



BSI Standards Publication

Industrial automation systems and integration — Process specification language

Part 42: Definitional extension: Temporal and state extensions

National foreword

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Industrial automation systems and integration — Process specification language —

Part 42: Temporal and state extensions

*Systèmes d'automatisation industrielle et intégration — Langage de
spécification de procédé —*

Partie 42: Extension de définition: Extensions temporelle et d'état



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ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
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Foreword

The International Organisation for Standardisation (ISO) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organisations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

This part of [ISO 18629](#) was prepared by the Technical committee ISO/TC 184 *Industrial automation systems and integration*, Subcommittee SC4, *Industrial data*.

A complete list of parts of [ISO 18629](#) is available from the Internet:

<http://www.tc184-sc4.org/titles/>

Introduction

[ISO 18629](#) is an International Standard for the computer-interpretable exchange of information related to manufacturing processes. Taken together, all the parts contained in the [ISO 18629](#) Standard provide a generic language for describing a manufacturing process throughout the entire production process within the same industrial company or across several industrial sectors or companies, independently from any particular representation model. The nature of this language makes it suitable for sharing process specifications and properties related to manufacturing during all the stages of a production process.

This part of [ISO 18629](#) provides a description of the definitional extensions of the language related to activity extensions defined within [ISO 18629](#).

All parts of [ISO 18629](#) are independent of any specific process representation model used in a given application. Collectively, they provide a structural framework for improving the interoperability of these applications.

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Industrial automation systems and integration — Process specification language —

Part 42:

Definitional extension: Temporal and state extensions

1 Scope

This part of [ISO 18629](#) provides a specification of non-primitive concepts of the language, using a set of definitions written in the language of [ISO 18629](#). These definitions provide axioms for terminology in this part of [ISO 18629](#).

The following is within the scope of this part of [ISO 18629](#):

- definitions of state and time-related concepts specified using concepts of [ISO 18629-11](#) and [ISO 18629-12](#);
- constraints on the occurrences of activities that are expressed using time relations from [ISO 18629-11](#) and state relations from [ISO 18629-12](#).

The following is outside the scope of this part of [ISO 18629](#):

- definitions of concepts specified using concepts of [ISO 18629-11](#) and [ISO 18629-12](#) that are independent of state and time relations.

NOTE: state and time-related concepts are concepts that are related to the time and the status of any entity related to manufacturing process and needed to specify it.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[ISO/IEC 8824-1](#), *Information technology — Abstract Syntax Notation One (ASN.1) — Part 1: Specification of basic notation*

[ISO 10303-1](#), *Industrial automation systems and integration — Product data representation and exchange — Part 1: Overview and fundamental principles*

[ISO 15531-1](#), *Industrial automation systems and integration — Industrial manufacturing management data — Part 1: General overview*

ISO 18629-1: 2004, *Industrial automation systems and integration — Process specification language — Part 1: Overview and basic principles*

ISO 18629-11: 2005, *Industrial automation systems and integration — Process specification language — Part 11: PSL core*

[ISO 18629-12](#), *Industrial automation systems and integration — Process specification language — Part 12: Outer core*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply:

3.1.1

axiom

well-formed formula in a formal language that provides constraints on the interpretation of symbols in the lexicon of a language

[SOURCE: ISO 18629-1]

3.1.2

defined lexicon

set of symbols in the non-logical lexicon which denote defined concepts

Note 1 to entry: Defined lexicon is divided into constant, function and relation symbols.

EXAMPLE terms with conservative definitions.

[SOURCE: ISO 18629-1]

3.1.3

definitional extension

extension of PSL-Core that introduces new linguistic items which can be completely defined in terms of the PSL-Core

Note 1 to entry: Definitional extensions add no new expressive power to PSL-Core but are used to specify the semantics and terminology in the domain application.

[SOURCE: ISO 18629-1]

3.1.4

extension

augmentation of PSL-Core containing additional axioms

Note 1 to entry: The PSL-Core is a relatively simple set of axioms that is adequate for expressing a wide range of basic processes. However, more complex processes require expressive resources that exceed those of the PSL-Core. Rather than clutter the PSL-Core itself with every conceivable concept that might prove useful in describing one process or another, a variety of separate, modular extensions need to be developed and added to the PSL-Core as necessary. In this way a user can tailor the language precisely to suit his or her expressive needs.

Note 2 to entry: All extensions are core theories or definitional extensions.

