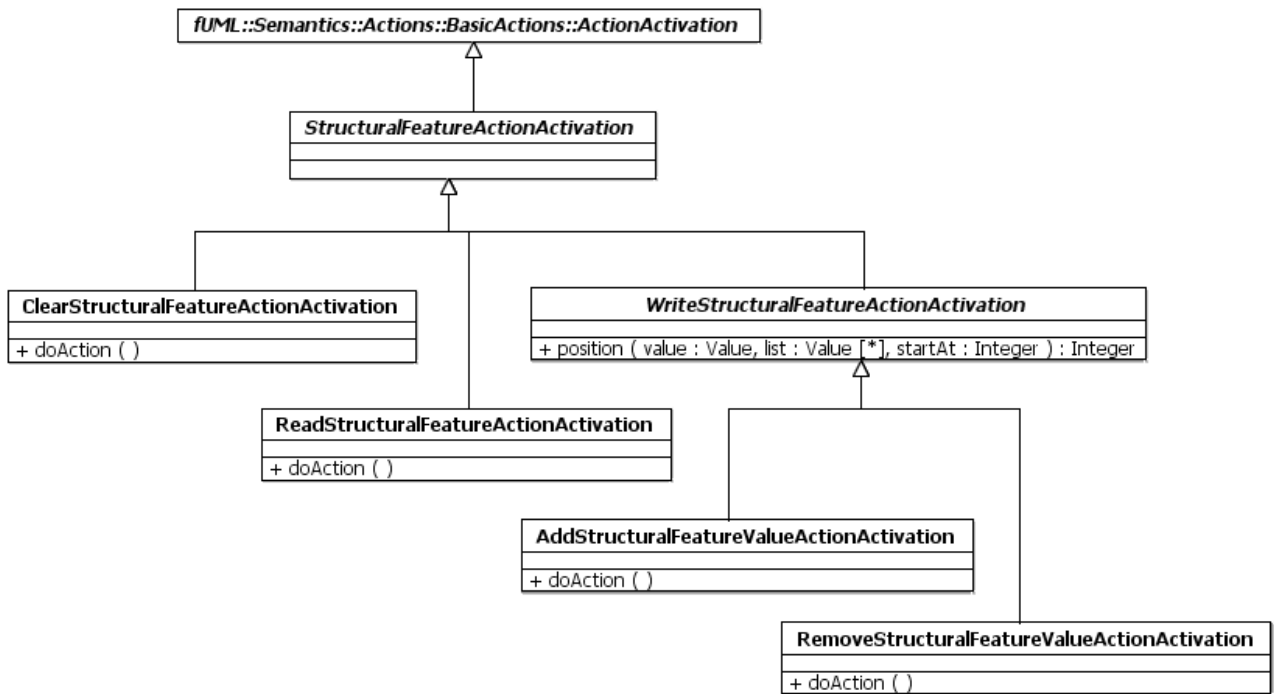


Figure 76 - Structural Feature Action Activations

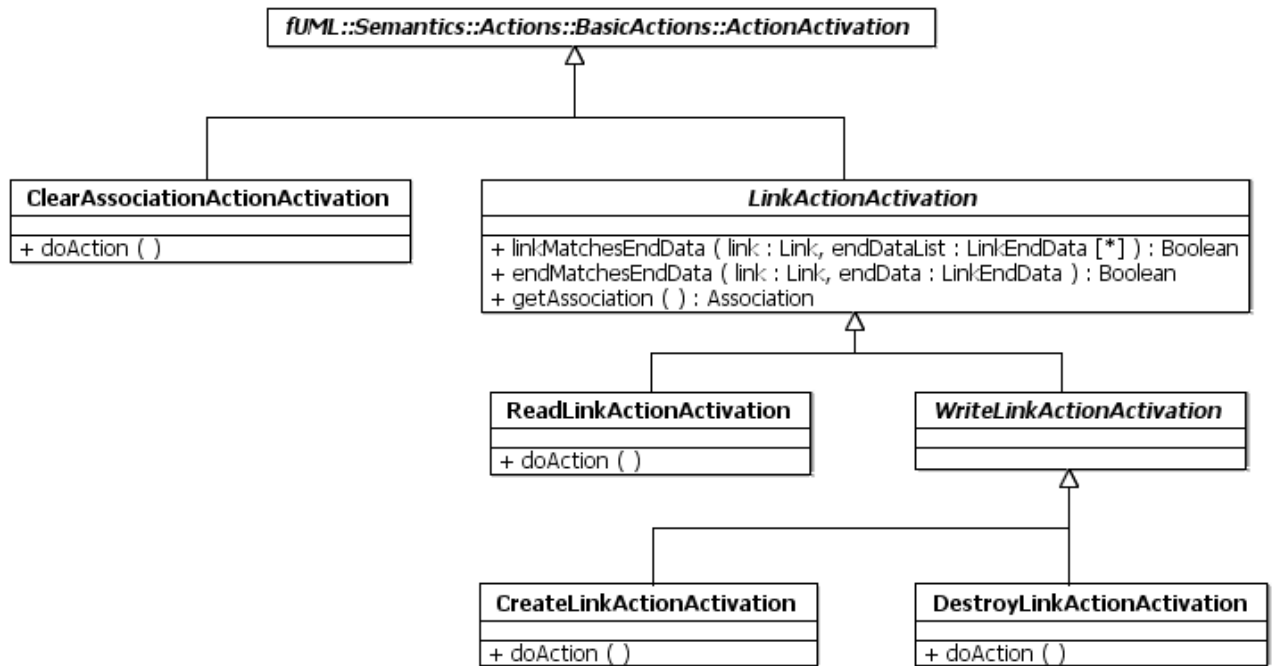


Figure 77 - Link Action Activations

8.6.3.2 Class Descriptions

8.6.3.2.1 AddStructuralFeatureValueActionActivation

An add structural feature action value activation is a write structural feature action activation for an add structural feature value action.

Generalizations

- [WriteStructuralFeatureActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the value of the object input pin. If it is not a structural value, do nothing.
Otherwise do the following.
// Get the value on the value input pin.
// If isReplaceAll is true, set the appropriate feature of the input object to the input
values.
// Otherwise, get the current values of the feature and insert the input value at the
position given by the value of the insertAt pin.

AddStructuralFeatureValueAction action = (AddStructuralFeatureValueAction)(this.node);

Value value = this.takeTokens(action.object).getValue(0);

if (value instanceof StructuredValue) {
    StructuredValue structuredValue = (StructuredValue)value;
    ValueList inputValues = this.takeTokens(action.value);

    if (action.isReplaceAll) {
        structuredValue.setFeatureValue(action.structuralFeature, inputValues, 0);
    } else {
        FeatureValue featureValue =
structuredValue.getFeatureValue(action.structuralFeature);

        int insertAt = 1;
        if (featureValue.values.size() > 0 ) {
            if (action.insertAt == null) {
                // *** If there is no insertAt pin, then the structural feature must be
unordered, and the insertion position is immaterial. ***
                insertAt =
((ChoiceStrategy)this.getExecutionLocus().factory.getStrategy("choice")).choose(featureVal
ue.values.size());
            } else {
                insertAt =
((UnlimitedNaturalValue)this.takeTokens(action.insertAt).getValue(0)).value.naturalValue;
            }
        }

        // NOTE: Multiplicity of the value input pin is required to be 1..1.
        Value inputValue = inputValues.getValue(0);

        if (action.structuralFeature.multiplicityElement.isUnique) {
            // Remove any existing value that duplicates the input value
```

```

        int j = position(inputValue, featureValue.values, 1);
        if (j > 0) {
            featureValue.values.remove(j-1);
            if (insertAt > 0 & j < insertAt) {
                insertAt = insertAt - 1;
            }
        }
    }

    if (insertAt < 0) { // This indicates an unlimited value of "*"
        featureValue.values.addValue(inputValue);
    } else {
        featureValue.values.addValue(insertAt - 1, inputValue);
    }
}

if (action.result != null) {
    this.putToken(action.result, value);
}
}

```

8.6.3.2.2 ClearAssociationActionActivation

A clear association action activation is an action activation for a clear association action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction()

```

// Get the extent, at the current execution locus, of the given association.
// Read the object input pin. Destroy all links in which the object participates.

ClearAssociationAction action = (ClearAssociationAction)(this.node);

ExtensionalValueList extent = this.getExecutionLocus().getExtent(action.association);
Value objectValue = this.takeTokens(action.object).getValue(0);

for (int i = 0; i < extent.size(); i++) {
    Link link = (Link)(extent.getValue(i));
    if (this.valueParticipatesInLink(objectValue, link)) {
        link.destroy();
    }
}
}

```

8.6.3.2.3 ClearStructuralFeatureActionActivation

A clear structural feature action activation is a structural feature action activation for a clear structural feature action.

Generalizations

- [StructuralFeatureActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the value of the object input pin. If it is not a structured value, then do
nothing.
// Otherwise, set the appropriate feature of the input value to be empty.

ClearStructuralFeatureAction action = (ClearStructuralFeatureAction)(this.node);

Value value = this.takeTokens(action.object).getValue(0);

if (value instanceof StructuredValue) {
    ((StructuredValue)value).setFeatureValue(action.structuralFeature, new ValueList(),
0);
    if (action.result != null) {
        this.putToken(action.result, value);
    }
}
```

8.6.3.2.4 CreateLinkActionActivation

A create link action activation is a write link action activation for a create link action.

Generalizations

- [WriteLinkActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the extent at the current execution locus of the association for which a link is
being created.
// Destroy all links that have a value for any end for which isReplaceAll is true.
// Create a new link for the association, at the current locus, with the given end data
values, inserted at the given insertAt position (for ordered ends).

CreateLinkAction action = (CreateLinkAction)(this.node);
LinkEndCreationDataList endDataList = action.endData;

Association linkAssociation = this.getAssociation();
ExtensionalValueList extent = this.getExecutionLocus().getExtent(linkAssociation);
```

```

for (int i = 0; i < extent.size(); i++) {
    ExtensionalValue value = extent.getValue(i);
    Link link = (Link)value;

    boolean noMatch = true;
    int j = 1;
    while (noMatch & j <= endDataList.size()) {
        LinkEndCreationData endData = endDataList.getValue(j-1);
        if (endData.isReplaceAll & this.endMatchesEndData(link, endData)) {
            link.destroy();
            noMatch = false;
        }
        j = j + 1;
    }
}

Link newLink = new Link();
newLink.type = linkAssociation;

for (int i = 0; i < endDataList.size(); i++) {
    LinkEndCreationData endData = endDataList.getValue(i);

    int insertAt;
    if (endData.insertAt == null) {
        insertAt = 0;
    } else {
        insertAt = ((UnlimitedNaturalValue)
(this.takeTokens(endData.insertAt).getValue(0))).value.naturalValue;
    }
    newLink.setFeatureValue(endData.end, this.takeTokens(endData.value), insertAt);
}

this.getExecutionLocus().add(newLink);

```

8.6.3.2.5 CreateObjectActionActivation

A create object action activation is an action activation for a create object action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```

// Create an object with the given classifier (which must be a class) as its type, at the
// same locus as the action activation.
// Place a reference to the object on the result pin of the action.

```

```

CreateObjectAction action = (CreateObjectAction)(this.node);

```

```

Reference reference = new Reference();
reference.referent = this.getExecutionLocus().instantiate((Class_)(action.classifier));

```

```
this.putToken(action.result, reference);
```

8.6.3.2.6 DestroyLinkActionActivation

A destroy link action activation is a write link action activation for a destroy link action.

Generalizations

- [WriteLinkActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the extent, at the current execution locus, of the association for which links are
// being destroyed.
// Destroy all links that match the given link end destruction data.
// For unique ends, or non-unique ends for which isDestroyDuplicates is true, match links
// with a matching value for that end.
// For non-unique, ordered ends for which isDestroyDuplicates is false, match links with
// an end value at the given destroyAt position. [Must a value be given, too, in this case?]
// For non-unique, non-ordered ends for which isDestroyDuplicates is false, pick one
// matching link (if any) non-deterministically. [The semantics of this case is not clear
// from the current spec.]
```

```
DestroyLinkAction action = (DestroyLinkAction)(this.node);
LinkEndDestructionDataList destructionDataList = action.endData;
```

```
boolean destroyOnlyOne = false;
int j = 1;
while (!destroyOnlyOne & j <= destructionDataList.size()) {
    LinkEndDestructionData endData = destructionDataList.getValue(j-1);
    destroyOnlyOne = !endData.end.multiplicityElement.isUnique & !
endData.end.multiplicityElement.isOrdered & !endData.isDestroyDuplicates;
    j = j + 1;
}
```

```
LinkEndDataList endDataList = new LinkEndDataList();
for (int i = 0; i < destructionDataList.size(); i++) {
    LinkEndDestructionData endData = destructionDataList.getValue(i);
    endDataList.addValue(endData);
}
```

```
ExtensionalValueList extent = this.getExecutionLocus().getExtent(this.getAssociation());
ExtensionalValueList matchingLinks = new ExtensionalValueList();
```

```
for (int i = 0; i < extent.size(); i++) {
    ExtensionalValue value = extent.getValue(i);
    Link link = (Link)value;
    if (this.linkMatchesEndData(link, endDataList)) {
        matchingLinks.addValue(link);
    }
}
```

```

// Now that matching is done, ensure that all tokens on end data input pins
// are consumed.
for (int i = 0; i < destructionDataList.size(); i++) {
    LinkEndDestructionData endData = destructionDataList.getValue(i);
    Property end = endData.end;
    if (!endData.isDestroyDuplicates
        & !end.multiplicityElement.isUnique & end.multiplicityElement.isOrdered) {
        this.takeTokens(endData.destroyAt);
    }
    this.takeTokens(endData.value);
}

if (destroyOnlyOne) {
    // *** If there is more than one matching link, non-deterministically choose one. ***
    if (matchingLinks.size() > 0) {
        int i =
((ChoiceStrategy) this.getExecutionLocus().factory.getStrategy("choice")).choose(matchingLinks.size());
        matchingLinks.getValue(i-1).destroy();
    }
} else {
    for (int i = 0; i < matchingLinks.size(); i++) {
        ExtensionalValue matchingLink = matchingLinks.getValue(i);
        matchingLink.destroy();
    }
}
}

```

8.6.3.2.7 DestroyObjectActionActivation

A destroy object action activation is an action activation for a destroy object action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] destroyObject (in value : Value, in isDestroyLinks : Boolean, in isDestroyOwnedObjects : Boolean)

// If the given value is a reference, then destroy the referenced object, per the given destroy action attribute values.

// Debug.println("[destroyObject] object = " + value.objectId());

```

if (value instanceof Reference) {
    Reference reference = (Reference)value;

    if (isDestroyLinks | isDestroyOwnedObjects) {
        Debug.println("[destroyObject] Destroying links...");
        ExtensionalValueList extensionalValues =
this.getExecutionLocus().extensionalValues;
        for (int i = 0; i < extensionalValues.size(); i++) {
            ExtensionalValue extensionalValue = extensionalValues.getValue(i);
            if (extensionalValue instanceof Link) {
                Link link = (Link)extensionalValue;

```

```

        if (this.valueParticipatesInLink(reference, link)) {
            if (isDestroyLinks | this.objectIsComposite(reference, link)) {
                // Debug.println("[destroyObject] Destroying link " +
link.objectId());
                link.destroy();
            }
        }
    }
}

if (isDestroyOwnedObjects) {
    Debug.println("[destroyObject] Destroying owned objects...");
    FeatureValueList objectFeatureValues = reference.getFeatureValues();
    for (int i = 0; i < objectFeatureValues.size(); i++) {
        FeatureValue featureValue = objectFeatureValues.getValue(i);
        if (((Property)featureValue.feature).aggregation == AggregationKind.composite)
{
            ValueList values = featureValue.values;
            for (int j = 0; j < values.size(); j++) {
                Value ownedValue = values.getValue(j);
                this.destroyObject(ownedValue, isDestroyLinks, isDestroyOwnedObjects);
            }
        }
    }

    reference.destroy();
}

```

[2] doAction ()

```

// Get the value on the target input pin.
// If the value is not a reference, then the action has no effect. Otherwise, do the
following.
// If isDestroyLinks is true, destroy all links in which the referent participates.
// If isDestroyOwnedObjects is true, destroy all objects owned by the referent via
composition links.
// Destroy the referent object.

DestroyObjectAction action = (DestroyObjectAction) (this.node);
Value value = this.takeTokens(action.target).getValue(0);

this.destroyObject(value, action.isDestroyLinks, action.isDestroyOwnedObjects);

```

[3] objectIsComposite (in reference : Reference, in link : Link) : Boolean

```

// Test whether the given reference participates in the given link as a composite.

FeatureValueList linkFeatureValues = link.getFeatureValues();

boolean isComposite = false;
int i = 1;
while (!isComposite & i <= linkFeatureValues.size()) {
    FeatureValue featureValue = linkFeatureValues.getValue(i-1);
    if (!featureValue.values.getValue(0).equals(reference) &
        ((Property)featureValue.feature).aggregation == AggregationKind.composite) {
        isComposite = true;
    }
}

```



```
return isComposite;
```

8.6.3.2.8 LinkActionActivation

A link action activation is an action activation for a link action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] endMatchesEndData (in link : Link, in endData : LinkEndData) : Boolean

```
// Test whether the appropriate end of the given link matches the given end data.

boolean matches = false;
if (endData.value == null) {
    matches = true;
} else {
    Property end = endData.end;
    FeatureValue linkFeatureValue = link.getFeatureValue(end);
    Value endValue = this.getTokens(endData.value).getValue(0);
    if (endData instanceof LinkEndDestructionData) {
        if (!(LinkEndDestructionData)endData).isDestroyDuplicates & !
end.multiplicityElement.isUnique & end.multiplicityElement.isOrdered) {
            int destroyAt = ((UnlimitedNaturalValue)
(this.getTokens(((LinkEndDestructionData)endData).destroyAt).getValue(0))).value.naturalVa
lue;
            matches = linkFeatureValue.values.getValue(0).equals(endValue) &&
linkFeatureValue.position == destroyAt;
        } else {
            matches = linkFeatureValue.values.getValue(0).equals(endValue);
        }
    } else {
        matches = linkFeatureValue.values.getValue(0).equals(endValue);
    }
}

return matches;
```

[2] getAssociation () : Association

```
// Get the association for the link action of this activation.

return (Association)((LinkAction)(this.node)).endData.getValue(0).end.association;
```

[3] linkMatchesEndData (in link : Link, in endDataList : LinkEndData [0..*]) : Boolean

```
// Test whether the given link matches the given end data.
```

```

boolean matches = true;
int i = 1;
while (matches & i <= endDataList.size()) {
    matches = this.endMatchesEndData(link, endDataList.getValue(i-1));
    i = i + 1;
}

return matches;

```

8.6.3.2.9 ReadLinkActionActivation

A read link action activation is a link action activation for a read link action.

Generalizations

- [LinkActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```

// Get the extent, at the current execution locus, of the association to which the action
// applies.
// For all links that match the link end data, place the value of the remaining "open" end
// on the result pin.

ReadLinkAction action = (ReadLinkAction)(this.node);
LinkEndDataList endDataList = action.endData;
LinkEndData openEnd = null;

int i = 1;
while((openEnd == null) & i <= endDataList.size()) {
    if (endDataList.getValue(i-1).value == null) {
        openEnd = endDataList.getValue(i-1);
    }
    i = i + 1;
}

ExtensionalValueList extent = this.getExecutionLocus().getExtent(this.getAssociation());

for (int j = 0; j < extent.size(); j++) {
    ExtensionalValue value = extent.getValue(j);
    Link link = (Link)value;
    if (this.linkMatchesEndData(link, endDataList)) {
        Value resultValue = link.getFeatureValue(openEnd.end).values.getValue(0);
        this.putToken(action.result, resultValue);
    }
}

// Now that matching is done, ensure that all tokens on end data input pins
// are consumed.
for (int k=0; k<endDataList.size(); k++) {
    LinkEndData endData = endDataList.getValue(k);
    if (endData.value != null) {

```

```

        this.takeTokens(endData.value);
    }
}

```

8.6.3.2.10 ReadSelfActionActivation

A read self action activation is an action activation for a read self action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```

// Get the context object of the activity execution containing this action activation and
place a reference to it on the result output pin.

```

```

// Debug.println("[ReadSelfActionActivation] Start...");

```

```

Reference context = new Reference();
context.referent = this.getExecutionContext();

```

```

Debug.println("[ReadSelfActionActivation] context object = " + context.referent);

```

```

OutputPin resultPin = ((ReadSelfAction) (this.node)).result;
this.putToken(resultPin, context);

```

8.6.3.2.11 ReadStructuralFeatureActionActivation

A read structural feature action activation is an action activation for a read structural feature action.

Generalizations

- [StructuralFeatureActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```

// Get the value of the object input pin. If the value is not a structural value, do
nothing.

```

```

// Otherwise, get the values of the appropriate feature of the input value and place them

```

on the result output pin.

```
ReadStructuralFeatureAction action = (ReadStructuralFeatureAction) (this.node);

Value value = this.takeTokens(action.object).getValue(0);

if (value instanceof StructuredValue) {
//   Debug.println("[ReadStructuralFeatureActionActivation] value = " + value +",
structural feature = " + action.structuralFeature.name);
    ValueList resultValues =
((StructuredValue)value).getFeatureValue(action.structuralFeature).values;
    this.putTokens(action.result, resultValues);
}
```

8.6.3.2.12 RemoveStructuralFeatureValueActionActivation

A remove structural feature action activation is a write structural feature action activation for a remove structural feature value action.

Generalizations

- [WriteStructuralFeatureActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction()

```
// Get the value of the object input pin. If it is not a structural value, do nothing.
Otherwise do the following.
// Get the values of the appropriate feature of the input object. Get the value of the
value input pin.
// If isRemoveDuplicates is true, then remove all feature values equal to the input
value.
// If isRemoveDuplicates is false and there is no removeAt input pin, remove any one
feature value equal to the input value (if there are any that are equal).
// If isRemoveDuplicates is false, there is a removeAt input pin and the feature value at
the removeAt position is equal to the input value, remove that feature value.
// Set the appropriate feature of the input object to have the modified set of values.

RemoveStructuralFeatureValueAction action = (RemoveStructuralFeatureValueAction)
(this.node);

Value value = this.takeTokens(action.object).getValue(0);

if (value instanceof StructuredValue) {
    Value inputValue = this.takeTokens(action.value).getValue(0);
    FeatureValue featureValue =
((StructuredValue)value).getFeatureValue(action.structuralFeature);

    if (action.isRemoveDuplicates) {
        int j = this.position(value, featureValue.values, 1);
        while (j > 0) {
            featureValue.values.remove(j-1);
            j = this.position(value, featureValue.values, j);
        }
    }
}
```

```

    }
} else if (action.removeAt == null) {
    ValueList values = featureValue.values;
    intList positions = new intList();
    for (int i = 0; i < values.size(); i++) {
        Value thisValue = values.getValue(i);
        if (thisValue.equals(inputValue)) {
            positions.addValue(i+1);
        }
    }
    if (positions.size()>0) {
        // *** Nondeterministically choose which value to remove. ***
        int j =
((ChoiceStrategy)this.getExecutionLocus().factory.getStrategy("choice")).choose(positions.size());
        featureValue.values.remove(positions.getValue(j-1) - 1);
    }
} else {
    int removeAt = ((UnlimitedNaturalValue)
(this.takeTokens(action.removeAt).getValue(0))).value.naturalValue;
    if (featureValue.values.getValue(removeAt-1).equals(inputValue)) {
        featureValue.values.remove(removeAt-1);
    }
}
if (action.result != null) {
    this.putToken(action.result, value);
}
}

```

8.6.3.2.13 StructuralFeatureActionActivation

A structural feature action activation is an action activation for a structural feature action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

None

8.6.3.2.14 TestIdentityActionActivation

A test identity action activation is an action activation for a test identity action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the values from the first and second input pins and test if they are equal. (Note
the equality of references is defined to be that they have identical referents.)
// If they are equal, place true on the pin execution for the result output pin, otherwise
place false.
```

```
TestIdentityAction action = (TestIdentityAction)(this.node);
```

```
Value firstValue = this.takeTokens(action.first).getValue(0);
Value secondValue = this.takeTokens(action.second).getValue(0);
```

```
Value testResult = this.makeBooleanValue(firstValue.equals(secondValue));
this.putToken(action.result, testResult);
```

8.6.3.2.15 ValueSpecificationActionActivation

A value specification action activation is an action activation for a value specification action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Evaluate the value specification for the action and place the result on the result pin
of the action.
```

```
ValueSpecificationAction action = (ValueSpecificationAction)(this.node);
```

```
Value value = this.getExecutionLocus().executor.evaluate(action.value);
this.putToken(action.result, value);
```

8.6.3.2.16 WriteLinkActionActivation

A write link action activation is a link action activation for a write link action.

Generalizations

- [LinkActionActivation](#)

Attributes

None

Associations

None

Operations

None

8.6.3.2.17 WriteStructuralFeatureActionActivation

A write structural feature action activation is a structural feature action activation for a write structural feature action.

Generalizations

- [StructuralFeatureActionActivation](#)

Attributes

None

Associations

None

Operations

[1] position (in value : Value, in list : Value [0..*], in startAt : Integer) : Integer

// Return the position (counting from 1) of the first occurrence of the given value in the given list at or after the starting index, or 0 if it is not found.

```
boolean found = false;
int i = startAt;
while (!found & i <= list.size()) {
    found = list.getValue(i-1).equals(value);
    i = i + 1;
}

if (!found) {
    i = 1;
}

return i - 1;
```

8.6.4 Complete Actions**8.6.4.1 Overview****Object Classification Actions**

At the Complete Actions level, fUML includes three additional actions related to object classification (see Figure 78 for the corresponding activation model).

- *Read Extent Action.* This action is used to obtain the extent of a class at the execution locus of the activity activation containing the action activation. The action outputs references to each of the objects in the extent. Note that the extent of a class is considered to also include the instances of all subclasses of the identified class. In fUML, the classifier associated with this action must be a class (see Subclause 7.5.4).

- *Read Is Classified Object Action.* This action is used to test whether its input value is of a given type. The input value does not actually have to be an object reference but can also be a data value. The action produces a true output if the input has the given classifier as one of its types (objects may have multiple types). If `isDirect` is false, then the action also outputs true of any type of the input value is a specialization (directly or indirectly) of the given classifier. Otherwise, the action outputs false.
- *Reclassify Object Action.* This action is used to change the type(s) of an object. In fUML, the input value must be a reference to an object and all the classifiers associated with the action must be classes (see Subclause 7.5.4). Per the semantics of UML 2 for reclassification (see Subclause 11.3.9 of the UML 2 Superstructure Specification), this action removes the indicated old classifiers as types of the input object and adds the new classifiers, taking into account cases in which a classifier may be in both sets. Note that, if a classifier with a classifier behavior is removed, then any execution the input object may have for this behavior is terminated (see also Subclause 8.5.3). However, if a classifier is added with a classifier behavior, this behavior is *not* started until an explicit start object behavior action is performed (see below).

Start Object Behavior Action

At the Complete Actions level, fUML also adds the start object behavior action. This action is used to start the execution of an instantiated behavior or a classifier behavior of an active object.

In general UML, a start object behavior action is a kind of call action and its behavior invocation may be either synchronous or asynchronous. However, in fUML, only asynchronous invocation is supported (see Subclause 7.5.2). Therefore, `StartObjectBehaviorActionActivation` is a subclass of `InvocationAction` rather than `CallActionActivation` (see Figure 78), since `CallActionActivation` only provides synchronous call semantics (see Subclause 8.6.2).

If the input object to the action activation is an active object of the type of the input pin of the start object behavior action, then the effect of the action is to start the classifier behavior associated with that type. The start object behavior activation `doAction` method calls the `startBehavior` operation on the input object, passing as parameter values the values on the argument input pin activations for the action activation. This results in the input object having an object activation with a classifier behavior execution for that classifier behavior (see Subclause 8.4.3). Once the classifier behavior execution starts, it executes concurrently, so the execution thread of the start object behavior action activation can continue without blocking. If the classifier behavior for the indicated type already has an execution for the given object, then the action has no effect.

If the input pin to the start object behavior action activation does not have a type, then the effect of the action is to start the classifier behaviors for *all* types of the input object that have classifier behaviors that are not already executing. Note that, in this case, it is not possible to specify input parameter values for the classifier behaviors.

If the input object to the action activation is itself an execution object (i.e., an instance of a behavior), then the effect is to start the execution of the behavior (if it isn't already executing). However, since the execution must proceed asynchronously to the execution of the start object behavior action, it is necessary to start a new execution thread. This is achieved in the execution model by starting the execution of the behavior in the same way as a classifier behavior. That is, the input execution object is given an object activation with a classifier behavior execution that provides a new execution thread *for the execution object itself*. The `execute` operation for the input execution object is called on this new thread, so that the thread of the start object behavior action activation can continue without blocking. (See also Subclause 8.4.3.)

NOTE: fUML also includes the start classifier behavior action. This acts similarly to a start object behavior action, but it only handles active objects with classifier behaviors and it does not provide a mechanism for specifying input parameters. Start classifier behavior actions are supported in fUML for compatibility with past practice, but they should be considered deprecated in favor of start object behavior actions.

Accept Event Action

An accept event action is used in an activity to wait for the occurrence of a specific event. In fUML, the only events that such an action can wait for are signal events (see Subclause 7.5.4).

To wait for the dispatching of a signal event, the accept event action activation must register itself as an event acceptor with its context object. Actually, the action activation does not directly register itself, but, instead, it creates an accept event action event acceptor object, which is a kind of event acceptor (see Subclause 8.4.3), and registers this with the context object (see Figure 79). This registration happens when the accept event action activation fires (the only prerequisites for this action are that it receives a control token), and the doAction operation is not called in this case.

Instead, the behavior of the action is triggered when a signal instance is dispatched from the event pool of the context object that matches the trigger specification of the accept event action. In this case, the object activation dispatchEvent operation calls the *accept* operation on the accept event action event acceptor object (see Subclause 8.6.3). The event acceptor then forwards the call to the accept operation of the accept event action activation, starting a new thread within the activity containing the start object behavior action.

Reduce Action

Finally, the Complete Actions level also includes the reduce action. This action calls a *reducer* behavior repeatedly in order to reduce a set of input values to a single value. Similarly to a call action, the reduce action activation creates an execution object for the reducer behavior (see Figure 80). A new execution object is created for each call and is destroyed at the end of the call.

