



## RIF Production Rule Dialect

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### Abstract

This document specifies RIF-PRD, a [Rule Interchange Format \(RIF\)](#) dialect to enable the interchange of production rules.

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#### Summary of Changes

@@TDB

## Last Call

The Working Group believes it has completed its design work for the technologies specified in this document, so this is a "Last Call" draft. The design is not expected to change significantly, going forward, and now is the key time for external review, before the implementation phase.

## Please Comment By 3 July 2009

The [Rule Interchange Format \(RIF\) Working Group](#) seeks public feedback on this Working Draft. Please send your comments to [public-rif-comments@w3.org](mailto:public-rif-comments@w3.org) ([public archive](#)). If possible, please offer specific changes to the text that would address your concern. You may also wish to check the [Wiki Version](#) of this document and see if the relevant text has already been updated.

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## 1 Overview

This document specifies the production rule dialect of the W3C rule interchange format (RIF-PRD), a standard XML serialization format for production rule languages.

The production rule dialect is one of a set of rule interchange dialects that also includes the RIF Core dialect ([\[RIF-Core\]](#)) and the RIF basic logic dialect ([\[RIF-BLD\]](#)).

RIF-Core, the core dialect of the W3C rule interchange format, is designed to support the interchange of definite Horn rules without function symbols ("Datalog"). RIF-Core has both a standard first-order semantics and an operational semantics. Syntactically, RIF-Core has a number of extensions of Datalog:

- frames as in F-logic [[KLW95](#)],
- internationalized resource identifiers (or IRIs, defined by [[RFC-3987](#)]) as identifiers for concepts, and
- XML Schema datatypes [[XML-SCHEMA2](#)].

RIF-Core is based on a rich set of datatypes and built-ins that are aligned with Web-aware rule system implementations [[RIF-DTB](#)]. In addition, [RIF, RDF, and OWL Compatibility](#) defines the syntax and semantics of combinations of RIF-Core, RDF, and OWL documents.

RIF-Core is intended to be the common core of all RIF dialects, and it has been designed, in particular, to be a useful common subset of RIF-BLD and RIF-PRD. RIF-PRD includes and extends RIF-Core, and, therefore, RIF-PRD inherits all RIF-Core features. These features make RIF-PRD a Web-aware (even a semantic Web-aware) language. However, it should be kept in mind that RIF is designed to enable interoperability among rule languages in general, and its uses are not limited to the Web.

This document targets designers and developers of RIF-PRD implementations. A RIF-PRD implementation is a software application that serializes production rules as RIF-PRD XML (producer application) and/or that deserializes RIF-PRD XML documents into production rules (consumer application).

## 1.1 Production rule interchange

Production rules have an *if* part, or *condition*, and a *then* part, or *action*. The condition is like the condition part of logic rules (as covered by RIF-Core and its basic logic dialect extension, RIF-BLD). The *then* part contains actions. An action can assert facts, modify facts, retract facts, and have other side-effects. In general, an action is different from the conclusion of a logic rule, which contains only a logical statement. However, the conclusion of rules interchanged using RIF-Core can be interpreted, according to RIF-PRD operational semantics, as actions that assert facts in the knowledge base.

**Example 1.1.** *The following are examples of production rules:*

- *A customer becomes a "Gold" customer when his cumulative purchases during the current year reach \$5000.*
- *Customers that become "Gold" customers must be notified immediately, and a golden customer card will be printed and sent to them within one week.*
- *For shopping carts worth more than \$1000, "Gold" customers receive an additional discount of 10% of the total amount. □*

Because RIF-PRD is a production rule interchange format, it specifies an abstract syntax that shares features with concrete production rule languages, and it associates the abstract constructs with normative semantics and a normative XML concrete syntax. Annotations (e.g. rule author) are the only constructs in RIF-PRD without a formal semantics.

The abstract syntax is specified in mathematical English, and the abstract syntactic constructs that are defined in the sections [Abstract Syntax of Conditions](#), [Abstract Syntax of Actions](#) and [Abstract Syntax of Rules and Rulesets](#), are mapped into the concrete XML constructs in the section [XML syntax](#). A lightweight notation is used, instead of the XML syntax, to tie the abstract syntax to the specification of the semantics. A more complete presentation syntax is specified using an EBNF in [Presentation Syntax](#). However, only the XML syntax and the associated semantics are normative. The normative XML schema is included in [Appendix: XML Schema](#).

**Example 1.2.** In RIF-PRD presentation syntax, the first rule in example 1.1. can be represented as follows:

```
Prefix(ex <http://example.com/2008/prd1#>)
(* ex:rule_1 *)
Forall ?customer ?purchasesYTD (
  If And( ?customer#ex:Customer
          ?customer[ex:purchasesYTD->?purchasesYTD]
          External(pred:numeric-greater-than(?purchasesYTD 5000)) )
  Then Do( Modify(?customer[ex:status->"Gold"]) ) )
```

□

Production rules are statements of programming logic that specify the execution of one or more actions when their conditions are satisfied. Production rules have an operational semantics, that the OMG Production Rule Representation specification [PRR] summarizes it as follows:

1. *Match*: the rules are instantiated based on the definition of the rule conditions and the current state of the data source;
2. *Conflict resolution*: a decision algorithm, often called *the conflict resolution strategy*, is applied to select which rule instance will be executed;
3. *Act*: the state of the data source is changed, by executing the selected rule instance's actions. If a terminal state has not been reached, the control loops back to the first step (*Match*).

In the section [Operational semantics of rules and rule sets](#), the semantics for rules and rule sets is specified, accordingly, as a labeled terminal transition system ([PLO04](#)), where state transitions result from executing the action part of instantiated rules. When several rules are found to be executable at the same time, during the rule execution process, a *conflict resolution strategy* is used to select the rule to execute. [Instance Selection](#) specifies how a conflict resolution strategy can be attached to a rule set. RIF-PRD defines a default conflict resolution strategy.

In the section [Semantics of condition formulas](#), the semantics of the condition part of rules in RIF-PRD is specified operationally, in terms of matching substitutions. To emphasize the overlap between the rule conditions of RIF-BLD and RIF-PRD, and to share the same RIF definitions for datatypes and built-ins [[RIF-DTB](#)], an alternative, and equivalent, specification of the semantics of rule conditions in RIF-PRD, using a model theory, is provided in the appendix [Model-theoretic semantics of RIF-PRD condition formulas](#).

The semantics of condition formulas and the semantics of rules and rule sets make no assumption regarding how condition formulas are evaluated. In particular, they do not require that condition formula be evaluated using pattern matching. However, RIF-PRD conformance, as defined in the section [Conformance and interoperability](#), requires only support for [safe rules](#), that is, forward-chaining rules where the conditions can be evaluated based on pattern matching only.

In the section [Operational semantics of actions](#), the semantics of the action part of rules in RIF-PRD is specified using a transition relation between successive states of the data source, represented by ground condition formulas, thus making the link between the model-theoretic semantics of conditions and the operational semantics of rules and rule sets.

The abstract syntax of RIF-PRD documents, and the semantics of the combination of multiple RIF-PRD documents, is specified in the section [Documents and imports](#).

In addition to externally specified functions and predicates, and in particular, in addition to the functions and predicates built-ins defined in [[RIF-DTB](#)], RIF-PRD supports externally specified actions, and defines one action built-in, as specified in the section [Built-in functions, predicates and actions](#).

## 1.2 Running example

The same example rules will be used throughout the document to illustrate the syntax and the semantics of RIF-PRD. The complete RIF XML document corresponding to the example rule set is attached as [Appendix: Complete RIF-PRD XML example](#).

The rules are about the status of customers at a shop, and the discount awarded to them. The rule set contains four rules, to be applied when a customer checks out:

1. Gold rule: A "Silver" customer with a shopping cart worth at least \$2,000 is awarded the "Gold" status.
2. Discount rule "Silver" and "Gold" customers are awarded a 5% discount on the total worth of their shopping cart.
3. New customer and widget rule: A "New" customer who buys a widget is awarded a 10% discount on the total worth of her shopping cart, but she loses any voucher she may have been awarded.

4. Unknown status rule: *A message must be printed, identifying any customer whose status is unknown (that is, neither "New", "Bronze", "Silver" or "Gold"), and the customer must be assigned the status: "New".*

The *Gold rule* must be applied first; that is, e.g., a customer with "Silver" status and a shopping cart worth exactly \$2,000 should be promoted to "Gold" status, before being given the 5% discount that would disallow the application of the *Gold rule* (since the total worth of his shopping cart would then be only \$1,900).

In the remainder of this document, the prefix `ex1` stands for the fictitious namespace of this example: `http://example.com/2009/prd2#`.

## 2 Conditions

This section specifies the syntax and semantics of the condition language of RIF-PRD.

The RIF-PRD condition language specification depends on Section [Constants, Symbol Spaces, and Datatypes](#) of RIF data types and builtins [[RIF-DTB](#)].

### 2.1 Abstract syntax

The alphabet of the RIF-PRD condition language consists of:

- a countably infinite set of **constant symbols**  $\text{Const}$ ,
- a countably infinite set of **variable symbols**  $\text{Var}$  (disjoint from  $\text{Const}$ ),
- and syntactic constructs to denote:
  - lists,
  - function calls,
  - relations, including equality, class membership and subclass relations
  - conjunction, disjunction and negation,
  - and existential conditions.

For the sake of readability and simplicity, this specification introduces a notation for these constructs. The notation is not intended to be a concrete syntax, so it leaves out many details. The only concrete syntax for RIF-PRD is the XML syntax.

RIF-PRD supports externally defined functions only (including the built-in functions specified in [[RIF-DTB](#)]). RIF-PRD, unlike [RIF-BLD](#), does not support uninterpreted function symbols (sometimes called logically defined functions).

RIF-PRD supports a form of negation. Neither [RIF-Core](#) nor [RIF-BLD](#) support negation, because logic rule languages use many different and incompatible kinds of negation. See also the RIF framework for logic dialects [[RIF-FLD](#)].



### 2.1.1 Terms

The most basic construct in the RIF-PRD condition language is the *term*. RIF-PRD defines several kinds of term: *constants*, *variables*, *lists* and *positional terms*.

#### Definition (Term).

1. *Constants and variables*. If  $t \in \text{Const}$  or  $t \in \text{Var}$  then  $t$  is a **simple term**;
2. *List terms*. A **list** has the form  $\text{List}(t_1 \dots t_m)$ , where  $m \geq 0$  and  $t_1, \dots, t_m$  are ground terms, i.e. without variables. A list of the form  $\text{List}()$  (i.e., a list in which  $m=0$ ) is called the **empty list**;
3. *Positional terms*. If  $t \in \text{Const}$  and  $t_1, \dots, t_n, n \geq 0$ , are terms then  $t(t_1 \dots t_n)$  is a **positional term**.  
Here, the constant  $t$  represents a function and  $t_1, \dots, t_n$  represent argument values.  $\square$

To emphasize interoperability with [RIF-BLD](#), positional terms may also be written:  $\text{External}(t(t_1 \dots t_n))$ .

#### Example 2.1.

- *List("New" "Bronze" "Silver" "Gold") is a term that denotes the list of the values for a customer's status that are known to the system. The elements of the list, "New", "Bronze", "Silver" and "Gold" are terms denoting string constants;*
- *[func:numeric-multiply](#)(?value, 0.90) is a positional term that denotes the product of the value assigned to the variable ?value and the constant 0.90. That positional term can be used, for instance, to represent the new value, taking the discount into account, to be assigned a customer's shopping cart, in the rule New customer and widget rule. An alternative notation is to mark explicitly the positional term as externally defined, by wrapping it with the External indication:  
 $\text{External}(\text{func:numeric-multiply}(\text{?value}, 0.90))$   $\square$*

The function **Var(e)** that maps a term  $e$  to the set of its free variables is defined as follows:

- if  $e \in \text{Const}$ , then  $\text{Var}(e) = \{\}$ ;
- if  $e \in \text{Var}$ , then  $\text{Var}(e) = \{e\}$ ;
- if  $f(\text{arg}_1 \dots \text{arg}_n)$ ,  $n \geq 0$ , is a positional term, then,  $\text{Var}(f(\text{arg}_1 \dots \text{arg}_n)) = \cup_{i=1 \dots n} \text{Var}(\text{arg}_i)$ ;

### 2.1.2 Atomic formulas

*Atomic formulas* are the basic tests of the RIF-PRD condition language.