3.1.5

grammar

specification of how logical symbols and lexical terms can be combined to make well-formed formulae

[SOURCE: ISO 18629-1]

3.1.6

information

facts, concepts, or instructions

[SOURCE: ISO 10303-1]

3.1.7

language

combination of a lexicon and a grammar

[SOURCE: ISO 18629-1]

3.1.8

manufacturing

function or act of converting or transforming material from raw material or semi-finished state to a state of further completion

[SOURCE: ISO 15531-1]

3.1.9

manufacturing process

structured set of activities or operations performed upon material to convert it from the raw material or a semfinished state to a state of further completion

Note 1 to entry: Manufacturing processes may be arranged in process layout, product layout, cellular layout or fixed position layout. Manufacturing processes may be planned to support make-to-stock, make-to-order, assemble-to-order, etc., based on strategic use and placements of inventories.

[SOURCE: ISO 15531-1]

3.1.10

model

combination of a set of elements and a truth assignment that satisfies all well-formed formulae in a theory

Note 1 to entry: The word "model" is used, in logic, in a way that differs from the way it is used in most scientific and everyday contexts : if a sentence is true in a certain interpretation, it is possible to say that the interpretation is a model of the sentence. The kind of semantics presented here is often called model-theoretical semantics.

Note 2 to entry: A model is typically represented as a set with some additional structure (partial ordering, lattice, or vector space). The model then defines meanings for the terminology and a notion of truth for sentences of the language in terms of this model. Given a model, the underlying set of axioms of the mathematical structures used in the set of axioms then becomes available as a basis for reasoning about the concepts intended by the terms of the language and their logical relationships, so that the set of models constitutes the formal semantics of the ontology.

[SOURCE: ISO 18629-1]

3.1.11

ontology

a lexicon of specialised terminology along with some specification of the meaning of terms in the lexicon

Note 1 to entry: structured set of related terms given with a specification of the meaning of the terms in a formal language. The specification of meaning explains why and how the terms are related and conditions how the set is partitioned and structured.

Note 2 to entry: The primary component of a process specification language such as [ISO 18629](#) is an ontology. The primitive concepts in the ontology according to [ISO 18629](#) are adequate for describing basic manufacturing, engineering, and business processes.

Note 3 to entry: The focus of an ontology is not only on terms, but also on their meaning. An arbitrary set of terms is included in the ontology, but these terms can only be shared if there is an agreement about their meaning. It is the intended semantics of the terms that is being shared, not simply the terms.

Note 4 to entry: Any term used without an explicit definition is a possible source of ambiguity and confusion. The challenge for an ontology is that a framework is needed for making explicit the meaning of the terms within it. For the [ISO 18629](#) ontology, it is necessary to provide a rigorous mathematical characterisation of process information as well as a precise expression of the basic logical properties of that information in the [ISO 18629](#) language.

Note 5 to entry: In practice, extensions incorporate the axioms of the Outer Core.

[SOURCE: ISO 18629-1]

3.1.12

primitive concept

lexical term that has no conservative definition

[SOURCE: ISO 18629-1]

3.1.13

primitive lexicon

set of symbols in the non-logical lexicon which denote primitive concepts

Note 1 to entry: Primitive lexicon is divided into constant, function and relation symbols.

[SOURCE: ISO 18629-1]

3.1.14

process

structured set of activities involving various enterprise entities, that is designed and organised for a given purpose

Note 1 to entry: The definition provided here is very close to that given in [ISO 10303-49](#). Nevertheless [ISO 15531](#) needs the notion of structured set of activities, without any predefined reference to the time or steps. In addition, from the point of view of flow management, some empty processes may be needed for a synchronisation purpose although they are not actually doing anything (ghost task).

[SOURCE: ISO 15531-1]

3.1.15

product

a thing or substance produced by a natural or artificial process

[SOURCE: ISO 10303-1]

3.1.16

resource

any device, tool and means, excepted raw material and final product components, at the disposal of the enterprise to produce goods or services

Note 1 to entry: Resources as they are defined here include human resources considered as specific means with a given capability and a given capacity. Those means are considered as being able to be involved in the manufacturing process through assigned tasks. That does not include any modelling of an individual or common behaviour of human resource excepted in their capability to perform a given task in the manufacturing process (e.g.: transformation of raw material or component, provision of logistic services). That means that human resources are only considered, as the other, from the point of view of their functions, their capabilities and their status (e.g.: idle, busy). That excludes any modelling or representation of any aspect of individual or common «social» behaviour.