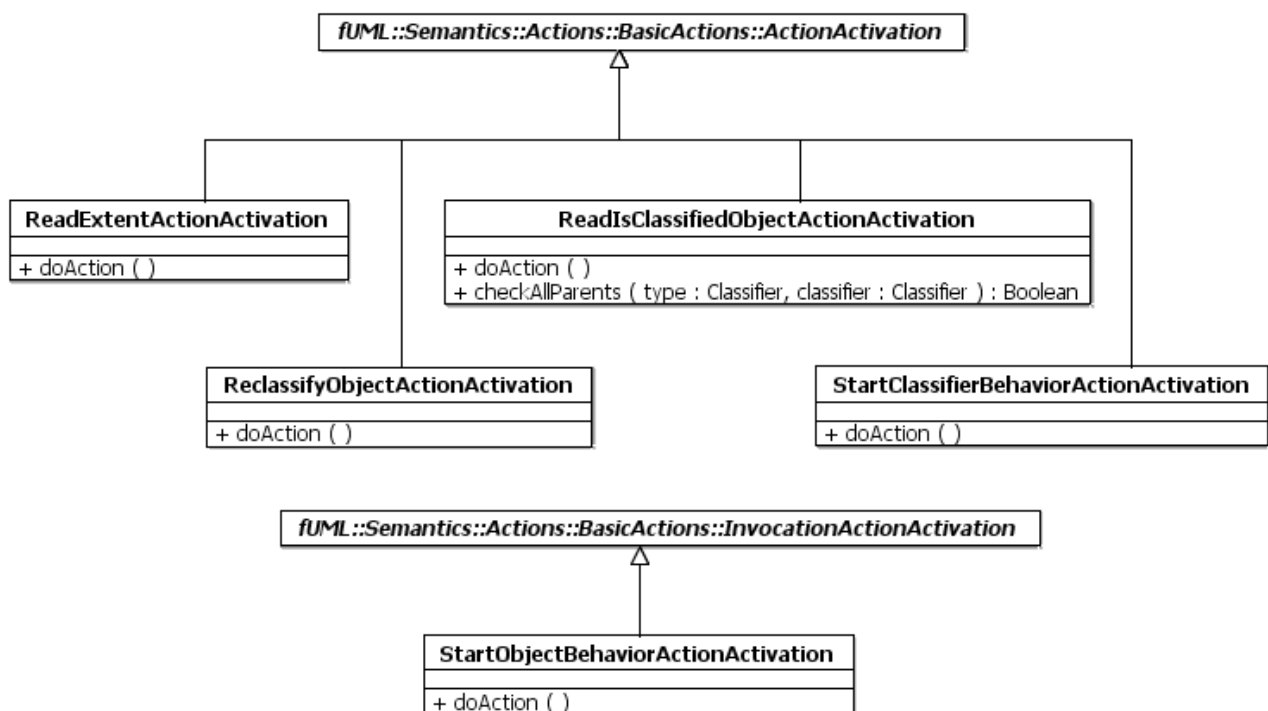


Figure 78 - Object Action Activations

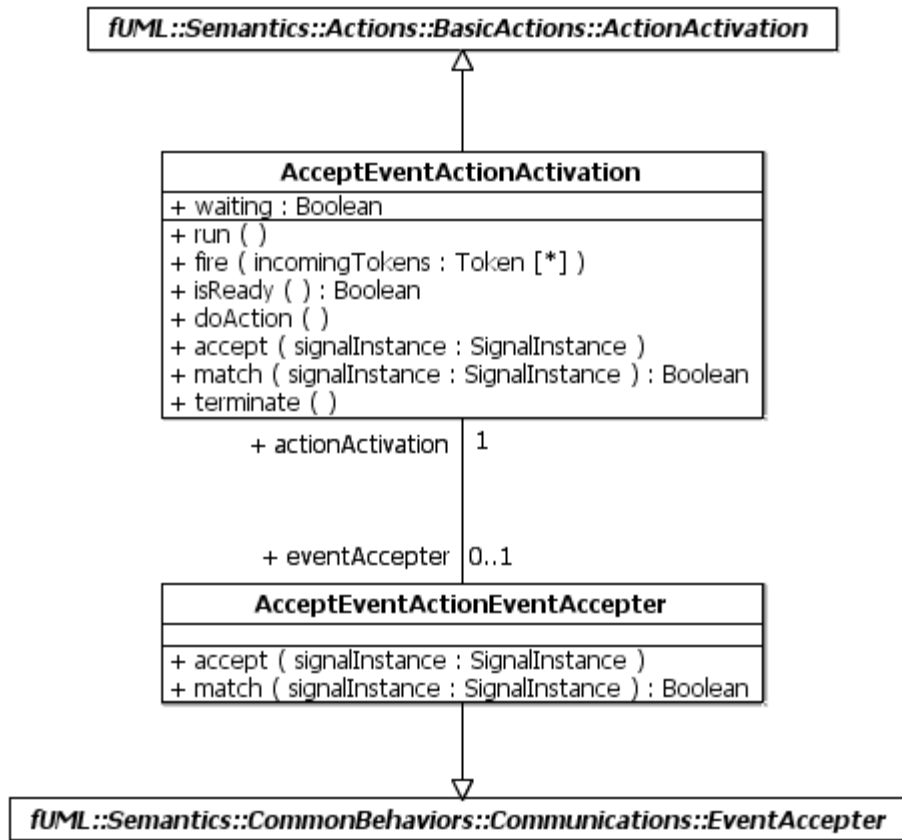


Figure 79 - Accept Action Activations

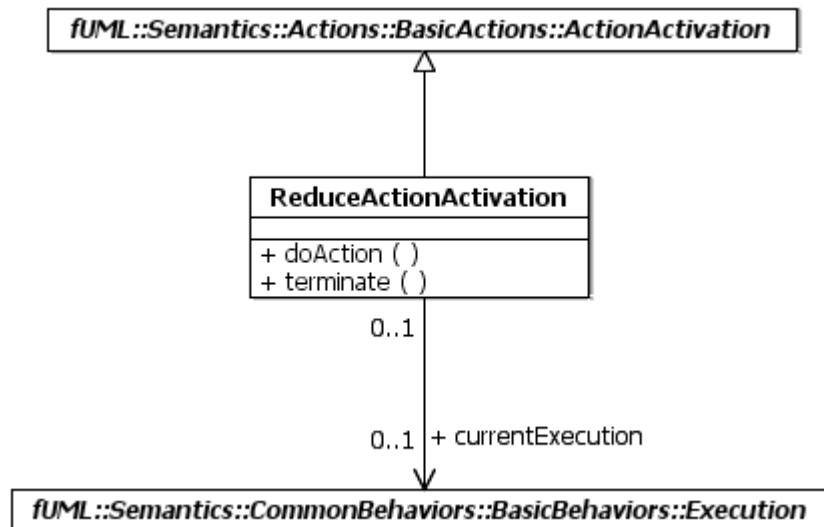


Figure 80 - Reduce Action Activations

8.6.4.2 Class Descriptions

8.6.4.2.1 AcceptEventActionActivation

An accept event action activation is an action activation for an accept event action.

Generalizations

- [ActionActivation](#)

Attributes

- waiting : Boolean

Associations

- eventAcceptor : AcceptEventActionEventAcceptor [0..1]

If the accept event action activation is waiting for an event, then this is the accepter it has registered for the event.

Operations

[1] accept (in signalInstance : SignalInstance)

```
// Accept a signal occurrence for the given signal instance.
// If the action does not unmarshall, then place the signal instance on the result pin.
// If the action does unmarshall, then get the feature values of the signal instance, and
// place the values for each feature on the corresponding output pin, if any.
// Concurrently fire all output pins while offering a single control token.
// If there are no incoming edges, then re-register this accept event action execution
// with the context object.
```

```
AcceptEventAction action = (AcceptEventAction)(this.node);
OutputPinList resultPins = action.result;
```

```
Debug.println("[accept] action = " + action.name + ", signalInstance = " +
signalInstance);
```

```
if (this.running) {
    if (!action.isUnmarshall) {
        ValueList result = new ValueList();
        result.addValue(signalInstance);

        if (resultPins.size() > 0) {
            this.putTokens(resultPins.getValue(0), result);
        }
    } else {
        FeatureValueList featureValues = signalInstance.getFeatureValues();
        for (int i = 0; i < featureValues.size(); i++) {
            FeatureValue featureValue = featureValues.getValue(i);
            OutputPin resultPin = resultPins.getValue(i);
            this.putTokens(resultPin, featureValue.values);
        }
    }
}
```

```
this.sendOffers();
```

```
this.waiting = false;
```

```
Debug.println("[fire] Checking if " + this.node.name + " should fire again...");
```

```
// if (this.isReady()) {
//     this.fire();
```

```
//      }
    this.receiveOffer();
}
```

[2] doAction ()

```
// Do nothing. [This will never be called.]
return;
```

[3] fire (in incomingTokens : Token [0..*])

```
// Register the event accepter for this accept event action activation with the context
object of the enclosing activity execution
// and wait for an event to be accepted.

Debug.println("[fire] Action " + this.node.name + "...");

this.getExecutionContext().register(this.eventAcceptor);
this.waiting = true;
```

[4] isReady () : Boolean

```
// An accept event action activation is ready to fire only if it is not already waiting
for an event.

boolean ready;
if (this.waiting) {
    ready = false;
} else {
    ready = super.isReady();
}

return ready;
```

[5] match (in signalInstance : SignalInstance) : Boolean

```
// Return true if the given signal instance matches a trigger of the accept action of this
activation.

AcceptEventAction action = (AcceptEventAction) (this.node);
TriggerList triggers = action.trigger;
Signal signal = signalInstance.type;

boolean matches = false;
int i = 1;
while (!matches & i <= triggers.size()) {
    matches = ((SignalEvent) (triggers.getValue(i-1).event)).signal == signal;
    i = i + 1;
}

return matches;
```

[6] run ()

```
// Create an event accepter and initialize waiting to false.
```

```

super.run();

this.eventAcceptor = new AcceptEventActionEventAcceptor();
this.eventAcceptor.actionActivation = this;

this.waiting = false;

```

[7] terminate ()

```

// Terminate this action and unregister its event acceptor.
super.terminate();

if (this.waiting) {
    this.getExecutionContext().unregister(this.eventAcceptor);
    this.waiting = false;
}

```

8.6.4.2.2 AcceptEventActionEventAcceptor

An accept event action event acceptor handles signal reception events on the behalf of a specific accept event action activation.

Generalizations

- [EventAcceptor](#)

Attributes

None

Associations

- actionActivation : AcceptEventActionActivation
The accept event action activation on behalf of which this event acceptor is waiting.

Operations

[1] accept (in signalInstance : SignalInstance)

Accept a signal occurrence for the given signal instance.

```

// Accept a signal occurrence for the given signal instance.
// Forward the signal occurrence to the action activation.

this.actionActivation.accept(signalInstance);

```

[2] match (in signalInstance : SignalInstance) : Boolean

Determine if the given signal instance matches a trigger of the accept action of the action activation.

```

// Return true if the given signal instance matches a trigger of the accept action of the
action activation.

return this.actionActivation.match(signalInstance);

```

8.6.4.2.3 ReadExtentActionActivation

A read extent action activation is an action activation for a read extent action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the extent, at the current execution locus, of the classifier (which must be a
class) identified in the action.
// Place references to the resulting set of objects on the result pin.

ReadExtentAction action = (ReadExtentAction)(this.node);
ExtensionalValueList objects = this.getExecutionLocus().getExtent(action.classifier);

// Debug.println("[doAction] " + action.classifier.name + " has " + objects.size() + "
instance(s).");

ValueList references = new ValueList();
for (int i = 0; i < objects.size(); i++) {
    Value object = objects.getValue(i);
    Reference reference = new Reference();
    reference.referent = (Object_)object;
    references.addValue(reference);
}

this.putTokens(action.result, references);
```

8.6.4.2.4 ReadIsClassifiedObjectActionActivation

A read-is-classified object activation is an action activation for a read-is-classified object action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] checkAllParents (in type : Classifier, in classifier : Classifier) : Boolean

```
// Check if the given classifier matches any of the direct or indirect ancestors of a
given type.

ClassifierList directParents = type.general;
boolean matched = false;
int i = 1;
while (!matched & i <= directParents.size()) {
    Classifier directParent = directParents.getValue(i-1);
```

```

    if (directParent == classifier) {
        matched = true;
    } else {
        matched = this.checkAllParents(directParent, classifier);
    }
    i = i + 1;
}

return matched;

```

[2] doAction ()

```

// Get the value on the object input pin and determine if it is classified by the
// classifier specified in the action.
// If the isDirect attribute of the action is false, then place true on the result output
// pin if the input object has the specified classifier or of one its (direct or indirect)
// descendants as a type.
// If the isDirect attribute of the action is true, then place true on the result output
// pin if the input object has the specified classifier as a type.
// Otherwise place false on the result output pin.

```

```

ReadIsClassifiedObjectAction action = (ReadIsClassifiedObjectAction)(this.node);

```

```

Value input = this.takeTokens(action.object).getValue(0);
ClassifierList types = input.getTypes();

```

```

boolean result = false;
int i = 1;
while (!result & i <= types.size()) {
    Classifier type = types.getValue(i-1);

    if (type == action.classifier) {
        result = true;
    }
    else if (!action.isDirect) {
        result = this.checkAllParents(type, action.classifier);
    }

    i = i + 1;
}

```

```

ValueList values = new ValueList();
values.addValue(this.makeBooleanValue(result));

```

```

this.putTokens(action.result, values);

```

8.6.4.2.5 ReclassifyObjectActionActivation

A reclassify object activation is an action activation for a reclassify object action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the value of the object input pin. If it is not a reference, then do nothing.
Otherwise, do the following.
// Remove all types from the referent object that are in the set of old classifiers but
not the set of new classifiers (or just all types that are not new classifiers, if
isReplaceAll is true).
// Remove the feature values from the referent object for all classifiers that are
removed.
// Add all new classifiers as types of the referent object that are not already types.
// Add (empty) feature values to the referent object for the structural features of all
added classifiers.

ReclassifyObjectAction action = (ReclassifyObjectAction)(this.node);
ClassifierList newClassifiers = action.newClassifier;
ClassifierList oldClassifiers = action.oldClassifier;

Value input = this.takeTokens(action.object).getValue(0);

if (input instanceof Reference) {
    Object_ object = ((Reference)input).referent;

    int i = 1;
    while (i <= object.types.size()) {
        Class_ type = object.types.getValue(i-1);

        boolean toBeRemoved = true;
        int j = 1;
        while (toBeRemoved & j <= newClassifiers.size()) {
            toBeRemoved = (type != newClassifiers.getValue(j-1));
            j = j + 1;
        }

        if (toBeRemoved & !action.isReplaceAll) {
            boolean notInOld = true;
            int k = 1;
            while (notInOld & k <= oldClassifiers.size()) {
                notInOld = (type != oldClassifiers.getValue(k-1));
                k = k + 1;
            }
            toBeRemoved = !notInOld;
        }

        if (toBeRemoved) {
            object.types.removeValue(i-1);
            object.removeFeatureValues(type);
        } else {
            i = i + 1;
        }
    }

    for (int n = 0; n < newClassifiers.size(); n++) {
        Classifier classifier = newClassifiers.getValue(n);

        boolean toBeAdded = true;
        int j = 1;
        while (toBeAdded & j <= object.types.size()) {
            toBeAdded = (classifier != object.types.getValue(j-1));
            j = j + 1;
        }
    }
}
```



```

    if (toBeAdded) {
        object.types.addValue((Class_)classifier);
        NamedElementList members = classifier.member;
        for (int k = 0; k < members.size(); k++) {
            NamedElement member = members.getValue(k);
            if (member instanceof StructuralFeature) {
                object.setFeatureValue((StructuralFeature)member, new ValueList(), 0);
            }
        }
    }
}
}
}

```

8.6.4.2.6 ReduceActionActivation

A reduce action activation is an action activation for a reduce action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

- currentExecution : Execution [0..1]
The current execution of the reducer behavior.

Operations

[1] doAction ()

```

// Get the values of the collection input pin.
// If the input pin has no values, then do nothing. Otherwise, do the following.
// Repeatedly invoke the reducer behavior on successive pairs to reduce the collection to
a single value, and place that value on the result pin.
// To invoke the reducer behavior, compile it to create an execution, make the execution
the current execution, place the appropriate values on its input parameters, and execute
it.

```

```
ReduceAction action = (ReduceAction)(this.node);
```

```
ValueList values = this.takeTokens(action.collection);
```

```

if (values.size() > 0) {
    ParameterList parameters = action.reducer.ownedParameter;
    Parameter input1 = null;
    Parameter input2 = null;
    Parameter output = null;

    int i = 1;
    while (i <= parameters.size()) {
        Parameter parameter = parameters.getValue(i-1);
        if (parameter.direction == ParameterDirectionKind.in) {
            if (input1 != null) {
                input1 = parameter;
            }
            else {
                input2 = parameter;
            }
        }
    }
}

```

```

        else if (parameter.direction == ParameterDirectionKind.out) {
            output = parameter;
        }
        i = i + 1;
    }

    ParameterValue parameterValue1 = new ParameterValue();
    parameterValue1.parameter = input1;
    parameterValue1.values = new ValueList();
    parameterValue1.values.addValue(values.getValue(0));

    int j = 2;
    while (j <= values.size()) {
        this.currentExecution =
this.getExecutionLocus().factory.createExecution(action.reducer,
this.getExecutionContext());

        this.currentExecution.setParameterValue(parameterValue1);

        ParameterValue parameterValue2 = new ParameterValue();
        parameterValue2.parameter = input2;
        parameterValue2.values = new ValueList();
        parameterValue2.values.addValue(values.getValue(j-1));
        this.currentExecution.setParameterValue(parameterValue2);

        this.currentExecution.execute();

        parameterValue1 = this.currentExecution.getParameterValue(output);

        j = j + 1;
    }

    this.putTokens(action.result, parameterValue1.values);
}

```

[2] terminate ()

```

// If there is a current execution, terminate it. Then terminate self.

if (this.currentExecution != null) {
    this.currentExecution.terminate();
}

super.terminate();

```

8.6.4.2.7 StartClassifierBehaviorActionActivation

A start classifier behavior action activation is an action activation for a start classifier behavior action.

Generalizations

- [ActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the value on the object input pin. If it is not a reference, then do nothing.
// Start the classifier behavior of the referent object for the classifier given as the
// type of the object input pin.
// If the object input pin has no type, then start the classifier behaviors of all types
// of the referent object. [The required behavior in this case is not clear from the spec.]

StartClassifierBehaviorAction action = (StartClassifierBehaviorAction) (this.node);

Value object = this.takeTokens(action.object).getValue(0);

if (object instanceof Reference) {
    ((Reference)object).startBehavior((Class_) (action.object.typedElement.type), new
    ParameterValueList());
}
```

8.6.4.2.8 StartObjectBehaviorActionActivation

A start behavior action activation is an action activation for a start behavior action.

Generalizations

- [InvocationActionActivation](#)

Attributes

None

Associations

None

Operations

[1] doAction ()

```
// Get the value on the object input pin. If it is not a reference, then do nothing.
// Start the behavior of the referent object for the classifier given as the type of the
// object input pin, with parameter values taken from the argument input pins.
// If the object input pin has no type, then start the classifier behaviors of all types
// of the referent object.

StartObjectBehaviorAction action = (StartObjectBehaviorAction) (this.node);

Value object = this.takeTokens(action.object).getValue(0);

if (object instanceof Reference) {
    Class_ type = (Class_) (action.object.typedElement.type);
    InputPinList argumentPins = action.argument;

    ParameterValueList inputs = new ParameterValueList();

    if (type != null) {
        Behavior behavior;

        if (type instanceof Behavior) {
            behavior = (Behavior)type;
        } else {
            behavior = type.classifierBehavior;
        }
    }
}
```

```

if (behavior != null) {
    ParameterList parameters = behavior.ownedParameter;

    int pinNumber = 1;
    int i = 1;
    while (i <= parameters.size()) {
        Parameter parameter = parameters.getValue(i-1);
        int j = pinNumber;
        if (parameter.direction == ParameterDirectionKind.in |
            parameter.direction == ParameterDirectionKind.inout) {
            ParameterValue parameterValue = new ParameterValue();
            parameterValue.parameter = parameter;

            parameterValue.values = this.takeTokens(argumentPins.getValue(j-1));
            inputs.addValue(parameterValue);
            j = j + 1;
        }
        pinNumber = j;
        i = i + 1;
    }
}