**Definition (Atomic formula).** An *atomic formula* can have several different forms and is defined as follows:

1. *Positional atomic formulas.* If  $t \in \text{Const}$  and  $t_1, \dots, t_n, n \geq 0$ , are terms then  $t(t_1 \dots t_n)$  is a **positional atomic formula** (or simply an **atom**)
2. *Equality atomic formulas.*  $t = s$  is an **equality atomic formula** (or simply an **equality**), if  $t$  and  $s$  are terms
3. *Class membership atomic formulas.*  $t \# s$  is a **membership atomic formula** (or simply **membership**) if  $t$  and  $s$  are terms. The term  $t$  is the *object* and the term  $s$  is the *class*
4. *Subclass atomic formulas.*  $t \#\# s$  is a **subclass atomic formula** (or simply a **subclass**) if  $t$  and  $s$  are terms
5. *Frame atomic formulas.*  $t[p_1 \rightarrow v_1 \dots p_n \rightarrow v_n]$  is a **frame atomic formula** (or simply a **frame**) if  $t, p_1, \dots, p_n, v_1, \dots, v_n, n \geq 0$ , are terms. The term  $t$  is the *object* of the frame; the  $p_i$  are the *property* or *attribute* names; and the  $v_i$  are the property or attribute *values*. In this document, an attribute/value pair is sometimes called a *slot*
6. *Externally defined atomic formulas.* If  $t$  is a positional atomic formula then  $\text{External}(t)$  is an **externally defined atomic formula**.  $\square$

Class membership, subclass, and frame atomic formulas are used to represent classifications, class hierarchies and object-attribute-value relations.

Externally defined atomic formulas are used, in particular, for representing built-in predicates.

In the [RIF-BLD](#) specification, as is common practice in logic languages, atomic formulas are also called *terms*.

### Example 2.2.

- The membership formula `?customer # ex1:Customer` tests whether the individual bound to the variable `?customer` is a member of the class denoted by `ex1:Customer`.
- The atom `ex1:Gold(?customer)` tests whether the customer represented by the variable `?customer` has the "Gold" status.
- Alternatively, gold status can be tested in a way that is closer to an object-oriented representation using the frame formula `?customer[ex1:status->"Gold"]`.
- The following atom uses the built-in predicate [pred:list-contains](#) to validate the status of a customer against a list of allowed customer statuses: `External(pred:list-contains(List("New", "Bronze", "Silver", "Gold"), ?status))`.  $\square$

The function **Var**, that was [defined for terms](#), is extended to map an atomic formula to the set of its free variables:

- if  $p(arg_1 \dots arg_n)$ ,  $n \geq 0$ , is an atom, then,  $Var(p(arg_1 \dots arg_n)) = Var(External(p(arg_1 \dots arg_n))) = \cup_{i=1 \dots n} Var(arg_i)$ ;
- if  $t_1$  and  $t_2$  are terms, then  $Var(t_1 [=|\#|##| t_2]) = Var(t_1) \cup Var(t_2)$ ;
- if  $o'$ ,  $k_i$ ,  $i = 1 \dots n$ , and  $v_i$ ,  $i = 1 \dots n$ ,  $n \geq 1$ , are terms, then  $Var(o'[k_1 \rightarrow v_1 \dots k_n \rightarrow v_n]) = Var(o) \cup_{i=1 \dots n} Var(k_i) \cup_{i=1 \dots n} Var(v_i)$ .

RIF-PRD does not require that a conformant consumer be capable of constraint resolution to evaluate condition formulas. To help specify the corresponding syntactic restriction on RIF-PRD condition formulas, we define, for any atomic formula,  $a$ , the two following sets:

- a set **UBV(a)**, of the *unconditionally bindable variables* of  $a$ , that is, of the variables that occur in  $a$  and that are guaranteed to be bound without constraint resolution if  $a$  is satisfied;
- and a set, **CBV(a)**, of *conditionally bindable variables*. Each variable,  $v \in CBV(a)$  is associated with the set,  $BCOND(v, a)$ , that contains the set of the variables occurring in  $a$  that guarantee, if they are bound when  $a$  is evaluated, that  $v$  can be bound without constraint resolution, if  $a$  is satisfied.

The sets  $UBV(a)$  and  $CBV(a)$  of the unconditionally and conditionally bindable variables in an atomic formula  $a$  are defined as follows:

- if  $a$  is an atom,  $p(t_1 \dots t_n)$ ,  $n \geq 0$ , a frame,  $t_1[t_2 \rightarrow t_3]$ , a membership formula,  $t_1 \# t_2$ , or a subclass formula,  $t_1 \# \# t_2$ , then either
  - the only variables in  $a$  are arguments of the atomic formula itself:  $Var(a) \subseteq \{t_1 \dots t_n\}$ , and  $UBV(a) = Var(a)$  and  $CBV(a) = \emptyset$ ;
  - or no argument of the atomic formula is a variable:  $Var(a) \cap \{t_1 \dots t_n\} = \emptyset$ , and  $UBV(a) = CBV(a) = \emptyset$ ;
  - otherwise, that is, if some of the arguments of  $a$  are variables, but others are terms that contain variables, then  $UBV(a) = \emptyset$  and either
    - the conditional bindability of none of these variables depends on itself, that is,  $varg \cap cond = \emptyset$ , where  $varg = Var(a) \cap \{t_1 \dots t_n\}$  and  $cond = \cup_{i=1 \dots n} \{t_i \notin Var(a) \wedge Var(t_i)\}$ , and  $CBV(a) = varg$ , and,  $\forall v \in CBV(a), BCOND(v, a) = \{cond\}$ ;
    - or  $CBV(a) = \emptyset$ ;
- else if  $a$  is an equality formula,  $t_1 = t_2$ , or an externally defined equality predicate: [pred:numeric-equal](#)( $t_1, t_2$ ), [pred:boolean-equal](#)( $t_1, t_2$ ), [pred:date-time-equal](#)( $t_1, t_2$ ), [pred:date-equal](#)( $t_1, t_2$ ), [pred:time-equal](#)( $t_1, t_2$ ), [pred:duration-equal](#)( $t_1, t_2$ ), [pred:XMLLiteral-equal](#)( $t_1, t_2$ ); or the externally defined predicate [pred:iri-string](#)( $t_1, t_2$ ), then either
  - $t_1$  and  $t_2$  are, both, variables, and  $UBV(a) = \emptyset$  and  $CBV(a) = \{t_1, t_2\}$ , with  $BCOND(t_1, a) = \{t_2\}$  and  $BCOND(t_2, a) = \{t_1\}$ ;
  - or only  $t_1$  is a variable, and either
    - $Var(t_2) = \emptyset$ , and  $UBV(a) = \{t_1\}$  and  $CBV(a) = \emptyset$ ;
    - or  $t_1 \in Var(t_2)$ , and  $UBV(a) = \emptyset$  and  $CBV(a) = \emptyset$ ;

- or  $UBV(a) = \emptyset$  and  $CBV(a) = \{t_1\}$ , and  $BCOND(t_1, a) = \{Var(t_2)\}$ ;
  - or only  $t_2$  is a variable, and either
    - $Var(t_1) = \emptyset$ , and  $UBV(a) = \{t_2\}$  and  $CBV(a) = \emptyset$ ;
    - or  $t_2 \in Var(t_1)$ , and  $UBV(a) = \emptyset$  and  $CBV(a) = \emptyset$ ;
    - or  $UBV(a) = \emptyset$  and  $CBV(a) = \{t_2\}$ , and  $BCOND(t_2, a) = \{Var(t_1)\}$ ;
  - otherwise  $UBV(a) = CBV(a) = \emptyset$ ;
- else if  $a$  is the externally defined predicate `pred:list-contains` ( $l, e$ ), then either
  - $e$  is a variable, and either
    - $Var(l) = \emptyset$ , and  $UBV(a) = \{e\}$  and  $CBV(a) = \emptyset$ ;
    - or  $e \in Var(l)$ , and  $UBV(a) = CBV(a) = \emptyset$ ;
    - or  $CBV(a) = \{e\}$ , with  $BCOND(e, a) = \{Var(l)\}$ , and  $UBV(a) = \emptyset$ ;
  - or  $e$  is not a variable, and  $UBV(a) = CBV(a) = \emptyset$ ;
- else if  $a$  is any other externally defined predicate, then  $UBV(a) = CBV(a) = \emptyset$ .

### 2.1.3 Formulas

Composite truth-valued constructs are called *formulas*, in RIF-PRD.

Note that terms (constants, variables, lists and functions) are *not* formulas.

More general formulas are constructed out of atomic formulas with the help of logical connectives.

**Definition (Condition formula).** A **condition formula** can have several different forms and is defined as follows:

1. **Atomic formula:** If  $\varphi$  is an atomic formula then it is also a condition formula.
2. **Conjunction:** If  $\varphi_1, \dots, \varphi_n, n \geq 0$ , are condition formulas then so is `And`( $\varphi_1 \dots \varphi_n$ ), called a **conjunctive** formula. As a special case, `And()` is allowed and is treated as a tautology, i.e., a formula that is always true.
3. **Disjunction:** If  $\varphi_1, \dots, \varphi_n, n \geq 0$ , are condition formulas then so is `Or`( $\varphi_1 \dots \varphi_n$ ), called a **disjunctive** formula. As a special case, `Or()` is permitted and is treated as a contradiction, i.e., a formula that is always false.
4. **Negation:** If  $\varphi$  is a condition formula, then so is `Not`( $\varphi$ ), called a **negative** formula.
5. **Existentials:** If  $\varphi$  is a condition formula and  $?V_1, \dots, ?V_n, n > 0$ , are variables then `Exists`  $?V_1 \dots ?V_n(\varphi)$  is an **existential** formula.  $\square$

In the definition of a formula, the component formulas  $\varphi$  and  $\varphi_i$  are said to be **subformulas** of the respective condition formulas that are built using these components.

**Example 2.3.**

- The condition of the [New customer and widget rule](#): A "New" customer who buys a widget, can be represented by the following RIF-PRD condition formula:

```
And( ?customer # ex1:Customer
     ?customer[ex1:status->"New"]
     Exists ?shoppingCart ?item ( And ( ?customer[ex1:shoppingCart->?shoppingCart
                                       ?shoppingCart[ex1:containsItem->?item
                                       ?item # ex1:Widget) )
                                   )
   )
```

□

The function **Var**, that was [defined for atomic formulas](#), is extended to map a condition formula to the set of its free variables:

- if  $f_i, i = 0 \dots n, n \geq 0$ , are condition formulas, then  $Var([And|Or](f_1 \dots f_n)) = \cup_{i=0 \dots n} Var(f_i)$ ;
- if  $f$  is a condition formula, then  $Var(Not(f)) = Var(f)$ ;
- if  $f$  is a condition formula and  $x_i \in Var$  for  $i = 1 \dots n$ , then,  $Var(Exists x_1 \dots x_n (f)) = Var(f) - \{x_i \mid i = 1 \dots n\}$ .

**Definition (Ground formula).** A condition formula  $\varphi$  is a **ground formula** if and only if  $Var_\varphi = \{\}$  and  $\varphi$  does not contain any existential subformula. □

In other words, a ground formula does not contain any variable term.

The definition of the set **UBV(f)** of the *unconditionally bindable variables* and the set **CBV(f)** of the *conditionally bindable variables*, that have been [defined for atomic formulas](#) is also extended to any condition formula.

When condition formulas are combined, a variable,  $x$ , that was conditionally bindable in one component, depending on another variable,  $y$  being bound, may become unconditionally bindable in the combination, e.g. because  $y$  is unconditionally bindable in the combination, or because the combination is a conjunction, and  $x$ , itself, is unconditionally bindable in another conjunct.

To take care of that, we define, first, the function *reduceBCV*, that updates iteratively the status of conditionally bindable variables in a formula,  $f$ , based on the state of the set of unconditionally bindable variables in  $f$ .

reduceCBV (f)

While  $\exists v \in CBV(f)$ ,  $\exists c \in BCOND(v, f)$ , such that  $c \subseteq UBV(f)$   
 $BCV(f) := BCV(f) \setminus v$   
 $UBV(f) := UBV(f) + v$

The definition of the sets  $UBV(f)$  and  $CBV(f)$  is extended recursively, as follows, to a condition formula  $f$ .