Note 2 to entry: This definition includes [ISO 10303-49](#) definition but is included in the definition that applies for ISO 18629-14 and [ISO 18629-44](#) that includes raw materials and consumables.

[SOURCE: ISO 15531-1]

3.1.17

theory

set of axioms and definitions that pertain to a given concept or set of concepts

Note 1 to entry: this definition reflects the approach of artificial intelligence in which a theory is the set of assumptions on which the meaning of the related concept is based.

[SOURCE: ISO 18629-1]

3.2 Abbreviations

— **KIF** Knowledge Interchange Format.

4 Overview of parts 41 to 49 of ISO 18629¹⁾

Parts 41 to 49 of [ISO 18629](#) specify definitional extensions needed to give precise definitions and related axioms of non-primitive concepts of [ISO 18629](#). Definitional extensions are extensions of [ISO 18629-11](#) and [ISO 18629-12](#) that introduce new items for the lexicon. The items found in definitional extensions can be completely defined using theories of [ISO 18629-11](#) and [ISO 18629-12](#). The definitional extensions provide precise semantic definitions for elements used in the specification of individual applications or types of applications for the purpose of interoperability. Definitional extensions exist in the following categories:

- Activity Extensions;
- Temporal and State Extensions;
- Activity Ordering and Duration Extensions;
- Resource Roles;
- Resource Sets;
- Processor Activity Extensions.

Individual users or groups of users of [ISO 18629](#) may need to extend [ISO 18629](#) for specifying concepts that are currently absent in parts 41 to 49 of [ISO 18629](#). They shall use the elements presented in [ISO 18629](#) for doing so. User-defined extensions and their definitions constitute definitional extensions but shall not become part of parts 41 to 49 of [ISO 18629](#).

NOTE: User-defined extensions must conform to [ISO 18629](#) as defined in ISO 18629-1 : 2004, 5.1 and 5.2.

The following are within the scope of parts 41 to 49 of [ISO 18629](#) :

- the semantic definitions, using concepts in [ISO 18629-11](#) and [ISO 18629-12](#), of elements that are specific to the six concepts outlined above;
- a set of axioms for constraining the use of elements in definitional extensions.

The following are outside the scope of parts 41 to 49 of [ISO 18629](#):

- definitions and axioms for concepts that are part of [ISO 18629-11](#) and [ISO 18629-12](#);
- elements that are not defined using the elements in [ISO 18629-11](#) and [ISO 18629-12](#);
- user-defined extensions.

5 Organization of this part of ISO 18629

5.1 Introduction

This clause specifies the fundamental theories of which this part of [ISO 18629](#) is composed.

5.2 Extensions in this part of ISO 18629

The fundamental theories that constitute this part of [ISO 18629](#) are:

- State-based preconditions for activities;
- Time-based preconditions for activities;
- Preconditions based on state and time;

1) Certain parts are under development

- Occurrence-based preconditions for activities;
- Preventable conditions for activities;
- Periodic preconditions for activities;
- Spoilage preconditions for activities;
- Effects of activities;
- Effects of activities: occurrence constraints;
- Effects of activities: temporal and occurrence constraints;
- Fluent trees;
- Distribution of complex activities;
- State-based distribution of complex activities;
- Time-based distribution of complex activities;
- Mixed distribution of complex activities;
- Variation of complex activities;
- State-based variation of complex activities;
- Time-based variation of complex activities;
- Mixed variation based of complex activities;
- Embedded activities: plans;
- Embedded activities: temporal spread;
- Variation for upwards atomic activities;
- Variation for downwards atomic activities;
- Preconditions for concurrent activities;
- Effects for concurrent activities;
- Variation of interfering preconditions;
- Variation off clobbering effects.

All definitional extensions in this part of [ISO 18629](#) are extensions of [ISO 18629-12](#), itself an extension of [ISO 18629-11](#).

6 State-based preconditions for activities

This clause characterizes all definitions pertaining to state-based preconditions for activities. The criterion used to classify these activities is whether or not legal occurrences of an activity depend only on the state prior to the occurrences.

6.1 Primitive lexicon of the State-based preconditions for activities

No primitive relations are required by the lexicon of State-based preconditions for activities.

6.2 Defined lexicon for concepts of State-based preconditions for activities

The following relations are defined in this clause:

- (state_equiv ?s1 ?s2);
- (markov_precond ?a);
- (partial_state ?a);
- (rigid_state ?a).

Each concept is described by informal semantics and a KIF axiom.