((Reference)object).startBehavior(type, inputs);
}

```

9 Foundational Model Library

This clause defines the basic Foundational Model Library for fUML. This is a library of user-level model elements that can be referenced in a fUML model. These capabilities are provided in an overall package called FoundationalModelLibrary, with the sub-packages shown in Figure 81 and described in the following subclauses.

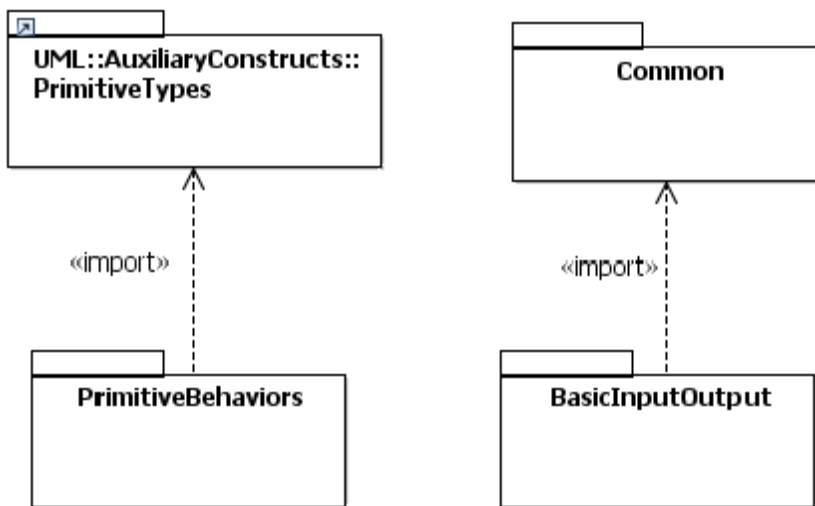


Figure 81 - Foundation Model Library packages

9.1 Primitive Types

Note in Figure 81 that the PrimitiveBehaviors package imports the AuxiliaryConstructs::PrimitiveTypes package from the UML 2 metamodel (see Subclause 17.4 of the UML 2 Superstructure Specification). This package defines the

primitive types Boolean, Integer, String and UnlimitedNatural. These are the types for which corresponding literal values can be specified in fUML (see Subclause 7.2.1). Since they are used in the construction of literal values, these types must all be registered with the execution factory at every locus (see Subclause 8.2.1). By importing the AuxiliaryConstructs::PrimitiveTypes package from UML, a user model may also directly reference these types.

Table 1 describes the value domains of these primitive types as they are provided in fUML. In the fUML execution model, values of these primitive types are represented by the various subclasses of PrimitiveValue (see Subclause 8.3.2.1). Each of these subclasses defines a *value* attribute, which is, itself, typed by a similarly named primitive type (e.g., the type of BooleanValue::value is Boolean). However, the semantics for the primitive types used within the execution model are given by the base semantics in Clause 10. The formalizations of these types in the base semantics provides the grounding for the semantics of the corresponding primitive types as used in fUML models.

Table 1 - Primitive Types

| Type Name | Description |
|------------------|---|
| Boolean | The Boolean type has two literal values, true and false. Note, however, that Boolean is defined as a primitive type, not an enumeration. |
| Integer | The Integer type has literal values in the (infinite) set of integers (...-2, -1, 0, 1, 2...). However, a conforming implementation may limit the supported values to a finite set. |
| String | The String type has literal values that are sequences of zero or more characters. The actual character set used is not specified in this standard and the maximum string size is unbounded. |
| UnlimitedNatural | The UnlimitedNatural type has literal values in the (infinite) set of integers (0, 1, 2...) plus the additional value “unbounded”. If a conforming implementation limits the set of integers supported, then the set of unlimited natural values supported (other than “unbounded”) must be exactly the same as the supported set of non-negative integer values. |

9.2 Primitive Behaviors

The FoundationalModelLibrary::PrimitiveBehaviors package contains a set of primitive behaviors that operation on the primitive data types defined in Subclause 9.1. As shown in Figure 82, the package is divided into sub-packages for each primitive type.

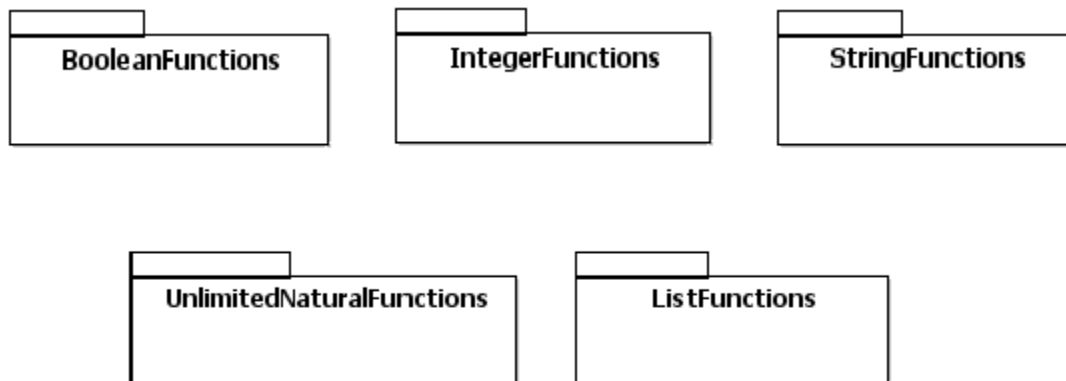


Figure 82 - Foundation Model Library PrimitiveBehaviors package

Within each of the sub-packages shown in Figure 82, the primitive behaviors are modeled as function behaviors with no side effects. If implemented in the execution environment of a conforming execution tool, implementations for these behaviors are considered to be registered at the locus of execution that models that environment (see Subclause 8.2.1). They may be called from user models using the call behavior action (see Subclause 8.4.2).

The primitive behaviors provided in the Foundation Model Library for Boolean, Integer and String have been largely based on the operations provided for the corresponding primitive types in OCL 2.0 (see Subclauses 11.4 and 11.5 of the OCL 2.0 Specification). However, while OCL uses an object-oriented operational style for primitive functions (e.g., in binary arithmetic operations, one of the arguments acts as the “target” of the operation invocation), the corresponding behaviors in the Foundation Model Library are invoked more traditionally as functions of all their arguments (particularly since fUML does not allow operations on data types—see Subclause 7.2). Other substantive differences from the OCL operations are noted below in the descriptions of the Foundation Model Library behaviors.

NOTE: An equality function is not provided as a primitive behavior, since this functionality is provided by the test identity action, which tests by value for primitive data types (see Subclause 8.4.3). In particular, since strings are primitive values, the equality test on strings is by value.

In the following descriptions, if the behavior of a primitive behavior can be described in terms of other primitive behaviors, then this is formalized by giving a post-condition for the first behavior. The semantics of primitive behaviors for which no post-condition is given are to be considered to be specified directly by the axioms of the base semantics (see Clause 10).

In some case, pre-conditions are also specified for primitive behaviors. In this case, if the pre-condition is violated, then the behavior completes execution, but produces no output value. The result parameters for such behaviors are specified to have multiplicity 0..1 to allow for this.

NOTE: For readability of the pre- and post-condition expressions in the following, an infix notation is used to denote the invocation of binary function behaviors. For example the invocation of the “And” behavior is written “x And y,” not “And(x,y).” However, this is still intended to denote the result of the invocation of the named Foundational Model Library primitive behavior on the given arguments. An infix notation “x = y” is also used for equality, with the intended semantics being those of a test identity action on data value arguments (see Subclause 8.4.3).

9.2.1 Boolean Functions

Table 2 lists the function behaviors that are included in the package BooleanFunctions. The naming is consistent with OCL, except that names are capitalized, per the usual convention for behaviors (as kinds of classes). The Foundation Model Library also provides ToString and ToBoolean functions not found in OCL.

Table 2 - Foundation Model Library Boolean Functions

| Function Signature | Description |
|--|---|
| Or(x: Boolean, y: Boolean): Boolean | True if either <i>x</i> or <i>y</i> is true. <i>Post: if x then result = true else result = y endif</i> |
| Xor(x: Boolean, y: Boolean): Boolean | True if either <i>x</i> or <i>y</i> is true, but not both. <i>Post: result = (x Or y) And Not(x And y)</i> |
| And(x: Boolean, y: Boolean): Boolean | True if both <i>x</i> and <i>y</i> are true. <i>Post: if x then result = y else result = true endif</i> |
| Not(x: Boolean): Boolean | True if <i>x</i> is false. <i>Post: if x then result = false else result = true endif</i> |
| Implies(x: Boolean, y: Boolean): Boolean | True if <i>x</i> is false, or if <i>x</i> is true and <i>y</i> is true. |

| | |
|-------------------------------------|--|
| | <i>Post: result = Not(x) Or (x And y)</i> |
| ToString(x: Boolean): String | Converts x to a String value. <i>Post: if x then result = "true" else result = "false" endif</i> |
| ToBoolean(x: String): Boolean[0..1] | Converts x to a Boolean value. <i>Pre: (lower(x) = "true") or (lower(x) = "false")</i> <i>Post: if lower(x) = "true" then result = true else result = false endif</i> Note: The notation " <i>lower(x)</i> " above is <i>not</i> intended to be an invocation of a Foundation Model Library primitive behavior but, rather, is intended to denote that value of the string x with any uppercase letters converted to the corresponding lowercase letters. |

9.2.2 Integer Functions

Table 3 lists the function behaviors that are included in the package IntegerFunctions. The naming is consistent with OCL, including the use of the conventional symbols for arithmetic functions, except that the negation function is named "Neg," rather than overloading the symbol "-", and alphabetic names are capitalized, per the usual convention for behaviors (as kinds of classes). The OCL "/" operation is not included, since this returns a Real value, and the Foundational Model Library does not support a Real primitive type. The Foundation Model Library also provides ToString and ToUnlimitedNatural functions not found in OCL. The ToInteger function does correspond to an OCL operation, though, in OCL, it is a String operation.

Table 3 - Foundation Model Library Integer Functions

| Function Signature | Description |
|--|---|
| Neg(x: Integer): Integer | The negative value of x . |
| +(x: Integer, y: Integer): Integer | The value of the addition of x and y . |
| -(x: Integer, y: Integer): Integer | The value of the subtraction of x and y . <i>Post: result + y = x</i> |
| *(x: Integer, y: Integer): Integer | The value of the multiplication of x and y . <i>Post:</i> <i>if $y < 0$ then result = Neg (x * Neg(y))</i> <i>else if $y = 0$ then result = 0</i> <i>else result = (x * (y-1)) + x</i> <i>endif endif</i> |
| Abs(x: Integer): Integer | The absolute value of x . <i>Post: if $x < 0$ then result = Neg(x) else result = x endif</i> |
| Div(x: Integer, y: Integer): Integer[0..1] | The number of times that y fits completely within x . <i>Pre: $y <> 0$</i> <i>Post:</i> <i>if (x * y) >= 0 then</i> <i>((result * y) <= x) And ((result+1) * y) > x)</i> |

| | |
|---|---|
| | <pre> else ((Neg(result) * y) <= Neg(x)) And ((Neg(result)+1) * y) > Neg(x) endif </pre> |
| Mod(x: Integer, y: Integer): Integer | <p>The result is x modulo y.</p> <p><i>Post: result = $x - (x \text{ Div } y) * y$</i></p> |
| Max(x: Integer, y: Integer): Integer | <p>The maximum of x and y.</p> <p><i>Post: if $x \geq y$ then result = x else result = y endif</i></p> |
| Min(x: Integer, y: Integer): Integer | <p>The minimum of x and y.</p> <p><i>Post: if $x \leq y$ then result = x else result = y endif</i></p> |
| <(x: Integer, y: Integer): Boolean | <p>True if x is less than y.</p> |
| >(x: Integer, y: Integer): Boolean | <p>True if x is greater than y.</p> <p><i>Post: result = Not($x \leq y$)</i></p> |
| <=(Integer, Integer): Boolean | <p>True if x is less than or equal to y.</p> <p><i>Post: result = ($x = y$) Or ($x < y$)</i></p> |
| >=(Integer, Integer): Boolean | <p>True if x is greater than or equal to y.</p> <p><i>Post: result = ($x = y$) Or ($x > y$)</i></p> |
| ToString(x: Integer): String | <p>Converts x to a String value.</p> <p><i>Post: ToInteger(result) = x</i></p> |
| ToUnlimitedNatural(x: Integer): UnlimitedNatural[0..1] | <p>Converts x to an UnlimitedNatural value.</p> <p><i>Pre: $x \geq 0$</i></p> <p><i>Post: ToInteger(result) = x</i></p> |
| ToInteger(x: String): Integer[0..1] | <p>Converts x to an Integer value.</p> <p><i>Pre: x has the form of a legal integer value</i></p> |

9.2.3 String Functions

Table 4 function behaviors are included in the package StringFunctions. The naming is consistent with OCL, except that names are capitalized, per the usual convention for behaviors (as kinds of classes). In the Foundation Model Library, ToInteger is provided as an integer function rather than a string operation, and ToReal is not provided because the Foundation Model Library does not support a Real primitive type.

Table 4 - Foundation Model Library String Functions

| Function Signature | Description |
|--|---|
| Concat(x: String, y: String):String | The concatenation of x and y . <i>Post:</i> ($Size(result) = Size(x) + Size(y)$) And ($Substring(result, 1, Size(x)) = x$) And ($Substring(result, Size(x)+1, Size(result)) = y$) |
| Size(x: String):Integer | The number of characters in x . |
| Substring(x: String, lower: Integer, upper: Integer): String[0..1] | The substring of x starting at character number $lower$, up to and including character number $upper$. Character numbers run from 1 to $Size(x)$. <i>Pre:</i> ($1 \leq lower$) And ($lower \leq upper$) And ($upper \leq Size(x)$) |

9.2.4 UnlimitedNatural Functions

Table 5 list the function behaviors that are included in the package UnlimitedNaturalFunctions. Only comparison and conversion functions are provided. Arithmetic can be performed on UnlimitedNatural values by converting them to Integers. (Arithmetic on the “unbounded” value is thus not defined.)

Table 5 - Foundation Model Library UnlimitedNatural Functions

| Function Signature | Description |
|---|---|
| Max(x: UnlimitedNatural, y: UnlimitedNatural): UnlimitedNatural | The maximum of x and y . <i>Post: if $x \geq y$ then result = x else result = y endif</i> |
| Min(x: UnlimitedNatural, y: UnlimitedNatural): UnlimitedNatural | The minimum of x and y . <i>Post: if $x \leq y$ then result = x else result = y endif</i> |
| <(x: UnlimitedNatural, y: UnlimitedNatural): Boolean | True if x is less than y . Every value other than “unbounded” is less than “unbounded”. |
| >(x: UnlimitedNatural, y: UnlimitedNatural): Boolean | True if x is greater than y . <i>Post: result = Not($x \leq y$)</i> |
| <=(UnlimitedNatural, UnlimitedNatural): Boolean | True if x is less than or equal to y . <i>Post: result = ($x = y$) Or ($x < y$)</i> |
| >=(UnlimitedNatural, UnlimitedNatural): Boolean | True if x is greater than or equal to y . <i>Post: result = ($x = y$) Or ($x > y$)</i> |
| ToString(x: UnlimitedNatural): String | Converts x to a String value. The value “unbounded” is represented by the string “*”. <i>Post: ToUnlimitedNatural(result) = x</i> |
| ToInteger(x: UnlimitedNatural): Integer[0..1] | Converts x to an Integer value. |

| | |
|--|---|
| | <i>Pre: x <> unbounded</i> |
| ToUnlimitedNatural(x: String): Integer[0..1] | <p>Converts <i>x</i> to an Integer value.</p> <p><i>Pre: (x has the form of a legal integer value) Or (x = “*”)</i></p> <p><i>Post:</i> <i>if x = “*” then result = unbounded</i> <i>else result = ToUnlimitedNatural(ToInteger(x))</i></p> |

9.2.5 List Functions

Table 6 lists the function behaviors that are included in the ListFunctions package. These are convenience functions for querying values with multiplicity [*]. Note that the *list* argument for both list functions is untyped and that the result of ListGet is also untyped.

NOTE: The functionality of the list functions could actually be implemented as activities using expansion regions. However, it is generally much more convenient to be to invoke this simple functionality as if it was primitive behavior, rather than having to model it explicitly.

NOTE: The list functions are also used in the Java to UML Activity Model mapping (see Annex A).

Table 6 - Foundational Model Library List Functions

| Function Signature | Description |
|--|---|
| ListSize(list[*]): Integer | Returns cardinality of the input values in the <i>list</i> . |
| ListGet(list[*]{ordered}, index: Integer) [0..1] | <p>Returns the value at the position given by <i>index</i> in the ordered <i>list</i>. Positions run from 1 to ListSize(list).</p> <p><i>Pre: (index > 0) And (index <= ListSize(list))</i></p> |

9.3 Common

9.3.1 Overview

The FoundationModelLibrary::Common package contains classifiers shown in Figure 83. These classifiers are currently only used in the basic input/output model (see Subclause 9.3.2.1). However, they are considered potentially usable in a wider context in the future, so they have been separated into their own sub-package. They are further described below in Subclause 9.3.2.

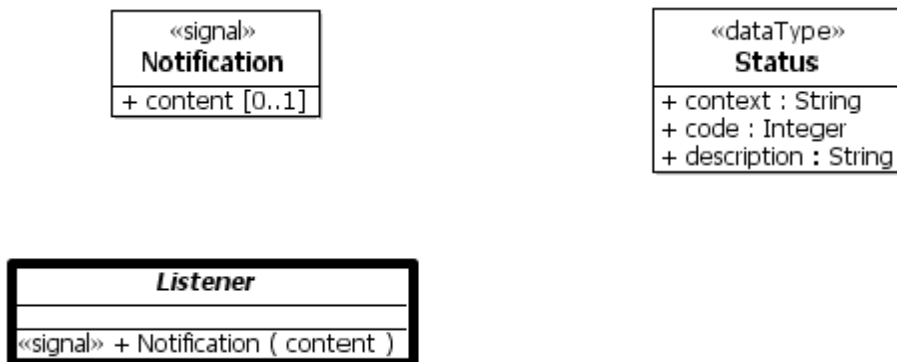


Figure 83 - Foundation Model Library Common package

9.3.2 Classifier Descriptions

9.3.2.1 Listener (active class)

A listener is an active class that can asynchronously receive a notification.

Generalization

None

Receptions

- Notification(content[0..1])
The Listener class declares its ability to receive a Notification signal. Any concrete subclass of Listener should have a classifier behavior that can accept such a signal.

9.3.2.2 Notification (signal)

A notification is a signal used to asynchronously send content to a listener.

Generalization

None

Attributes

- *content* [0..1]
An optional value (of any type) sent as the content of the notification.

9.3.2.3 Status (data type)

The Status data type provides a common structure for reporting the normal or error status of a service such as a channel. Operations whose execution may cause an error condition have an optional error status output parameter to report this condition (exceptions are not included in the fUML subset). This output is generated *only* if there is an error condition—if the operation completes normally, no value is produced. A service may also have an operation to report its current status as of the execution of the last operation on it.

Generalization

None

Attributes

- context: String
A name (generally a class name) indicating the context in which the status is defined.
- code: Integer
A numeric status code. A value of zero is the default for normal operation. A value less than zero indicates an error condition. A value greater than zero indicates an informational status condition. Status codes must be unique within a given context, but not necessarily across contexts.
- description: String
A textual description of the status condition.

9.4 Basic Input/Output

This subclause defines basic capabilities for input and output, provided by set of classes that can be directly referenced from a user model. While this is thus a library of user-model classes, not classes within the execution model itself, the methods implementing the operations of these classes must be provided as primitive capabilities as part of any actual implementation of the library model.

The goal of the basic library defined here is to primarily provide a simple semantic foundation for what it means to receive input into and send output from an executing model. It is not intended to be a complete input/output library, but, rather, to act as the underpinning for more sophisticated future library. Nevertheless, in addition to the foundational input/output mechanism, it does also include a basic set of standard capabilities that allow the expected baseline of textual input and output.

9.4.1 The Channel Model

Within the context of a single model, all communication is between known source and target elements within the model. In this sense, an executing model is a “closed universe.” Input and output is, in effect, a controlled means for providing “openings” in this universe for communications in which the actual source or target is not known within the model.

The fundamental abstraction providing for making these “openings” is that of the *channel*. The basic library model of channels is provided in the package `FoundationalModelLibrary::BasicInputOutput`. Figure 84 shows the classifiers included in this package, which are further described in Subclause.

An *input channel* provides a means for receiving values into an executing model from outside of it. Conversely, an *output channel* is a means for sending values out of an executing model. An *active channel* is like an input channel, except that it allows clients to receive input values asynchronously, instead of requesting them synchronously. In addition to the fundamental channel classes, specializations are provided for basic textual input and output capabilities.

Note that all the classes in this model are abstract. They are not intended to be directly instantiated by a user model. Instead, channels must be made available as or by “services” available at the current execution locus (see Subclause 8.2 for a discussion of loci and system services). For example, there may be at most one instance of the class `StandardInputChannel` and one instance of the class `StandardOutputChannel` “pre-instantiated” at each locus. Or a locus may provide a file service that is used to obtain channels that connect to an external file system.

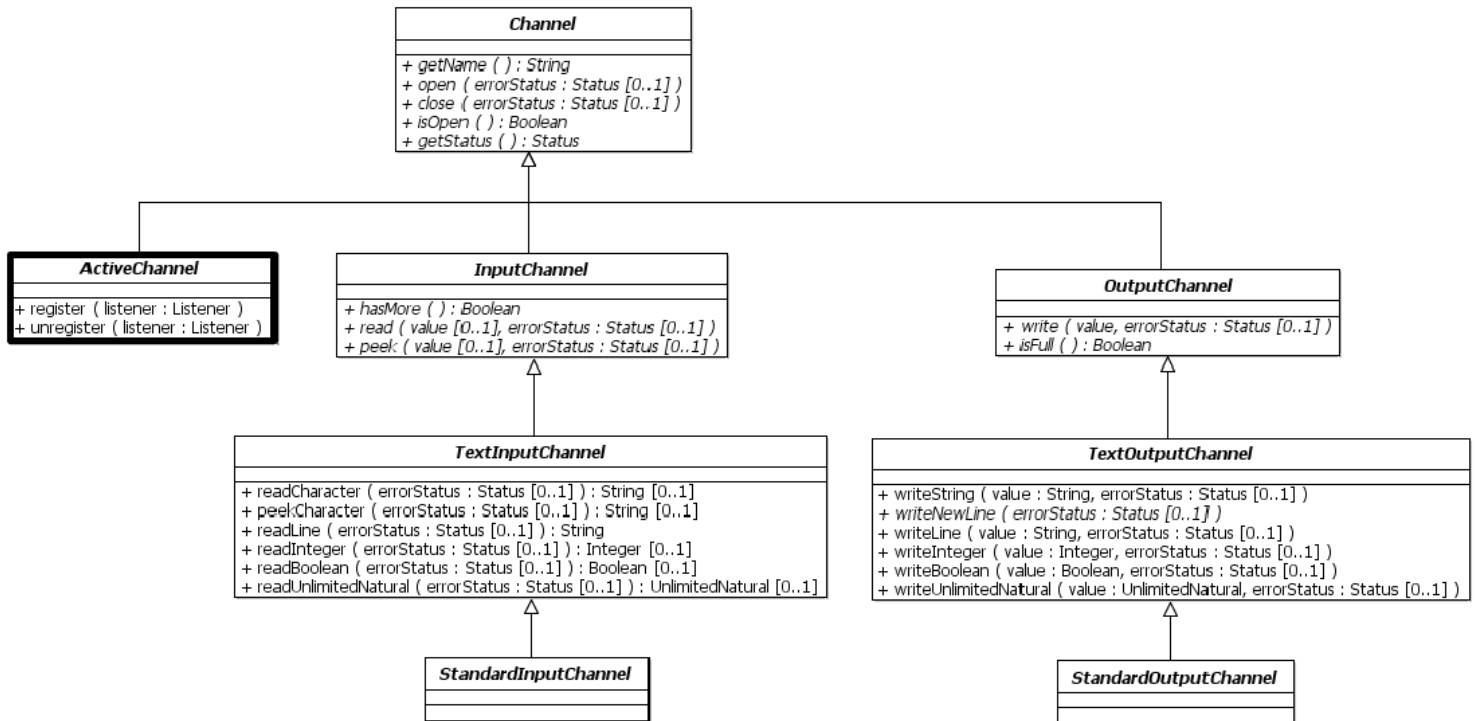


Figure 84 - Foundation Model Library BasicInputOutput Package: Channel Model

9.4.2 Pre-Defined ReadLine and WriteLine Behaviors

The BasicInputOutput package also includes two predefined convenience behaviors, `ReadLine` and `WriteLine`, which simplify textual input and output to the standard input and output channels. These behaviors may be called using the call

behavior action (see Subclause 8.4.2). Both of these behaviors may be formally defined as activities in terms of the functionality provided by the standard channel classes. Figure 85 shows an activity definition for ReadLine, and Figure 86 shows the definition for WriteLine. However, a conforming implementation may alternatively provide these as primitive behaviors with equivalent functionality.

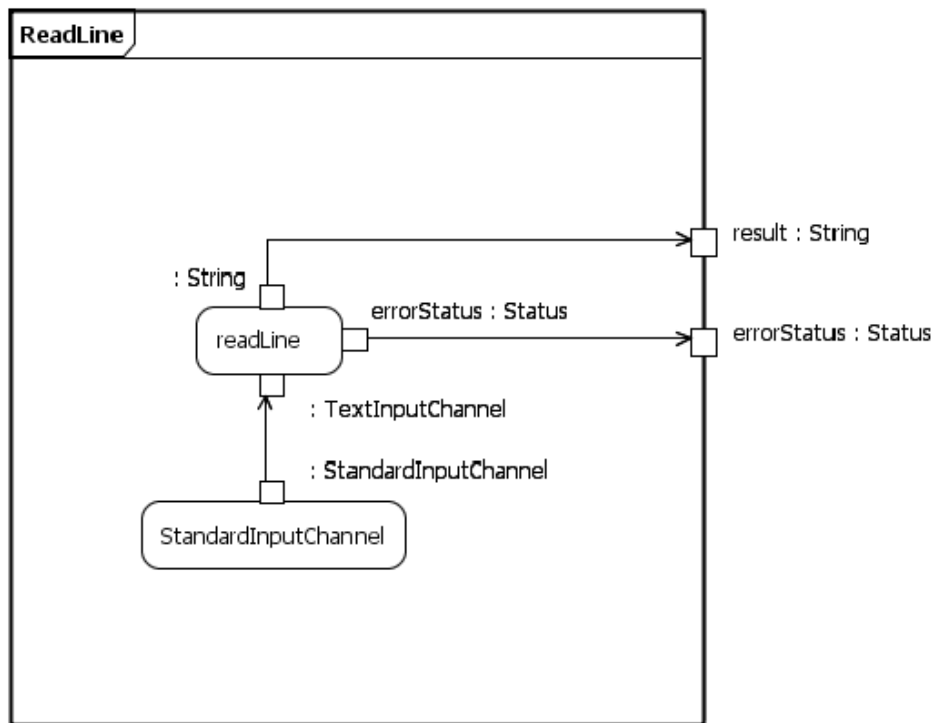


Figure 85 - An Activity Definition for the ReadLine behavior

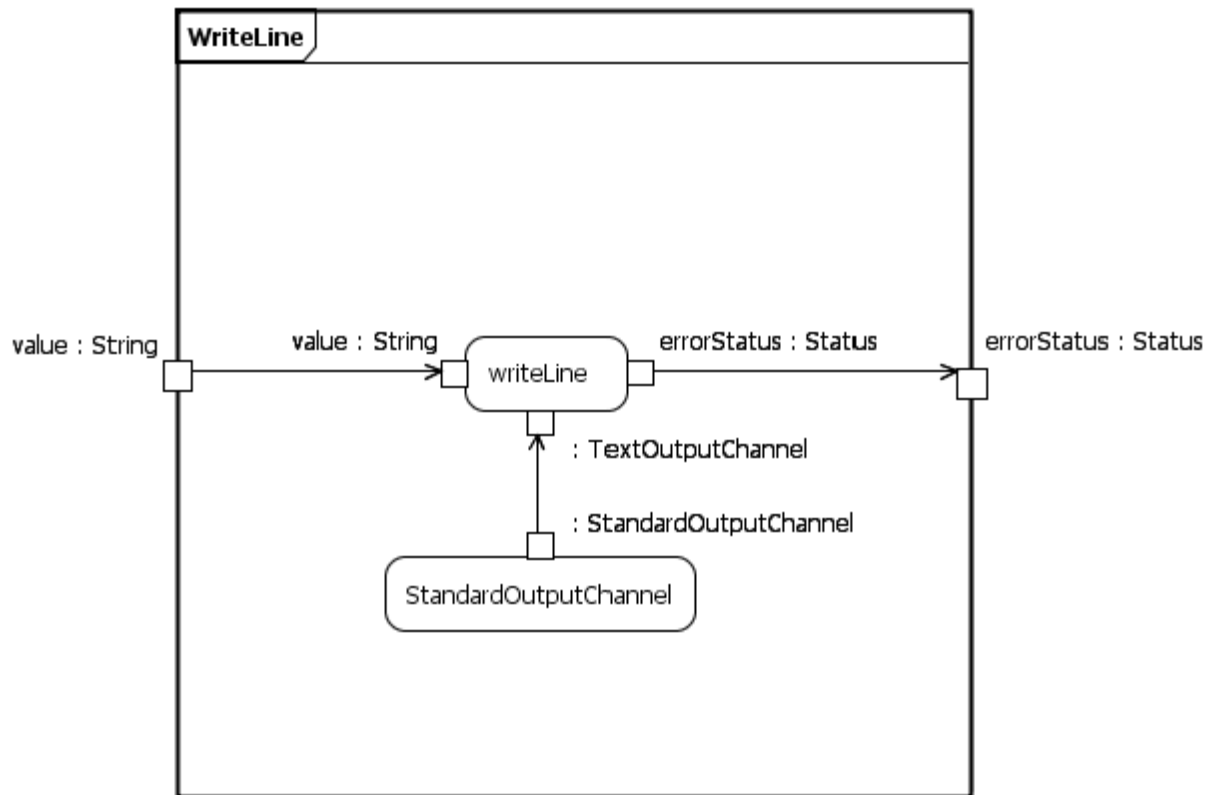


Figure 86 - An Activity Definition for the WriteLine behavior

9.4.3 Class Descriptions

9.4.3.1 ActiveChannel (active class)

An active channel is similar to an input channel, in that it is used to receive input into a model. However, instead of providing input in response to synchronous requests of clients, it allows clients to register as listeners for asynchronous notification of input as it arrives. As each input value arrives, it is sent as the content of a Notification signal to all registered listeners.

Generalization

Channel

Additional Operations

- register(listener: Listener)
The *register* operation is used to register a listener with an active channel. If the listener is already registered, then the operation has no effect.
- unregister(listener: Listener)
The *unregister* operation is used to remove the registration of a listener with an active channel. If the given listener is not registered with the channel, then the operation has no effect.

9.4.3.2 Channel

A channel is a means for receiving or sending values. A channel object within an executing model represents the end of the channel accessible to that model. What is at the other end of the channel—that is the source for input or the target for output—depends on the implementation of a specific channel and is not defined by the library model.

Two standard status codes are defined for every channel, as given in the table below. Additional status codes may be defined for specific kinds of channels (for example, see the descriptions below of the subclasses of Channel). In all cases, the name of the class in which the status is defined below is used as the context for the status code.

| Code | Description | Definition |
|------|-------------|---|
| 0 | Normal | The default for normal operation of the channel. |
| -1 | Not open | The last operation performed on the channel required the channel to be open, but the channel was closed. (All read and write operations of any sort on a channel require the channel to be open.) |

Generalization

None

Operations

- `getName(): String`
Each channel has a name. How the name of a channel is determined depends on the implementation of a specific channel, but every channel instantiated at a given locus is required to have a different name. The *getName* operation returns the name of the channel.
- `open([out] errorStatus: Status[0..1])`
A channel may be either *open* or *closed*. Attempting to receive input or send output on a closed channel has no effect. The *open* operation is used to open a channel that is closed. Opening a channel that is already open leaves the channel open and has no other effect.
- `close([out] errorStatus: Status[0..1])`
The *close* operation closes a channel that is open. Closing a channel that is already closed leaves the channel closed and has no other effect.
- `isOpen(): Boolean`
The *isOpen* operation returns true if a channel is open and false if it is closed.
- `getStatus(): Status`
The *getStatus* operation returns the current status of a channel (see the description of Status below).

9.4.3.3 InputChannel

An input channel is a channel for receiving input values into a model. The following additional status code is defined for input channels.

| Code | Description | Definition |
|------|-------------|---|
| -2 | No input | A read operation was attempted, but no more input is currently available on this channel. |

Generalization

Channel

Additional Operations

- `hasMore(): Boolean`
The *hasMore* operation returns true if there is a value available to be read from an input channel and false if there is not. The operation returns false if the channel is not open. It is an error to attempt to read from an input channel that does not have an available input.
- `read([out] value[0..1], [out] errorStatus: Status[0..1])`
The *read* operation is used to obtain an input value from an input channel. The operation has a value out

parameter that has no type, which means that it may return a value of any type. If the read operation completes without producing an output value, then the error status is required to have an error value indicating the reason for this.

NOTE: The read operation uses an out parameter rather than a return result because there is no UML surface syntax for displaying an operation with a return parameter that does not have a type.

- peek([out] value[0..1], [out] errorStatus: Status[0..1])
The *peek* operation has the same behavior as *read*, except that the value returned is not consumed from the input channel. That is, if the channel has an available value, multiple sequential *peek* calls will continue to return that same value, without removing it from the channel, until the *read* operation is called.

9.4.3.4 OutputChannel

An output channel is a channel for sending output values out of a model. The following additional status codes are defined for output channels.

| Code | Description | Definition |
|------|--------------------|---|
| -2 | Full | A write operation was attempted, but the channel is not able to accept any further output. |
| -3 | Type not supported | A write operation was attempted for a value of a type that is not supported by the channel. |

Generalization

Channel

Additional Operations

- isFull(): Boolean
The *isFull* operation returns false if an output channel is able to accept more output values and true if it is not. The operation returns true if the channel is not open. It is an error to attempt to write to an output channel that is full.
- write(value, [out] errorStatus: Status[0..1])
The *write* operation is used to send an output value on an output channel. The operation has a single parameter. This parameter has no type, which means that it may be a value of any type. If the channel is full, then attempting a write operation is an error condition, but the operation is still required to complete its execution (which will have no other effect then to return the appropriate error status).

9.4.3.5 StandardInputChannel

A standard input channel is a text input channel that may be provided as a pre-instantiated service at a locus. Any locus may have at most one instance of the StandardInputChannel class, with the name “StandardInput.” Since there can be at most one instance, this instance, if it exists, can be easily obtained by executing a Read Extent action on the StandardInputChannel class.

Generalization

TextInputChannel

Additional Operations

None

9.4.3.6 StandardOutputChannel

A standard output channel is a text output channel that may be provided as a pre-instantiated service at a locus. Any locus may have at most one instance of the StandardOutputChannel class, with the name “StandardOutput.” Since there can be

at most one instance, this instance, if it exists, can be easily obtained by executing a Read Extent action on the `StandardOutputChannel` class.

Generalization

`TextOutputChannel`

Additional Operations

None

9.4.3.7 `TextInputChannel`

A text input channel is an input channel whose values are text characters. A *read* operation on a text input channel will always return a string value which contains a single character. The additional operations on a text input channel provide convenient capabilities for reading longer strings of characters and, in some cases, treating them as representations of other primitive values. The following additional status code is defined for text input channels.

| Code | Description | Definition |
|------|----------------|--|
| -3 | Cannot convert | An attempt was made to read an integer, Boolean or unlimited natural, but the characters available from the channel do not conform to the required syntax. |

Generalization

`InputChannel`

Additional Operations

- `readCharacter([out] errorStatus: Status[0..1]): String[0..1]`
 The *readCharacter* operation reads the next value from a text input channel and returns it as a string of a single character. No value is returned if none is available from the channel. This is an error condition.
- `peekCharacter([out] errorStatus: Status[0..1]): String[0..1]`
 The *peekCharacter* operation has the same behavior as *readCharacter*, except that the character returned is not consumed from the text input channel. That is, if a character is available on the channel, multiple *peekCharacter* calls will continue to return that character without removing it from the channel, until some read operation is called.
- `readLine([out] errorStatus: Status[0..1]): String`
 The *readLine* operation continues to read characters from the input channel until the end of a line is reached or there are no more characters available from the channel. The characters read are returned, in order, as a string value. The character encoding of a new line is not defined in this specification. Nevertheless, the new line character(s) are required to be consumed by the *readLine* operation, but they are not included in the returned string. Note that if no character is available from the channel when the operation is called, or if the only character(s) read are the new line character(s), then the operation returns the empty string. This is not an error.
- `readInteger([out] errorStatus: Status[0..1]): Integer[0..1]`
 The *readInteger* operation is used to read a textual representation of an integer and return it as an integer value. The textual syntax for an integer is defined to be an optional '+' or '-' character followed by a string of one or more digits '0' through '9.' All characters are read up to (but not including) the first character that does not conform to the required syntax or until no more characters are available. No value is returned if no characters are available from the channel or if the available characters do not begin with a string that conforms to the required syntax, in which case no values are read from the channel. This is an error condition.
- `readBoolean([out] errorStatus: Status[0..1]): Boolean[0..1]`
 The *readBoolean* operation is used to read a textual representation of a Boolean and return it as a Boolean value. The textual syntax for a Boolean is defined to be either the string "true" or the string "false," or any string obtained by capitalizing some or all of the characters of these strings. All characters are read up to (but not including) the first character that does not conform to the required syntax or until no more characters are

available. No value is returned if no characters are available from the channel or if the available characters do not begin with a string that conforms to the required syntax, in which case no values are read from the channel. This is an error condition.

- `readUnlimitedNatural([out] errorStatus: Status[0..1]): UnlimitedNatural[0..1]`
The *readUnlimitedNatural* operation is used to read a textual representation of an unlimited natural number and return it as an integer value. The textual syntax for an unlimited natural is defined to be either the single character ‘*’ or string of one or more digits ‘0’ through ‘9.’ All characters are read up to (but not including) the first character that does not conform to the required syntax or until no more characters are available. No value is returned if no characters are available from the channel or if the available characters do not begin with a string that conforms to the required syntax, in which case no values are read from the channel. This is an error condition.

9.4.3.8 TextOutputChannel

A text output channel is an output channel whose values are text characters. A *write* operation on a text output channel always places characters onto the channel.

- For a string value, each of the characters in the string is sequentially written to the channel.
- Primitive values of types Integer, Boolean and UnlimitedNatural are written using the syntax given for the *writeInteger*, *writeBoolean* and *writeUnlimitedNatural* operations as described below.
- Enumeration values are written using the names of the corresponding enumeration literal.
- No standard textual representation is defined for other kinds of values, but it is *not* an error to attempt to write them. The actual representation of such values is determined by the specific implementation of the channel.

If, during the execution of any write operation on a text output channel, the channel becomes full, then the operation returns immediately. This is an error condition, but, if the operation was writing multiple characters, all characters up to the point the channel became full will have been successfully output to the channel.

Generalization

OutputChannel

Additional Operations

- `writeString(value: String, [out] errorStatus: Status[0..1])`
The *writeString* operation sequentially writes each of the characters in the given string value to a text output channel.
- `writeNewLine([out] errorStatus: Status[0..1])`
The *writeNewLine* operation writes the character(s) encoding a new line to a text output channel. The character encoding of a new line is not defined in this specification, but is determined by the implementation of a specific channel.
- `writeLine(value: String, [out] errorStatus: Status[0..1])`
The *writeLine* operation writes the given string value to a text output channel, followed by a new line.
- `writeInteger(value: Integer, [out] errorStatus: Status[0..1])`
The *writeInteger* operation is used to write a textual representation of an integer. The textual syntax for an integer is defined to be an optional ‘-’ character (for a negative integer) followed by a string of one or more digits ‘0’ through ‘9’ (note that no ‘+’ is included for a positive integer).
- `writeBoolean(value: Boolean, [out] errorStatus: Status[0..1])`
The *writeBoolean* operation is used to write a textual representation of a Boolean. The textual syntax for a Boolean is defined to be either the string “true” or the string “false.”
- `writeUnlimitedNatural(value: UnlimitedNatural, [out] errorStatus: Status[0..1])`
The *writeUnlimitedNatural* operation is used to write a textual representation of an unlimited natural number.

The textual syntax for an unlimited natural is defined to be either the single character ‘*’ (for the “unbounded” value) or string of one or more digits ‘0’ through ‘9.’

10 Base Semantics

10.1 Design Rationale

This clause gives semantics for the portion of fUML used in the Java to Activity mapping in Annex A (known as “base UML” or bUML, with semantics known as the “base semantics”). Base UML is expressive enough to define the execution model and must be used when specializing the execution model through explicit variation. The base semantics specifies when particular executions conform to a model defined in bUML. It does not generate executions. In particular, the base semantics does not define a virtual machine to execute models directly. The base semantics is expressed in axioms of first order logic. This has the advantage of being completely explicit, rather than using text to explain the behavior of a virtual machine. This enables automatic determination of whether an execution conforms to the execution model. It has the disadvantage of requiring axioms for the semantic interpretation of all syntactic patterns used in the execution model.

This clause assumes familiarity with these background documents:

- Common Logic Interchange Format (CLIF), the language in which the axioms are written.³
- Process Specification Language (PSL), a foundational axiomitization of processes.⁴

This clause uses an embedded approach to axiomitization, which enables syntax and semantics to be explicitly related through additional axioms, as compared to a translation that depends on a separate translation language.⁵ The clause gives axioms for semantics and any additional syntax needed just for the formalization. The semantic axioms identify a particular syntactical pattern used in the execution model and give it a semantic interpretation. The semantic interpretation is grounded in PSL.

10.2 Conventions

Naming conventions for relations used in this clause are:

- `buml`: Prefixed names are those of metaclasses and metaproperties in bUML. Metaclasses are formalized as unary predicates that are satisfied when applied to an instance of the metaclass. For example, `buml:Activity` is a predicate satisfied by activities in the execution model. Metaproperties are formalized as binary predicates that are satisfied when applied to two elements linked by the property, with the first being an instance of the owner of the property and the second being the value. For example, `buml:activity` is a binary predicate satisfied by a node in an activity, and an activity containing the node, in that order.⁶
- `psl`: Prefixed names are PSL relations.
- `form`: Prefixed names are relations introduced only for the formalization.

This clause assumes multiple generalization in bUML.

Basic additions to PSL used in this clause are:⁷

```
(forall (s occ)
  (iff (form:subactivity-occurrence-neq s occ)
    (and (psl:subactivity_occurrence s occ)
      (not (= s occSuper))))))
```

³ ISO 24707, [http://standards.iso.org/ittf/PubliclyAvailableStandards/c039175_ISO_IEC_24707_2007\(E\).zip](http://standards.iso.org/ittf/PubliclyAvailableStandards/c039175_ISO_IEC_24707_2007(E).zip).

⁴ ISO 18629, see <http://www.conradbock.org/#PSL> for introductory material, and <http://www.nist.gov/psl> for downloads and other material.

⁵ More about this at <http://www.ihmc.us/users/phayes/CL/SW2SCL.html> and <http://www.w3.org/TR/daml+oil-axioms>.

⁶ This clause assumes the execution model conforms to the abstract syntax of bUML, including constraints.

⁷ These are drawn from http://www.mel.nist.gov/msidlibrary/doc/NISTIR_7348.pdf.