- if  $f$  is a conjunction,  $And(f_1 \dots f_n)$ ,  $n \geq 0$ , then
  1.  $UBV(f)$  and  $CBV(f)$  are initialized with  $\cup_{i=1..n} UBV(f_i)$  and  $\cup_{i=1..n} CBV(f_i) - UBV(f)$ , respectively,
  2.  $\forall v \in CBV(f)$ ,  $BCOND(v, f) = \cup_{f_i=1..n} BCOND(v, f_i)$ : the bindability conditions associated to the variables in  $CBV(f)$  are updated, taking into account that a conditionally bindable variable can be bound if the variables in any bindability condition from any of the conjuncts are bound;
  3. and  $reduceCBV(f)$  is executed to update  $UBV(f)$  and  $CBV(f)$ , removing from  $CBV(f)$  and adding to  $UBV(f)$  all the variables that are conditionally bindable in some conjunct, conditioned on the bindability of variables that are unconditionally bindable in some other conjunct;
- else if  $f$  is a disjunction,  $Or(f_1 \dots f_n)$ ,  $n \geq 0$ , then  
 $UBV(f) = \cap_{i=1..n} UBV(f_i)$ ,  $CBV(f) = \cap_{i=1..n} CBV(f_i)$ , and  $\forall v \in CBV(f)$ ,  
 $BCOND(v, f) = \cup_{f_i=1..n} BCOND(v, f_i)$ . Since only the variables that are unconditionally bindable in all the disjuncts are in  $UBV(f)$ ,  $CBV(f)$  cannot be reduced;
- else if  $f$  is a negation,  $INeg(f')$ , and  $UBV(f) = CBV(f) = \emptyset$ ;
- else if  $f$  is an existentially quantified condition formula,  $Exists\ v_1 \dots v_n(f')$ , then either
  - $\{v_1 \dots v_n\} \subseteq UBV(f')$ , that is, all the quantified variables are unconditionally bindable in  $f'$ , and
    1.  $UBV(f) = UBV(f') - \{v_1 \dots v_n\}$ ;
    2.  $CBV(f) = CBV(f')$ ;
    3.  $\forall v \in CBV(f)$ ,  $BCOND(v, f) = BCOND(v, f') - \{c \in BCOND(v, f') \mid c \cap \{v_1 \dots v_n\} \neq \emptyset\}$ : bindability conditions that depend on variables that are existentially quantified in  $f$  are useless outside of  $f$ , and they are, accordingly, removed;
  - or it is guaranteed that some of the quantified variables cannot be bound, at least not without constraint resolution, and  $UBV(f) = CBV(f) = \emptyset$ . We call such an existential formula **unsafe**, by extension of the notion of *safeness* that is defined in [\[RIF-Core\]](#).

The definition of *unconditionally bindable variables* in RIF-PRD condition formulas extends the definition of *restricted variables* in [\[LEE08\]](#). We extend the definition of a safe formula accordingly.

**Definition (Safe condition formula).** A RIF-PRD condition formula,  $f$ , is **safe** if and only if, either

- $f$  is an existential condition formula,  $\exists \{v_1 \dots v_n\} (f)$ , and  $\{v_1 \dots v_n\} \subseteq \text{UBV}(f)$ ;
- or  $f$  does not contain any existential sub-formula,
- or all the existential sub-formulas of  $f$  are safe.  $\square$

#### 2.1.4 Well-formed formulas

Not all formulas are well-formed in RIF-PRD: it is required that no constant appear in more than one context. What this means precisely is explained below.

The set of all constant symbols,  $\text{Const}$ , is partitioned into the following subsets:

- A subset of individuals. The symbols in  $\text{Const}$  that belong to the primitive datatypes are required to be individuals;
- A subset for external function symbols;
- A subset of plain predicate symbols;
- A subset for external predicate symbols.

As seen from the following definitions, these subsets are not specified explicitly but, rather, are inferred from the occurrences of the symbols.

**Definition (Context of a symbol).** The *context of an occurrence* of a symbol,  $s \in \text{Const}$ , in a formula,  $\varphi$ , is determined as follows:

- If  $s$  occurs as a predicate in an atomic [subformula](#) of the form  $s(\dots)$  then  $s$  occurs in the *context of a (plain) predicate symbol*;
- If  $s$  occurs as a predicate in an atomic subformula  $\text{External}(s(\dots))$  then  $s$  occurs in the *context of an external predicate symbol*;
- If  $s$  occurs as a function in a term (which is not a subformula)  $s(\dots)$  (or  $\text{External}(s(\dots))$ ) then  $s$  occurs in the *context of an (external) function symbol*;
- If  $s$  occurs in any other context (e.g. in a frame:  $s[\dots], \dots [s \rightarrow \dots]$ , or  $\dots [\dots \rightarrow s]$ ; or in a positional atom:  $p(\dots s \dots)$ ), it is said to occur as an *individual*.  $\square$

**Definition (Well-formed formula).** A formula  $\varphi$  is **well-formed** iff:

- every constant symbol mentioned in  $\varphi$  occurs in exactly one [context](#);
- whenever a formula contains a positional term,  $t$  (or  $\text{External}(t)$ ), or an external atomic formula,  $\text{External}(t)$ ,  $t$  must be an instance of a schema in the coherent set of external schemas (Section [Schemas for Externally Defined Terms](#) of [RIF-DTB]) associated with the [language of RIF-PRD](#);

- if  $\tau$  is an instance of a schema in the coherent set of external schemas associated with the language then  $\tau$  can occur only as an external term or atomic formula.  $\square$

**Definition (RIF-PRD condition language).** The *RIF-PRD condition language* consists of the set of all well-formed formulas.  $\square$

## 2.2 Operational semantics of condition formulas

This section specifies the semantics of the condition formulas in a RIF-PRD document.

Informally, a condition formula is evaluated with respect to a state of facts and it is *satisfied*, or *true*, if and only if:

- it is an atomic condition formula and its variables are bound to individuals such that, when these constants are substituted for the variables, either
  - it matches a fact, or
  - it is implied by some background knowledge, or
  - it is an externally defined predicate, and its evaluation yields *true*, or
- it is a compound condition formula: conjunction, disjunction, negation or existential; and it is evaluated as expected, based on the truth value of its atomic components.

The semantics is specified in terms of matching substitutions in the sections below. The specification makes no assumption regarding how matching substitutions are determined, and [safeness](#) if, therefore, not required from [well-formed condition formulas](#). However, [RIF-PRD conformance](#) requires processing of [safe condition formulas](#) only.

For compatibility with other RIF specifications (in particular, RIF data types and built-ins [[RIF-DTB](#)] and RIF RDF and OWL compatibility [[RIF-RDF+OWL](#)]), and to make explicit the interoperability with RIF logic dialects (in particular RIF Core [[RIF-Core](#)] and RIF-BLD [[RIF-BLD](#)]), the semantics of RIF-PRD condition formulas is also specified using model theory, in [appendix Model theoretic semantics of RIF-PRD condition formulas](#).

The two specifications are equivalent and normative.

### 2.2.1 Matching substitution

Let  $\text{Term}$  be the set of the terms in the RIF-PRD condition language (as defined in section [Terms](#)).

**Definition (Substitution).** A *substitution* is a finitely non-identical assignment of terms to variables; i.e., a function  $\sigma$  from  $\text{Var}$  to  $\text{Term}$  such that the set  $\{x \in \text{Var} \mid x \neq \sigma(x)\}$  is finite. This set is called the domain of  $\sigma$  and denoted by  $\text{Dom}(\sigma)$ . Such a



substitution is also written as a set such as  $\sigma = \{t_i/x_i\}_{i=1..n}$  where  $Dom(\sigma) = \{x_i\}_{i=1..n}$  and  $\sigma(x_i) = t_i, i = 1..n$ .  $\square$

**Definition (Ground Substitution).** A *ground substitution* is a substitution  $\sigma$  that assigns only ground terms to the variables in  $Dom(\sigma)$ :  $\forall x \in Dom(\sigma), Var(\sigma(x)) = \emptyset$ .  $\square$

Because RIF-PRD covers only external defined interpreted functions, a ground functional term can always be replaced by its value. As a consequence, a ground substitution can always be restricted, without loss of generality, to assign only constants to the variable in its domain. In the remainder of this document, it will always be assumed that a ground substitution assigns only constants to the variables in its domain.

If  $t$  is a term or a condition formula, and if  $\sigma$  is a ground substitution such that  $Var(t) \subseteq Dom(\sigma)$ ,  $\sigma(t)$  denotes the ground term or the ground condition formula obtained by substituting, in  $t$ :

- $\sigma(x)$  for all  $x \in Var(t)$ , and
- the externally defined results of interpreting a function with ground arguments, for all externally defined terms.

**Definition (Matching substitution).** Let  $\psi$  be a RIF-PRD condition formula; let  $\sigma$  be a ground substitution such that  $Var(\psi) \subseteq Dom(\sigma)$ ; and let  $\Phi$  be a set of ground RIF-PRD atomic formulas.

We say that the ground substitution  $\sigma$  *matches*  $\psi$  to  $\Phi$  if and only if one of the following is true:

- $\psi$  is an atomic formula and either
  - $\sigma(\psi) \in \Phi$ , or
  - $\psi$  is an equality formula,  $t_1 = t_2$ , and the ground terms  $\sigma(t_1)$  and  $\sigma(t_2)$  are equal; or
  - $\psi$  is an external atomic formula and the external definition maps  $\sigma(\psi)$  to **t** (or *true*),
- $\psi$  is `Not`( $f$ ) and  $\sigma$  does not match the condition formula  $f$  to  $\Phi$ ,
- $\psi$  is `And`( $f_1 \dots f_n$ ) and either  $n = 0$  or  $\forall i, 1 \leq i \leq n$ ,  $\sigma$  matches  $f_i$  to  $\Phi$ ,
- $\psi$  is `Or`( $f_1 \dots f_n$ ) and  $n > 0$  and  $\exists i, 1 \leq i \leq n$ , such that  $\sigma$  matches  $f_i$  to  $\Phi$ , or
- $\psi$  is `Exists`  $?v_1 \dots ?v_n$  ( $f$ ), and there is a substitution  $\sigma'$  that extends  $\sigma$  in such a way that  $\sigma'$  agrees with  $\sigma$  where  $\sigma$  is defined, and  $Var(f) \subseteq Dom(\sigma')$ ; and  $\sigma'$  matches  $f$  to  $\Phi$ .  $\square$

### 2.2.2 Condition satisfaction

We define, now, what it means for a *state of the fact base* to satisfy a condition formula. The satisfaction of condition formulas in a state of the fact base provides

formal underpinning to the operational semantics of rule sets interchanged using RIF-PRD.

**Definition (State of the fact base).** A *state of the fact base*,  $w_\Phi$ , is associated to every set of ground atomic formulas,  $\Phi$ . We say that  $w_\Phi$  is *represented* by  $\Phi$ ; or, equivalently, by the conjunction of all the ground atomic formulas in  $\Phi$ .  $\square$

**Definition (Condition satisfaction).** A RIF-PRD condition formula  $\psi$  is *satisfied* in a state of the fact base,  $w$ , if and only if  $w$  is represented by a set of ground atomic formulas  $\Phi$ , and there is a ground substitution  $\sigma$  that matches  $\psi$  to  $\Phi$ .  $\square$

Alternative, but equivalent, definitions of a state of the fact base and of the satisfaction of a condition are given in the [appendix Model theoretic semantics of RIF-PRD condition formulas](#): they provide the formal link between the model theory of RIF-PRD condition formulas and the operational semantics of RIF-PRD documents.

### 3 Actions

This section specifies the syntax and semantics of the RIF-PRD *action* language. The conclusion of a production rule is often called the *action* part, the *then* part, or the *right-hand side*, or *RHS*.

The RIF-PRD action language is used to add, delete and modify facts in the fact base. As a rule interchange format, RIF-PRD does not make any assumption regarding the nature of the data sources that the producer or the consumer of a RIF-PRD document uses (e.g. a rule engine's working memory, an external data base, etc). As a consequence, the syntax of the actions that RIF-PRD supports are defined with respect to the RIF-PRD condition formulas that represent the facts that the actions affect. In the same way, the semantics of the actions is specified in terms of how their execution affects the evaluation of rule conditions.

#### 3.1 Abstract syntax

The alphabet of the RIF-PRD action language includes symbols to denote:

- the assertion of a fact represented by a positional atom, a frame, or a membership atomic formula,
- the retraction of a fact represented by a positional atom or a frame,
- the addition of a new frame object,
- the removal of a frame object and the retraction of all the facts about it, represented by the corresponding frame and class membership atomic formulas,
- the replacement of all the values of an object's attribute by a single, new value,
- the execution of an externally defined action, and

- a sequence of these actions, including the declaration of local variables and a mechanism to bind a local variable to a frame slot value or a new frame object.

### 3.1.1 Atomic actions

Atomic action constructs take constructs from the RIF-PRD condition language as their arguments.

**Definition (Atomic action).** An *atomic action* can have several different forms and is defined as follows:

1. *Assert*: If  $\varphi$  is a [positional atom](#), a [frame](#) or a [membership atomic formula](#) in the RIF-PRD condition language, then `Assert( $\varphi$ )` is an atomic action.  $\varphi$  is called the *target* of the action.
2. *Retract*: If  $\varphi$  is a [positional atom](#) or a [frame](#) in the RIF-PRD condition language, then `Retract( $\varphi$ )` is an atomic action.  $\varphi$  is called the *target* of the action.
3. *Retract object*: If  $t$  is a [term](#) in the RIF-PRD condition language, then `Retract( $t$ )` is an atomic action.  $t$  is called the *target* of the action.
4. *Modify*: if  $\varphi$  is a [frame](#) in the RIF-PRD condition language, then `Modify( $\varphi$ )` is an atomic action.  $\varphi$  is called the *target* of the action;
5. *Execute*: if  $\varphi$  is a [positional atom](#) in the RIF-PRD condition language, then `Execute( $\varphi$ )` is an atomic action.  $\varphi$  is called the *target* of the action.  $\square$

**Definition (Ground atomic action).** An atomic action with target  $t$  is a *ground atomic action* if and only if  $Var(t) = \emptyset$ .  $\square$

#### Example 3.1.

- `Assert( ?customer[ex1:voucher->?voucher] ),`  
`Retract( ?customer[ex1:voucher->?voucher] ),` and  
`Modify( ?customer[ex1:voucher->?voucher] )` denote three atomic actions with the frame `?customer[ex1:voucher->?voucher]` as their target,
- `Retract( ?voucher )` denotes an atomic action whose target is the individual bound to the variable `?voucher`,
- `Execute( act:print("Hello, world!") )` denotes an atomic action whose target is the externally defined action `act:print`.  $\square$

### 3.1.2 Action blocks

The *action block* is the top level construct to represent the conclusions of RIF-PRD rules. An action block contains a non-empty sequence of atomic actions. It may also include *action variable declarations*.