6.3 Core theories required by State-based preconditions for activities

This extension requires:

- act_occ.th;
- complex.th;
- atomic.th;
- subactivity.th;
- disc_state.th;
- occtree.th;
- psl_core.th.

6.4 Definitional extensions required by State-based preconditions for activities

The following definitional extension is required by the State-based preconditions for activities:

- precondition.def.

6.5 Definitions of concepts for State-based preconditions for activities

The following concepts are defined for State-based preconditions for activities.

6.5.1 state_equiv

Two activity occurrences are state equivalent if the same states hold after the occurrences.

```
(forall (?s1 ?s2) (iff (state_equiv ?s1 ?s2)
  (forall (?f)
    (iff (holds ?f ?s1)
      (holds ?f ?s2))))))
```

6.5.2 markov_precond

An activity is a markov preconditional activity if whenever two occurrences agree on state, then they agree on the extension of poss for the activity.

```
(forall (?a) (iff (markov_precond ?a)
  (forall (?s1 ?s2)
    (implies (state_equiv ?s1 ?s2)
      (poss_equiv ?a ?s1 ?s2)))))
```

6.5.3 partial_state

An activity is a partially state constrained activity if and only if there exist occurrence-preserving fluent permutations.

```
(forall (?a) (iff (partial_state ?a)
  (and (exists (?s1)
    (forall (?s2)
      (implies (state_equiv ?s1 ?s2)
        (poss_equiv ?a ?s1 ?s2))))
    (exists (?s3 ?s4)
      (and (state_equiv ?s3 ?s4)
        (not (poss_equiv ?a ?s3 ?s4))))))))
```

6.5.4 rigid_state

An activity is a rigid state activity if and only if the only occurrence-preserving fluent permutation is the trivial one.

```
(forall (?a) (iff (rigid_state ?a)
  (forall (?s1)
    (exists (?s2)
      (and (state_equiv ?s1 ?s2)
        (not (poss_equiv ?a ?s1 ?s2)))))))
```

6.6 Grammar for relations of State-based preconditions for activities

The following grammar sentences describe process descriptions and auxiliary rules specified in KIF for State-based preconditions for activities.

NOTE: The function and importance of grammar sentences in [ISO 18629](#) is explained in ISO 18629-1 : 2004, 3.3.8, 4.2.4, and 5.1.

```
< simple_state_precond > ::= (forall (?s)
  (implies (and (occurrence ?s )
    (legal ?s))
    < simple_state_axiom >))) |
  (forall (?s)
    (implies (and (legal ?s)
      < simple_state_axiom >
      (legal (successor < term > ?s))))))

< state_precond > ::= (forall (< variable >*)
  (implies (and (occurrence < variable > < term >
    (legal < term >))
    < state_axiom >))) |
  (forall (< variable >*)
    (implies (and (legal < term >
      < state_axiom >
      (legal (successor < term > < term >))))))

< simple_state_literal > ::= (prior < term > ?s)
< simple_state_formula > ::= < simple_state_literal > |
  (not < simple_state_formula >) |
  ({and | or} < simple_state_formula >*) |
  ({implies | iff} < simple_state_formula >)

< simple_state_axiom > ::= ({forall | exists} < variable >*)
  < simple_state_formula >

< state_literal > ::= (prior < term > < variable >)
< state_formula > ::= < state_literal > |
  (not < state_formula >) |
  ({and | or} < state_formula >) |
  ({implies | iff} < state_formula >*)

< state_axiom > ::= (forall (< variable >+) < state_formula >)</biblioset>
```

7 Time-based preconditions for activities

This clause characterizes all definitions pertaining to Time-based preconditions for activities. The criterion used to classify these activities is whether or not legal occurrences of an activity depend only on the time at which the activities occur.

7.1 Primitive lexicon of Time-based preconditions for activities

No primitive relations are required by the lexicon of Time-based preconditions for activities.

7.2 Defined lexicon for concepts of Time-based preconditions for activities

The following relations are defined in this clause:

- (begin_equiv ?s1 ?s2);
- (time_precond ?a);
- (partial_time ?a);
- (rigid_time ?a).

Each concept is described by informal semantics and a KIF axiom.

7.3 Theories required by Time-based preconditions for activities

This theory requires :

- disc_state.th;
- occtree.th;
- psl_core.th.

7.4 Definitional extensions required by Time-based preconditions for activities

The following definitional extensions are required by Time-based preconditions for activities:

- precondition.def;
- start.def.