```

(forall (f s)
  (iff (form:priorA f s)
    (exists (sRoot)
      (and (psl:root_occ sRoot s)
        (psl:prior f sRoot))))))

(forall (f s)
  (iff (form:holdsA f s)
    (exists (sLeaf)
      (and (psl:leaf_occ sLeaf s)
        (psl:holds f sLeaf))))))

(forall (s1 s2 a)
  (iff (form:min-precedesA s1 s2 a)
    (exists (s1Leaf s2Root)
      (and (psl:leaf_occ s1Leaf s1)
        (psl:root_occ s2Root s2)
        (psl:min_precedes s1Leaf s2Root a))))))

```

10.3 Structure

This subclause covers the structural aspects of the base semantics.

10.3.1 Primitive Types

This subclause covers primitive types in bUML: Boolean, UnlimitedNatural, Integer, and String, as well as other kinds of numbers and sequences introduced for the formalization.

10.3.1.1 Boolean

```

(forall (x)
  (if (buml:Boolean x)
    (or (= x form:true)
      (= x form:false))))

(not (= form:true form:false))

(forall (x y)
  (if (form:not x y)
    (and (buml:Boolean x)
      (buml:Boolean y))))

(forall (x y)
  (if (form:not x y)
    (not (= x y))))

(forall (x y z)
  (if (form:and x y z)
    (and (buml:Boolean x)
      (buml:Boolean y)
      (buml:Boolean z))))

(forall (x y z)
  (if (form:and x y z)
    (and (iff (= z form:false)
      (or (= x form:false)
        (= y form:false)))
      (iff (= z form:true)

```

```
(and (= x form:true)
      (= y form:true))))))
```

10.3.1.2 Numbers

The add-one relation.

```
(forall (x y)
  (if (form:add-one x y)
      (and (form:Number x)
            (form:Number y))))

(forall (x y1 y2)
  (if (and (form:add-one x y1)
           (form:add-one x y2))
      (= y1 y2)))

(forall (x)
  (if (form:Number x)
      (exists (y)
              (form:add-one x y))))
```

The add relation.

```
(forall (x y z)
  (if (form:add x y z)
      (and (form:Number x)
            (form:Number y)
            (form:Number z))))

(forall (x y z1 z2)
  (if (and (form:add x y z1)
           (form:add x y z2))
      (= z1 z2)))

(forall (x y)
  (if (and (form:Number x)
           (form:Number y))
      (exists (z)
              (form:add x y z))))

(forall (y y1 x z1 z)
  (if (and (form:add-one y y1)
           (form:add x y1 z1)
           (form:add x y z))
      (form:add-one z z1)))
```

Basic numeric constants.

```
(form:Number form:0)
(form:add-one form:0 form:1)
(form:add-one form:-1 form:0)
```

The less-than relation.

```
(forall (x y)
  (if (form:less-than x y)
      (and (form:Number x)
            (form:Number y))))
```

```
(forall (x y)
  (iff (form:less-than x y)
    (exists (z)
      (and (form:Number z)
        (not (= z form:0))
        (form:add x z y))))))
```

Specialized numbers: whole, natural, unlimited natural, and integers.

```
(forall (x)
  (iff (form:WholeNumber x)
    (or (= x form:1)
      (exists (y)
        (and (form:WholeNumber y)
          (form:add-one y x))))))
```

```
(forall (x)
  (iff (form:NaturalNumber x)
    (or (= x form:0)
      (form:WholeNumber x))))
```

```
(forall (x)
  (if (buml:UnlimitedNatural x)
    (or (form:NaturalNumber x)
      (= x buml:*)))))
```

```
(forall (x)
  (if (form:NaturalNumber x)
    (buml:Integer x)))
```

```
(forall (x)
  (iff (buml:Integer x)
    (or (= x form:-1)
      (exists (y)
        (and (buml:Integer y)
          (or (form:add-one y x)
            (form:add-one x y))))))))
```

```
(forall (x y)
  (iff (form:negate x y)
    (form:add x y form:0)))
```

10.3.1.3 Sequences

Sequences are a finite series of things, where the same thing can appear more than once in the series.. The serial aspect is represented by positions, each of which identifies exactly one thing. This thing can be the same as ones identified by other positions in the series.

The in-sequence relation links sequences to their positions.

```
(forall (s pt)
  (if (form:in-sequence s pt)
    (and (form:Sequence s)
      (form:Position pt))))
```

```
(forall (s1 s2 pt)
  (if (and (form:in-sequence s1 pt)
    (form:in-sequence s2 pt))
    (= s1 s2)))
```

```
(forall (pt)
  (if (form:Position pt)
    (exists (s)
      (form:in-sequence s pt))))
```

The before-in-sequence relation serializes positions.

```
(forall (s pt1 pt2)
  (if (form:before-in-sequence s pt1 pt2)
    (and (buml:Sequence s)
      (form:Position pt1)
      (form:Position pt2))))
```

```
(forall (s pt1 pt2)
  (if (form:before-in-sequence s pt1 pt2)
    (and (form:in-sequence s pt1)
      (form:in-sequence s pt2))))
```

```
(not (exists (s pt1 pt2)
  (and (form:before-in-sequence s pt1 pt2)
    (form:before-in-sequence s pt2 pt1))))
```

```
(forall (s pt1 pt2 pt11 pt22)
  (if (and (form:before-in-sequence s pt1 pt2)
    (form:before-in-sequence s pt11 pt22))
    (iff (= pt1 pt11)
      (= pt2 pt22))))
```

```
(forall (s)
  (if (form:Sequence s)
    (if (exists (pt)
      (form:in-sequence s pt))
      (and (exists (pt1)
        (not (exists (pt2)
          (form:before-in-sequence s pt1 pt2))))
        (exists (pt2)
          (not (exists (pt1)
            (form:before-in-sequence s pt1 pt2))))))))))
```

```
(forall (s pt1 pt11)
  (if (and (form:Sequence s)
    (not (exists (pt2)
      (form:before-in-sequence s pt1 pt2)))
    (not (exists (pt2)
      (form:before-in-sequence s pt11 pt2))))
    (= pt1 pt11)))
```

```
(forall (s)
  (if (form:Sequence s)
    (exists (pt2)
      (not (exists (pt1)
        (form:before-in-sequence s pt1 pt2))))))
```

```
(forall (s pt2 pt22)
  (if (and (form:Sequence s)
    (not (exists (pt1)
      (form:before-in-sequence s pt1 pt2)))
    (not (exists (pt1)
      (form:before-in-sequence s pt1 pt22))))
```

```

                (form:before-in-sequence s pt1 pt22))))
    (= pt2 pt22)))

```

An empty sequence has no positions.

```

(forall (s)
  (if (form:empty-sequence s)
      (form:Sequence s)))

(forall (s)
  (if (form:Sequence s)
      (iff (form:empty-sequence s)
           (not (exists (pt)
                       (form:in-sequence s pt)))))))

```

The position-count relation links positions to how far they are along in the sequence.

```

(forall (s pt n)
  (if (form:position-count s pt n)
      (and (form:Sequence s)
           (form:Position pt)
           (buml:UnlimitedNatural n))))

(forall (s pt n1 n2)
  (if (and (form:position-count s pt n1)
          (form:position-count s pt n2))
      (= n1 n2)))

(forall (s pt)
  (if (form:in-sequence s pt)
      (exists (n)
              (form:position-count s pt n))))

(forall (s pt2)
  (if (and (form:Sequence s)
          (not (exists (pt1)
                      (form:before-in-sequence s pt1 pt2))))
      (form:position-count s pt2 form:1)))

(forall (s pt1 n1 pt2 n2)
  (if (and (form:position-count s pt1 n1)
          (form:before-in-sequence s pt1 pt2)
          (form:position-count s pt2 n2))
      (form:add-one n1 n2)))

```

The sequence-length relation links sequences to how many positions they have.

```

(forall (s n)
  (if (form:sequence-length s n)
      (and (form:Sequence s)
           (buml:UnlimitedNatural n))))

(forall (s n)
  (iff (form:sequence-length s n)
      (or (and (form:empty-sequence s)
              (= n form:0))
          (exists (pt1)
                  (and (not (exists (pt2)
                                    (form:before-in-sequence s pt1 pt2)))
                     (form:position-count s pt1 n)))))))

```


The in-position relation links positions to things they identify. Each position identifies exactly one thing.

```
(forall (pt x)
  (if (form:in-position pt x)
      (form:Position pt)))

(forall (pt x1 x2)
  (if (and (form:in-position pt x1)
          (form:in-position pt x2))
      (= x1 x2)))

(forall (pt)
  (if (form:Position pt)
      (exists (x)
        (form:in-position pt x))))
```

The in-position-count relation links sequences to a thing based on how far along the position is in the sequence.

```
(forall (s n x)
  (if (form:in-position-count s n x)
      (and (buml:Sequence s)
           (form:NaturalNumber n))))

(forall (s n x)
  (iff (form:in-position-count s n x)
       (exists (pt)
         (and (form:in-position pt x)
              (form:position-count s pt n)))))
```

The same-sequence relation is true for sequences that identify the same things in the same order.

```
(forall (s1 s2)
  (if (form:same-sequence s1 s2)
      (and (form:Sequence s1)
           (form:Sequence s2))))

(forall (s1 s2)
  (iff (form:same-sequence s1 s2)
       (forall (x n)
         (iff (form:in-position-count s1 n x)
              (form:in-position-count s2 n x)))))
```

10.3.1.4 Strings

Strings are sequences of characters.

```
(forall (s)
  (if (buml:String s)
      (form:Sequence s)))

(forall (s pt x)
  (if (and (buml:String s)
          (form:in-sequence s pt)
          (form:in-position pt x))
      (form:Character x)))
```

The string-index-character relation links strings to a character based on how far along the position is in the sequence.

```
(forall (s n ch)
  (if (form:string-index-character s n ch)
      (and (buml:String s)
           (form:WholeNumber n)
           (form:Character ch))))
```

```
(forall (s n ch)
  (if (buml:String s)
    (iff (form:string-index-char s n ch)
      (form:in-position-count s n ch))))
```

The string-length relation links strings to how many positions they have.

```
(forall (s n)
  (if (form:string-length s n)
    (and (buml:String s)
      (form:NaturalNumber n))))
```

```
(forall (s)
  (if (buml:String s)
    (forall (n)
      (iff (form:string-length s n)
        (form:sequence-length s n))))))
```

The same-string relation is true for string that identify the same characters in the same order.

```
(forall (s1 s2)
  (if (form:same-string s1 s2)
    (and (buml:String s1)
      (buml:String s2))))
```

```
(forall (s1 s2)
  (if (and (buml:String s1)
    (buml:String s2))
    (iff (form:same-string s1 s2)
      (form:same-sequence s1 s2))))
```

10.3.2 Classification and Generalization

Classification links classifiers to the the things they classify. Classifiers are categories into which things fall.

```
(forall (c o f)
  (if (form:classifies c o f)
    (and (buml:Classifier c)
      (psl:state f))))
```

A classifier is more general than another when the things classified by the specialized classifier are classified by the general classifier.

```
(forall (csub csuper o f)
  (iff (buml:general csub csuper)
    (if (form:classifies csub o f)
      (form:classifies csuper o f))))
```

Classification applies in all PSL states prior to legal occurrences or to none. In PSL, states holding after an occurrence are the same as states prior to legal successor occurrences, so this constant applies to states holding after occurrences as well as prior.

```
(forall (occ f c o)
  (if (and (psl:occurrence occ)
    (psl:legal occ)
    (psl:prior f occ)
    (form:classifies c o f))
    (forall (f2)
      (if (psl:prior f2 occ)
        (form:classifies c o f2))))))
```

10.3.3 Classifier Cardinality

Classifier cardinality is the number of things classified by a classifier in a PSL state.

```
(forall (c card f)
  (if (form:classifier-cardinality c card f)
    (and (buml:Classifier c)
         (form:NaturalNumber card)
         (psl:state f))))

(forall (c1 c2)
  (if (and (buml:Classifier c1)
           (buml:Classifier c2))
    (buml:Classifier (form:union c1 c2))))

(forall (c1 c2 o f)
  (iff (form:classifies (form:union c1 c2) o f)
    (or (form:classifies c1 o f)
        (form:classifies c2 o f))))

(forall (c1 c2 c1Card o1 f c1Card1)
  (if (and (buml:Classifier c1)
           (form:NaturalNumber c1Card)
           (form:classifier-cardinality c1 c1Card f)
           (not (form:classifies c1 o1 f))
           (buml:Classifier c2)
           (forall (o2)
             (iff (form:classifies c2 o2 f)
                  (= o1 o2))))
    (form:add-one c1Card c1Card1))
  (form:classifier-cardinality (form:union c1 c2) c1Card1 f)))
```

10.3.4 Properties

Properties link things to other things in a certain PSL state.

```
(forall (o p v f)
  (if (form:property-value o p v f)
    (and (buml:Property p)
         (psl:state f))))
```

Property values apply in all PSL states prior to legal occurrences or to none. In PSL, states holding after an occurrence are the same as states prior to legal successor occurrences, so this constraint applies to states holding after occurrences as well as prior.

```
(forall (occ f o p v)
  (if (and (psl:occurrence occ)
           (psl:legal occ)
           (psl:prior f occ)
           (form:property-value o p v f))
    (forall (f2)
      (if (psl:prior f2 occ)
        (form:property-value o p v f2))))))
```

Things with property values must be classified by the class owning the property (classes are classifiers in UML).

```
(forall (c p occ f o v)
  (if (and (buml:ownedAttribute c p)
           (psl:occurrence occ)
           (psl:legal occ)
           (psl:prior f occ)
           (form:property-value o p v f))
    (exists (f2)
      (and (psl:prior f2 occ)
```

```
(form:classifies c o f2))))))
```

Property values must be classified by the type of the property.

```
(forall (p c occ f o v)
  (if (and (buml:type p c)
          (psl:occurrence occ)
          (psl:legal occ)
          (psl:prior f occ)
          (form:property-value o p v f))
    (exists (f2)
      (and (psl:prior f2 occ)
            (form:classifies c v f2))))))
```

The achieves-property-value relation links objects, properties, and values to occurrences that give the property the value.. The property does not have the achieved value before the occurrence and does after.

```
(forall (o p v occ)
  (iff (form:achieves-property-value o p v occ)
    (and (forall (f)
      (if (form:priorA f occ)
        (not (form:property-value o p v f))))
      (exists (f)
        (and (form:holdsA f occ)
              (form:property-value o p v f))))))
```

Property value cardinality is number of values of a property on a particular thing.

```
(forall (o p n f)
  (if (form:property-value-cardinality o p n f)
    (and (buml:Property p)
          (psl:state f)
          (form:NaturalNumber n))))))

(forall (occ f o p n)
  (if (and (psl:occurrence occ)
          (psl:legal occ)
          (psl:prior f occ)
          (form:property-value-cardinality o p n f))
    (exists (fv fp fvc vc)
      (and (psl:prior fv occ)
            (psl:prior fp occ)
            (psl:prior fvc occ)
            (forall (v)
              (iff (form:classifies vc v fv)
                    (form:property-value o p v fp))))
            (form:classifier-cardinality vc n fvc))))))
```

Property value cardinality is constrained by the multiplicity of the property, but when the constraints are enforced is not defined in UML. For example, when an object is created, it will violate non-zero lower multiplicities on its properties.

```
(forall (p m c occ fc o n fp)
  (if (and (buml:lower p m)
          (buml:ownedAttribute c p)
          (psl:occurrence occ)
          (psl:legal occ)
          (psl:prior fc occ)
          (form:classifies c o fc)
          (psl:prior fp occ)
          (form:property-value-cardinality o p n fp))
    (or (= m n)
        (form:less-than m n))))))
```

```

(forall (p m c occ fc o n fp)
  (if (and (buml:upper p m)
    (buml:ownedAttribute c p)
    (psl:occurrence occ)
    (psl:legal occ)
    (psl:prior fc occ)
    (form:classifies c o fc)
    (psl:prior fp occ)
    (form:property-value-cardinality o p n fp))
    (or (= m n)
      (form:less-than n m))))

```

Composite properties collectively do not have values that form cycles. Destruction propagation is not formalized because the execution model does not destroy things.

```

(forall (x y f)
  (iff (form:composite-link-trans x y f)
    (forall (occ)
      (if (and (psl:occurrence occ)
        (psl:legal occ)
        (psl:prior f occ))
        (or (exists (f2 p)
          (and (psl:prior f2 occ)
            (form:property-value y p x f2)
            (buml:aggregation p buml:composite)))
          (exists (f2 p z f3)
            (and (psl:prior f2 occ)
              (form:property-value z p x f2)
              (buml:aggregation p buml:composite)
              (psl:prior f3 occ)
              (form:composite-link-trans z y f3))))))))))
(forall (occ)
  (iff (and (psl:occurrence occ)
    (psl:legal occ))
    (not (exists (x f)
      (and (psl:prior f occ)
        (form:composite-link-trans x x f))))))

```

Properties in bUML are ordered and nonunique, which means the values are ordered, and the same value can appear more than once in the order. The property-value-sequence gives the sequence of values of a property in a PSL state.

```

(forall (o p s f)
  (if (form:property-value-sequence o p s f)
    (and (buml:Property p)
      (form:Sequence s)
      (psl:state f))))

```

Property values sequences apply in all PSL states prior to legal occurrences or to none. In PSL, states holding after an occurrence are the same as states prior to legal successor occurrences, so this constraint applies to states holding after occurrences as well as prior.

```

(forall (occ f o p s)
  (if (and (psl:occurrence occ)
    (psl:legal occ)
    (psl:prior f occ)
    (form:property-value-sequence o p s f))
    (forall (f2)
      (if (psl:prior f2 occ)
        (form:property-value-sequence o p s f2))))))

```

```

(forall (occ f1 f2 o p s1 s2)
  (if (and (psl:occurrence occ)
    (psl:legal occ)
    (psl:prior f1 occ)
    (psl:prior f2 occ)
    (form:property-value-sequence o p s1 f1)
    (form:property-value-sequence o p s2 f2))
    (= s1 s2)))

(forall (occ f)
  (if (and (psl:occurrence occ)
    (psl:legal occ)
    (psl:prior f occ))
    (forall (o p v)
      (iff (form:property-value o p v f)
        (exists (f2 s pt)
          (and (psl:prior f2 occ)
            (form:property-value-sequence o p s f2)
            (form:in-sequence s pt)
            (form:in-position pt v)))))))

(forall (occ f)
  (if (and (psl:occurrence occ)
    (psl:legal occ)
    (psl:prior f occ))
    (forall (o p)
      (iff (not (exists (v)
        (form:property-value o p v f)))
        (or (not (exists (f2 s)
          (and (psl:prior f2 occ)
            (form:property-value-sequence o p s f2))))
          (exists (f2 s)
            (and (psl:prior f2 occ)
              (form:property-value-sequence o p s f2)
              (form:empty-sequence s))))))))))

```

10.4 Behavior

This subclause covers the behavioral aspects of the base semantics.

10.4.1 Property Value Modifiers

This subclause specifies PSL activities that modify property values.

```

(forall (o p v a)
  (if (or (form:add-property-value o p v a)
    (form:remove-property-value o p v a))
    (and (buml:Property p)
      (psl:activity a))))

(forall (o p v a aocc)
  (if (and (form:add-property-value o p v a)
    (psl:occurrence_of aocc a))
    (exists (f)
      (and (psl:holds f aocc)
        (form:property-value o p v f))))))

(forall (a o p v aocc)

```

```

(if (and (form:remove-property-value o p v a)
        (psl:occurrence_of aocc a))
    (forall (f)
      (and (psl:holds f aocc)
           (not (form:property-value o p v f))))))

(forall (o p s a aocc)
  (if (and (form:set-property-value-sequence o p s a)
          (psl:occurrence_of aocc a))
      (exists (f s2)
        (and (psl:holds f aocc)
              (form:property-value-sequence o p s2 f)
              (form:same-sequence s s2))))))

(forall (o p a aocc)
  (if (and (form:clear-property-value-sequence o p a)
          (psl:occurrence_of aocc a))
      (exists (f s)
        (and (psl:holds f aocc)
              (form:property-value-sequence o p s f)
              (form:empty-sequence s))))))

```

10.4.2 Common Behavior

This subclause covers the semantics of elements used in all behaviors. It includes Operations, which appear the bUML Kernel, rather than Common Behavior.

10.4.2.1 Syntax

Behaviors are classes of executions, as in UML. Behaviors specify constraints on their valid executions.

Operations are formalized as abstract behaviors that specify only inputs and outputs. More details about the executed behavior are not determined until runtime, when the operation is called on a particular object and a more detailed behavior is selected (“dispatch”). Operations are not formalized as features or properties on classes because they have no values at runtime. This subclause adds a generalization of `bml:Behavior` and `buml:Operation` that parameterizes them (`form:ProcessDefinition`).

```

(forall (pd)
  (if (form:ProcessDefinition pd)
      (and (buml:Class pd)
           (psl:activity pd))))

(forall (x)
  (if (or (buml:Behavior x)
          (buml:Operation x))
      (form:ProcessDefinition x)))

(forall (op b c)
  (if (form:method op b c)
      (and (buml:Operation op)
            (buml:Behavior b)
            (buml:Class c))))

```

Parameters are formalized as properties. The value of a parameter as a property on an execution is the value of the parameter for that execution in a particular PSL state. This assumes no inout parameters.

```

(forall (p)

```

```

    (if (buml:Parameter p)
        (buml:Property p)))

(forall (pd p)
  (if (form:ownedParameter pd p)
      (and (form:ProcessDefinition pd)
            (buml:Parameter p))))

(forall (po p)
  (if (buml:ownedParameter po p)
      (form:ownedParameter po p)))

(forall (po1 p po2)
  (if (and (form:ownedParameter po1 p)
            (form:ownedParameter po2 p))
      (= po1 po2)))

(forall (p)
  (if (buml:Parameter p)
      (exists (po)
              (form:ownedParameter po p))))

(forall (po p)
  (if (form:ownedParameter po p)
      (buml:ownedAttribute po p)))

(forall (p dk)
  (iff (form:InputParameter p)
      (and (buml:direction p dk)
            (= dk buml:in))))

(forall (p)
  (iff (form:OutputParameter p)
      (forall (dk)
        (and (buml:direction p dk)
              (or (= dk buml:out)
                  (= dk buml:return)))))))

```

10.4.2.2 Semantics

Behaviors are classes of executions. Behaviors specify constraints on their valid executions. Executions are interpreted as PSL activity occurrences, which represent one of potentially many possible traces that might transpire when the execution model is executing. Behaviors classify their executions independently of PSL state (the classifies relation on behaviors is never used with PSL states that are constrained against occurrences), and similarly for property values of occurrences when the values are also occurrences.

```

(forall (pd x f)
  (if (and (form:ProcessDefinition pd)
            (form:classifies pd x f))
      (form:execution x)))

(forall (pd x f)
  (if (and (form:ProcessDefinition pd)
            (form:classifies pd x f))
      (forall (f2)
        (form:classifies pd x f2))))

```

The rest of the axioms in this subclass relate PSL occurrences to executions to support multiple classification of executions.


```

(forall (x occ)
  (if (form:execution-occ x occ)
    (and (form:execution x)
      (psl:activity_occurrence occ))))

(forall (x1 x2 occ)
  (if (and (form:execution-occ x1 occ)
    (form:execution-occ x2 occ))
    (= x1 x2)))

(forall (x occ1 occ2)
  (if (and (form:execution-occ x occ1)
    (form:execution-occ x occ2))
    (form:same-suboccs occ1 occ2)))

(forall (occ1 occ2 subocc)
  (iff (form:same-suboccs occ1 occ2)
    (iff (form:subactivity-occurrence-neq subocc occ1)
      (form:subactivity-occurrence-neq subocc occ2))))

(forall (x)
  (if (form:execution x)
    (and (psl:activity_occurrence x)
      (exists (xocc)
        (and (form:execution-occ x xocc)
          (= x xocc))))))

(forall (pd x f)
  (if (and (form:ProcessDefinition pd)
    (form:classifies pd x f)
    (not (psl:atomic pd)))
    (exists (occ)
      (and (form:execution-occ x occ)
        (psl:occurrence_of occ pd)))))

(forall (pd x f)
  (if (and (form:ProcessDefinition pd)
    (form:classifies pd x f)
    (psl:atomic pd))
    (exists (occ cab)
      (and (form:execution-occ x occ)
        (form:complex-atomic cab pd)
        (psl:occurrence_of occ cab)))))

(forall (b cab)
  (iff (form:complex-atomic cab b)
    (and (not (psl:atomic cab))
      (atomic b)
      (forall (cabocc)
        (if (psl:occurrence_of cabocc cab)
          (exists (bocc)
            (and (psl:occurrence_of bocc b)
              (psl:root_occ bocc cabocc)
              (psl:leaf_occ bocc cabocc))))))))))

```

10.4.3 Activity Edges Generally

This subclause specifies additional syntactic relations on activity edges for the formalization, including a generalization of activity edges that generalizes activity nodes also (form:ActivityElement), see Subclause.

```
(forall (x)
  (if (buml:ActivityEdge x)
      (form:ActivityElement x)))

(forall (n)
  (if (buml:ActivityNode n)
      (iff (form:max-one-incoming-edge-node n)
          (forall (e1 e2)
            (if (and (buml:incoming n e1)
                    (buml:incoming n e2))
                (= e1 e2)))))))

(forall (n)
  (iff (form:no-incoming-edge n)
      (not (exists (e)
              (buml:incoming n e)))))

(forall (n)
  (iff (form:no-outgoing-edge n)
      (not (exists (e)
              (buml:outgoing n e)))))

(forall (n)
  (iff (form:max-one-incoming-edge n)
      (forall (e1 e2)
        (if (and (buml:incoming n e1)
                (buml:incoming n e2))
            (= e1 e2)))))

(forall (n)
  (iff (form:max-one-outgoing-edge n)
      (forall (e1 e2)
        (if (and (buml:outgoing n e1)
                (buml:outgoing n e2))
            (= e1 e2)))))
```

10.4.4 Activity Nodes Generally

10.4.4.1 Syntax

This subclause specifies additional syntactic relations on activity edges for the formalization, including a generalization of activity nodes that generalizes activity edges also (form:ActivityElement), see Subclause 10.4.3

```
(forall (x)
  (if (buml:ActivityNode x)
      (form:ActivityElement x)))
```

Executable nodes and object nodes are formalized as properties (executable nodes generalize actions and structured nodes, and object nodes generalize pins and activity parameter nodes). Execution nodes are properties of the activities that contain them, typed by behaviors that vary according by the particular executable node. The value of an execution

node as a property on an activity execution is the execution of that node. The value of an object node as a property on an activity execution is the value in that object node in a particular PSL state.^{8,9}

```
(forall (n)
  (if (or (buml:ExecutableNode n)
          (buml:ObjectNode n))
      (buml:Property n)))
```

The activity relation in the formalization links activity elements to the activity that contains them, regardless of intervening structured nodes.

```
(forall (ae a)
  (if (form:activity ae a)
      (and (form:ActivityElement ae)
           (buml:Activity a))))
```

```
(forall (ae a1 a2)
  (if (and (form:activity ae a1)
          (form:activity ae a2))
      (= a1 a2)))
```

```
(forall (ae)
  (if (form:ActivityElement ae)
      (exists (a)
              (form:activity ae a))))
```

```
(forall (ae a)
  (if (buml:activity ae a)
      (form:activity ae a)))
```

```
(forall (n a)
  (if (and (or (buml:ExecutableNode n)
              (buml:ObjectNode n))
          (form:activity n a))
      (buml:ownedAttribute a n)))
```

Executable nodes as properties have exactly one type, which is a behavior (UML allows at most one type per property).