The *action variable declaration* construct is used to declare variables that are local to the action block, called *action variables*, and to assign them a value within the action block.

**Definition (Action variable declaration).** An *action variable declaration* is a pair,  $(v\ p)$  made of an *action variable*,  $v$ , and an *action variable binding* (or, simply, *binding*),  $p$ , where  $p$  has one of two forms:

1. *frame object declaration*: if the action variable,  $v$ , is to be assigned the identifier of a new frame, then the action variable binding is a *frame object declaration*: `New()`. In that case, the notation for the action variable declaration is:  $(?o\ New())$ ;
2. *frame slot value*: if the action variable,  $v$ , is to be assigned the value of a slot of a ground frame, then the action variable binding is a frame:  $p = o[s \rightarrow v]$ , where  $o$  is a term that represents the identifier of the ground frame and  $s$  is a term that represents the name of the slot. The associated notation is:  $(?value\ o[s \rightarrow ?value])$ .  $\square$

**Definition (Action block).** If  $(v_1\ p_1), \dots, (v_n\ p_n), n \geq 0$ , are action variable declarations, and if  $a_1, \dots, a_m, m \geq 1$ , are atomic actions, then  $Do((v_1\ p_1) \dots (v_n\ p_n)\ a_1 \dots a_m)$  denotes an **action block**.  $\square$

**Example 3.2.** In the following action block, a local variable `?oldValue` is bound to a value of the attribute `value` of the object bound to the variable `?shoppingCart`. The `?oldValue` is then used to compute a new value, and the `Modify` action is used to overwrite the old value with the new value in the fact base:

```
Do( (?oldValue ?shoppingCart[ex1:value->?oldValue])
    Modify( ?shoppingCart[ex1:value->func:numeric-multiply(?oldValue 0.90)] )
```

$\square$

### 3.1.3 Well-formed action blocks

Not all action blocks are well-formed in RIF-PRD:

- one and only one action variable binding can assign a value to each action variable, and
- the assertion of a membership atomic formula is meaningful only if it is about a frame object that is created in the same action block.

The notion of well-formedness, already [defined for condition formulas](#), is extended to atomic actions, action variable declarations and action blocks.

**Definition (Well-formed atomic action).** An atomic action  $\alpha$  is **well-formed** if and only if one of the following is true:

- $\alpha$  is an `Assert` and its target is a well-formed atom, a well-formed frame or a well-formed membership atomic formula,
- $\alpha$  is a `Retract` and its target is a well-formed term or a well-formed atom or a well-formed frame atomic formula,
- $\alpha$  is a `Modify` and its target is a well-formed frame, or
- $\alpha$  is an `Execute` and its content is an instance of the coherent set of external schemas (Section [Schemas for Externally Defined Terms](#) of RIF data types and builtins [[RIF-DTB](#)]) associated with the RIF-PRD language (section [Built-in functions, predicates and actions](#)).  $\square$

**Definition (Well-formed action variable declaration).** An action variable declaration  $(?v p)$  is **well-formed** if and only if one of the following is true:

- the action variable binding,  $p$ , is the declaration of a new frame object:  $p = \text{New}()$ , or
- the action variable binding,  $p$ , is a well formed frame atomic formula,  $p = o[a_1 \rightarrow t_1 \dots a_n \rightarrow t_n]$ ,  $n \geq 1$ , and the action variable,  $v$  occurs in the position of a slot value, and nowhere else, that is:  $v \in \{t_1 \dots t_n\}$  and  $\forall t_i$ , either  $v = t_i$  or  $v \notin \text{Var}(t_i)$  and  $v \notin \text{Var}(o) \cup \text{Var}(a_1) \cup \dots \cup \text{Var}(a_n)$ .  $\square$

For the definition of a well-formed action block, the function  $\text{Var}(f)$ , that has been [defined for condition formulas](#), is extended to atomic actions and frame object declarations as follows:

- if  $f$  is an atomic action with target  $t$ , then  $\text{Var}(f) = \text{Var}(t)$ ;
- if  $f$  is a frame object declaration,  $\text{New}()$ , then  $\text{Var}(f) = \emptyset$ .

**Definition (Well-formed action block).** An action block is **well-formed** if and only if all of the following are true:

- all the action variable declarations, if any, are well-formed,
- each action variable, if any, is assigned a value by one and only one action binding, that is: if  $b_1 = (v_1 p_1)$  and  $b_2 = (v_2 p_2)$  are two action variable declarations in the action block with different bindings:  $p_1 \neq p_2$ , then  $v_1 \neq v_2$ ,
- in addition, the action variable declarations, if any, are partially ordered by the ordering defined as follows: if  $b_1 = (v_1 p_1)$  and  $b_2 = (v_2 p_2)$  are two action variable declarations in the action block, then  $b_1 \leq b_2$  if and only if  $v_1 \in \text{Var}(p_2)$ ,
- all the actions in the action block are well-formed atomic actions, and
- if an atomic action in the action block asserts a membership atomic formula,  $\text{Assert}(t_1 \# t_2)$ , then the object term in the membership atomic formula,  $t_1$ , is an action variable that is declared in the action block and the action variable binding is a [frame object declaration](#).  $\square$

**Definition (RIF-PRD action language).** The **RIF-PRD action language** consists of the set of all the well-formed action blocks.  $\square$

### 3.2 Operational semantics of atomic actions

This section specifies the semantics of the atomic actions in a RIF-PRD document.

The effect of the ground atomic actions in the RIF-PRD action language is to modify the state of the fact base, in such a way that it changes the set of conditions that are satisfied before and after each atomic action is performed.

As a consequence, the semantics of the ground atomic actions in the RIF-PRD action language determines a relation, called the *RIF-PRD transition relation*:  $\rightarrow_{\text{RIF-PRD}} \subseteq W \times L \times W$ , where  $W$  denotes the set of all the states of the fact base, and where  $L$  denotes the set of all the ground atomic actions in the RIF-PRD action language.

Individual states of the fact base are represented by sets of ground atomic formulas (Section [Satisfaction of a condition](#)). In the following, the operational semantics of RIF-PRD atomic actions, rules, and rule sets is specified by describing the changes they induce in the fact base.

**Definition (RIF-PRD transition relation).** The semantics of RIF-PRD atomic actions is specified by the **transition relation**  $\rightarrow_{\text{RIF-PRD}} \subseteq W \times L \times W$ .  $(w, \alpha, w') \in \rightarrow_{\text{RIF-PRD}}$  if and only if  $w \in W$ ,  $w' \in W$ ,  $\alpha$  is a ground atomic action, and one of the following is true:

1.  $\alpha$  is `Assert` ( $\varphi$ ), where  $\varphi$  is a ground atomic formula, and  $w' = w \cup \{\varphi\}$ ;
2.  $\alpha$  is `Retract` ( $\varphi$ ), where  $\varphi$  is a ground atomic formula, and  $w' = w \setminus \{\varphi\}$ ;
3.  $\alpha$  is `Retract` ( $o$ ), where  $o$  is a constant, and  $w' = w \setminus \{o[s \rightarrow v] \mid \text{for all the values of terms } s \text{ and } v\} - \{o\#c \mid \text{for all the values of term } c\}$ ;
4.  $\alpha$  is `Modify` ( $\varphi$ ), where  $\varphi$  is a ground atomic frame with object  $o$  and slot name  $s$ , and  $w' = (w \setminus \{o[s \rightarrow v] \mid \text{for all the values of term } v\}) \cup \{\varphi\}$ ;
5.  $\alpha$  is `Execute` ( $\varphi$ ), where  $\varphi$  is a ground atomic builtin action, and  $w' = w$ .

□

Rule 1 says that all the condition formulas that were satisfied before an assertion will be satisfied after, and that, in addition, the condition formulas that are satisfied by the asserted ground formula will be satisfied after the assertion. No other condition formula will be satisfied after the execution of the action.

Rule 2 says that all the condition formulas that were satisfied before a retraction will be satisfied after, except if they are satisfied only by the retracted fact. No other condition formula will be satisfied after the execution of the action.

Rule 3 says that all the condition formulas that were satisfied before the removal of a frame object will be satisfied after, except if they are satisfied only by one of the frame or membership formulas about the removed object or a conjunction of such formulas. No other condition formula will be satisfied after the execution of the action.

Rule 4 says that all the condition formulas that were satisfied before the modification of a frame object will be satisfied after, except if they are satisfied only by one of the frame formulas about the modified slot of the modified object, with the exception of the frame that is asserted as the target of the action, or a conjunction of such formulas. No other condition formula will be satisfied after the execution of the action.

Rule 5 says that all the condition formulas that were satisfied before the execution of an action builtin will be satisfied after. No other condition formula will be satisfied after the execution of the action.

**Example 3.3.** Assume an initial state of the fact base that is represented by the following set,  $w_0$ , of ground atomic formulas, where  $_c1$ ,  $_v1$  and  $_s1$  denote individuals and where  $ex1:Customer$ ,  $ex1:Voucher$  and  $ex1:ShoppingCart$  represent classes:

- *Initial state*
  - $w_0 = \{ \_c1\#ex1:Customer \_v1\#ex1:Voucher \_s1\#ex1:ShoppingCart \_c1[ex1:voucher-\>_v1] \_c1[ex1:shoppingCart-\>_s1] \_v1[ex1:value-\>5] \_s1[ex1:value-\>500] \}$
- *Assert(  $\_c1[ex1:status-\>"New"]$  ) denotes an atomic action that adds to the fact base, a fact that is represented by the ground atomic formula:  $\_c1[ex1:status-\>"New"]$ . After the action is executed, the new state of the fact base is represented by*
  - $w_1 = \{ \_c1\#ex1:Customer \_v1\#ex1:Voucher \_s1\#ex1:ShoppingCart \_c1[ex1:voucher-\>_v1] \_c1[ex1:shoppingCart-\>_s1] \_v1[ex1:value-\>5] \_s1[ex1:value-\>500] \_c1[ex1:status-\>"New"] \}$
- *Retract(  $\_c1[ex1:voucher-\>_v1]$  ) denotes an atomic action that removes from the fact base, the fact that is represented by the ground atomic formula  $\_c1[ex1:voucher-\>_v1]$ . After the action, the new state of the fact base is represented by:*
  - $w_2 = \{ \_c1\#ex1:Customer \_v1\#ex1:Voucher \_s1\#ex1:ShoppingCart \_c1[ex1:shoppingCart-\>_s1] \_v1[ex1:value-\>5] \_s1[ex1:value-\>500] \_c1[ex1:status-\>"New"] \}$
- *Retract(  $\_v1$  ) denotes an atomic action that removes the individual denoted by the constant  $\_v1$  from the fact base. All the class membership and the object-attribute-value facts where  $\_v1$  is the object are removed. After the action, the new state of the fact base is represented by:*
  - $w_3 = \{ \_c1\#ex1:Customer \_s1\#ex1:ShoppingCart \_c1[ex1:shoppingCart-\>_s1] \_s1[ex1:value-\>500] \_c1[ex1:status-\>"New"] \}$
- *Modify(  $\_s1[ex1:value-\>450]$  ) denotes an atomic action that replace all the object-attribute-value facts that assign a  $ex1:value$  to the  $ex1:ShoppingCart \_s1$  by the single fact that is represented by the*

ground frame:  $\_s1[ex1:value \rightarrow 450]$ . After the action, the new state of the fact base is represented by:

- $w4 = \{ \_c1\#ex1:Customer \_s1\#ex1:ShoppingCart \_c1[ex1:shoppingCart \rightarrow \_s1] \_s1[ex1:value \rightarrow 450] \_c1[ex1:status \rightarrow "New"] \}$
- *Execute*( [act:print](#) ([func:concat](#) ("New customer: "  $\_c1$ )) ) denotes an action that does not impact the state of the fact base, but that prints a string to an output stream. After the action, the new state of the fact base is represented by:
  - $w5 = w4 = \{ \_c1\#ex1:Customer \_s1\#ex1:ShoppingCart \_c1[ex1:shoppingCart \rightarrow \_s1] \_s1[ex1:value \rightarrow 450] \_c1[ex1:status \rightarrow "New"] \}$  □

## 4 Production rules and rule sets

This section specifies the syntax and semantics of RIF-PRD rules and rule sets.