7.5 Definitions of Time-based preconditions for activities

The following concepts are defined for Time-based preconditions for activities.

7.5.1 begin_equiv

Two atomic activity occurrences are begin-equivalent if and only if they have equal beginof timepoints.

```
(forall (?s1 ?s2) (iff (begin_equiv ?s1 ?s2)
  (= (beginof ?s1) (beginof ?s2))))
```

7.5.2 time_precond

An activity is a time precondition activity if whenever two atomic occurrences in the occurrence tree agree on their beginof timepoints, then they agree on the extension of poss for the activity.

```
(forall (?a) (iff (time_precond ?a)
(forall (?s1 ?s2)
(implies (begin_equiv ?s1 ?s2))
(poss_equiv ?a ?s1 ?s2))))))
```

7.5.3 partial_timeprecond

An activity is a partially temporally constrained activity if and only if there exist occurrence-preserving permutations

```
(forall (?a) (iff (partial_time ?a)
(and (exists (?s1)
(forall (?s2)
(implies (begin_equiv ?s1 ?s2)
(poss_equiv ?a ?s1 ?s2))))
(exists (?s3 ?s4)
(and (begin_equiv ?s3 ?s4)
(not(poss_equiv ?a ?s3 ?s4)))))))
```

7.5.4 rigid_time

An activity is a rigid time activity if and only if the only occurrence-preserving timeline permutation is the trivial one.

```
(forall (?a) (iff (rigid_time ?a)
(forall (?s1)
(exists (?s2)
(and (begin_equiv ?s1 ?s2)
(not(poss_equiv ?a ?s1 ?s2)))))))
```

7.6 Grammar for process descriptions of Time-based preconditions for activities

The following grammar sentences describe process descriptions and auxiliary rules specified in KIF for Time-based preconditions for activities.

```
< simple_time_precond > ::= (forall (?s)
(implies (and (occurrence ?s < term >)
(legal ?s))
< simple_time_axiom >))) |
(forall (?s)
(implies (and (legal ?s)
< simple_time_axiom >)
(legal (successor < term > ?s)))))
< time_precond > ::= (forall (?s)
(implies (and (occurrence ?s < term >)
(legal ?s))
< time_axiom >))) |
(forall (?s)
(implies (and (legal ?s)
< time_axiom >)
(legal (successor < term > ?s)))))
< simple_time_literal > ::= (= (beginof ?s) < term >)
< simple_time_formula > ::= (and < simple_time_literal >*)
< simple_time_axiom > ::= ({forall | exists} < variable >*) < simple_time_formula >
< ordered_time_literal > ::= < simple_time_literal > |
(before (beginof ?s) < term >) |
(before < term > (beginof ?s))
< time_formula > ::= < ordered_time_literal > |
(not < time_formula >) |
({and | or} < time_formula >*) |
({implies | iff} < time_formula >)
< time_axiom > ::= ({forall | exists} < variable >*) < time_formula >
```

8 Preconditions based on state and time

This clause characterizes all definitions pertaining to Preconditions based on state and time. The criterion used to classify these activities is whether or not legal occurrences of an activity depend on the state prior to the occurrences and the times at which the activities occur.

8.1 Primitive lexicon of Preconditions based on state and time

No primitive relations are required by the lexicon of Preconditions based on state and time.

8.2 Defined lexicon of Preconditions based on state and time

The following relations are defined in this clause:

- (mixed_precond ?s);
- (partial_mixed ?s);
- (rigid_mixed ?s).

Each concept is described by informal semantics and a KIF axiom.

8.3 Theories required by Preconditions based on state and time

This theory requires:

- disc_state.th;
- occtree.th;
- psl_core.th.

8.4 Definitional extensions required by Preconditions based on state and time

No Definitional Extensions are required by Preconditions based on state and time.

8.5 Definitions of Preconditions based on state and time

The following concepts are defined for Preconditions based on state and time.