```
(forall (n b)
  (if (and (buml:ExecutableNode n)
          (buml:type n b))
      (buml:Behavior b)))
```

```
(forall (n)
  (if (buml:ExecutableNode n)
      (exists (b)
              (buml:type n b))))
```

10.4.4.2 Semantics

Executions that are values of executable nodes as properties of activity executions are PSL subactivity occurrences of the activity execution. PSL subactivity occurrences happen during their superoccurrences.

```
(forall (n a xa f xn)
  (if (and (buml:ExecutableNode n)
```

⁸ This happens to give multiplicities to parameter nodes, which do not have them in bUML. The formalization does not use multiplicities on parameter nodes.

⁹ The semantics of property multiplicity (constraints on number of property values) differs from the semantics of pin multiplicity (constraints on the number of input and output values for each execution), but the upper multiplicities do not conflict in the base semantics because the execution engine does not offer more tokens to input pins than an action can accept in one execution, and lower multiplicities are not enforced, see Subclause 10.3.4.

```

    (form:activity n a)
    (form:classifies a xa f)
    (form:property-value xa n xn f))
(form:subactivity_occurrence-neq xn xa))

```

Executions that are values of executable nodes as properties of activity executions are values in all PSL states or none. PSL states are not used to formalize the state of execution.

```

(forall (n a xa f xn)
  (if (and (buml:ExecutableNode n)
    (form:activity n a)
    (form:classifies a xa f)
    (form:property-value xa n xn f))
    (forall (f2)
      (form:property-value xa n xn f2))))

(forall (n a xa1 xa2 f xn rxa1 rxa2)
  (if (and (buml:ExecutableNode n)
    (form:activity n a)
    (form:classifies a xa1 f)
    (form:classifies a xa2 f)
    (form:property-value xa1 n xn f)
    (form:property-value xa2 n xn f)
    (psl:root_occ rxa1 xa1)
    (psl:root_occ rxa2 xa2))
    (= rxa1 rxa2)))

```

10.4.5 Structured Nodes Generally

Executions that are values of structured nodes as properties of activity executions are PSL subactivity occurrences of the structured node execution. PSL subactivity occurrences happen during their superoccurrences.

```

(forall (n sn a xa f xn xsn)
  (if (and (buml:inStructuredNode n sn)
    (buml:ExecutableNode n)
    (form:activity n a)
    (form:classifies a xa f)
    (form:property-value xa n xn f)
    (form:property-value xa sn xsn f))
    (form:subactivity_occurrence-neq xn xsn)))

(forall (ip a)
  (if (and (buml:InputPin ip)
    (form:activity ip a))
    (iff (form:required-inputpin ip)
      (forall (ipmin)
        (if (buml:lower ip ipmin)
          (not (= ipmin form:0))))))))

(forall (n)
  (iff (form:executable-without-input n)
    (and (buml:ExecutableNode n)
      (form:no-incoming-edge n)
      (forall (ip)

        (if (buml:input n ip)

```

```

(not (or (form:required-inputpin ip)
        (exists (e)
                 (buml:incoming ip e)))))))))

```

This constraint applies to the syntactic pattern of a structured activity node containing executable nodes that have no incoming control flows, no incoming object flows to any pins, and no required inputs. It requires the contained nodes to execute when the structured node does.

```

(forall (sn n a)
  (if (and (buml:inStructuredNode sn n)
           (form:executable-without-input n)
           (form:activity n a))
    (forall (xa f xsn)
      (if (and (form:classifies a xa f)
               (form:property-value xa sn xsn f))
        (exists (xn)
                 (form:property-value xa n xn f))))))

(forall (a xa sn xsn)
  (iff (form:move-structured-pin-values a xa sn xsn)
    (and (forall (ip on2 fxsns sip xsnroot asnroot)
           (if (and (buml:input sn ip)
                    (form:structured-input-or-output ip on2)
                    (form:flows-trans-fork-merge ip on2)
                    (form:priorA fxsns xsn)
                    (form:property-value-sequence xa ip sip fxsns)
                    (psl:root_occ xsnroot xsn)
                    (psl:occurrence_of xsnroot asnroot))
              (form:set-property-value-sequence xa on2 sip asnroot)))
        (forall (op on2 xsnleaf asnleaf fxsnsleaf son2)
          (if (and (buml:output sn op)
                   (form:structured-input-or-output on2 op)
                   (form:flows-trans-fork-merge on2 op)
                   (psl:leaf_occ xsnleaf xsn)
                   (psl:occurrence_of xsnleaf asnleaf)
                   (form:priorA fxsnsleaf xsnleaf)
                   (form:property-value-sequence xa on2 son2 fxsnsleaf))
             (and (form:clear-property-value-sequence xa on2 asnleaf)
                   (form:set-property-value-sequence xa op son2
              asnleaf)))))))))

```

This constraint requires values of structured node pins to be transferred in and out of the structured node when the node execution begins and ends respectively.

```

(forall (sn a)
  (if (and (buml:StructuredNode sn)
           (form:activity sn a))
    (forall (xa f xsn)
      (if (and (form:classifies a xa f)
               (form:property-value xa sn xsn f))
        (form:move-structured-pin-values a xa sn xsn))))))

```

This constraint ensures executions of isolated structured nodes do not read objects modified by external executions during the execution of the structured node.

```

(forall (sn a)
  (if (and (buml:StructuredNode sn)
           (buml:isMustIsolate sn form:true)

```

```

    (form:activity sn a))
  (forall (xa f xsn xacrsf xa2 acrsf oip o fxacrsf)
    (if (and (form:classifies a xa f)
      (form:property-value xa sn xsn f)
      (form:subactivity_occurrence-neq xacrsf xsn)
      (psl:subactivity_occurrence xa2 xsn)
      (form:property-value xa2 acrsf xacrsf f)
      (buml:ReadStructuralFeatureAction acrsf)
      (buml:object acrsf oip)
      (form:priorA xacrsf fxacrsf)
      (form:property-value xa2 oip o fxacrsf))
      (not (exists (xout p v)
        (and (not (form:subactivity_occurrence-neq xout xsn))
          (form:achieves-property-value o p v xout))))))))))

```

10.4.6 Expansion Regions

10.4.6.1 Syntax

Expansion regions are formalized as call actions, where the activity called is constructed from the nodes in the region. The activity has parameter nodes corresponding to the pins of the expansion region, including the expansion nodes.¹⁰

```

(forall (n)
  (if (buml:ExpansionRegion n)
    (buml:CallAction n)))

```

The expansion-activity relation links expansion regions to the constructed activity it calls.

```

(forall (ac a)
  (if (form:expansion-activity ac a)
    (and (buml:ExpansionRegion ac)
      (buml:Activity a))))

```

```

(forall (ac a)
  (if (form:expansion-activity ac a)
    (form:called ac a)))

```

```

(forall (ac1 ac2 a)
  (if (and (form:expansion-activity ac1 a)
    (form:expansion-activity ac2 a))
    (= ac1 ac2)))

```

Expansion nodes are formalized as pins.

```

(forall (n)
  (if (buml:ExpansionNode n)
    (buml:Pin n)))

```

10.4.6.2 Semantics

All the values of input expansion nodes are taken as a single collection, whereas in UML each value is taken as a separate collection.¹¹ It is assumed edges do not cross expansion region boundaries and expansion regions are not nested.

The expansion-input-value-xcall relation links executions of expansion region actions (the `xac` variable) and positions (`pt`) in a property value sequence of an input expansion node with executions of its constructed activity (`xcall`) (in the execution model, all input expansion nodes have the same number of values at the beginning of region execution). For each expansion region action executions, this relation is one-to-one between positions and executions of the constructed activity, see the necessary condition on expansion region executions at the end of this subclause.

¹⁰ A separate behavior is needed to group multiple executions of the region into a single execution for reuse of the generic flow semantics outside the region. The called behavior is used at exactly one expansion region.

¹¹ This does not support queuing of collections, but the execution model does not use token queuing.

```

(forall (xac pt xcall)
  (if (form:expansion-input-value-xcall xac pt xcall)
    (and (form:execution xac)
      (form:Position pt)
      (form:execution xcall))))
(forall (xac pt1 xcall1 pt2 xcall2)
  (if (and (form:expansion-input-value-xcall xac pt1 xcall1)
    (form:expansion-input-value-xcall xac pt2 xcall2))
    (iff (= pt1 pt2)
      (= xcall1 xcall2))))

```

The expanded-value-to-fill relation links expansion region actions (the *xac* variable) under activity executions (*xa*), executions of the expansion region constructed activity (*xcall*) to input expansion nodes of the region (*ip*) and a value of the expansion node (*v*) to pass to a constructed activity execution. It uses expansion-input-value-xcall to link each value of the expansion node to one of the constructed activity executions.

```

(forall (xa xac xcall ip v)
  (iff (form:expanded-value-to-fill xa xac xcall ip v)
    (forall (ptindex sindex n)
      (if (and (form:expansion-input-value-xcall xac ptindex xcall)
        (form:position-count sindex ptindex n))
        (exists (fxac s pt)
          (and (form:priorA fxac xac)
            (form:property-value-sequence xa ip s fxac)
            (form:position-count s pt n)
            (form:in-position pt v)))))))

```

The fill-input-parameter-node relation ensures executions of expansion region actions (the *xac* variable) transfer values from an input pin of the expansion region (*ip*) to the corresponding input parameter nodes of the executions of the constructed activity (*xcall*). It assumes input pins never have more tokens than the action can accept in one execution, and input pin multiplicity upper is one or unlimited (*ipmax*).

```

(forall (xa xac xcall ip ipmax)
  (iff (form:fill-input-parameter-node xa xac xcall ip ipmax)
    (forall (srootxac arootxac p pnode a)
      (if (and (psl:root_occ srootxac xac)
        (psl:occurrence_of srootxac arootxac)
        (form:pin-parameter-match ip p)
        (buml:parameter pnode p)
        (form:activity pnode a)
        (form:activity ip a))
        (or (and (= ipmax form:l)
          (forall (v)
            (if (and (if (buml:ExpansionNode ip)
              (form:expanded-value-to-fill xa xac xcall ip v))
              (if (not (buml:ExpansionNode ip))
                (exists (fxac)
                  (and (form:priorA fxac xac)
                    (form:property-value xa ip v fxac))))))
              (form:add-property-value xcall pnode v arootxac))))
            (and (= ipmax buml:*)
              (forall (fxac s)
                (if (and (form:priorA fxac xac)
                  (form:property-value-sequence xa ip s fxac)
                  (form:set-property-value-sequence xcall pnode s
                    arootxac))))))))))

```

The empty-output-parameter-node relation ensures executions of expansion region action (the *xac* variable) transfer values from an output parameter node of the executions of the constructed activity (*xcall*) to the corresponding output pin of the expansion region (*op*). It assumes output pin multiplicity upper (*opmax*) is one or unlimited. This does not put null tokens in output pins when output parameter nodes are empty, as in UML.

```

(forall (xa xac xcall op opmax)

```

```

(iff (form:empty-output-parameter-node xa xac xcall op opmax)
  (forall (sleafxac aleafxac p pnode a fxcall)
    (if (and (psl:leaf_occ sleafxac xac)
      (psl:occurrence_of sleafxac aleafxac)
      (form:pin-parameter-match op p)
      (buml:parameter pnode p)
      (form:activity pnode a)
      (form:activity op a)
      (form:holdsA fxcall xcall))
      (or (and (= opmax form:1)
        (forall (v)
          (if (form:property-value xcall pnode v fxcall)
            (form:add-property-value xa op v aleafxac))))
        (and (= opmax buml:*)
          (forall (s)
            (if (form:property-value-sequence xcall pnode s
              fxcall)
              (form:set-property-value-sequence xa op s
                aleafxac))))))))))
)

```

The fill-empty-parameter-node relation combines the fill-input-parameter-node relation and empty-output-parameter-node relations.

```

(forall (a xa ac xac xcall)
  (iff (form:fill-empty-parameter-node a xa ac xac xcall)
    (and (forall (ip ipmax)
      (if (and (buml:input ac ip)
        (not (buml:ExpansionNode ip))
        (buml:upper ip ipmax))
        (form:fill-input-parameter-node xa xac xac ip ipmax)))
      (forall (op opmax)
        (if (and (buml:output ac op)
          (not (buml:ExpansionNode op))
          (buml:upper op opmax))
          (form:empty-output-parameter-node xa xac xac op opmax))))))
)

```

The expansion-input-value-output relation links two sequences and their positions. The relation is one-to-one, except not all positions in the first sequence are necessarily in the second sequence. The relation preserves the ordering of the sequences.

```

(forall (s1 pt1 s2 pt2)
  (if (form:expansion-input-value-output s1 pt1 s2 pt2)
    (and (form:Sequence s1)
      (form:Position pt1)
      (form:in-sequence s1 pt1)
      (form:Sequence s2)
      (form:Position pt2)
      (form:in-sequence s2 pt2))))
)
(forall (s1 pt1 pt12 s2 pt21 pt22)
  (if (and (form:expansion-input-value-output s1 pt1 s2 pt12)
    (form:expansion-input-value-output s1 pt21 s2 pt22))
    (iff (= pt1 pt21)
      (= pt12 pt22))))
)
(forall (s1 pt1 pt12 s2 pt2 pt22 )
  (if (and (form:expansion-input-value-output s1 pt1 s2 pt2)
    (form:expansion-input-value-output s1 pt12 s2 pt22))
    (iff (forall (n1 n2)
      (and (form:position-count s1 pt1 n1)
        (form:position-count s1 pt12 n2)

```



```

        (form:less-than n1 n2)))
(forall (n1 n2)
  (and (form:position-count s2 pt2 n1)
    (form:position-count s2 pt22 n2)
    (form:less-than n1 n2))))))

```

The contracted-sequence-to-empty relation links executions of expansion region actions (the `xac` variable) and executions of its constructed activity (`xcall`) with property value sequences (`s`) of an output pin (`op`). It assumes each execution of the body of the expansion region supplies no more than one value to each output expansion node. It ensures the value of the output parameter node of the constructed activity execution, if any, is in the output expansion node in the proper order. It uses the expansion-input-value-output relation for output value ordering.

```

(forall (xa xac xcall op sout)
  (iff (form:contracted-sequence-to-empty xa xac xcall op sout)
    (forall (ptin sin n pnode p a)
      (if (and (form:expansion-input-value-xcall xac ptin xcall)
        (form:position-count sin ptin n)
        (form:pin-parameter-match op p)
        (buml:parameter pnode p)
        (form:activity pnode a)
        (form:activity op a))
        (and (forall (v fxcallv)
          (if (and (form:holdsA fxcallv xcall)
            (form:property-value xcall pnode v fxcallv))
            (exists (ptout)
              (and (form:in-sequence sout ptout)
                (form:in-position ptout v)
                (form:expansion-input-value-output sin ptin sout
                  ptout))))))
          (if (not (exists (v fxcallv)
            (and (form:holdsA fxcallv xcall)
              (form:property-value xcall pnode v fxcallv))))
            (not (exists (ptout)
              (form:expansion-input-value-output sin ptin sout ptout))))
            (forall (ptout)
              (iff (form:in-sequence sout ptout)
                (exists (ptin2)
                  (form:expansion-input-value-output sin ptin2 sout
                    ptout))))))))))

```

This is a necessary condition on executions of expansion region actions that its constructed activity execute as many times as there are input values in the input expansion nodes (in the execution model, all input expansion nodes have the same number of values at the beginning of region execution), that values are transferred between pins of the action and parameter nodes of the constructed activity execution, and if the region mode is iterative that the executions are ordered in time in the same way as the input values (see the three conditions in the large conjunction). This assumes parallel expansion nodes have no output expansion nodes.

```

(forall (ac a acall)
  (if (and (buml:ExpansionRegion ac)
    (form:activity ac a)
    (form:expansion-activity ac acall))
    (forall (xa xac f)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f))
        (and (forall (ipindex fxac s pt)
          (if (and (buml:input ac ipindex)
            (buml:ExpansionNode ipindex)
            (form:priorA fxac xac)
            (form:property-value-sequence xa ipindex s fxac)
            (form:in-sequence s pt))
            (exists (xcall)
              (and (form:classifies acall xcall f)
                (form:subactivity_occurrence-neq xcall xac)
                (form:expansion-input-value-xcall xac pt xcall))))))

```

```

(forall (ptany xcall)
  (if (form:expansion-node-value-xcall xac ptany xcall)
    (and (form:fill-empty-parameter-node a xa ac xac xcall)
      (forall (ip)
        (if (and (buml:input ac ip)
          (buml:ExpansionNode ip))
          (form:fill-input-parameter-node xa xac xcall ip
form:l)))
      (forall (op)
        (if (and (buml:output ac op)
          (buml:ExpansionNode op))
          (and (form:empty-output-parameter-node xa xac xcall op
form:l)
            (exists (s2 fxacs)
              (and (form:contracted-sequence-to-empty xa xac
xcall op s2)
                (form:holdsA fxacs xac)
                (form:property-value-sequence xa op s2
fxacs)))))))
))
(forall (ptany1 xcall1 ptany2 xcall2)
  (if (and (buml:mode ac buml:iterative)
    (form:expansion-node-value-xcall xac ptany1 xcall2)
    (form:expansion-node-value-xcall xac ptany2 xcall2)
    (not (= xcall1 xcall2)))
    (forall (xcall1root xcall1leaf xcall2root xcall2leaf)
      (if (and (form:expansion-input-value-xcall xac ptany1 xcall2)
        (form:expansion-input-value-xcall xac ptany2 xcall2)
        (not (= xcall1 xcall2))
        (psl:root_occ xcall1root xcall1)
        (psl:leaf_occ xcall1leaf xcall1)
        (psl:root_occ xcall2root xcall2)
        (psl:leaf_occ xcall2leaf xcall2))
        (or (psl:earlier xcall1root xcall2leaf)
          (psl:earlier xcall1leaf xcall2root))))))))))

```

10.4.7 Control Flow

This section gives sufficient conditions for existence of action execution due to control flow, except for Subclause 10.4.7.3, which gives a necessary condition. The syntactic patterns of this subclause do not include any object flows.

10.4.7.1 Top level action

This subclause applies to the syntactic pattern of an action directly contained in an activity that requires no input to start. The constraint requires the action to execute for every execution of the containing activity.

```

(forall (n a)
  (if (and (buml:activity n a)
    (form:executable-without-input n))
    (forall (xa f)
      (if (form:classifies a xa f)
        (exists (xn)
          (form:property-value xa n xn f))))))

```

10.4.7.2 Initial Node to Action

This subclause applies to the syntactic pattern of a control flow from an initial node to an action, with no more than one edge going out of the initial node, no more than one edge coming into the action, and no pins on the action (for example, see Statement Sequence pattern in Annex A.3.1). It requires the action to execute for every execution of the containing activity

```

(forall (n1 n2)
  (iff (form:same-syntactic-container n1 n2)
    (exists (c)
      (or (and (buml:inStructuredNode n1 c)
                (buml:inStructuredNode n2 c))
          (and (buml:activity n1 c)
                (buml:activity n2 c)))))))

(forall (i e ac a)
  (if (and (buml:InitialNode i)
            (form:max-one-outgoing-edge i)
            (buml:target e ac)
            (form:same-syntactic-container i ac)
            (buml:Action ac)
            (not (exists (ip)
                      (buml:input ac ip))))
      (form:activity i a))
    (forall (xa sn xsn f)
      (if (and (form:classifies a xa f)
                (or (not (buml:inStructuredNode i sn))
                    (form:property-value xa sn xsn f)))
          (exists (xac)
            (form:property-value xa ac xac f))))))

```

10.4.7.3 Action to Action, general necessary condition

This subclause applies to syntactic pattern of a control flow between actions, with any intervening and chained control nodes, and regardless of any other flows. It requires each target action execution to follow no more than one source action execution, and each source action execution to be followed by no more than one source action execution. It does not require the target action to execute.¹²

```

(forall (n1 n2)
  (iff (form:flow-trans-control-node n1 n2)
    (exists (e)
      (and (buml:outgoing n1 e)
           (or (buml:target e n2)
               (exists (nt)
                 (and (buml:target e nt)
                      (buml:ControlNode nt)
                      (form:flow-trans-control-node nt n2))))))))))

```

The follows relation links two PSL occurrences (s_1 and s_2 variables) under an execution of an activity (a), where the first occurrence happens sometime before the second. The follows relation is used in sufficient conditions for the existence of action executions due to control flow from other actions, for example in Subclause.

```

(forall (s1 s2 a)
  (if (form:follows s1 s2 a)
      (form:min-precedesA s1 s2 a)))

(forall (ac1 ac2 a)
  (if (and (buml:Action ac1)
            (buml:Action ac2)
            (form:flow-trans-control-node ac1 ac2)
            (form:activity ac1 a))
      (forall (xa f xac1 xac2 xac12 xac22)

```

¹² This constraint does not apply to forks followed by merges, or decision nodes followed by joins, but the execution model does not use these syntactic patterns.

```

(if (and (form:classifies a xa f)
        (form:property-value xa ac1 xac1 f)
        (form:property-value xa ac2 xac2 f)
        (form:property-value xa ac1 xac12 f)
        (form:property-value xa ac2 xac22 f)
        (form:follows xac1 xac2 a)
        (form:follows xac12 xac22 a))
    (iff (= xac1 xac12)
         (= xac2 xac22))))))

```

10.4.7.4 Action to Action, single control flow, optional merge/fork

This subclause applies to the syntactic pattern of a control flow between actions, with any intervening and chained fork and merge nodes (for example, see the Statement Sequence pattern in Annex A.3.1). The target action has no other incoming control flows and no input pins. The constraint requires the target action to execute after the source action does.

The flow-trans-fork-merge links activity nodes that have a control or object flow between them (the *n1* variable as source, *n2* as target), possibly with intervening and chained fork and merge nodes. The flow will be a control flow if the nodes are actions and an object flow if the nodes are object nodes.

```

(forall (n1 n2)
  (iff (form:flow-trans-fork-merge n1 n2)
      (exists (e)
        (and (buml:outgoing n1 e)
              (or (buml:target e n2)
                  (exists (nt)
                    (and (buml:target e nt)
                        (or (buml:ForkNode nt)
                            (buml:MergeNode nt))
                        (form:flow-trans-fork-merge nt n2))))))))))
(forall (ac1 ac2 a)
  (if (and (buml:Action ac1)
           (buml:Action ac2)
           (form:max-one-incoming-edge ac2)
           (form:flow-trans-fork-merge ac1 ac2)
           (not (exists (ip)
                  (buml:input ac ip))))
      (form:activity ac1 a))
  (forall (xa f xac1)
    (if (and (form:classifies a xa f)
            (form:property-value xa ac1 xac1 f))
        (exists (xac2)
          (and (form:property-value xa ac2 xac2 f)
               (form:follows xac1 xac2 a))))))

```

10.4.8 Object Flow

This section gives sufficient conditions for the presence of values in object nodes in Subclauses 10.4.8.1 and 10.4.8.2 and for the existence of action execution due to object flow in Subclauses 10.4.8.3 through 10.4.8.6, and also control flow in Subclauses 10.4.8.4 through 10.4.8.6. The syntactic patterns of this subclause do not have object nodes with more than one outgoing edge (no token competition).

10.4.8.1 Object node to object node, optional fork/merge

This subclause applies to the syntactic pattern of object flow between object nodes, with any intervening and chained fork and merge nodes, where the flow is not into or out of a structured node pin (for example, see the two Instance

Variable Assignment patterns in Annex A.3.4 and A.3.5). The source object node has exactly one outgoing object flow. The constraints require values in the source object node be transferred to the target object node.

```
(forall (n sn)
  (iff (form:inStructuredNode-trans n sn)
    (or (buml:inStructuredNode n sn)
      (exists (nt)
        (and (buml:inStructuredNode n nt)
          (form:inStructuredNode-trans nt sn))))))
```

The structured-input-or-output relation links input pins (the on1 variable) or output pins (on2) of structured nodes with object nodes in the structured node.

```
(forall (on1 on2)
  (iff (form:structured-input-or-output on1 on2)
    (exists (sn)
      (and (buml:StructuredNode sn)
        (or (and (buml:input sn on1)
          (form:inStructuredNode-trans on2 sn))
          (and (buml:output sn on2)
            (form:inStructuredNode-trans on1 sn)))))))

(forall (on1 on2 a)
  (if (and (buml:ObjectNode on1)
    (buml:ObjectNode on2)
    (not (form:structured-input-or-output on1 on2))
    (form:max-one-outgoing-edge on1)
    (form:flows-trans-fork-merge on1 on2)
    (form:activity on1 a))
    (forall (xa f xsub v fonls sonl)
      (if (and (form:classifies a xa f)
        (form:subactivity_occurrence-neq xsub xa)
        (form:achieves-property-value xa sonl v xsub)
        (psl:holds fonls xsub)
        (form:property-value-sequence xa on1 sonl fonls))
        (exists (amove)
          (and (form:clear-property-value-sequence xa on1 amove)
            (form:set-property-value-sequence xa on2 sonl amove)
            (form:subactivity_occurrence-neq
              (psl:successor amove xsub) xa))))))
```

10.4.8.2 Object node to object node, decision, optional fork/merge

This subclause applies to the syntactic pattern of object flow between object nodes, with any intervening and chained fork and merge nodes, one intervening decision node, where the flow is not into or out of a structured node pin (for example, see the Do-While Loop pattern in Annex A.3.10). The decision input flow comes from an output pin on the same action as the output pin providing the decision input. The source object node has exactly one outgoing object flow. The constraints require the values in the source object node to be transferred to the target object node if the decision input matches the guard.

The flow-trans-fork-merge-decision relation links activity nodes that have a control or object flow between them (the n1 variable as source, n2 as target), where the flow is not into or out of a structured node pin, possibly with intervening and chained fork and merge nodes. The flow has one intervening decision node with a decision input flow from an output pin (dip), possibly with intervening and chained fork and merge nodes, and a guard specification (g). The flow will be a control flow if the nodes (n1 and n2) are actions and an object flow if the nodes are object nodes.

```
(forall (n1 n2 dip g)
  (iff (form:flow-trans-fork-merge-decision n1 n2 dip g)
    (exists (dn)
      (and (buml:DecisionNode dn)
```

```

(form:flow-trans-fork-merge n1 dn)
(form:flow-trans-fork-merge dn n2)
(exists (edn nt gvs)
  (and (buml:outgoing dn edn)
        (buml:target edn nt)
        (or (= nt n2)
              (form:flow-trans-fork-merge nt n2))
        (buml:guard edn gvs)
        (buml:value gvs g)))
(form:flow-trans-fork-merge dip dn)
(buml:OutputPin dip)
(exists (edn nt)
  (and (buml:incoming dn edn)
        (buml:decisionNodeInputFlow dn edn)
        (buml:source edn nt)
        (or (= nt dip)
              (form:flow-trans-fork-merge dip nt))))))

```

This assumes the output pin providing the decision input has exactly one value.

```

(forall (on1 on2 ac dip g a)
  (if (and (buml:ObjectNode on1)
           (buml:ObjectNode on2)
           (not (form:structured-input-or-output on1 on2))
           (buml:Action ac)
           (buml:output ac on1)
           (buml:output ac dip)
           (form:max-one-outgoing-edge on1)
           (form:max-one-outgoing-edge dip)
           (form:flow-trans-fork-merge-decision on1 on2 dip g)
           (form:activity on1 a))
    (forall (xa f xac fxac vdip son1)
      (if (and (form:classifies a xa f)
                (form:property-value xa ac xac f)
                (form:holdsA fxac xac)
                (form:property-value xa dip vdip fxac)
                (= vdip g)
                (form:property-value-sequence xa on1 son1 fxac))
          (exists (amove occmove)
            (and (form:remove-property-value xa dip vdip amove)
                  (form:clear-property-value-sequence xa on1 amove)
                  (form:set-property-value-sequence xa on2 son1 amove)
                  (psl:occurrence_of occmove amove)
                  (psl:next_subocc xac occmove a))))))

```

10.4.8.3 Action with pins, no incoming control flow or one from initial

This subclause applies to the syntactic pattern of an action with pins, and no incoming control flow or one from an initial node (for example, see the Testing String Equality pattern in Annex A.4.9). It requires the action to execute for every execution of the activity when the input pins are provided enough values to meet their lower multiplicity.

The action-input-pins-satisfied links actions (the *ac* variable) under executions of their containing activities (*xa*), with other executions (*xsub*) after which the values in the action's pins meet their lower multiplicity. An incoming control flow is required if all input pins are optional (lower multiplicity of zero). It assumes that the input pin multiplicity lower bound is zero or one.

```

(forall (ac xa xsub)
  (iff (form:action-input-pins-satisfied ac xa xsub)
    (and (forall (ip ipmin)
      (if (and (buml:input ac ip)

```

```

        (buml:lower ip ipmin))
    (or (= ipmin form:0)
        (and (= ipmin form:1)
            (exists (v f)
                (and (form:holdsA f xsub)
                    (form:property-value xa ip v f))))))
(or (exists (e)
    (buml:target e ac))
    (exists (ip)
        (and (buml:input ac ip)
            (exists (v f)
                (and (form:holdsA f xsub)
                    (form:property-value xa ip v f)))))))))

```

The action-pin-trigger relation links actions (the *ac* variable) under executions of their containing activities (*xa*), with other executions (*xsub*) under the activity execution before which the action input pins are not satisfied and after which they are.

```

    (iff (form:action-pin-trigger ac xsub xa)
        (and (form:subactivity_occurrence-neq xsub xa)
            (forall (xsub alsb)
                (if (and (psl:leaf_occ xsub xsub)
                    (psl:occurrence_of xsub alsb))
                    (exists (xsub)
                        (and (= xsub (psl:successor xsub alsb))
                            (not (form:action-input-pins-satisfied ac xa xsub))
                            (form:action-input-pins-satisfied ac xa xsub)))))))))

```

The take-input relation ensures that executions (the *xac* variable) remove values from input pins that are values just after another execution is complete (*xsub*). The other execution brings about pin satisfaction, see action-pin-trigger above. It assumes that the input pin multiplicity upper bound is one or unlimited.