### 4.1 Abstract syntax

The alphabet of the RIF-PRD rule language includes the alphabets of the [RIF-PRD condition language](#) and the [RIF-PRD action language](#) and adds symbols for:

- combining a condition and an action block into a rule,
- declaring (some) variables that are free in a rule  $R$ , specifying their bindings, and combining them with  $R$  into a new rule  $R'$  (with fewer free variables),
- grouping rules and associating specific operational semantics to groups of rules.

#### 4.1.1 Rules

**Definition (Rule).** A *rule* can be one of:

- an *unconditional action block*,
- a *conditional action block*: if *condition* is a formula in the RIF-PRD condition language, and if *action* is a well-formed action block, then *If condition, Then action* is a rule,
- a *rule with variable declaration*: if  $?v_1 \dots ?v_n$ ,  $n \geq 1$ , are variables;  $p_1 \dots p_m$ ,  $m \geq 1$ , are condition formulas (called *binding patterns*), and *rule* is a rule, then *Forall*  $?v_1 \dots ?v_n$  such that  $(p_1 \dots p_m)$  (*rule*) is a rule. □



**Example 4.1.** The Gold rule, from the [running example](#): A "Silver" customer with a shopping cart worth at least \$2,000 is awarded the "Gold" status, *can be represented using the following rule with variable declaration*:

```
Forall ?customer such that And( ?customer # ex1:Customer
                               ?customer[ex1:status->"Silver"] )
  (Forall ?shoppingCart such that And( ?shoppingCart # ex1:ShoppingCart
                                       ?customer[ex1:shoppingCart->?shoppingCart]
                                       (If Exists ?value (And( ?shoppingCart[ex1:value->?value]
                                                             pred:numeric-greater-than-or-equal(?value 2000))
                                       Then Do( Modify( ?customer[ex1:status->"Gold"] ) ) )
```

□

#### 4.1.2 Groups

As was already mentioned in the [Overview](#), production rules have an operational semantics that can be described in terms of matching rules against states of the fact base, selecting rule instances to be executed, and executing rule instances' actions to transition to new states of the fact base.

When production rules are interchanged, the intended rule instance selection strategy, often called the *conflict resolution strategy*, needs to be interchanged along with the rules. In RIF-PRD, the *group* construct is used to group sets of rules and to associate them with a conflict resolution strategy. Many production rule systems use priorities associated with rules as part of their conflict resolution strategy. In RIF-PRD, the group is also used to carry the priority information that may be associated with the interchanged rules.

**Definition (Group).** A *group* consists of a, possibly empty, set of rules and groups, associated with a resolution conflict strategy and, a priority. If *strategy* is an IRI that identifies a conflict resolution strategy, if *priority* is an integer, and if each  $rg_j$ ,  $0 \leq j \leq n$ , is either a rule or a group, then any of the following represents a group:

- Group ( $rg_0 \dots rg_n$ ),  $n \geq 0$ ;
- Group strategy ( $rg_0 \dots rg_n$ ),  $n \geq 0$ ;
- Group priority ( $rg_0 \dots rg_n$ ),  $n \geq 0$ ;
- Group strategy priority ( $rg_0 \dots rg_n$ ),  $n \geq 0$ .

If a conflict resolution strategy is not explicitly attached to a group, the strategy defaults to `rif:forwardChaining` (specified below, in [section Conflict resolution](#)). □

#### 4.1.3 Well-formed rules and groups

The function  $Var(f)$ , that has been [defined for condition formulas](#) and [extended to actions](#), is further extended to rules, as follows:

- if  $f$  is an action block that declares action variables  $?v_1 \dots ?v_n$ ,  $n \geq 0$ , and that contains actions  $a_1 \dots a_m$ ,  $m \geq 1$ , then  $Var(f) = \bigcup_{1 \leq i \leq m} Var(a_i) \setminus \{?v_1 \dots ?v_n\}$ ;
- if  $f$  is a conditional action block where  $c$  is the condition formula and  $a$  is the action block, then  $Var(f) = Var(c) \cup Var(a)$ ;
- if  $f$  is a quantified rule where  $?v_1 \dots ?v_n$ ,  $n > 0$ , are the declared variables;  $p_1 \dots p_m$ ,  $m \geq 0$ , are the binding patterns, and  $r$  is the rule, then  $Var(f) = (Var(r) \cup Var(p_1) \cup \dots \cup Var(p_m)) \setminus \{?v_1 \dots ?v_n\}$ .

If  $f$  is a rule,  $Var(f)$  is the set of the free variables in  $f$ . In addition, we define the functions  $CVar(r)$  and  $AVar(r)$ , that return, respectively, the set of the condition variables and the of the action variables in a rule,  $r$ .

- if  $r$  is an action block that declares action variables  $?v_1 \dots ?v_n$ ,  $n \geq 0$ , and that contains actions  $a_1 \dots a_m$ ,  $m \geq 1$ , then  $CVar(r) = \emptyset$  and  $AVar(r) = \bigcup_{1 \leq i \leq m} Var(a_i) \setminus \{?v_1 \dots ?v_n\}$ ;
- if  $r$  is a conditional action block where  $c$  is the condition formula and  $a$  is the action block, then  $CVar(r) = Var(c)$  and  $AVar(r) = AVar(a)$ ;
- if  $r$  is a rule with quantified variables,  $\text{Forall } ?v_1 \dots ?v_n$  such that  $(p_1 \dots p_m) (r')$ ,  $n \geq 1$ ,  $m \geq 0$ , then  $AVar(r) = AVar(r')$  and  $CVar(r) = CVar(r') \cup Var(p_1) \cup \dots \cup Var(p_m)$ .

The definition of the sets **UBV(r)** and **CBV(r)**, that have been [defined for condition formulas](#), is extended to any rule,  $r$ , as follows:

- if  $r$  is an unconditional action block, then  $UBV(r) = CBV(r) = \emptyset$ ; or
- else if  $r$  is a conditional action block,  $\text{if } C \text{ then } A$ , then  $UBV(r) = UBV(C)$  and  $CBV(r) = CBV(C)$ ; or
- else if  $r$  is a rule with declared variables,  $\text{Forall } ?v_1 \dots ?v_n$  such that  $(f_1 \dots f_{m-1}) (f_m)$ , where  $n \geq 1$ ,  $m \geq 1$ , and  $f_n$  is a rule, then consider the formula  $f' = \text{And}(f_1 \dots f_m)$ , and compute  $UBV(f')$  and  $CBV(f')$  (according to the definition in the section [Formulas](#)). Either
  - if  $\{v_1 \dots v_n\} \subseteq UBV(f')$ , that is, all the quantified variables are unconditionally bindable in  $f'$ , then
    1.  $UBV(f) = UBV(f') - \{v_1 \dots v_n\}$ ;
    2.  $CBV(f) = CBV(f')$ ;
    3.  $\forall v \in CBF(f)$ ,  $BCOND(v, f) = BCOND(v, f') - \{c \in BCOND(v, f') \mid c \cap \{v_1 \dots v_n\} \neq \emptyset\}$ : bindability conditions that depend on variables that are universally quantified in  $f$  are useless outside of  $f$ , and they are, accordingly, removed;

- else it is guaranteed that some of the quantified variables cannot be bound, at least not without constraint resolution, and  $UBV(f) = CBV(f) = \emptyset$ . We call such a rule **unsafe**, by extension of the notion of *safeness* that is defined in [RIF-Core].

RIF-PRD extends the definition of safeness in [RIF-Core] as follows.

**Definition (Safe rule).** A RIF-PRD rule,  $r$ , is **safe** if and only if and, either

- it is an unconditional or a conditional action block,
- or it is a rule with quantified variables,  $\text{Forall } ?v_1 \dots ?v_n$  such that  $(p_1 \dots p_m) (r')$ ,  $n \geq 1$ ,  $m \geq 0$ , and
  - $\{v_1 \dots v_n\} \subseteq UBV(\text{And}(p_1, \dots, p_m, r'))$ ,
  - and the binding patterns,  $p_1, \dots, p_m$ , if any, are all [safe condition formulas](#),
  - and the rule in the scope of the quantifier,  $r'$ , is safe,
  - and either  $\text{Var}(r) \neq \emptyset$  or  $\text{AVar}(r) \subseteq \text{CVar}(r)$ .  $\square$

A *safe rule set* contains only safe rules.

**Definition (Well-formed rule).** A rule,  $r$ , is a **well-formed rule** if and only if either

- $r$  is an unconditional [well-formed action block](#),  $a$ ,
- or  $r$  is a conditional action block where the condition formula,  $c$ , is a [well-formed condition formula](#), and the action block,  $a$ , is a [well-formed action block](#),
- or  $r$  is a quantified rule (with or without binding patterns),  $\text{Forall } V$  [such that  $P$ ] ( $r'$ ), and
  - each of the binding patterns,  $p_i \in P = \{p_1, \dots, p_n\}$ ,  $n \geq 0$ , is a [well-formed condition formula](#),
  - and the quantified rule,  $r'$ , is a well-formed rule.  $\square$

**Definition (Well-formed group).** A **well-formed group** is either:

- a group that contains no rule or group (an empty group), or
- a group,  $G$  that contains only well-formed groups,  $g_1 \dots g_n$ ,  $n \geq 0$ , and well-formed rules,  $r_1 \dots r_m$ ,  $m \geq 0$ , such that  $\forall r_i \in G$ ,  $\text{Var}(r_i) = \emptyset$  and  $\text{AVar}(r_i) \subseteq \text{CVar}(r_i)$ .  $\square$

The set of the well-formed groups contains all the production rule sets that can be meaningfully interchanged using RIF-PRD.

The specification of the operational semantics of rules and rule sets assumes that all the variables that occur in the action blocks of a rule are bound during the evaluation the condition or binding patterns of the same rule. It makes no assumption regarding how condition formulas, in the rules, are evaluated: it is not required, therefore, that a [well-formed group](#) contains only [safe rules](#). [RIF-PRD conformance](#), however, requires only processing of [safe rules](#).

## 4.2 Operational semantics of rules and rule sets

### 4.2.1 Motivation and example

As mentioned in the [Overview](#), the description of a production rule system as a transition system is used to specify the semantics of production rules and rule sets interchanged using RIF-PRD.

The intuition of describing a production rule system as a transition system is that, given a set of production rules  $RS$  and a fact base  $w_0$ , the rules in  $RS$  that are satisfied, in some sense, in  $w_0$  determine an action  $a_1$ , whose execution results in a new fact base  $w_1$ ; the rules in  $RS$  that are satisfied in  $w_1$  determine an action  $a_2$  to execute in  $w_1$ , and so on, until the system reaches a final state and stops. The result is the fact base  $w_n$  when the system stops.

**Example 4.2.** *The Rif Shop, Inc. is a rif-raf retail chain, with brick and mortar shops all over the world and virtual storefronts in many on-line shops. The Rif Shop, Inc. maintains its customer fidelity management policies in the form of production rule sets. The customer management department uses RIF-PRD to publish rule sets to all the shops and licensees so that everyone uses the latest version of the rules, even though several different rule engines are in use (in fact, some of the smallest shops actually run the rules by hand).*

*Here is a small rule set that governs discounts and customer status updates at checkout time (to keep the example short, this is a subset of the rules described in the [running example](#)):*

```
(* ex1:CheckoutRuleset *)
Group rif:forwardChaining (

  (* ex1:GoldRule *)
  Group 10 (
    Forall ?customer such that (And( ?customer # ex1:Customer
                                     ?customer[ex1:status->"Silver"] ) )
    (Forall ?shoppingCart such that (?customer[ex1:shoppingCart->?shoppingCart]
    (If Exists ?value (And( ?shoppingCart[ex1:value->?value]
                           pred:numeric-greater-than-or-equal(?value
    Then Do( Modify( ?customer[ex1:status->"Gold"] ) ) ) ) )

  (* ex1:DiscountRule *)
  Group (
    Forall ?customer such that (And( ?customer # ex1:Customer ) )
    (If Or (?customer[ex1:status->"Silver"]
           ?customer[ex1:status->"Gold"] )
    Then Do( (?s ?customer[ex1:shoppingCart->?s])
             (?v ?s[ex1:value->?v])
             Modify( ?s[ex1:value->func:numeric-multiply(?v 0.95)] ) ) ) )
```

To see how the rule set works, consider the case of a shop where the checkout processing of customer John is about to start. The initial state of the fact base can be represented as follows:

```
w0 = {_john#ex1:Customer _john[ex1:status->"Silver"]
      _s1#ex1:ShoppingCart _john[ex1:shoppingCart->_s1]
      _s1[ex1:value->2000]}
```

When instantiated against  $w_0$ , the first pattern in the "Gold rule":

*And( ?customer#ex1:Customer ?customer[ex1:status->"Silver"] )* yields the single matching substitution:  $\{(\_john/?customer)\}$ . The second pattern in the same rule also yields a single matching substitution:  $\{(\_john/?customer)(\_s1/?shoppingCart)\}$ , for which the existential condition is satisfied.