8.5.1 mixed_precond

An activity is a mixed preconditional activity iff whenever two occurrences agree on state and their beginof timepoints, then they agree on the extension of poss for the activity.

```
(forall (?a) (iff (mixed_precond ?a)
  (forall (?s1 ?s2)
    (implies (and (state_equiv ?s1 ?s2)
                  (begin_equiv ?s1 ?s2))
              (poss_equiv ?a ?s1 ?s2))))))
```

8.5.2 partial_mixed

An activity is a partially mixed constrained activity if and only if there exist occurrence-preserving permutations.

```
(forall (?a) (iff (partial_mixed ?a)
  (and (exists (?s1)
        (forall (?s2)
```

```
(implies (and (state_equiv ?s1 ?s2)
              (begin_equiv ?s1 ?s2))
  (poss_equiv ?a ?s1 ?s2)))
(exists (?s3 ?s4)
  (and (state_equiv ?s3 ?s4)
        (begin_equiv ?s3 ?s4)
        (not (poss_equiv ?a ?s3 ?s4))))))
```

8.5.3 rigid_mixed

An activity is a rigid mixed activity if and only if the only occurrence-preserving permutation that is both a fluent permutation and a timeline permutation, is the trivial one.

```
(forall (?a) (iff (rigid_mixed ?a)
  (forall (?s1)
    (exists (?s2)
      (and (state_equiv ?s1 ?s2)
            (begin_equiv ?s1 ?s2)
            (not (poss_equiv ?a ?s1 ?s2)))))))
```

8.6 Grammar for Preconditions based on state and time

The following grammar sentences describe process descriptions and auxiliary rules specified in KIF for Preconditions based on state and time.

```
< simple_mix_precond > ::= (forall (?s)
  (implies (and (occurrence ?s < term >)
                (legal ?s))
    < simple_mix_axiom >))) |
  (forall (?s)
    (implies (and (legal ?s)
                  < simple_mix_axiom >)
      (legal (successor < term > ?s)))))
< mix_precond > ::= (forall (?s)
  (implies (and (occurrence ?s < term >)
                (legal ?s))
    < mix_formula >)))
< simple_mix_literal > ::= (= (beginof ?s) < term >) (prior ?s)
< simple_mix_formula > ::= (and < simple_mix_literal >*)
< simple_mix_axiom > ::= ({forall | exists} < variable >*) < simple_mix_formula >
< ordered_mix_literal > ::= < simple_mix_literal > |
  (before (beginof ?s) < term >) (prior < term > ?s) |
  (before < term > (beginof ?s)) (prior < term > ?s)
< mix_formula > ::= < ordered_mix_literal > |
  (not < mix_formula >) |
  ({and | or} < mix_formula >*) |
  ({implies | iff} < mix_formula >)
< mix_axiom > ::= ({forall | exists} < variable >*) < mix_formula >
```

9 Occurrence-based preconditions for activities

This clause characterizes all definitions pertaining to Occurrence-based preconditions for activities. The criterion used to classify these activities is whether or not legal occurrences of an activity depend on the occurrences of other activities.

9.1 Primitive lexicon of Occurrence-based preconditions for activities

No primitive relations are introduced in the lexicon of Occurrence-based preconditions for activities.

9.2 Defined relations of Occurrence-based preconditions for activities

The following relations are defined in this clause:

- (tree_equiv ?s1 ?s2) ;
- (occurrence_constrained ?a);
- (occurrence_dependent ?a);
- (occurrence_independent ?a).

Each concept is described by informal semantics and a KIF axiom.

9.3 Theories required by Occurrence-based preconditions for activities

This theory requires:

- occtree.th;
- psl_core.th.

9.4 Definitional extensions required by Occurrence-based preconditions for activities

The following Definitional Extensions are required by the Occurrence-based preconditions for activities:

- precondition.def.

9.5 Definitions of Occurrence-based preconditions for activities

The following concepts are defined for Occurrence-based preconditions for activities.

9.5.1 tree_equiv

Two activity occurrences are tree equivalent if only if they are mapped to each other by some transformation of the occurrence tree.

```
(forall (?a ?s1 ?s2)
  (iff (tree_equiv (successor ?a ?s1) (successor ?a ?s2))
    (and (legal_equiv ?s1 ?s2)
      (or (tree_equiv ?s1 ?s2)
        (initial ?s1)
        (initial ?s2))))))
```

9.5.2 occurrence_constrained

An activity is occurrence constrained if and only if all transformations of the occurrence tree preserve legal occurrences of the activity.

```
(forall (?a) (iff (occurrence_constrained ?a)
  (forall (?s1 ?s2)
    (implies (and (occurrence ?s1 ?a)
      (occurrence ?s2 ?a)
      (tree_equiv ?s1 ?s2))
      (legal_equiv ?s1 ?s2))))))
```

9.5.3 occurrence_dependent

An activity is occurrence dependent if and only if there exist transformation of the occurrence tree that preserve legal occurrences of the activity.