```

(forall (xac ac xa xsub)
    (iff (form:take-input xac ac xa xsub)
        (forall (srootxac arootxac ip ipmax)
            (if (and (psl:root_occ srootxac xac)
                (psl:occurrence_of srootxac arootxac)
                (buml:input ac ip)
                (buml:upper ip ipmax))
                (or (and (= ipmax form:1)
                    (forall (fxsubh v)
                        (if (and (form:holdsA fxsubh xsub)
                            (form:property-value xa ip v fxsubh))
                            (form:remove-property-value xa ip v arootxac))))
                    (and (= ipmax buml:*)
                        (forall (fxsubh v)
                            (if (and (form:holdsA fxsubh xsub)
                                (form:property-value xa ip v fxsubh))
                                (form:remove-property-value xa ip v
                                    arootxac))))))))))
    (forall (n)
        (iff (form:no-incoming-edge-or-one-from-initial n)
            (and (forall (e1 e2)
                (if (and (buml:incoming e1 n)
                    (buml:incoming e2 n))
                    (= e1 e2)))
                (forall (n2)
                    (if (form:flow-trans-fork-merge n2 n)
                        (buml:InitialNode n2)))))))))

```

```

(forall (ac a ip)
  (if (and (buml:Action ac)
    (form:no-incoming-edge-or-one-from-initial ac)
    (buml:input ac ip)
    (form:activity ac a))
    (forall (xa f xsub)
      (if (and (form:classifies a xa f)
        (form:action-pin-trigger ac xsub xa))
        (exists (xac)
          (and (form:property-value xa ac xac f)
            (psl:min_precedes xsub xac a)
            (form:take-input xac ac xa xsub)))))))

```

10.4.8.4 Action with pins, one incoming control flow from action, optional fork/merge

This subclause applies to the syntactic pattern of an action with pins, and one incoming control flow from another action with any intervening and chained fork and merge nodes (for example, see the Method Call pattern in Annex A.4.11). It requires the target action to execute after the source action when the input pins are provided enough values to meet their lower multiplicity.

The joinable-control-input relation links actions and their executions (the *ac0* and *xac0* variables respectively) under executions of their containing activities (*xa* and *a*, respectively), with other executions (*xsub*) under the activity execution that satisfy the pins of a target action (*ac*). The action executions (*xac0*) and the other pin-satisfying executions (*xsub*) are paired one-to-one in time order. The pairing begins with action executions and pin-satisfying executions that have no other ones before them (the first part of the disjunction), and the pairs after that are in time order (the second part of the disjunction).

```

(forall (xac0 xsub xa a ac0)
  (iff (form:joinable-control-input ac0 xac0 xsub ac a xa)
    (forall (f)
      (or (and (not (exists (xac00)
        (and (form:property-value xa ac0 xac00 f)
          (psl:min_precedes xac00 xac0 a))))
        (not (exists (xsub0)
          (and (form:action-pin-trigger ac xsub0 xa)
            (psl:min_precedes xsub0 xsub a))))))
        (exists (xac02 xsub2)
          (and (form:joinable-control-input ac0 xac02 xsub2 ac a xa)
            (not (exists (xac00)
              (and (form:property-value xa ac0 xac00 f)
                (psl:min_precedes xac02 xac00 a)
                (psl:min_precedes xac00 xac0 a))))
            (not (exists (xsub0)
              (and (form:action-pin-trigger ac0 xsub0 xa)
                (psl:min_precedes xsub2 xsub0 a)
                (psl:min_precedes xsub0 xsub a))))))))))

```

The joined-follows relation links PSL occurrences where two of the occurrences (the *s1* and *s2* variables) happen before the third (*s3*) under execution of an activity (*a*). The third occurrence is constrained to follow no more than one pair of the other two occurrences, and each pair of the other two occurrences to be followed by no more than one of the third (compare to the follows relation in Subclause 10.4.7.3).

```

(forall (s1 s2 s3 a)
  (if (form:joined-follows s1 s2 s3 a)
    (and (form:min_precedesA s1 s3 a)
      (form:min_precedesA s2 s3 a))))

(forall (s1 s2 s3 s12 s22 s32 a)
  (if (and (form:joined-follows s1 s2 s3 a)
    (form:joined-follows s12 s22 s32 a))

```



```

    (iff (and (= s1 s12)
              (= s2 s22))
         (= s3 s32)))

```

The `joined-action-execution-exists` relation establishes existence of executions of actions (the `ac` variable) under activity executions (`xa`, an execution of activity `a`) where an action execution happens after its input pins are satisfied, and after another action execution completes (`xac0`, an execution of action `ac0`). An earlier constraint requires the source of control flow (`xac0`) to execute before the target action (`ac`), see Subclause 10.4.7.3. The constraint below addresses the remaining cases, one where the input pins are satisfied at the time the source of control flow is completed (the first part of the disjunction), and another where the input pins are satisfied sometime after the source of control flow is completed (the second part of the disjunction), see `action-pin-trigger` and `joinable-control-input`.

```

(forall (ac ac0 xac0 a xa)
  (iff (form:joined-action-execution-exists ac ac0 xac0 a xa)
    (forall (f)
      (or (and (form:action-input-pins-satisfied ac xa xac0)
                (exists (xac)
                  (and (form:property-value xa ac xac f)
                       (form:take-input xac ac xa xac0))))
          (and (not (form:action-input-pins-satisfied ac xa xac0))
                (forall (xsub)
                  (if (and (form:action-pin-trigger ac xsub xa)
                          (form:joinable-control-input ac0 xac0 xsub ac a
xa))
                    (exists (xac)
                      (and (form:property-value xa ac xac f)
                           (form:follows xac0 xac a)
                           (form:joined-follows xac0 xsub xac a)
                           (form:take-input xac ac xa xsub))))))))))
  (forall (ac0 ac a)
    (if (and (buml:Action ac0)
              (buml:Action ac)
              (form:max-one-incoming-edge ac)
              (form:flow-trans-fork-merge ac0 ac)
              (form:activity ac a))
      (forall (xa f xac0)
        (if (and (form:classifies a xa f)
                  (form:property-value xa ac0 xac0 f))
            (form:joined-action-execution-exists ac ac0 xac0 a xa))))))

```

10.4.8.5 Action with pins, one incoming control flow from action, decision with decision flow from same action, optional fork/merge

This subclause applies to the syntactic pattern an action with pins, and one incoming control flow from another action with any intervening and chained fork and merge nodes, and one intervening decision node in both the object flows and control flows (for example, see the Do-While pattern in Annex A.3.10). The decision inputs come from output pins on the same action as the source of the control flow. It requires the target action to execute after the source action when the input pins are provided enough values to meet their lower multiplicity.

The `guarded-joined-action-execution-exists` relation augments the `joined-action-execution-exists` relation for a syntactic pattern that has a decision node with a decision input from an output pin (the `dip` variable) and guard value (`g`). It assumes the output pin has exactly one value, and the guard is a literal value specification. It ensures the value of the output pin is removed.

```

(forall (ac ac0 dip g a)
  (iff (form:guarded-joined-action-execution-exists ac ac0 dip g a)
    (forall (xa f xac0 vdip fxac0)
      (if (and (form:classifies a xa f)
                (form:property-value xa ac0 xac0 f)
                (form:holdsA fxac0 xac0))
          (form:guarded-joined-action-execution-exists ac ac0 dip g a))))

```

```

                (form:property-value xa dip vdip fxac0)
                (= vdip g))
        (and (form:joined-action-execution-exists ac ac0 xac0 a xa)
            (exists (amove occmove)
                (and (form:remove-property-value xa dip vdip amove)
                    (psl:occurrence_of occmove amove)
                    (psl:next_subocc xac0 occmove a))))))
(forall (ac0 ac dip g a)
  (if (and (buml:Action ac0)
          (buml:Action ac)
          (form:max-one-incoming-edge ac)
          (form:flow-trans-fork-merge-decision ac0 ac dip g)
          (buml:output ac0 dip)
          (form:activity ac a))
      (form:guarded-joined-action-execution-exists ac ac0 dip g a)))

```

10.4.8.6 Action with pins, one incoming control flow from initial, decision with decision flow from initial action in same, optional fork/merge

This subclause applies to the syntactic pattern an action with pins, and one incoming control flow from and initial node with any intervening and chained fork and merge nodes, and one intervening decision node the control flow (for example, see the If Statement pattern in Annex A.3.9). The decision inputs come from output pins on the same action as the source of the control flow. It requires the target action to execute for every execution of the activity when the input pins are provided enough values to meet their lower multiplicity.

```

(forall (i ac dip g ac0 a)
  (if (and (buml:InitialNode i)
          (buml:Action ac)
          (form:max-one-incoming-edge ac)
          (form:flow-trans-fork-merge-decision i ac dip g)
          (buml:output ac0 dip)
          (form:executable-without-input ac0)
          (form:same-syntactic-container i ac)
          (form:same-syntactic-container i ac0)
          (form:activity ac a))
      (form:guarded-joined-action-execution-exists ac ac0 dip g a)))

```

10.4.9 Invocation Actions

10.4.9.1 Syntax

This subclause specifies additional syntax for invocation actions. The called relation links call actions to behaviors and operations that are called.

```

(forall (ac pd)
  (if (form:called ac pd)
      (and (buml:CallAction ac)
          (form: ProcessDefinition pd))))

(forall (ac po1 po2)
  (if (and (form:called ac po1)
          (form:called ac po2))
      (= po1 po2)))

(forall (ac)
  (if (buml:CallAction ac)
      (exists (po)
          (form:called ac po))))

```

The pin-parameter-match relation links pins and called parameters as derived from pin and parameter ordering in the model.

```

(forall (pn p)
  (if (form:pin-parameter-match pn p)
      (and (buml:Pin pn)
            (buml:Parameter p))))

(forall (pn1 p1 pn2 p2)
  (if (and (form:pin-parameter-match pn1 p1)
            (form:pin-parameter-match pn2 p2))
      (iff (= pn1 pn2)
            (= p1 p2))))

(forall (pn p)
  (if (form:pin-parameter-match pn p)
      (and (if (form:InputParameter p)
                (buml:InputPin pn))
            (if (form:OutputParameter p)
                (buml:OutputPin pn)))))

(forall (pn p)
  (if (form:pin-parameter-match pn p)
      (forall (m)
        (and (iff (buml:lower pn m)
                  (buml:lower p m))
              (iff (buml:upper pn m)
                  (buml:upper p m))
              (iff (buml:type pn m)
                  (buml:type p m))))))

(forall (pn p)
  (if (form:pin-parameter-match pn p)
      (forall (t)
        (iff (buml:type pn t)
            (buml:type p t)))))

(forall (ac po)
  (if (and (buml:CallAction ac)
            (form:called ac po))
      (forall (pn p)
        (iff (and (form:put ac pn)
                  (form:pin-parameter-match pn p))
            (form:ownedParameter po p)))))

(forall (ac b)
  (if (buml:behavior ac b)
      (buml:type ac b)))

(forall (ac b)
  (if (buml:behavior ac b)
      (form:called ac b)))

(forall (ac op)
  (if (buml:operation ac op)
      (form:called ac op)))

(forall (ac op)

```

```
(if (buml:operation ac op)
    (buml:type ac op)))
```

The pin-property-match relation links pins and properties as derived from pin and signal property ordering in the model.

```
(forall (pn p)
  (if (form:pin-property-match pn p)
      (and (buml:Pin pn)
            (buml:Property p))))

(forall (pn1 p1 pn2 p2)
  (if (and (form:pin-property-match pn1 p1)
            (form:pin-property-match pn2 p2))
      (iff (= pn1 pn2)
            (= p1 p2))))

(forall (pn p)
  (if (form:pin-property-match pn p)
      (forall (m)
        (and (iff (buml:lower pn m)
                  (buml:lower p m))
              (iff (buml:upper pn m)
                  (buml:upper p m))
              (iff (buml:type pn m)
                  (buml:type p m)))))))

(forall (ac sig)
  (if (and (buml:SendSignalAction ac)
            (form:signal ac sig))
      (forall (pn p)
        (iff (and (form:argument ac pn)
                  (form:pin-property-match pn p))
              (buml:ownedAttribute sig p))))))
```

10.4.9.2 Semantics

This subclause gives necessary conditions on executions of invocation actions as used in the execution engine (CallBehaviorAction, CallOpertationAction, and SendSignalAction).

The change-only-pin relation links actions and their executions under the activity executions, where the action executions only affect spins of the action.

```
(forall (ac xac xa)
  (iff (form:change-only-pin ac xac xa)
      (forall (xsub o p v)
        (if (and (form:subactivity_occurrence-neq xsub xac)
                  (form:achieves-property-value o p v xsub))
            (and (= o xa)
                  (or (buml:input ac p)
                      (buml:input ac p))))))))
```

This ensures activities invoked with call behavior actions transfer values between pins and parameter nodes, and that called function behaviors only affect pins of their calling actions.

```
(forall (ac a b)
  (if (and (buml:CallBehaviorAction ac)
            (form:activity ac a)
            (buml:type ac b))
      (forall (xa xac f)
        (if (and (form:classifies a xa f)
                  (form:property-value xa ac xac f))
            (and (if (buml:Activity b)
```

```

        (form:fill-empty-parameter-node a xa ac xac xac))
      (if (buml:FunctionBehavior b)
          (form:change-only-pin ac xac xa))))))

```

The dispatch relation links objects to operations and behaviors in a PSL states. It is used to determine more detailed behavior (method) based on the thing on which an operation is invoked. It assumes multiple generalization does not affect the choice of method.

```

(forall (o op b f)
  (if (form:dispatch o op b f)
      (and (buml:Operation op)
            (buml:Behavior b)
            (psl:state f))))

(forall (o op b f)
  (if (form:dispatch o op b f)
      (exists (c)
        (and (form:classifies c o f)
              (form:method op b c)
              (not (exists (c2 b2)
                (and (not (= c c2))
                     (buml:general c2 c)
                     (form:method op b2 c)
                     (form:classifies c2 o f))))))))

```

The execution-performer relation links executions to things performing those executions.

```

(forall (x o)
  (if (form:execution-performer x o)
      (form:execution x)))

(forall (x o1 o2)
  (if (and (form:execution-performer x o1)
            (form:execution-performer x o2))
      (= o1 o2)))

```

This ensures activities invoked with call operation actions transfer values between pins and parameter nodes, and that called function behaviors only affect pins of their calling actions.

```

(forall (ac a op b tip)
  (if (and (buml:CallOperationAction ac)
            (form:activity ac a)
            (buml:operation ac op)
            (buml:target ac tip))
      (forall (xa xac f fxac to)
        (if (and (form:classifies a xa f)
                  (form:property-value xa ac xac f)
                  (form:priorA fxac xac)
                  (form:property-value xa tip to fxac)
                  (form:dispatch to op b fxac))
            (and (form:classifies b xac f)
                  (form:execution-performer xac to)
                  (form:fill-empty-parameter-node a xa ac xac xac))))))

```

The new-object relation links things to PSL occurrences before which the object does not exist.

```

(forall (o occ)
  (if (form:new-object o occ)
      (psl:occurrence occ)))

(forall (o occ)
  (if (form:new-object o occ)

```

```

(and (forall (locc occ2)
      (if (and (psl:leaf_occ locc occ)
              (psl:earlierEq occ2 locc))
          (not (exists (f p s o2 c)
                      (and (psl:prior f occ2)
                          (or (form:property-value-sequence o p s f)
                              (form:property-value-sequence o2 p o f)
                              (form:classifies c o f))))))
      (exists (f p s o2 c)
              (and (psl:holdsA f occ)
                  (or (form:property-value-sequence o p s f)
                      (form:property-value-sequence o2 p o f)
                      (form:classifies c o f))))))

```

The fill-signal-property relation links signal objects to input pins that have values for properties of the signal. It assumes input pin multiplicity upper is one or unlimited.

```

(forall (osig ip ipmax xa xac)
  (iff (form:fill-signal-property osig ip ipmax xa xac)
      (forall (srootxac arootxac p fxac)
        (if (and (psl:root_occ srootxac xac)
                (psl:occurrence_of srootxac arootxac)
                (form:pin-property-match ip p)
                (form:priorA fxac xac))
            (or (and (= ipmax buml:*)
                    (forall (s)
                      (if (form:property-value-sequence xa ip s fxac)
                          (form:set-property-value-sequence osig p s
                                                              arootxac))))
                (and (= ipmax form:1)
                    (forall (v)
                      (if (form:property-value xa ip v fxac)
                          (form:add-property-value osig p v arootxac))))))))))

```

The event-pool relation links things to collections of events sent to them and waiting to be processed.

```

(forall (o osig f)
  (if (form:event-pool o osig f)
      (psl:state f)))

```

This ensures ensures send signal action executions transfer values between pins and signal properties, and that the signal is in the event pool of the target.

```

(forall (ac a sig tip)
  (if (and (buml:SendSignalAction ac)
          (form:activity ac a)
          (buml:signal ac sig)
          (buml:target ac tip))
      (forall (xa xac f fxac to)
        (if (and (form:classifies a xa f)
                (form:property-value xa ac xac f)
                (form:priorA fxac xac)
                (form:property-value xa tip to fxac))
            (exists (fxac2 osig)
                    (and (form:holdsA fxac2 xac)
                        (form:classifies sig osig fxac2)
                        (form:new-object osig xac)
                        (forall (ip ipmax)
                          (if (and (buml:argument ac ip)
                                      (buml:upper ip ipmax))
                              (form:property-value xa ip to fxac))))))))

```

```

        (form:fill-signal-property osig ip ipmax xa xac)))
    (form:event-pool to osig fxac2))))))

```

10.4.10 Object Actions (Intermediate)

This subclause specifies necessary conditions on executions of intermediate object actions as used in the execution engine (CreateObjectAction, TestIdentityAction, ReadSelfAction, and ValueSpecificationAction).

```

(forall (ac a c op)
  (if (and (buml:CreateObjectAction ac)
    (form:activity ac a)
    (buml:classifier ac c)
    (buml:result ac op))
    (forall (xa xac f)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f))
        (exists (fxac o)
          (and (form:holdsA fxac xac)
            (form:classifies c o fxac)
            (form:new-object o xac)
            (form:property-value xa op o fxac)))))))

```

This covers testing equivalence of datatype values, which the UML TestIdentityAction does not.

```

(forall (ac a ip1 ip2 op)
  (if (and (buml:TestIdentityAction ac)
    (form:activity ac a)
    (buml:first ac ip1)
    (buml:first ac ip2)
    (buml:result ac op))
    (forall (xa xac f v1 v2 fxac)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f)
        (form:priorA fxac xac)
        (form:property-value xa ip1 v1 fxac)
        (form:property-value xa ip2 v2 fxac))
        (exists (fxac2)
          (and (form:holdsA fxac2 xac)
            (if (or (= v1 v2)
              (form:same-string v1 v2))
              (form:property-value xa op form:true fxac2))
            (if (not (= v1 v2))
              (form:property-value xa op form:false fxac2))))))))))
(forall (ac a op)
  (if (and (buml:ReadSelfAction ac)
    (form:activity ac a)
    (buml:result ac op))
    (forall (xa xac f xsuper o)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f)
        (form:subactivity_occurrence-neq xac xsuper)
        (form:execution-performer o xsuper)
        (not (exists (xsuper2 o2)
          (and (form:subactivity_occurrence-neq xac xsuper2)
            (form:subactivity_occurrence-neq xsuper2 xsuper)
            (form:execution-performer o2 xsuper2))))))
        (exists (fxac)
          (and (form:holdsA fxac xac)
            (form:property-value xa op o fxac)))))))
(forall (ac a vs op)

```

```

(if (and (buml:ValueSpecificationAction ac)
        (form:activity ac a)
        (buml:value ac vs)
        (buml:result ac op))
    (forall (xa xac f)
      (if (and (form:classifies a xa f)
              (form:property-value xa ac xac f))
          (exists (fxac)
            (and (form:holdsA fxac xac)
                 (forall (v)
                   (if (buml:value vs v)
                       (form:property-value xa op v fxac)))
                 (if (buml:LiteralNull vs)
                     (form:property-value xa op form:null fxac))
                 (if (buml:InstanceValue vs)
                     (forall (i)
                       (if (buml:instance vs i)
                           (form:property-value xa op i fxac))))))))))

```

10.4.11 Structural Feature Actions

This subclause specifies necessary conditions on executions of intermediate object actions as used in the execution model (ReadStructuralFeatureAction, ClearStructuralFeatureAction, AddStructuralFeatureAction, RemoveStructuralFeatureAction).

```

(forall (ac a p oip op)
  (if (and (buml:ReadStructuralFeatureAction ac)
          (form:activity ac a)
          (buml:structuralFeature ac p)
          (buml:object ac oip)
          (buml:result ac op))
      (forall (xa xac f o fxac v)
        (if (and (form:classifies a xa f)
                (form:property-value xa ac xac f)
                (form:priorA fxac xac)
                (form:property-value xa oip o fxac)
                (form:property-value o p v fxac))
            (exists (fxac2)
              (and (form:holdsA fxac2 xac)
                   (form:property-value xa op v fxac2))))))
    (forall (ac a p oip op)
      (if (and (buml:ClearStructuralFeatureAction ac)
              (form:activity ac a)
              (buml:structuralFeature ac p)
              (buml:object ac oip)
              (buml:result ac op))
          (forall (xa xac f o fxac)
            (if (and (form:classifies a xa f)
                    (form:property-value xa ac xac f)
                    (form:priorA fxac xac)
                    (form:property-value xa oip o fxac))
                (and (not (exists (fxac2 v)
                              (and (form:holdsA fxac2 xac)
                                   (form:property-value o p v fxac2))))
                    (exists (fxac2)
                      (and (form:holdsA fxac2 xac)
                           (form:property-value xa op o fxac2))))))

```



```

(forall (ac a p oip vip)
  (if (and (buml:AddStructuralFeatureAction ac)
    (form:activity ac a)
    (buml:structuralFeature ac p)
    (buml:object ac oip)
    (buml:value ac vip))
    (forall (xa xac f o fxac v)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f)
        (form:priorA fxac xac)
        (form:property-value xa oip o fxac)
        (form:property-value xa vip v fxac))
        (and (form:property-value o p v fxac)
          (forall (iraip irav)
            (if (and (buml:isReplaceAll ac iraip)
              (form:property-value xa iraip irav fxac)
              (= iraip form:true))
              (not (exists (fxac2 v2)
                (and (form:holdsA fxac2 xac)
                  (form:property-value o p v2 fxac2)
                  (not (= v v2))))))))
            (forall (iaip iav s sl s11 n)
              (if (and (buml:insertAt ac iaip)
                (form:property-value xa iaip iav fxac)
                (form:property-value-sequence o p s fxac)
                (form:sequence-length s sl)
                (form:add-one sl s11)
                (if (= iav buml:*)
                  (= n s11))
                (if (not (= iav buml:*))
                  (= n iav)))
                (exists (fxac2 s2)
                  (and (or (= iav buml:*)
                    (and (form:WholeNumber iav)
                      (form:less-than iav s11)))
                    (form:holdsA fxac2 xac)
                    (form:property-value-sequence o p s2 fxac2)
                    (form:in-position-count s2 v n)
                    (forall (nless v2)
                      (if (and (form:WholeNumber nless)
                        (form:less-than nless n)
                        (form:in-position-count s v2 nless))
                        (form:in-position-count s2 v2 nless))))
                    (if (form:WholeNumber iav)
                      (forall (nmore v2 nmore1)
                        (if (and (form:WholeNumber nmore)
                          (form:less-than n nmore)
                          (form:less-than nmore s11)
                          (form:in-position-count s v2
                            (form:add-one nmore nmore1))
                          (form:in-position-count s2 v2
                            nmore1))))))))))))))))))
          )
    )
  )
)

```

This assumes isRemoveDuplicates on the action is false.

```

(forall (ac a p oip vip)
  (if (and (buml:RemoveStructuralFeatureAction ac)

```

```

    (form:activity ac a)
    (buml:structuralFeature ac p)
    (buml:object ac oip)
    (buml:value ac vip))
(forall (xa xac f o fxac v)
  (if (and (form:classifies a xa f)
    (form:property-value xa ac xac f)
    (form:priorA fxac xac)
    (form:property-value xa oip o fxac)
    (form:property-value xa vip v fxac))
    (and (if (not (exists (raip)
      (buml:insertAt ac raip)))
      (not (exists (fxac2)
        (and (form:holdsA fxac2 xac)
          (form:property-value o p v fxac))))))
      (forall (raip n s sl sl1)
        (if (and (buml:removeAt ac raip)
          (form:property-value xa raip n fxac)
          (form:property-value-sequence o p s fxac)
          (form:sequence-length s sl)
          (form:add-one sl sl1))
          (exists (fxac2 s2)
            (and (form:holds fxac2 xac)
              (form:property-value-sequence o p s2 fxac2)
              (form:WholeNumber n)
              (form:less-than n sl1)
              (forall (nless v2)
                (if (and (form:WholeNumber nless)
                  (form:less-than nless n)
                  (form:in-position-count s v2
                    (form:in-position-count s2 v2 nless))))
                (forall (nmore v2 nmore1)
                  (if (and (form:WholeNumber nmore)
                    (form:less-than n nmore)
                    (form:less-than nmore sl1)
                    (form:in-position-count s v2 nmore)
                    (form:add-one nmore1 nmore))
                    (form:in-position-count s2 v2
                      nmore1))))))))))
          )
nless))
)

```

10.4.12 Object Actions (Complete)

This subclause specifies necessary conditions on executions of complete object actions as used in the execution model (ReadIsClassifiedObjectAction and StartObjectBehaviorAction).

This assumes the isDirect attribute on the action is false.

```

(forall (ac a ip c op)
  (if (and (buml:ReadIsClassifiedObjectAction ac)
    (form:activity ac a)
    (buml:object ac ip)
    (buml:classifier ac c)
    (buml:result ac op))
    (forall (xa xac f o fxac)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f)
        (form:priorA fxac xac)

```

```

        (form:property-value xa ip o fxac))
    (exists (fxac2)
      (and (form:holdsA fxac2 xac)
        (if (form:classifies c o fxac)
          (form:property-value xa op form:true fxac2))
        (if (not (form:classifies c o fxac))
          (form:property-value xa op form:false fxac2)))))))))

```

This assumes the object input is not a behavior, that no arguments are passed, and the action is not synchronous.

```

(forall (ac a ip)
  (if (and (buml:StartObjectBehaviorAction ac)
    (form:activity ac a)
    (buml:object ac ip))
    (forall (xa xac f o fxac c b)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f)
        (form:priorA fxac xac)
        (form:property-value xa ip o fxac)
        (form:classifies c o fxac)
        (buml:classifierBehavior c b))
        (exists (xb srootxb)
          (and (form:classifies b xb f)
            (form:execution-performer xb o)
            (psl:root_occ srootxb xb)
            (form:subactivity_occurrence-neq srootxb xac))))))

```

10.4.13 Accept Event Action

This subclause specifies necessary conditions on executions of AcceptEventAction. The getNextEvent relation links things and triggers with signal objects in the thing's event pool in a PSL state.