Likewise, the instantiation of the "Discount rule" yields a single matching substitution that satisfies the condition:  $\{(\_john/?customer)\}$ . The conflict set is:  $\{ex1:GoldRule/\{(\_john/?customer)(\_s1/?shoppingCart)\}, ex1:DiscountRule/\{(\_john/?customer)\}\}$

The instance  $ex1:GoldRule/\{(\_john/?customer)(\_s1/?shoppingCart)\}$  is selected because of its higher priority. The ground atomic action: *Modify(\_john[ex1:status->"Gold"])*, is executed, resulting in a new state of the fact base, represented as follows:

```
w1 = {_john#ex1:Customer _john[ex1:status->"Gold"]
      _s1#ex1:ShoppingCart _john[ex1:shoppingCart->_s1]
      _s1[ex1:value->2000]}
```

In the next cycle, there is no substitution for the rule variable  $?customer$  that matches the pattern to the state of the fact base, and the only matching rule instance is:  $ex1:DiscountRule/\{(\_john/?customer)\}$ , which is selected for execution. The action variables  $?s$  and  $?v$  are bound, based on the state of the fact base, to  $\_s1$  and 200, respectively, and the ground atomic action: *Modify(\_s1[ex1:value->1900])* is executed, resulting in a new state of the fact base:

```
w2 = {_john#ex1:Customer _john[ex1:status->"Gold"]
      _s1#ex1:ShoppingCart _john[ex1:shoppingCart->_s1]
      _s1[ex1:value->1900]}
```

In  $w_2$ , the only matching rule instance is, again:  $ex1:DiscountRule/\{(\_john/?customer)\}$ . However, that same instance has already been selected and the corresponding action has been executed. Nothing has changed in the state of the fact base that would justify that the rule instance be selected again. The principle of refraction applies, and the rule instance is removed from consideration.

This leaves the conflict set empty, and the system, having detected a final state, stops.

The result of the execution of the system is  $w_2$ .  $\square$

#### 4.2.2 Definitions and notational conventions

Formally, a production rule system is defined as a labeled terminal transition system (e.g. [PLO04](#)), for the purpose of specifying the semantics of a RIF-PRD [rule](#) or [group of rules](#).

**Definition (labeled terminal transition system):** A labeled terminal transition system is a structure  $\{\mathbf{C}, \mathbf{L}, \rightarrow, \mathbf{T}\}$ , where

- $\mathbf{C}$  is a set of elements,  $c$ , called configurations, or states;
- $\mathbf{L}$  is a set of elements,  $a$ , called labels, or actions;
- $\rightarrow \subseteq \mathbf{C} \times \mathbf{L} \times \mathbf{C}$  is the transition relation, that is:  $(c, a, c') \in \rightarrow$  iff there is a transition labeled  $a$  from the state  $c$  to the state  $c'$ . In the case of a production rule system: in the state  $c$  of the fact base, the execution of action  $a$  causes a transition to state the  $c'$  of the fact base;
- $\mathbf{T} \subseteq \mathbf{C}$  is the set of final states, that is, the set of all the states  $c$  from which there are no transitions:  $\mathbf{T} = \{c \in \mathbf{C} \mid \forall a \in \mathbf{L}, \forall c' \in \mathbf{C}, (c, a, c') \notin \rightarrow\}$ .  $\square$

For many purposes, a representation of the states of the fact base is an appropriate representation of the states of a production rule system seen as a transition system. However, the most widely used conflict resolution strategies require information about the history of the system, in particular with respect to the rule instances that have been selected for execution in previous states. Therefore, each state of the transition system used to represent a production rule system must keep a memory of the previous states and the rule instances that were selected and triggered the transition in those states.

To avoid confusion between the states of the fact base and the states of the transition system, the latter will be called *production rule system states*.

**Definition (Production rule system state).** A *production rule system state* (or, simply, a *system state*),  $s$ , is characterized by

- a state of the fact base,  $facts(s)$ ;
- if  $s$  is not the initial state: a previous system state,  $previous(s)$ , such that, given two system states  $s_1$  and  $s_2$ ,  $s_1 = previous(s_2)$  if and only if the sequential execution of the action parts of the rule instances in  $picked(s_1)$  transitioned the system from system state  $s_1$  to system state  $s_2$ ;
- if  $s$  is not the current state: the ordered set of rule instances,  $picked(s)$ , that the conflict resolution strategy picked, among the set of all the rule instances that matched  $facts(s)$ .  $\square$

Here, a *rule instance* is defined as the result of the substitution of constants for all the rule variables in a rule.

In the following, we will write  $previous(s) = NIL$  to denote that a system state  $s$  is the initial state.

Let  $R$  denote the set of all the rules in the rule language under consideration.

**Definition (Rule instance).** Given a rule,  $r \in R$ , and a [ground substitution](#),  $\sigma$ , such that  $CVar(r) \subseteq Dom(\sigma)$ , where  $CVar(r)$  denotes the set of the rule variables in  $r$ , the result,  $ri = \sigma(r)$ , of the substitution of the constant  $\sigma(?x)$  for each variable  $?x \in CVar(r)$  is a **rule instance** (or, simply, an **instance**) of  $r$ .  $\square$

Given a rule instance  $ri$ , let  $rule(ri)$  identify the rule from which  $ri$  is derived by substitution of constants for the rule variables, and let  $substitution(ri)$  denote the substitution by which  $ri$  is derived from  $rule(ri)$ .

In the following, two rule instances  $ri_1$  and  $ri_2$  of a same rule  $r$  will be considered *different* if and only if  $substitution(ri_1)$  and  $substitution(ri_2)$  substitute a different constant for at least one of the rule variables in  $CVar(r)$ .

In the [definition of a production rule system state](#), a rule instance,  $ri$ , is said to match a state of a fact base,  $w$ , if its defining substitution,  $substitution(ri)$ , matches the RIF-PRD condition formula that represents the condition of the instantiated rule,  $rule(ri)$ , to the set of ground atomic formulas that represents the state of facts  $w$ .

Let  $W$  denote the set of all the possible states of a fact base.

**Definition (Matching rule instance).** Given a rule instance,  $ri$ , and a state of the fact base,  $w \in W$ ,  $ri$  is said to **match**  $w$  if and only if one of the following is true:

- $rule(ri)$  is an [unconditional action block](#);
- $rule(ri)$  is a [conditional action block](#): If condition, Then action, and  $substitution(ri)$  [matches](#) the condition formula  $condition$  to the set of ground atomic condition formulas that represents  $w$ ;
- $rule(ri)$  is a [rule with variable declaration](#): For all  $?v_1 \dots ?v_n$  ( $p_1 \dots p_n$ ) ( $r'$ ),  $n \geq 0$ ,  $m \geq 0$ , and  $substitution(ri)$  [matches](#) each of the condition formulas  $p_i$ ,  $0 \leq i \leq m$ , to the set of ground atomic condition formulas that represents  $w$ , and the rule instance  $ri'$  matches  $w$ , where  $rule(ri') = r'$  and  $substitution(ri') = substitution(ri)$ .  $\square$

**Definition (Conflict set).** Given a rule set,  $RS \subseteq R$ , and a system state,  $s$ , the **conflict set** determined by  $RS$  in  $s$  is the set,  $conflictSet(RS, s)$  of all the different instances of the rules in  $RS$  that match the state of the fact base,  $facts(s) \in W$ .  $\square$

The rule instances that are in the conflict set are, sometimes, said to be *fireable*.

In each non-final state,  $s$ , of a production rule system, a subset,  $picked(s)$ , of the rule instances in the conflict set is selected and ordered; their action parts are instantiated, and the resulting sequence of ground atomic actions is executed. This is sometimes called: *firing* the selected instances.

**Definition (Action instance).** Given a system state,  $s$ , given a rule instance,  $ri$ , of a rule in a rule set,  $RS$ , and given the action block in the action part of the rule  $rule(ri): Do((v_1 p_1) \dots (v_n p_n) a_1 \dots a_m)$ ,  $n \geq 0$ ,  $m \geq 1$ , where the  $(v_i p_i)$ ,  $0 \leq i \leq n$ , represent the [action variable declarations](#) and the  $a_j$ ,  $1 \leq j \leq m$ , represent the sequence of atomic actions in the action block; if  $ri$  is a matching instance in the conflict set determined by  $RS$  in system state  $s$ :  $ri \in conflictSet(RS, s)$ , the substitution  $\sigma = substitution(ri)$  is extended to the action variables  $v_1 \dots v_n$ ,  $n \geq 0$ , in the following way:

- if the binding,  $p_i$ , associated to  $v_i$ , in the action variable declaration, is the declaration of a new frame object:  $(v_i New())$ , then  $\sigma(v_i) = c_{new}$ , where  $c_{new}$  is a constant of type `rif:IRI` that does not occur in any of the ground atomic formulas in the set that represents  $facts(s)$ , the state of the fact base that is associated to  $s$ ;
- if  $v_i$  is assigned the value of a frame's slot by the action variable declaration:  $(v_i o [s \rightarrow v_i])$ , then  $\sigma(v_i)$  is a constant such that the substitution  $\sigma$  [matches](#) the frame formula  $o [s \rightarrow v_i]$  to the state of the fact base  $facts(s)$ .

The sequence of ground atomic actions that is the result of substituting a constant for each variable in the atomic actions of the action block of the rule instance,  $ri$ , according to the extended substitution, is the **action instance** associated to  $ri$ .  $\square$

Let  $actions(ri)$  denote the action instance that is associated to a rule instance  $ri$ . By extension, given an ordered set of rule instances,  $ori$ ,  $actions(ori)$  denotes the sequence of ground atomic actions that is the concatenation, preserving the order in  $ori$ , of the action instances associated to the rule instances in  $ori$ .

#### 4.2.3 Operational semantics of a production rule system

All the elements that are required to define a production rule system as a [labeled terminal transition system](#) have now been defined.

**Definition (RIF-PRD Production Rule System).** A **RIF-PRD production rule system** is defined as a labeled terminal transition system  $PRS = \{S, A, \rightarrow_{PRS}, T\}$ , where :

- $S$  is a set of system states;
- $A$  is a set of transition labels, where each transition label is a sequence of ground RIF-PRD atomic actions;
- The transition relation  $\rightarrow_{PRS} \subseteq S \times A \times S$ , is defined as follows:  
 $\forall (s, a, s') \in S \times A \times S, (s, a, s') \in \rightarrow_{PRS}$  if and only if all of the following hold:
  1.  $(facts(s), a, facts(s')) \in \rightarrow_{RIF-PRD}^*$ , where  $\rightarrow_{RIF-PRD}^*$  denotes the transitive closure of the transition relation  $\rightarrow_{RIF-PRD}$  that is



- determined by the specification of the semantics of the atomic actions supported by RIF-PRD;
2.  $a = \text{actions}(\text{picked}(s))$ ;
- $T \subseteq S$ , a set of final system states.  $\square$

Intuitively, the first condition in the definition of the transition relation  $\rightarrow_{PRS}$  states that a production rule system can transition from one system state to another only if the state of facts in the latter system state can be reached from the state of facts in the former by performing a sequence of ground atomic actions supported by RIF-PRD, according to the [semantics of the atomic actions](#).

The second condition states that the allowed paths out of any given system state are determined only by how rule instances are *picked* for execution, from the conflict set, by the conflict resolution strategy.

Given a rule set  $RS \subseteq R$ , the associated conflict resolution strategy,  $LS$ , and halting test,  $H$ , and an initial state of the fact base,  $w \in W$ , the input function to a [RIF-PRD production rule system](#) is defined as:

$Eval(RS, LS, H, w) \rightarrow_{PRS}^* s \in S$ , such that  $facts(s) = w$  and  $previous(s) = NIL$ .  
Using  $\rightarrow_{PRS}$  to denote the transitive closure of the transition relation  $\rightarrow_{PRS}$ , there are zero, one or more final states of the system,  $s' \in T$ , such that:

$$Eval(RS, LS, H, w) \rightarrow_{PRS}^* s'$$

The execution of a rule set,  $RS$ , in a state,  $w$ , of a fact base, may result in zero, one or more final state of the fact base,  $w' = facts(s')$ , depending on the conflict resolution strategy and the set of final system states.

Therefore, the behavior of a [RIF-PRD production rule system](#) also depends on:

1. the conflict resolution strategy, that is, how rule instances are precisely selected for execution from the rule instances that match a given state of the fact base, and
2. how the set  $T$  of final system states is precisely defined.

#### 4.2.4 Conflict resolution

The process of selecting one or more [rule instances](#) from the [conflict set](#) for firing is often called: *conflict resolution*.

In RIF-PRD the conflict resolution algorithm (or conflict resolution *strategy*) that is intended for a set of rules is denoted by a keyword or a set of keywords that is attached to the rule set. In this version of the RIF-PRD specification, a single conflict resolution strategy is specified normatively: it is denoted by the keyword `rif:forwardChaining` (a constant of type `rif:IRI`), for it accounts for a common conflict resolution strategy used in most forward-chaining production rule systems. That conflict resolution strategy selects a single rule instance for execution.

Future versions of the RIF-PRD specification may specify normatively the intended conflict resolution strategies to be attached to additional keywords. In addition, RIF-

PRD documents may include non-standard keywords: it is the responsibility of the producers and consumers of such document to agree on the intended conflict resolution strategies that are denoted by such non-standard keywords. Future or non-standard conflict resolution strategies may select an ordered set of rule instances for execution, instead of a single one: the functions *picked* and *actions*, in the previous section, have been defined to take this case into account.

**Conflict resolution strategy: `rif:forwardChaining`**

Most existing production rule systems implement conflict resolution algorithms that are a combination of the following elements (under these or other, idiosyncratic names; and possibly combined with additional, idiosyncratic rules):

- *Refraction*. The essential idea of *refraction* is that a given instance of a rule must not be fired more than once as long as the reasons that made it eligible for firing hold. In other terms, if an instance has been fired in a given state of the system, it is no longer eligible for firing as long as it satisfies the states of facts associated to all the subsequent system states;
- *Priority*. The rule instances are ordered by priority of the instantiated rules, and only the rule instances with the highest priority are eligible for firing;
- *Recency*. the rule instances are ordered by the number of consecutive system states, or the number of consecutive cycles, in which they have been in the conflict set, and only the most recently fireable ones are eligible for firing. Note that the recency rule, used alone, results in depth-first processing.

Many existing production rule systems implement also some kind of *fire the most specific rule first* strategy, in combination with the above. However, whereas they agree on the definition of refraction and the priority or recency ordering, existing production rule systems vary widely on the precise definition of the specificity ordering. As a consequence, rule instance specificity was not included in the basic conflict resolution strategy that RIF-PRD specifies normatively.

The RIF-PRD keyword `rif:forwardChaining` denotes the common conflict resolution strategy that can be summarized as follows: given a conflict set

1. Refraction is applied to the conflict set, that is, all the refracted rule instances are removed from further consideration;
2. The remaining rule instances are ordered by decreasing priority, and only the rule instances with the highest priority are kept for further consideration;
3. The remaining rule instances are ordered by decreasing recency, and only the most recent rule instances are kept for further consideration;
4. Any remaining tie is broken in some way, and a single rule instance is kept for firing.

As specified earlier, *picked(s)* denotes the ordered list of the rule instances that were picked in a system state, *s*. Under the conflict resolution strategy denoted by

*rif:forwardChaining*, for any given system state, *s*, the list denoted by *picked(s)* contains a single rule instance.

Given a system state, *s*, a rule set, *RS*, and a rule instance,  $ri \in \text{conflictSet}(RS, s)$ , let *recency(ri, s)* denote the number of system states before *s*, in which *ri* has been continuously a matching instance: if *s* is the current system state, *recency(ri, s)* provides a measure of the recency of the rule instance *ri*. *recency(ri, s)* is specified recursively as follows:

- if *previous(s) = NIL*, then *recency(ri, s) = 1*;
- else if  $ri \in \text{conflictSet}(RS, \text{previous}(s))$ , then *recency(ri, s) = 1 + recency(ri, previous(s))*;
- else, *recency(ri, s) = 1*.

In the same way, given a rule instance, *ri*, and a system state, *s*, let *lastPicked(ri, s)* denote the number of system states before *s*, since *ri* has been last fired. *lastPicked(ri, s)* is specified recursively as follows:

- if *previous(s) = NIL*, then *lastPicked(ri, s) = 1*;
- else if  $ri \in \text{picked}(\text{previous}(s))$ , then *lastPicked(ri, s) = 1*;
- else, *lastPicked(ri, s) = 1 + lastPicked(ri, previous(s))*.

Given a rule instance, *ri*, let *priority(ri)* denote the priority that is associated to *rule(ri)*, or zero, if no priority is associated to *rule(ri)*. If *rule(ri)* is inside nested *Groups*, *priority(ri)* denotes the priority that is associated with the innermost *Group* to which a priority is explicitly associated, or zero.

**Example 4.3.** Consider the following RIF-PRD document:

```
Document (
  Prefix( ex2 <http://example.com/2009/prd3#> )
  (* ex2:ExampleRuleSet *)
  Group (
    (* ex2:Rule_1 *) Forall ...
    (* ex2:HighPriorityRules *)
    Group 10 (
      (* ex2:Rule_2 *) Forall ...
      (* ex2:Rule_3 *)
      Group 9 (Forall ... ) )
    (* ex2:NoPriorityRules *)
    Group (
      (* ex2:Rule_4 *) Forall ...
      (* ex2:Rule_5 *) Forall ... )
  )
)
```

*No conflict resolution strategy is identified explicitly, so the default strategy *rif:forwardChaining* is used.*

Because the `ex2:ExampleRuleSet` group does not specify a priority, the default priority 0 is used. Rule 1, not being in any other group, inherits its priority, 0, from the top-level group.

Rule 2 inherits its priority, 10, from the enclosing group, identified as `ex2:HighPriorityRules`. Rule 3 specifies its own, lower, priority: 9.

Since neither Rule 4 nor Rule 5 specify a priority, they inherit their priority from the enclosing group `ex2:NoPriorityRules`, which does not specify one either, and, thus, they inherit 0 from the top-level group, `ex2:ExampleRuleSet`. □

Given a set of rule instances, `cs`, the conflict resolution strategy `rif:forwardChaining` can now be described with the help of four rules, where `ri` and `ri'` are rule instances:

1. **Refraction rule:** if  $ri \in cs$  and  $lastPicked(ri, s) < recency(ri, s)$ , then  $cs = cs - ri$ ;
2. **Priority rule:** if  $ri \in cs$  and  $ri' \in cs$  and  $priority(ri) < priority(ri')$ , then  $cs = cs - ri$ ;
3. **Recency rule:** if  $ri \in cs$  and  $ri' \in cs$  and  $recency(ri, s) > recency(ri', s)$ , then  $cs = cs - ri$ ;
4. **Tie-break rule:** if  $ri \in cs$ , then  $cs = \{ri\}$ . RIF-PRD does not specify the tie-break rule more precisely: how a single instance is selected from the remaining set is implementation specific.

The *refraction rule* removes the instances that have been in the conflict set in all the system states at least since they were last fired; the *priority rule* removes the instances such that there is at least one instance with a higher priority; the *recency rule* removes the instances such that there is at least one instance that is more recent; and the *tie-break rule* keeps one rule from the set.

To select the singleton rule instance, *picked(s)*, to be fired in a system state, `s`, given a rule set, `RS`, the conflict resolution strategy denoted by the keyword `rif:forwardChaining` consists of the following sequence of steps:

1. initialize *picked(s)* with the conflict set, that a rule set `RS` determines in a system state `s`:  $picked(s) = conflictSet(RS, s)$ ;
2. apply the *refraction rule* to all the rule instances in *picked(s)*;
3. then apply the *priority rule* to all the remaining instances in *picked(s)*;
4. then apply the *recency rule* to all the remaining instances in *picked(s)*;
5. then apply the *tie-break rule* to the remaining instance in *picked(s)*;
6. return *picked(s)*.

**Example 4.4.** Consider, from [example 4.2](#), the conflict set that the rule set `ex1:CheckoutRuleset` determines in the system state, `s2`, that corresponds to the state `w2 = facts(s2)` of the fact base, and use it to initialize the set of rule instance considered for firing, *picked(s<sub>2</sub>)*:

$conflictSet(ex1 : CheckoutRuleset, s2) = \{ ex1:DiscountRule/\{(\_john/?customer)\} \} = picked(s2)$

The single rule instance in the conflict set,  $ri = ex1:DiscountRule/\{(\_john/?customer)\}$ , did already belong to the conflict sets in the two previous states,  $conflictSet(ex1 : CheckoutRuleset, s1)$  and  $conflictSet(ex1 : CheckoutRuleset, s0)$ ; so that its recency in  $s2$  is:  $recency(ri, s2) = 3$ .

On the other hand, that rule instance was fired in system state  $s1$ :  $picked(s1) = (ex1:DiscountRule/\{(\_john/?customer)\})$ ; so that, in  $s2$ , it has been last fired one cycle before:  $lastPicked(ri, s2) = 1$ .

Therefore,  $lastPicked(ri, s2) < recency(ri, s2)$ , and  $ri$  is removed from  $picked(s2)$  by refraction, leaving  $picked(s2)$  empty.  $\square$

#### 4.2.5 Halting test

By default, a system state is final, given a rule set,  $RS$ , and a conflict resolution strategy,  $LS$ , if there is no rule instance available for firing after application of the conflict resolution strategy.

For the conflict resolution strategy identified by the RIF-PRD keyword `rif:forwardChaining`, a system state,  $s$ , is **final** given a rule set,  $RS$  if and only if the remaining conflict set is empty after application of the *refraction rule* to all the rule instances in  $conflictSet(RS, s)$ . In particular, all the system states,  $s$ , such that  $conflictSet(RS, s) = \emptyset$  are final.

## 5 Document and imports

This section specifies the structure of a RIF-PRD document and its semantics when it includes import directives.

### 5.1 Abstract syntax

In addition to the language of conditions, actions, and rules, RIF-PRD provides a construct to denote the import of a RIF or non-RIF document. Import enables the modular interchange of RIF documents, and the interchange of combinations of multiple RIF and non-RIF documents.

#### 5.1.1 Import directive

**Definition (Import directive).** An *import directive* consists of:

- an IRI, the *locator*, that identifies and locates the document to be imported, and
- an optional second IRI that identifies the *profile* of the import.  $\square$

RIF-PRD gives meaning to one-argument import directives only. Such directives can be used to import other RIF-PRD and RIF-Core documents. Two-argument import directives are provided to enable import of other types of documents, and their semantics is covered by other specifications. For example, the syntax and semantics of the import of RDF and OWL documents, and their combination with a RIF document, is specified in [\[RIF-RDF+OWL\]](#).

### 5.1.2 RIF-PRD document

**Definition (RIF-PRD document).** A RIF-PRD *document* consists of zero or more import directives, and zero or one [group](#). □

**Definition (Imported document).** A document is said to be *directly imported* by a RIF document, *D*, if and only if it is identified by the locator IRI in an import directive in *D*. A document is said to be *imported* by a RIF document, *D*, if it is directly imported by *D*, or if it is imported, directly or not, by a RIF document that is directly imported by *D*. □

### 5.1.3 Well-formed documents

**Definition (Conflict resolution strategy associated with a document).** A *conflict resolution strategy is associated with a RIF-PRD document*, *D*, if and only if

- it is explicitly or implicitly attached to the top-level group in *D*, or
- it is explicitly or implicitly attached to the top-level group in a RIF-PRD document that is imported by *D*. □

**Definition (Well-formed RIF-PRD document).** A RIF-PRD document, *D*, is *well-formed* if and only if it satisfies all the following conditions:

- the locator IRI provided by all the import directives in *D*, if any, identify well-formed RIF-PRD documents,
- *D* contains a well-formed group or no group at all,
- *D* has only one associated conflict resolution strategy (that is, all the conflict resolution strategies that can be associated with it are the same), and
- every non-`rif:local` constant that occurs in *D* or in one of the documents imported by *D*, occurs in the same context in *D* and in all the documents imported by *D*. □

The last condition in the above definition makes the intent behind the `rif:local` constants clear: occurrences of such constants in different documents can be interpreted differently even if they have the same name. Therefore, each document can choose the names for the `rif:local` constants freely and without regard to the names of such constants used in the imported documents.

## 5.2 Operational semantics of RIF-PRD documents

The semantics of a [well-formed RIF-PRD document](#) that contains no import directive is the semantics of the rule set that is represented by the top-level group in the document, evaluated with the [conflict resolution strategy that is associated to the document](#), and the default halting test, as specified above, in [section Halting test](#).

The semantics of a [well-formed RIF-PRD document](#),  $D$ , that imports the [well-formed RIF-PRD documents](#)  $D_1, \dots, D_n, n \geq 1$ , is the semantics of the rule set that is the union of the rule sets represented by the top-level groups in  $D$  and the imported documents, with the `rif:local` constants renamed to ensure that the same symbol does not occur in two different component rule sets, and evaluated with the [conflict resolution strategy that is associated to the document](#), and the [default halting test](#).

## 6 Built-in functions, predicates and actions

In addition to externally specified functions and predicates, and in particular, in addition to the functions and predicates built-ins defined in [\[RIF-DTB\]](#), RIF-PRD supports externally specified actions, and defines action built-ins.

The syntax and semantics of action built-ins are specified like for the other built-ins, as described in the [section Syntax and Semantics of Built-ins](#) in [\[RIF-DTB\]](#). However, their formal semantics is trivial: action built-ins behave like predicates that are always true, since action built-ins, in RIF-PRD, MUST NOT affect the semantics of the rules.

Although they must not affect the semantics of the rules, action built-ins may have other side effects.