```

(forall (o osig tr f)
  (if (form:getNextEvent o osig tr f)
    (exists (ev sig)
      (and (form:event-pool o osig f)
        (buml:event tr ev)
        (buml:signal ev sig)
        (form:classifies sig osig f))))))
(forall (o osig1 tr osig2 f)
  (if (and (form:getNextEvent o osig1 tr f)
    (form:getNextEvent o osig2 tr f))
    (= osig1 osig2)))

(forall (ac)
  (if (buml:AcceptEventAction ac)
    (buml:type ac form:AcceptEventBehavior)))

(forall (ac a tr op)
  (if (and (buml:AcceptEventAction ac)
    (form:activity ac a)
    (buml:trigger ac tr)
    (buml:result ac op))
    (forall (xa xac f o xlac fxlac)
      (if (and (form:classifies a xa f)
        (form:property-value xa ac xac f)
        (form:execution-performer xac o)
        (psl:leaf_occ xlac xac)

```

```

        (form:priorA fxlac xlac))
(exists (osig)
  (and (form:getNextEvent o osig tr fxlac)
    (exists (fxac2)
      (and (psl:holds fxac2 xac)
        (not (form:event-pool o osig fxac2))
        (form:property-value xa op osig fxac2)))
    (not (exists (xac2 lxac2)
      (and (form:classifies form:AcceptEventBehavior xac2
        (form:execution-performer xac2 o)
        (not (= xac2 xac))
        (psl:leaf_occ lxac2 xac2)
        (psl:leaf_occ lxac2 xac))))))))))
f)

```

Annex A

Java to UML Activity Mapping

The specifications for the methods of operations in the execution model in Clause 8 are written as Java code. However, as discussed in Subclause 8.1, this Java code is to be interpreted as a surface syntax for UML activity model. This annex defines the normative mapping from the Java syntax used in the execution model to UML activity models.

Subclause A.1 defines the correspondence between type names in the Java code and types in UML. The remaining subclauses map Java behavioral code to UML activity models. In each case, the mapping is given in terms of a pattern of Java code and the pattern for the corresponding UML activity model (except for the case of a Java while loop, which is mapped to an equivalent Java do-while loop and, from that, to a UML activity model—see Subclause 10.4.13). The rules for the mapping are also described textually. The textual rules are intended to be used in conjunction with the graphical depiction of the mapping.

This mapping does not cover the entire Java language. Rather, there are specific conventions, noted in the following subclauses, which must be followed in the Java code in order to allow it to be mapped to UML. Further, the result of this mapping is only subset of the full set of possible UML activity models. This subset defines the behavioral modeling capabilities included in the *Base UML* (or “bUML”) subset of fUML that is used to write the fUML execution model. Clause 10 gives the base semantics for the bUML subset.

A.1 Type Names

Table 7 defines the mapping from type names mentioned in the Java code to corresponding UML types.

Note that Java variables typed by a class are always allowed to have the empty value “null”. This is considered to correspond, in UML, to the empty case of no values. Thus, all Java types are mapped to UML multiplicity elements with a lower bound of 0.

Further, types with names of the form “...List” map to UML multiplicity elements with an unlimited upper bound. See Subclause 10.4.13 for more on list types.

Table 7 - Java to UML Type Name Mapping

| Java | UML |
|------------------------------|--|
| Primitive types | |
| int | Integer |
| boolean | Boolean |
| String | String |
| fUML.Syntax.UnlimitedNatural | UnlimitedNatural |
| Classes | |
| <class name> | <class name> [0..1] |
| <package name>.<class name> | <package name>::<class name> [0..1] (Note: “.” separators are replaced by “::” in the package name) |
| Lists | |
| <type name>List | <type name> [*] {ordered, non-unique} |

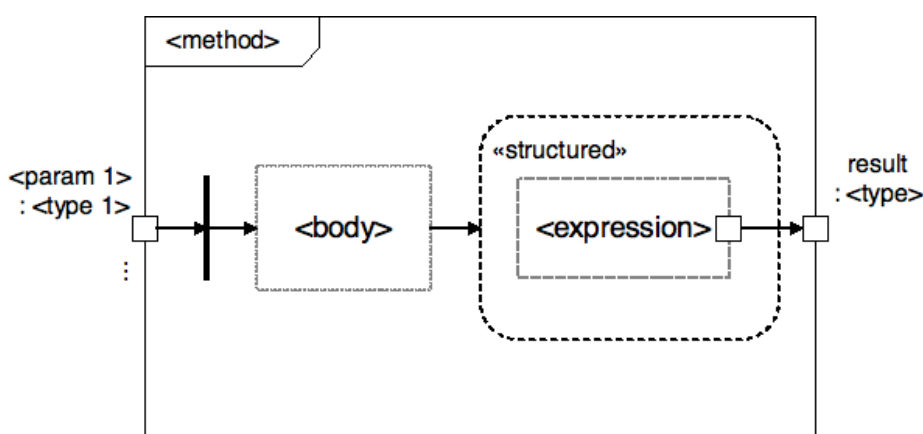
A.2 Method Declaration

Java

```
public <type> <method>
    (<type 1> <param 1>, ...)
{
    <body>
    return <expression>;
}
```

- A method with a non-void type must have a single return statement at the end of its body. A void method may not have any return statements, except that a method with no other statements may have a single “return” statement in its body.

UML



- A method maps to an activity with the corresponding operation as its specification.
- The parameters of the method map to input parameters of the activity, with corresponding activity parameter nodes. The result type of the method, of other than void, maps to a single result parameter of the activity, with a corresponding activity parameter node. If the method has a void type, the activity has no result parameter.
- The body of the method is mapped as a sequence of statements (see Subclause 10.4.13).
- Each input activity parameter node is connected by an object flow to a fork node. A use of a method parameter in the body maps to an object flow from the fork node connected to the corresponding input activity parameter node into the mapping of the body.
- A return statement (with an expression) maps to a structured activity node containing the mapping of the return expression (see Subclause A.4), with a control flow dependency on the mapping of the final statement of the body (unless this is empty). Object flows may flow from within the mapping of the body into the mapping of the expression. An object flow connects the result pin of the expression to the result activity parameter node. (A return statement for an otherwise empty method is not mapped to anything.)

A.3 Statements

The following mappings are for statements and sequences of statements that appear in the bodies of methods and structured statements. Statements often have embedded expressions, which are mapped according to the mappings given in Subclause A.4.

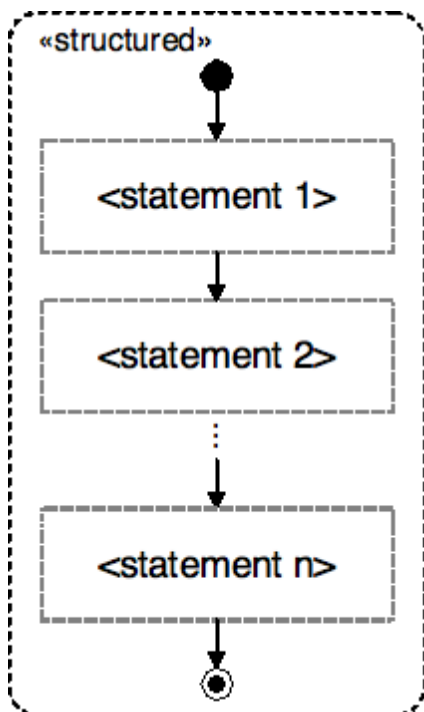
A.3.1 Statement Sequence

Java

```
<statement 1>;  
<statement 2>;  
...  
<statement n>;
```

- Allowable statements include only those with a form that has a mapping defined in the remainder of this subclause.

UML



- The mapping of a sequence of statements consists of a structured activity node that contains the mapping of each statement (as given in the remainder of this subclause).
- The mapping of the first statement in the sequence has an incoming control flow from an initial node. The mapping of each subsequent statement has a control flow from the mapping of the previous statement. The mapping of the last statement has an outgoing control flow to an activity final node. (An empty sequence maps to a structured activity node with an initial node connected directly to a final node.)
- Object flows from within the mapping of one statement may flow into the mapping of a subsequent statement.

Notes

- The actual sources and targets of the control flows within the statement mappings are noted in the mapping for each kind of statement.

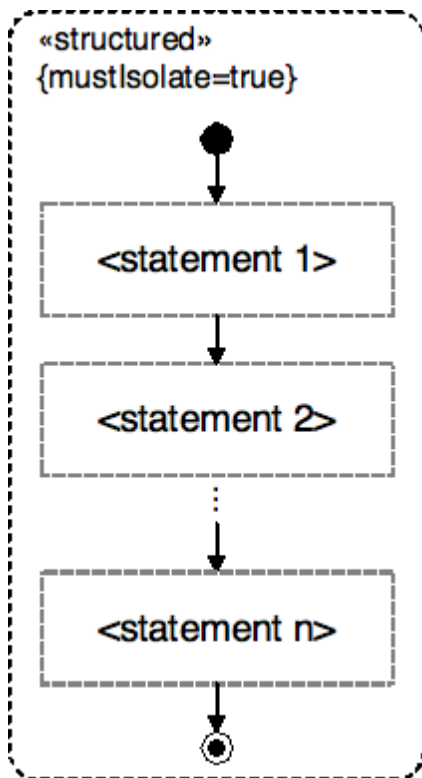
A.3.2 Statement Sequence (isolated)

Java

```
_beginIsolation();  
  <statement 1>;  
  <statement 2>;  
  ...  
  <statement n>;  
_endIsolation();
```

- A set of statements that must run in “isolation” are represented by a sequence of statements, the first statement of which is a call to the “_beginIsolation()” method and the last statement is a call to the “_endIsolation()” method.
- A user class may not define methods called “_beginIsolation” or “_endIsolation”.

UML



- The sequence of statements in the block is mapped in exactly the same way as for a normal sequence of statements (see Subclause 10.4.13), but the enclosing structured activity node has mustIsolate=true.

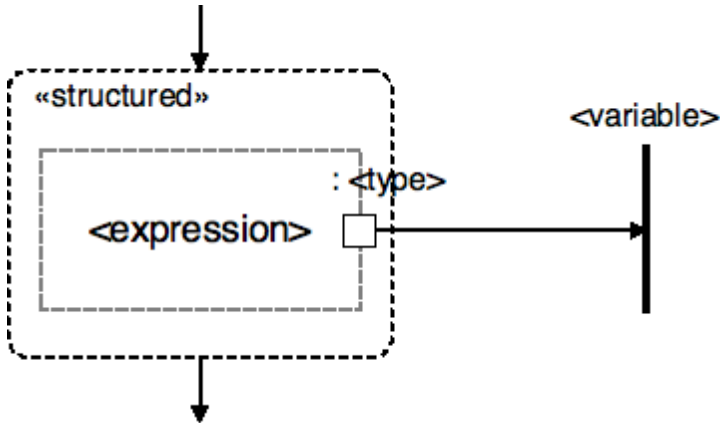
A.3.3 Local Variable Declaration

Java

```
<type> <variable> =  
<expression>;
```

- A local variable declaration is required to have an initialization expression.
- It is not permitted to reassign the value of a local variable, except as specifically allowed in the context of an if statement or loop (see Subclauses 10.4.13 and 10.4.13).

UML



- A local variable declaration maps to fork node that receives an object flow from the result of the mapping of the initialization expression (see Subclause A.4).
- The mapping of the initialization expression is nested inside a structured activity node. Incoming and outgoing control flows (if any) attach to the structured activity node.

Notes

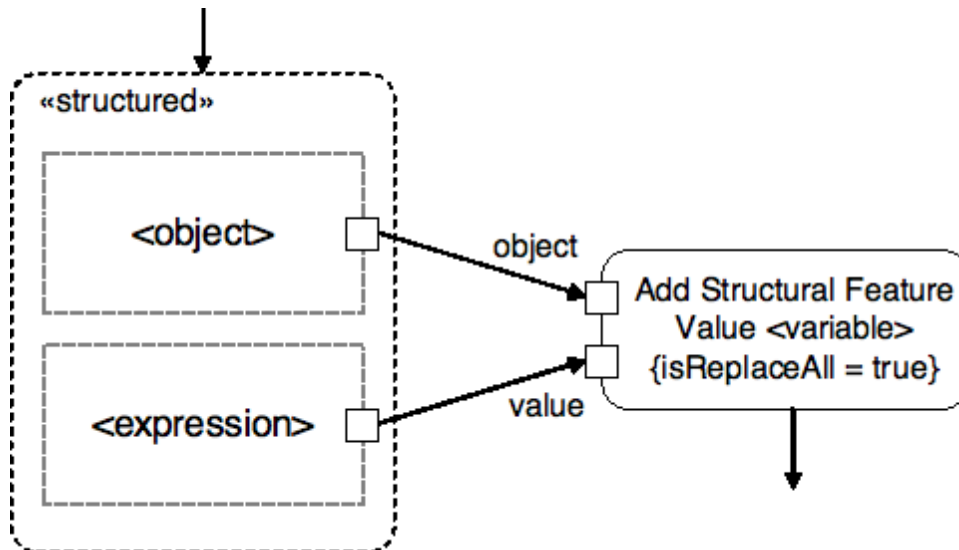
- The use of the fork node models the ability to read the value of a local variable multiple times.
- If the local variable is re-assigned as part of a subsequent if statement or loop, then uses of the variable after that point will be mapped to flows from a different fork node than the one resulting from the mapping of the variable declaration (see Subclauses 10.4.13 and 10.4.13).

A.3.4 Instance Variable Assignment (non-list)

Java

```
<object>.<variable> = <expression>;
```

UML



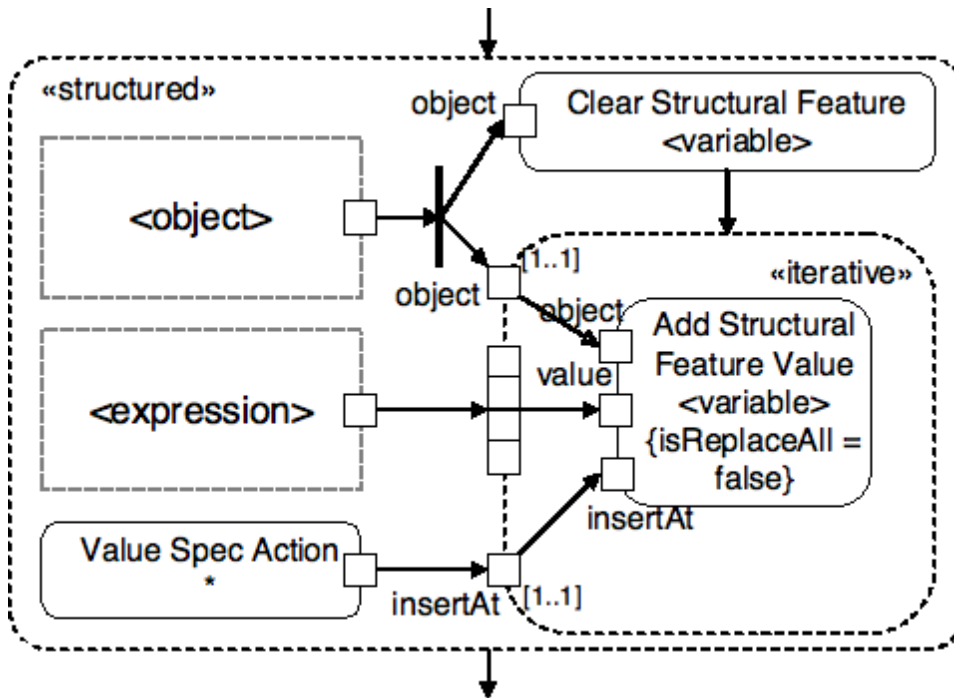
- The assignment of a non-list instance variable maps to an add structural feature value action with `isReplaceAll = true`. (For instance variables of a list type, see 10.4.13.)
- The object and assigned expressions map as given in Subclause A.4. Their mappings are nested in a structured activity node.
- The object input pin of the add structural feature value action is connected by an object flow to the result pin of the mapping of the object expression.
- The value pin of the add structure feature value action is connected by an object flow to the result pin of the mapping of the assigned expression.
- An incoming control flow (if any) attaches to the structured activity node containing the expression mappings. An outgoing control flow (if any) attaches to the add structural feature action.

A.3.5 Instance Variable Assignment (list)

Java

```
<object>.<variable> = <expression>;
```

UML



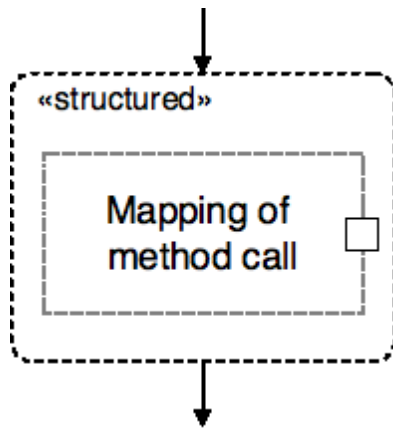
- The assignment of a list instance variable maps to a clear structural feature action followed by an expansion region containing an add structural feature value action with isReplaceAll = false. (For assignment of an instance variable of a non-list type, see Subclause 10.4.13.)
- The object and assigned expressions map as given in Subclause A.4.
- The object input pin of the clear structure feature action and an input pin (multiplicity [1..1]) of the expansion region are connected by object flows to a fork node that is connected by an object flow to the result pin of the mapping of the object expression.
- An input expansion node on the expansion region is connected by an object flow to the result pin of the mapping of the assigned expression.
- An input pin on the expansion region is connected by an object flow to the result ping of a value specification action that produces an unlimited natural * (unbounded) value.
- Inside the expansion region, the object input pin of the add structural feature value action is connection by an object flow to the object input pin of the expansion region, its value pin is connected by an object flow to the expansion node and its insertAt pin is connected by an object flow to the insertAt input pin of the expansion region.
- The expression mappings, clear structural feature action and expansion region are all nested in a structured activity node. Incoming and outgoing control flows (if any) attach to the structured activity node.

A.3.6 Method Call Statement

Java

```
<object>.<method>(<argument 1>, ...);
```

UML



- A statement containing only a method call maps as a method call expression (see Subclause 10.4.13). The result pin of the mapping (if any) has no outgoing object flow.
- The mapping of the method call is nested inside a structured activity node. Incoming and outgoing control flows (if any) attach to the structured activity node.
- A statement containing only a super call maps in a similar manner, but with a super call expression (see Subclause 10.4.13) rather than a method call expression.

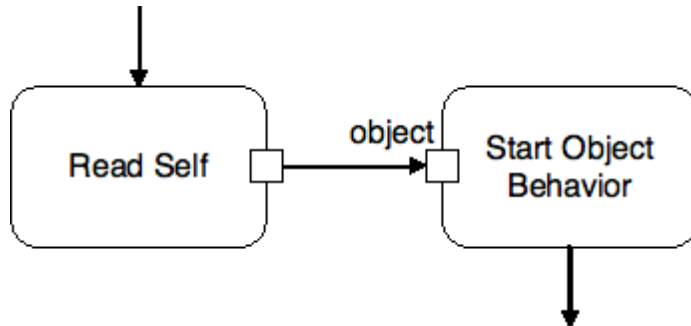
A.3.7 Start Object Behavior

Java

```
_startObjectBehavior();
```

- A class may not define a user operation called “_startObjectBehavior”.
- The _startObjectBehavior method may not be called explicitly on any other object.

UML



- A `_startObjectBehavior` call maps to a start object behavior action.
- The object input pin of the start object behavior action is connected by an object flow to the result pin of a read self action.
- An incoming control flow (if any) attaches to the read self action. An outgoing control flow (if any) attaches to the start object behavior action.

Notes

- An object can have at most one classifier behavior. The `_startObjectBehavior` method starts this in a separate thread and returns immediately.
- This mapping is an exception to the normal “Method Call Statement” mapping of Subclause 10.4.13.

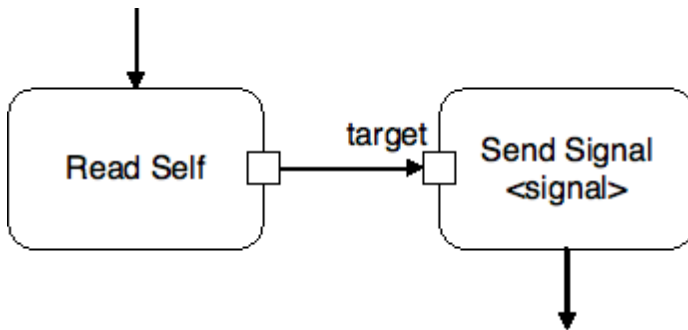
A.3.8 Signal Send

Java

```
_send(new <signal>());
```

- The constructor for a signal may not have any arguments. (Signals with attributes are not allowed.)

UML



- A `_send` method call maps to a send signal action for the constructed signal.
- The target input pin of the send signal operation is connected by an object flow to the result pin of a read self action.
- An incoming control flow (if any) attaches to the read self action. An outgoing control flow (if any) attaches to the send signal action.

Notes

- This is an exception to the normal “Method Call Statement” mapping of Subclause 10.4.13.
- The classifier behavior of the class containing the method making the `_send` call must have an accept event action for the signal.

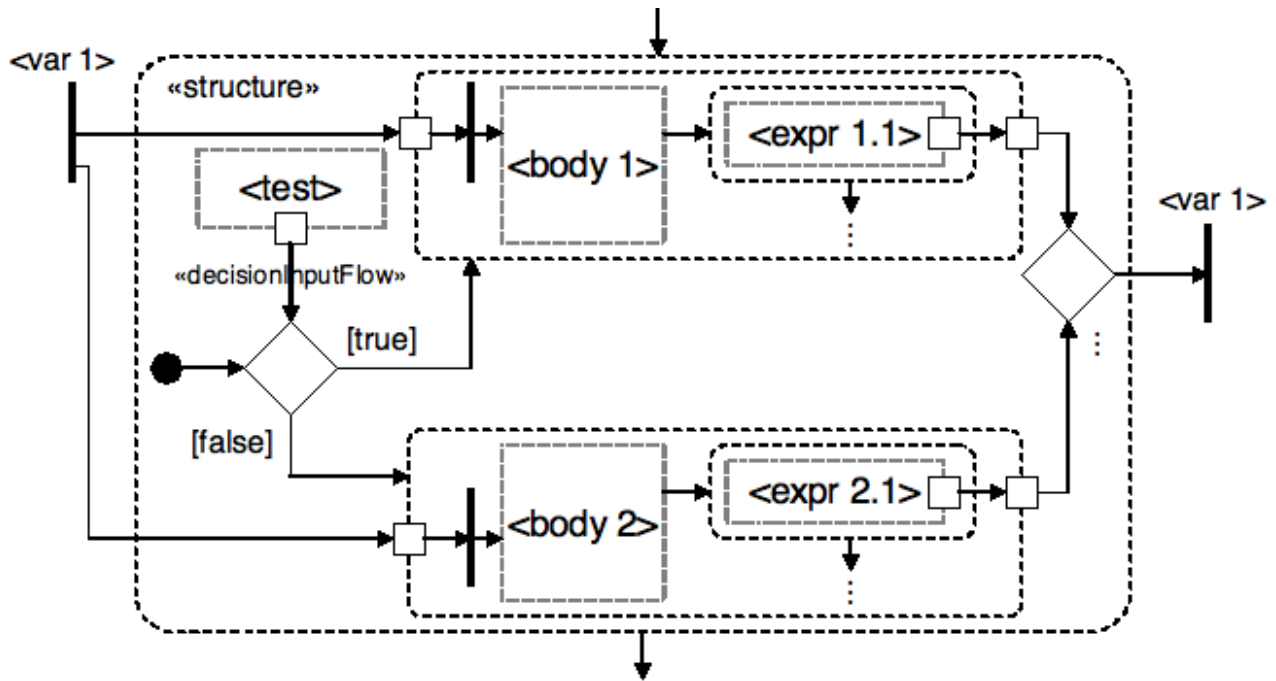
A.3.9 If Statement

Java

```
if (<test>) {  
    <body 1>  
    <var 1> = <expr 1.1>;  
    ...  
} else {  
    <body 2>  
    <var 1> = <expr 2.1>;  
    ...  
}
```

- At the end of the body of each branch of the if statement, there may be assignment statements for local variables declared *outside* the if statement.

UML



- An if statement maps to a decision node with two outgoing control flows, one with the guard “true” and one with the guard “false” and an incoming control flow from an initial node.
- The decision node has a “decision input” data flow from the result pin of the mapping of the test expression (see Subclause A.4).
- Each body maps as a structured activity node containing the mapping of a sequence of statements (see Subclause 10.4.13). The “true” control flow from the decision node connects to the structured activity node for the first body. The “false” control flow similarly connects to the structured activity node for the second (“else”) body.
- The structured activity nodes for each branch have input and output pins corresponding to the variables assigned in *either* branch. Object flows connect the source for each variable to the corresponding input pins and each input pin to a fork node within the structured activity node for the branch. Object flows connect the two output pins

corresponding to a variable (one from each branch) to a merge node, which then has an object flow to a fork node. The fork node acts as the source for all uses of the variable subsequently to the if statement.

- Each variable assignment maps to a structured activity node containing the mapping of the assigned expression. The first structured activity node has a control flow dependency on the mapping of the last statement of the branch body (if any) and each subsequent node has a control flow dependency on the previous node. The result pin of each expression has an object flow to the output pin for the branch corresponding to the variable being assigned. If a variable is not assigned in a branch, then the input pin for the variable is connected by an object flow directly to the output pin, within the structured activity node for the branch. If a variable is used in a subsequent assignment expression, then a fork node must be inserted to fork the object flow out of the expression result to both the branch output pin and any subsequent variable use(s).
- The input pins of a structured activity node for a branch act as the source for all uses of the corresponding variables within the branch. For any other variable uses, object flows may flow directly into the mappings of the parts of the if statement. Object flows from within the mapping of the body may flow into the mappings of the expressions.
- If the if statement has no else branch, but there are variable assignments in the “true” branch, then there is still a structured activity node for the “false” branch, with all input pins connected to output pins. If there is no else branch and no variable assignments, then the “false” branch structured activity node may be replaced by an activity final node.
- Incoming and outgoing control flows (if any) attach to the outermost structured activity node.

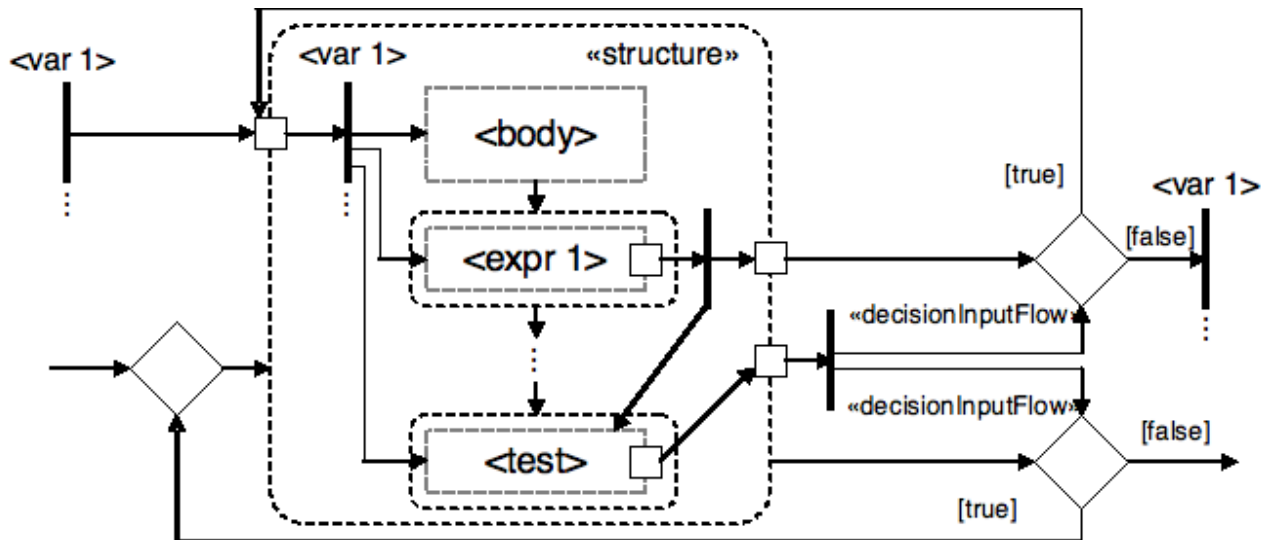
A.3.10 Do-While Loop

Java

```
do {  
    <body>  
    <var 1> = <expr 1>;  
    ...  
} while (<test>)
```

- A do-while loop may contain variable assignments at the end of its body for local variables declared *outside* the loop.

UML



- A do-while loop maps to a structured activity node with a looping control structure outside it, as shown above. An incoming control flow comes into the merge node shown on the left, and the outgoing control flow is the “false” flow out of the decision node shown on the bottom right.
- The body of the do-while loop maps as a sequence of statements (see Subclause 10.4.13).
- *Every* variable referenced in the body of the while loop (whether it is assigned or not) has corresponding input and output pins on the structured activity node for the loop. The input pin for the variable is connected by an object flow to the mapping for the variable from before the loop. Inside the structured activity node for the loop, each loop variable input pin is connected by an object flow to a fork node. This fork node is used as the source for the mapping of all uses of the variable within the loop (unless, possibly, if the variable is re-assigned within the loop – see below).
- Each variable assignment maps to a structured activity node containing the mapping of the assigned expression. The first structured activity node has a control flow dependency on the mapping of the loop body and each subsequent node has a control flow dependency on the previous node. The result pin of each expression is connected by an object flow to a fork node which then has an object node to the output pin of the outer structured activity node corresponding to the variable being assigned. (If there is no assignment for a variable within the loop, then there is an object flow that connects directly from the fork node for the variable within the loop’s structured activity node to the output pin for the variable.)

- The test expression maps to a structured activity node containing the mapping of the expression. There is a control flow from the structured activity node for the mapping of the last variable assignment expression to the structured activity node for the test expression. (If there are no variable assignments, the control flow comes from the mapping of the body.) The result pin of the test expression is connected by an object flow to an output pin of the outer structured activity node for the loop.
- If an assignment or test expression uses a variable previously assigned, then that use maps to an object flow from the fork node attached to the result pin of the assignment expression, rather than the fork node attached to the loop input pin.
- The test result output pin of the structured activity node for the loop is connected to a fork node outside the structured activity node, which is then connected by an object flow to the decision input flow of the loop control decision node. The output pin for each loop variable is connected by an object flow to a decision node. The decision input flow for the decision node is an object flow from the test result fork node. The “true” outgoing flow from the decision node connects back to the corresponding input pin and the false flow connects to a fork node, which is used as the source of the variable for all mappings of expressions after the while loop.

A.3.11 While Loop

Java

```
while (<test>) {
    <body>
    <var 1> = <expr 1>;
    ...
}
```

- A while loop may contain variable assignments at the end of its body for local variables declared *outside* the loop.

Equivalent Java

```
if (<test>) {
    do {
        <body>
        <var 1> = <expr 1>;
        ...
    } while (<test>)
}
```

- A while loop maps as if it was coded as a do-while loop (see Subclause 10.4.13) nested in an if statement (see Subclause 10.4.13), as shown above.

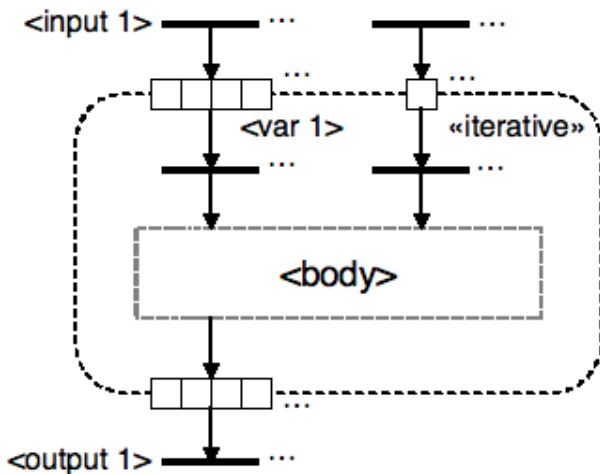
A.3.1 For Loop (iterative)

Java

```
<output type 1> <output 1> = new <output type 1>();  
...  
for (int <index> = 0;  
     <index> < <input 1>.size(); i++) {  
    <type 1> <var 1> = <input 1>.getValue(<index>);  
    ...  
    <body>  
}
```

- An iterative for loop must have a locally declared index variable of type “int” that is sequentially incremented (see also Subclause 10.4.13).
- The body of the for loop must begin with one or more loop variable declarations, each initialized by an access to a different list variable with the loop index variable. The list variables must be declared outside the loop and all have list types (see Subclause 10.4.13). The loop index variable may not otherwise be used in the body of the loop.
- The for loop must be indexed based on the size of the first list variable, as shown above.
- The for loop must *not* have any assignment statements at the end of its body.
- The body of the for loop may include nested statements of the form “<output n>.addValue(...)”, where “<output n>” is a variable of a list type declared outside the loop and initialized to an *empty* list of the appropriate type.

UML



- A for loop with the structure given above is mapped to an iterative expansion region.
- The local loop variables map to input expansion nodes on the expansion region. The expansion node for the variable is connected outside the expansion region by an object flow to the mapping for the corresponding list variable from before the loop. It is connected inside the expansion region to a fork node. A reference to a loop variable within the loop body maps to an object flow from the fork node connected to the corresponding expansion node.
- For any variable declared outside the loop and referenced within the body of the loop, other than the local loop variables as defined above, there is a corresponding input pin on the expansion region. The input pin is connected

outside the expansion region by an object flow to the fork node corresponding to the variable. The input pin is connected inside the expansion region to a fork node, which is then used as the source for references to the variable within the mapping of the body of the loop.

- The body of the loop maps as a sequence of statements (see Subclause 10.4.13) nested in the expansion region.
- If there are any “addValue” statements within the body of the loop, then there is an output expansion node for each referenced output list variable. Each “addValue” statement maps to an object flow from the result of the argument expression of the “addValue” call to the appropriate output expansion node. Each output expansion node is connected by an object flow to a fork node that is used as the source for references to the corresponding output list variable in any subsequent statements.

Notes

- The mapping for the element variables is an exception to the normal rules for list indexing (see Subclause 10.4.13) and for variable use (see Subclause 10.4.13).

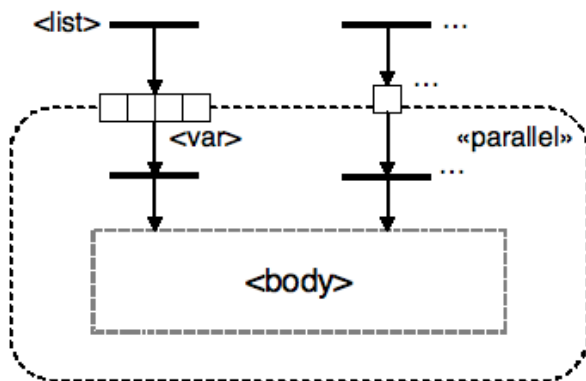
A.3.2 For Loop (parallel)

Java

```
for (Iterator <iter> = <list>.iterator();
     <iter>.hasNext();) {
  <type> <var> = (<type>)<list>.next();
  ...
  <body>
}
```

- A parallel for loop must be indexed by an iterator based on a list variable (see Subclause 10.4.13). The list variable must be declared outside the loop and have a list type (see Subclause 10.4.13).
- The body of the for loop must begin with exactly one variable declaration, initialized by an access to the loop iterator.
- The for loop must *not* have any assignment statements at the end of its body.
- The behavior of the body must not depend on the specific order in which list items are returned.

UML



- A for loop with the structure given above is mapped to a parallel expansion region.
- The local loop variable maps to a single input expansion node on the expansion region. (There are no output expansion nodes.) The expansion node for the variable is connected outside the expansion region by an object flow to the mapping for the corresponding list variable from before the loop. It is connected inside the expansion region to a fork node. A reference to a loop variable within the loop body maps to an object flow from the fork node connected to the corresponding expansion node.
- For any variable declared outside the loop and referenced within the body of the loop, other than the local loop variables as defined above, there is a corresponding input pin on the expansion region. The input pin is connected outside the expansion region by an object flow to the fork node corresponding to the variable. The input pin is connected inside the expansion region to a fork node, which is then used as the source for references to the variable within the mapping of the body of the loop.
- The body of the loop maps as a sequence of statements (see Subclause 10.4.13).

Notes

- The Java code will execute the body iterations in a specific sequential order, but the behavior of the Java is not allowed to depend on what that order actually is.
- The mapping for the element variables is an exception to the normal rules for list indexing (see Subclause 10.4.13) and for variable use (see Subclause 10.4.13).

A.4 Expressions

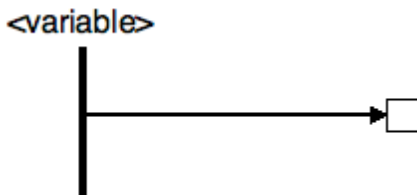
The following mappings are for expressions that are embedded within statements. Each expression maps to a fragment of an activity model that has a distinguished “result pin” (with the exception of the mapping of Subclause 10.4.13, “Local Variable or Method Parameter Use”). It is this result pin to which an object flow may be connected to obtain the output of the expression.

A.4.1 Local Variable or Method Parameter Use

Java

```
<variable>
```

UML



- The use of a local variable or method parameter in an expression maps to an object flow from the fork node corresponding to the variable or parameter to an input pin of the mapping of the remainder of the enclosing expression.

Notes

- The fork node may result from the mapping of a method parameter, directly from the mapping of the declaration of the variable (see Subclause 10.4.13), from the mapping of the output of an if statement or a loop (see Subclauses 10.4.13 and 10.4.13) or from the mapping of the loop variable of a fork node.

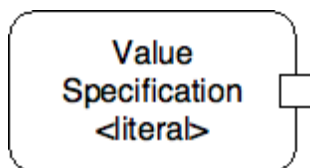
A.4.2 Literal

Java

```
<literal>
```

- The literal must be an integer, a boolean, a string or an UnlimitedNatural.
- An UnlimitedNatural literal is created using a constructor expression of the form “new fUML.Syntax.UnlimitedNatural(n)”, where n is a non-negative integer or -1 (used to represent “*”).
- The integer value of an UnlimitedNatural value “x” is obtained by an expression of the form “x.value.”

UML



- A literal is mapped to a value specification action with a corresponding literal value. The result output pin of the value specification action becomes the result pin of the mapping.

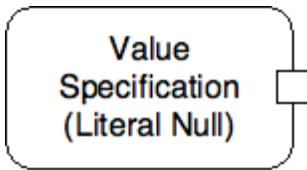
A.4.3 Null

Java

```
null
```

- A null value may not be used for a list type.

UML



- A null value maps to a value specification action for a literal null. The result output pin of the value specification action becomes the result pin of the mapping.

Notes

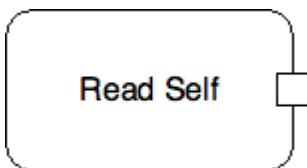
- All class types in Java allow “null” values. Such types map to types with “optional” multiplicity [0..1] in UML (see Subclause A.1). Java “null” is used to represent the case of “no value” (0 cardinality) allowed by this multiplicity. A value specification for a literal null places no values on its output pin when it executes, corresponding to the 0 cardinality case.
- Since a Java “null” maps to “no value” in UML, testing for a null value requires a special mapping (see Subclause 10.4.13).
- For the mapping of an empty list, see Subclause 10.4.13.

A.4.4 This

Java

```
this
```

UML



- A use of “this” maps to a read self action whose result pin is the result pin for the expression mapping.

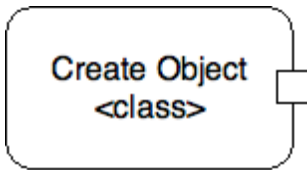
A.4.5 Constructor Call

Java

```
new <class>()
```

- Constructor calls are not allowed to have arguments.

UML



- A constructor call maps to a create object action for the named class. The result output pin of the create object action becomes the result pin for the mapping.

Notes

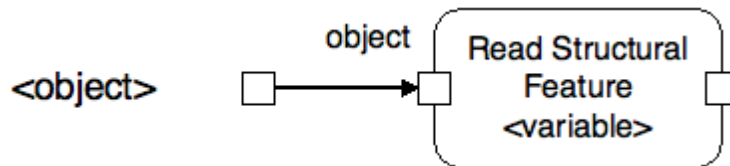
- This mapping does not apply to the case of the class being a list type (see Subclause 10.4.13 for the construction of an empty list).
- This mapping does not apply to the case of creating an UnlimitedNatural value (see Subclause 10.4.13).

A.4.6 Instance Variable Use

Java

```
<object>.<variable>
```

UML



- The use of an instance variable within an expression maps to a read structural feature action for the attribute corresponding to the instance variable. The result output pin of the read structural feature action becomes the result pin for the mapping.
- The object input pin of the read structural feature action is connected by an object flow to the result pin of the mapping of the expression evaluating to the target object.

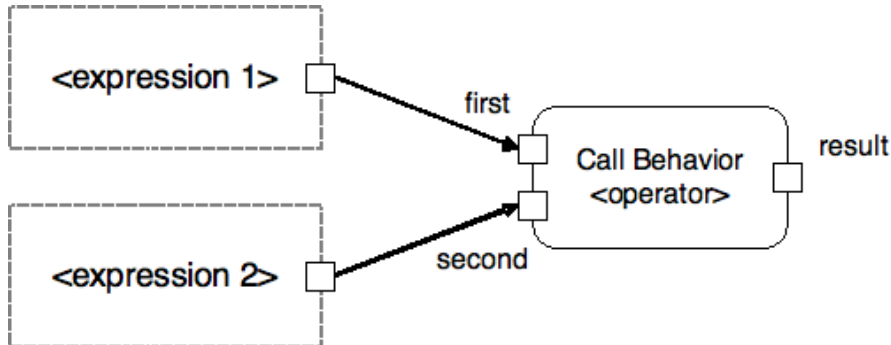
A.4.7 Operator Expression

Java

```
<expression 1> <operator> <expression 2>
```

- The operator must be an integer arithmetic operator or a boolean relational operator other than equals or not equals (for testing equality, see Subclauses 10.4.13 and 10.4.13).

UML



- An infix operator expression maps to a call behavior action for the primitive behavior corresponding to the operator (chosen from the Foundational Model Library, see Subclause 9.2). The result output pin of the call behavior action becomes the result pin of the mapping.
- The first argument input pin of the call behavior action is connected by an object flow to the result pin of the mapping of the left sub-expression. The second argument input pin of the call behavior action is connected by an object flow to the result pin of the mapping of the right sub-expression.
- A prefix operator is mapped similarly, except that there is only one sub-expression and only one argument input pin to the call behavior action.

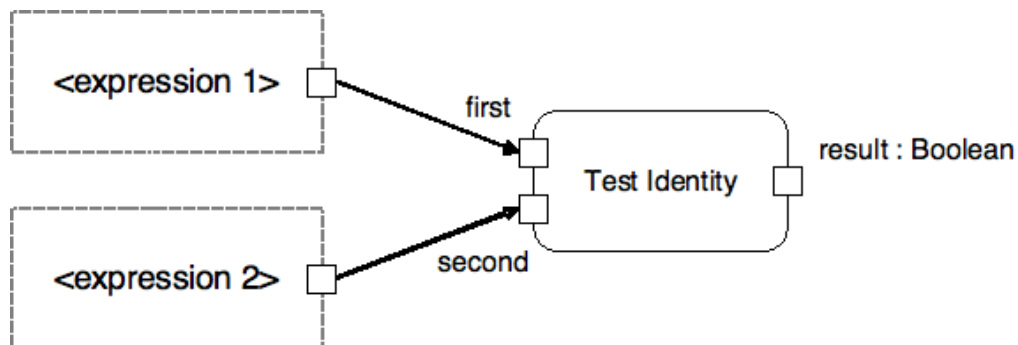
A.4.8 Testing For Equality

Java

```
<expression 1> == <expression 2>
```

- Neither expression may evaluate to null (for testing for null, see Subclause 10.4.13).
- For UnlimitedNatural values, their integer values must be compared, not the object themselves (see also Subclause 10.4.13).
- The expressions may not be of type String (for testing string equality, see Subclause 10.4.13).
- The expressions may not have list types (for more on lists, see Subclause 10.4.13).

UML



- An equality test maps to a test identity action. The result output pin of the test identity action becomes the result pin of the mapping.
- The first argument input pin of the test identity action is connected by an object flow to the result pin of the mapping of the left sub-expression. The second argument input pin of the test identity action is connected by an object flow to the result pin of the mapping of the right sub-expression.
- The expression “<expression 1> != <expression 2>” is mapped as if it was “!(<expression 1> == <expression 2>)”.

Notes

- For primitive values, the test identity action tests for equality of value. For object references, it tests the identity of the referent objects.

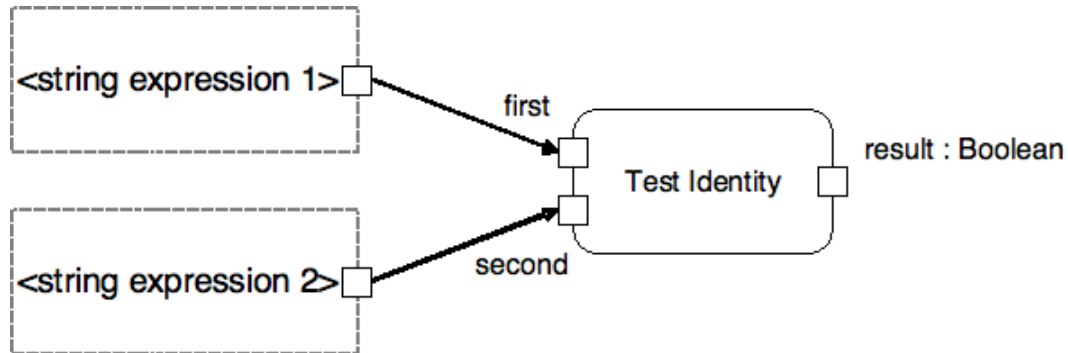
A.4.9 Testing String Equality

Java

```
<string expression 1>.equals(<string expression 2>)
```

- Strings are never tested for equality using “==”.

UML



- A string equality test maps to a test identity action. The result output pin of the test identity action becomes the result pin of the mapping.
- The first argument input pin of the test identity action is connected by an object flow to the result pin of the mapping of the left sub-expression. The second argument input pin of the test identity action is connected by an object flow to the result pin of the mapping of the right sub-expression.

Notes

- In Java String is a class, and testing string values using “==” tests the identity of the string objects being tested, not equality of their values. In UML String is a primitive type, and the test identity action tests for equality of value for strings.

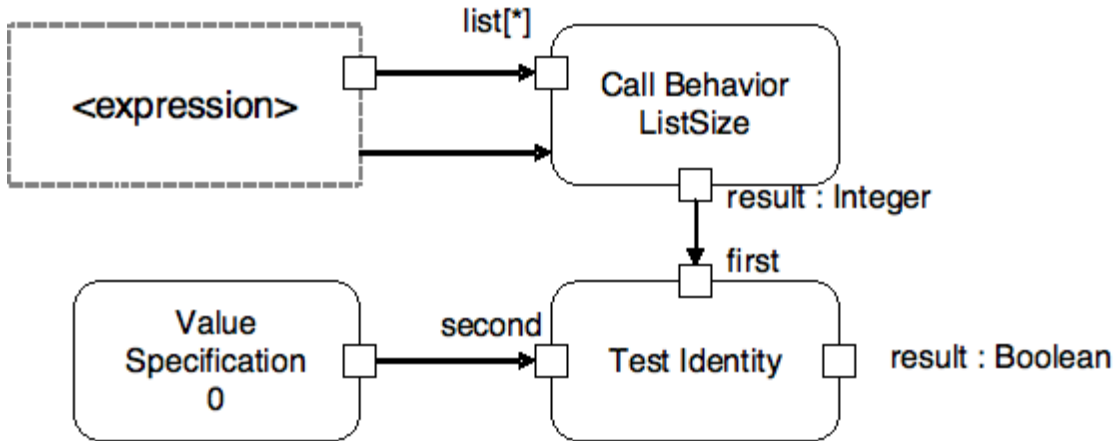
A.4.10 Testing For Null

Java

```
<expression> == null
```

- The expression being tested may not have a list type (see Subclause A.5).

UML



- A test for null is mapped to a test for whether the result of the mapping of the expression has a list size of zero.
- The result pin of the mapping of the expression is connected by an object flow to the argument pin of a call behavior action for the ListSize behavior (with multiplicity *).
- The call behavior action has a control flow from the action owning the result pin of the mapping of the list expression.
- The result output pin of the call behavior action is connected by an object flow to the first argument pin of a test identity action. The second argument pin of the test identity action is connected by an object flow to the result pin of a value specification action for the integer value “0”. The result output pin of the test identity action becomes the result pin for the mapping.
- The expression “`<expression> != null`” is mapped as if it was “`!(<expression> == null)`”.

Notes

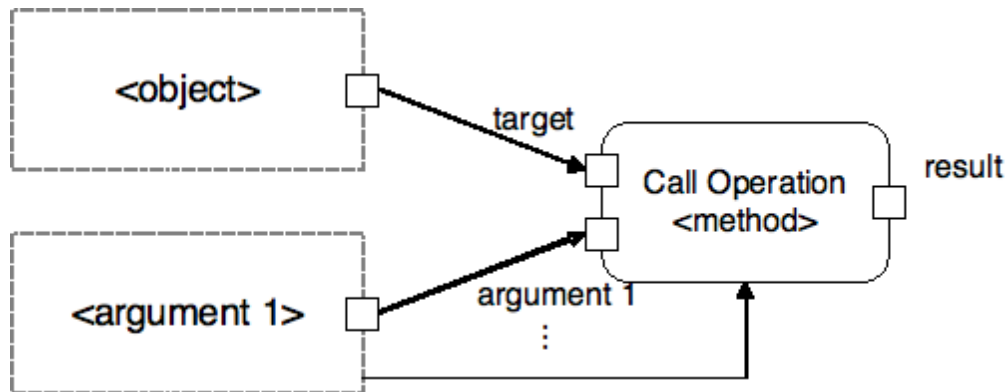
- Java null is used to represent the case of “no value” for a class type with multiplicity [0..1] (see Subclause A.4.3).
- The ListSize behavior is provided in the Foundational Model Library (see Subclause 9.2; see also Subclause 10.4.13).
- Since the input pin to the call behavior action has a multiplicity lower bound of 0, the control flow is necessary to ensure that the call does not happen before the completion of execution of the mapping of the list expression.

A.4.11 Method Call

Java

```
<object>.<method>(<argument 1>,...)
```

UML



- A method call maps to a call operation action for the operation corresponding to the named method. The result output pin of the call operation action becomes the result pin of mapping. (If the method has a void return type, then there is no result pin.)
- The target input pin of the call operation action is connected by an object flow to the result pin of the mapping of the object expression.
- Each argument input pin (if any) of the call operation action is connected by an object flow to the result pin of the mapping of the corresponding argument expression (in order).
- Unless an argument is of a primitive type, the call operation action has a control flow from the action that owns the result pin of the mapping of the argument expression.

Notes

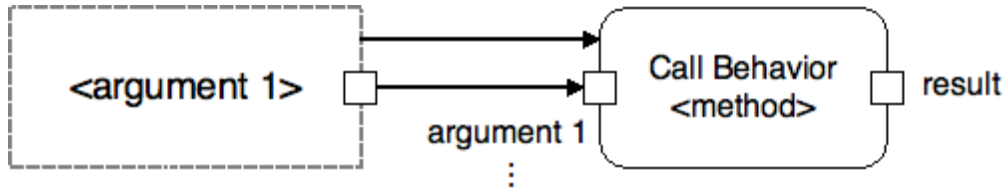
- Since all non-primitive types map to UML types with multiplicity [0..1] or [*] (see Subclause 10.4.13), the control flows are necessary to ensure that the call operation action does not start executing before the arguments are computed.

A.4.12 Super Call

Java

```
super.<method>(<argument 1>, ...)
```

UML



- A super call maps to a call behavior action for the UML method (the *behavior*, not the operation) that implements the UML operation corresponding to the Java method in the superclass. The result output pin of the call behavior action becomes the result pin of mapping. (If the method has a void return type, then there is no result pin.)
- Each argument input pin (if any) of the call behavior action is connected by an object flow to the result pin of the mapping of the corresponding argument expression (in order).
- Unless an argument is of a primitive type, the call operation action has a control flow from the action that owns the result pin of the mapping of the argument expression.

Notes

- Since all non-primitive types map to UML types with multiplicity [0..1] or [*] (see Subclause 10.4.13), the control flows are necessary to ensure that the call operation action does not start executing before the arguments are computed.
- This is different than the normal mapping of a method call (see Subclause 10.4.13), but it is not really an exception, since “super” is not actually a proper expression in Java.

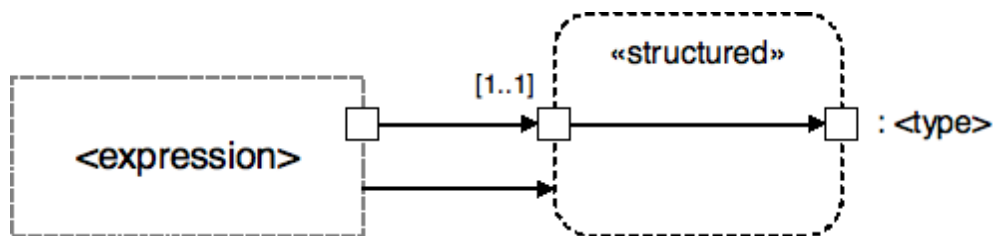
A.4.13 Type Cast

Java

```
(<type> <expression>
```

- The expression being cast cannot be of a primitive type.
- The expression being cast cannot be a list.

UML



- A type cast is mapped to a structured activity node that simply copies its input to its output. The input pin of the node is un-typed. The output pin of the node is given the result type of the cast, and it becomes the result pin of the mapping.
- The input pin of the structured activity node is connected by an object flow to the result pin of the mapping of the expression being cast.
- The action that owns the result pin of the mapping of the expression is connected by a control flow to the structured activity node.

Note

- This mapping presumes that the cast is legal. Its behavior is not defined if the result of the expression cannot be cast to the given type.

A.5 Lists

Classes with names of the form <base type>List are used to represent lists of values of the type <base type>. List classes are mapped to UML multiplicity elements of the form <base type>[*]{ordered, non-unique} (see Subclause 10.4.13). Lists of lists are not allowed.

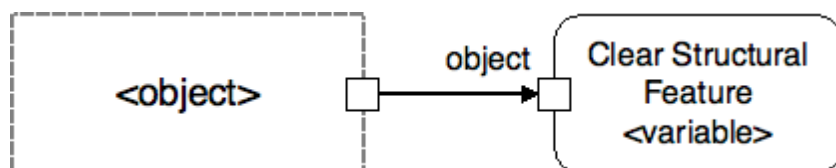
Calls to methods on list classes have special mappings. Calls to the clear, addValue and removeValue methods map as statements. These methods can only be used on instance variables. A list constructor and calls to the size and get methods map as expressions.

A.5.1 List Clear

Java

```
<object>.<variable>.clear();
```

UML



- A call to the list clear method maps to a clear structural feature action on the attribute corresponding to the list variable.
- The object input pin of the clear structural feature action has an object flow connection to the result pin of the mapping of the object expression.

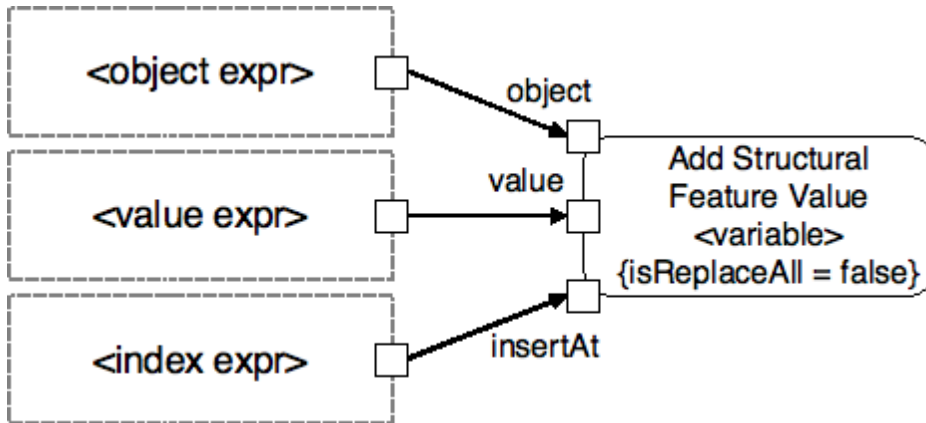
A.5.2 List Add

Java

```
<object expr>.<variable>.addValue(<index expr> - 1, <value expr>)
```

- The value expression must not evaluation to null.

UML



- A call to the list add method maps to an add structural feature value action with `isReplaceAll = false`.
- The object input pin of the add structural feature value action is connected to the result pin of the mapping of the object expression.
- The value input pin of the add structural feature value action is connected to the result pin of the mapping of the value expression.
- The insertAt input pin of the add structural feature value is connected to the result pin of the mapping of the index expression. If the call does not include an index expression, then the insertAt pin is connected to the result output pin of a value specification action for the UnlimitedNatural value “*”.

Note

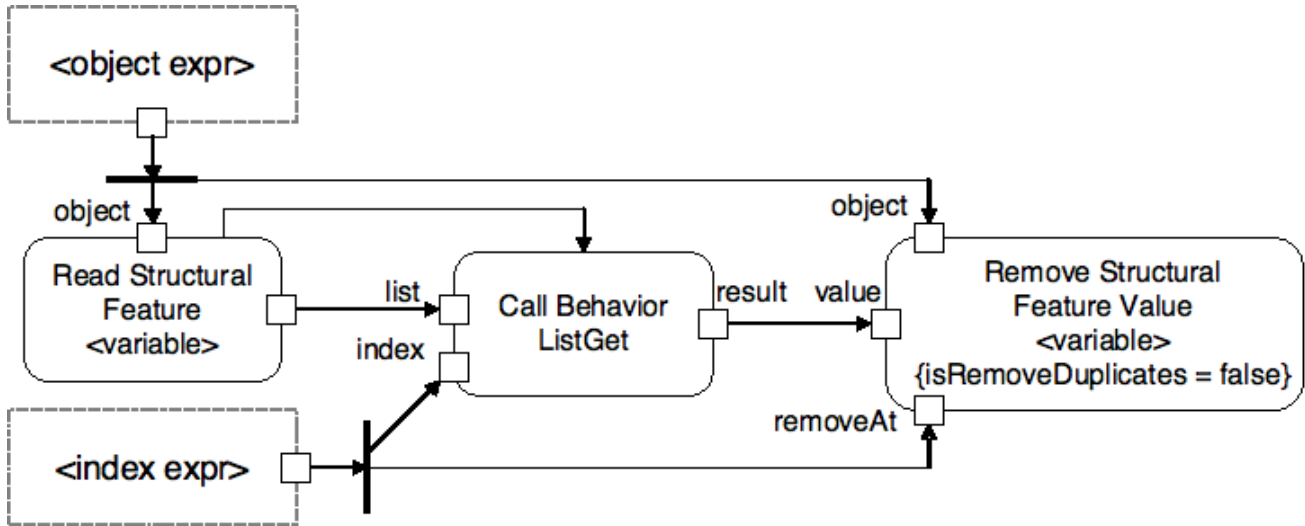
- The Java method indexes from 0, but the add structural feature action indexes from 1.
- Adding a single value to an empty list is an exception to this mapping (see Subclause 10.4.13 below).

A.5.3 List Remove

Java

```
<object expr>.<variable>.removeValue(<index expr> - 1)
```

UML



- A call to the list add method maps to a remove structural feature value action with `isRemoveDuplicates = false`.
- The result pin of the mapping of the object expression is connected by an object flow to a fork node, which, in turn, is connected to the object input pin of the remove structural feature value action and the object input pin of a read structural feature action.
- The result output pin of the read structural feature action is connected to the list input pin of a call behavior action calling the ListGet behavior (see Subclause 10.4.13). There is also a control flow from the read structural feature action to the call behavior action.
- The result pin of the mapping of the index expression is connected by an object flow to a fork node, which, in turn, is connected to the index input pin of the call behavior action and the removeAt pin of the remove structural feature value action.
- The result output pin of the call behavior action is connected by an object flow to the value input pin of the remove structural feature value action.

Note

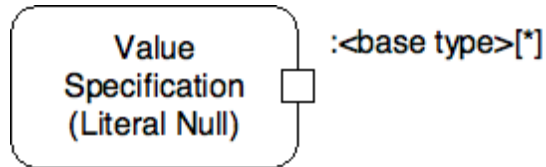
- The Java method indexes from 0, but the remove structural feature action indexes from 1.

A.5.4 Empty List

Java

```
new <base type>List();
```

UML



- A constructor expression for a list type maps to a value specification action for a literal null.

Notes

- A value specification for a literal null places no values on its output pin when it executes, corresponding to the 0 cardinality case of the multiplicity [*].
- This is an exception to the normal rule for mapping “addValue” calls (see Subclause 10.4.13).

A.5.5 List of One Element

Java

```
<base type>List <var> = new <base type>List();  
<var>.addValue(<expression>);
```

UML



- A list variable initialized by an empty list, immediately followed by adding a single value to that list, maps to the mapping for the expression that is the argument to the “addValue”, but with the output pin given multiplicity [*].

Notes

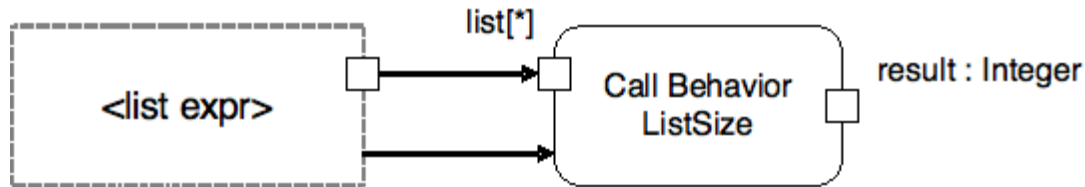
- Since in UML a single element (cardinality 1) conforms to the multiplicity “*”, it is not necessary to use an explicit add structural feature value in this case to create the effective mapping of a “list of one element”.
- This is an exception to the normal rule for mapping constructor calls (see Subclause 10.4.13).

A.5.6 List Size

Java

```
<list expr>.size()
```

UML



- A call to the list size method maps to a call behavior action for the ListSize behavior. The result output pin becomes the result pin for the mapping.
- The argument input pin of the call behavior action (with multiplicity *) is connected by an object flow to the result pin of the mapping of the list expression.
- The call behavior action has a control flow from the action owning the result pin of the mapping of the list expression.

Notes

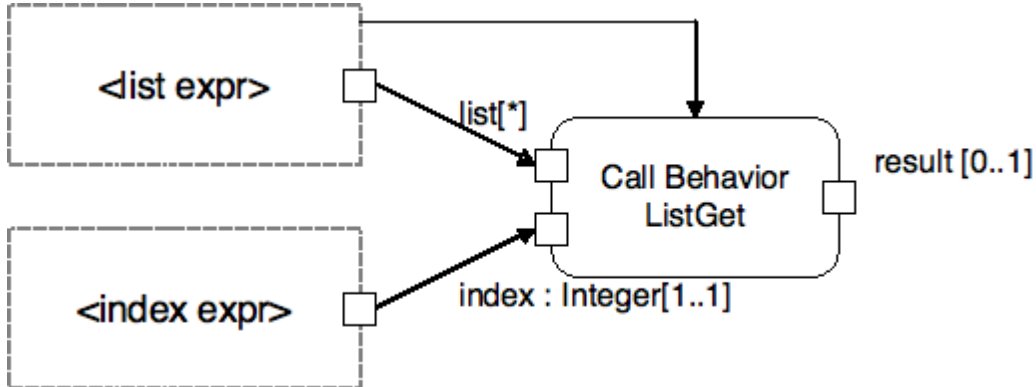
- The ListSize behavior is provided as part of the Foundational Model Library (see Subclause 9.2). (It can also be defined as an activity, so it does not have to be primitive.)
- Since the input pin to the call behavior action has a multiplicity lower bound of 0, the control flow is necessary to ensure that the call does not happen before the completion of execution of the mapping of the list expression.

A.5.7 List Indexing

Java

```
<list expr>.getValue(<index expr> - 1)
```

UML



- A call to the list get operation maps to a call behavior action for the ListGet behavior. The result output pin of the call behavior action becomes the result pin of the mapping.
- The list argument input pin of the call behavior action is connected to the result pin for the mapping of the list expression.
- The index argument input pin of the call behavior action is connected by an object flow to the result pin for the mapping of the index expression.
- The call behavior action has a control flow from the action that owns the result pin of the mapping of the list expression.

Notes

- The ListGet behavior is provided as part of the Foundational Model Library (see Subclause 9.2). (It can be defined as an activity and so does not have to be primitive.)
- Since the input pin to the call behavior action has a multiplicity lower bound of 0, the control flow is necessary to ensure that the call does not happen before the completion of execution of the mapping of the list expression.
- The Java method indexes from 0, but the ListGet behavior indexes from 1. If the input index value is less than 1 or greater than the size of the input list, no result is generated.