RIF action built-ins are defined in the namespace: <http://www.w3.org/2007/rif-builtin-action#>. In this document, we will use the prefix: `act:` to denote the RIF action built-ins namespace.

### 6.1 Built-in actions

#### 6.1.1 `act:print`

- *Schema:*

```
(?arg; act:print(?arg))
```

- *Domains:*

The value space of the single argument is `xs:string`.

- *Mapping:*

When  $s$  belongs to its domain,  $I_{\text{truth}} \circ I_{\text{External}}(\text{?arg; act:print(?arg)})(s) = t$ .

If an argument value is outside of its domain, the truth value of the function is left unspecified.

- *Side effects:*

The value of the argument **MUST** be printed to an output stream, to be determined by the user implementation.

## 7 Conformance and interoperability

### 7.1 Semantics-preserving transformations

RIF-PRD conformance is described partially in terms of semantics-preserving transformations.

The intuitive idea is that, for any initial state of facts, the conformant consumer of a conformant RIF-PRD document must reach at least one of the final state of facts intended by the conformant producer of the document, and that it must never reach any final state of facts that was not intended by the producer. That is:

- a conformant RIF-PRD producer,  $P$ , must translate any rule set from its own rule language,  $L_P$ , into RIF-PRD, in such a way that, for any possible initial state of the fact base, the RIF-PRD translation of the rule set must never produce, according to the semantics specified in this document, a final state of the fact base that would not be a possible result of the execution of the rule set according to the semantics of  $L_P$  (where the state of the facts base are meant to be represented in  $L_P$  or in RIF-PRD as appropriate), and
- a conformant RIF-PRD consumer,  $C$ , must translate any rule set from a RIF-PRD document into a rule set in its own language,  $L_C$ , in such a way that, for any possible initial state of the fact base, the translation in  $L_C$  of the rule set, must never produce, according to the semantics of  $L_C$ , a final state of the fact base that would not be a possible result of the execution of the rule set according to the semantics specified in this document (where the state of the facts base are meant to be represented in  $L_C$  or in RIF-PRD as appropriate).

Let  $T$  be a set of datatypes and symbol spaces that includes the datatypes specified in [\[RIF-DTB\]](#) and the symbol spaces `rif:iri` and `rif:local`. Suppose also that  $E$  is a set of external predicates and functions that includes the built-ins listed in [\[RIF-DTB\]](#) and in the [section Built-in actions](#). We say that a rule  $r$  is a *RIF-PRD<sub>T,E</sub>* rule if and only if

- $r$  is a [well-formed RIF-PRD rule](#),



- all the datatypes and symbol spaces used in  $r$  are in  $T$ , and
- all the externally defined functions and predicates used in  $r$  are in  $E$ .

Suppose, further, that  $C$  is a set of conflict resolution strategies that includes the one specified in [section Conflict resolution](#), and that  $H$  is a set of halting tests that includes the one specified in [section Halting test](#): we say that a rule set  $R$ , is a  $RIF-PRD_{T,E,C,H}$  rule set if and only if

- $R$  contains only  $RIF-PRD_{T,E}$  rules,
- the conflict resolution strategy that is associated to  $R$  is in  $C$ , and
- the halting test that is associated to  $R$  is in  $H$ .

Given a  $RIF-PRD_{T,E,C,H}$  rule set,  $R$ , an initial state of the fact base,  $w$ , a conflict resolution strategy  $c \in C$  and a halting test  $h \in H$ , let  $F_{R,w,c,h}$  denote the set of all the sets,  $f$ , of RIF-PRD ground atomic formulas that represent final states of the fact base,  $w'$ , according to the [operational semantics of a RIF-PRD production rule system](#), that is:  $f \in F_{R,w,c,h}$  if and only if there is a state,  $s'$ , of the system, such that  $Eval(R, c, h, w) \rightarrow_{PRS} s'$  and  $w' = facts(s')$  and  $f$  is a representation of  $w'$ .

In addition, given a rule language,  $L$ , a rule set expressed in  $L$ ,  $R_L$ , a conflict resolution strategy,  $c$ , a halting test,  $h$ , and an initial state of the fact base,  $w$ , let  $F_{L,R_L,c,h,w}$  denote the set of all the formulas in  $L$  that represent a final state of the fact base that an  $L$  processor can possibly reach.

**Definition (Semantics preserving mapping).**

- A mapping from a  $RIF-PRD_{T,E,C,H}$ ,  $R$ , to a rule set,  $R_L$ , expressed in a language  $L$ , is **semantics-preserving** if and only if, for any initial state of the fact base,  $w$ , conflict resolution strategy,  $c$ , and halting test,  $h$ , it also maps each  $L$  formula in  $F_{L,R_L,c,h,w}$  onto a set of RIF-PRD ground formulas in  $F_{R,w,c,h}$ ;
- A mapping from a rule set,  $R_L$ , expressed in a language  $L$ , to a  $RIF-PRD_{T,E,C,H}$ ,  $R$ , is **semantics-preserving** if and only if, for any initial state of the fact base,  $w$ , conflict resolution strategy,  $c$ , and halting test,  $h$ , it also maps each set of ground RIF-PRD atomic formulas in  $F_{R,w,c,h}$  onto an  $L$  formula in  $F_{L,R_L,c,h,w}$ .  $\square$

## 7.2 Conformance Clauses

**Definition (RIF-PRD conformance).**

- A RIF processor is a **conformant RIF-PRD<sub>T,E,C,H</sub> consumer** iff it implements a [semantics-preserving mapping](#) from the set of all [safe RIF-PRD<sub>T,E,C,H</sub>](#) rule sets to the language  $L$  of the processor;
- A RIF processor is a **conformant RIF-PRD<sub>T,E,C,H</sub> producer** iff it implements a [semantics-preserving mapping](#) from a subset of the language  $L$  of the processor to a set of [safe RIF-PRD<sub>T,E,C,H</sub>](#) rule sets;
- An **admissible document** is an XML document that conforms to all the syntactic constraints of RIF-PRD, including ones that cannot be checked by an XML Schema validator;

- A **conformant RIF-PRD consumer** is a conformant RIF-PRD<sub>T,E,C,H</sub> consumer in which T consists only of the symbol spaces and datatypes, E consists only of the externally defined functions and predicates, C consists only of the conflict resolution strategies, and H consists only of halting tests that are required by RIF-PRD. The required symbol spaces are `rif:iri` and `rif:local`, and the datatypes and externally defined terms (built-ins) are the ones specified in [RIF-DTB] and in the [section Built-in actions](#). The required conflict resolution strategy is the one that is identified as `rif:forwardChaining`, as specified in [section Conflict resolution](#); and the required halting test is the one specified in [section Halting test](#). A conformant RIF-PRD consumer must reject all inputs that do not match the syntax of RIF-PRD. If it implements extensions, it may do so under user control -- having a "strict RIF-PRD" mode and a "run-with-extensions" mode;
- A **conformant RIF-PRD producer** is a conformant RIF-PRD<sub>T,E,C,H</sub> producer which produces documents that include only the symbol spaces, datatypes, externals, conflict resolution strategies and halting tests that are required by RIF-PRD. □

In addition, conformant RIF-PRD producers and consumers SHOULD preserve annotations.

#### Feature At Risk #1: Strictness Requirement

*Note: This feature is "at risk" and may be removed from this specification based on feedback. Please send feedback to [public-rif-comments@w3.org](mailto:public-rif-comments@w3.org).*

The two preceding clauses are features **AT RISK**. In particular, the "strictness" requirement is under discussion.

### 7.3 Interoperability

[RIF-Core] is specified as a specialization of RIF-PRD: all valid [RIF-Core] documents are valid RIF-PRD documents and must be accepted by any conformant RIF-PRD consumer.

Conversely, it is desirable that any valid RIF-PRD document that uses only abstract syntax that is defined in [RIF-Core] be a valid [RIF-Core] document as well. For some abstract constructs that are defined in both RIF-Core and RIF-PRD, RIF-PRD defines alternative XML syntax that is not valid RIF-Core XML syntax. For example, an [action block](#) that contains no [action variable declaration](#) and only [assert atomic actions](#) can be expressed in RIF-PRD using the XML elements `Do` or `And`. Only the latter option is valid RIF-Core XML syntax.

To maximize interoperability with RIF-Core and its non-RIF-PRD extensions, a conformant RIF-PRD consumer SHOULD produce valid [RIF-Core] documents

whenever possible. Specifically, a conformant RIF-PRD producer SHOULD use only valid [\[RIF-Core\]](#) XML syntax to serialize a rule set that satisfies all of the following:

- the conflict resolution strategy is effectively equivalent to the strategy that RIF-PRD identifies by the IRI [rif:forwardChaining](#),
- no [condition formula](#) contains a negation, in any rule in the rule set,
- no rule in the rule set has an [action block](#) that contains a [action variable declaration](#), and
- in all the rules in the rule set, the [action block](#) contains only [assert atomic actions](#).

When processing a rule set that satisfies all the above conditions, a RIF-PRD producer is guaranteed to produce a valid [\[RIF-Core\]](#) XML document by applying the following rules recursively:

1. *Remove redundant information.* The `behavior` role element and all its sub-elements should be omitted in the RIF-PRD XML document;
2. *Remove nested rule variable declarations.* If the `rule` inside a [rule with variable declaration](#),  $r_1$ , is also a [rule with variable declaration](#),  $r_2$ , all the rule variable declarations and all the binding patterns that occur in  $r_1$  (and not in  $r_2$ ) should be added to the rule variable declarations and the binding patterns that occur in  $r_2$ , and, after the transform,  $r_1$  should be replaced by  $r_2$ , in the rule set;
3. *Remove binding patterns.* If a binding pattern occurs in a [rule with variable declaration](#),  $r_1$ :
  - if the `rule` inside  $r_1$  is a [unconditional action block](#),  $r_2$ ,  $r_2$  should be transformed into a [conditional action block](#), where the condition is the binding pattern, and the binding pattern should be removed from  $r_1$ ,
  - if the `rule` inside  $r_1$  is a [conditional action block](#),  $r_2$ , the formula that represents the condition in  $r_2$  should be replaced by the conjunction of that formula and the formula that represents the binding pattern, and the binding pattern should be removed from  $r_1$ ;
4. *Convert action blocks.* The action block, in each rule, should be replaced by a conjunction, and, inside the conjunction, each [assert action](#) should be replaced by its target atomic formula.

**Example 7.1.** Consider the following rule,  $R$ , derived from the Gold rule, in the [running example](#), to have only assertions in the action part:

```
R: Forall ?customer such that (And( ?customer # ex1:Customer
                                ?customer[status->"Silver"] ) )
  (Forall ?shoppingCart such that (?customer[shoppingCart->?shoppingCart]
  (If Exists ?value (And( ?shoppingCart[value->?value]
                        pred:numeric-greater-than-or-equal(?value
```

```

Then Do( Assert(ex1:Foo(?customer))
        Assert(ex1:Bar(?shoppingCart)) ) ) )

```

The serialization of R in the following RIF-Core conformant XML form does not impact its semantics (see [example 7.12](#) for another valid RIF-PRD XML serialization, that is not RIF-Core conformant):

```

<Forall>
  <declare><Var>?customer</Var></declare>
  <declare><Var>?shoppingCart</Var></declare>
  <formula>
    <Implies>
      <if>
        <And>
          <formula> <!-- first pattern -->
            <And>
              <formula><Member> ... </Member></formula>
              <formula><Frame> ... </Frame></formula>
            </And>
          </formula>
          <formula> <!-- second pattern -->
            <Member> ... </Member>
          </formula>
          <formula> <!-- original existential condition -->
            ...
          </formula>
        </And>
      </if>
      <then>
        <And>
          <formula> <!-- serialization of ex1:Foo(?customer) -->
            ...
          </formula>
          <formula> <!-- serialization of ex1:Bar(?shoppingCart) -->
            ...
          </formula>
        </And>
      </then>
    </Implies>
  </formula>
</Forall>

```

## 8 XML Syntax

This section specifies the concrete XML syntax of RIF-PRD. The concrete syntax is derived from the abstract syntax defined in sections 2.1, 3.1 and 4.1 using simple mappings. The semantics of the concrete syntax is the same as the semantics of the abstract syntax.

## 8.1 Notational conventions

### 8.1.1 Namespaces

Throughout this document, the `xsd:` prefix stands for the XML Schema namespace URI `http://www.w3.org/2001/XMLSchema#`, the `rdf:` prefix stands for `http://www.w3.org/1999/02/22-rdf-syntax-ns#`, and `rif:` stands for the URI of the RIF namespace, `http://www.w3.org/2007/rif#`.

Syntax such as `xsd:string` should be understood as a compact URI ([CURIE](#)) -- a macro that expands to a concatenation of the character sequence denoted by the prefix `xsd` and the string `string`. The compact URI notation is used for brevity only, and `xsd:string` should be understood, in this document, as an abbreviation for `http://www.w3.org/2001/XMLSchema#string`.

### 8.1.2 BNF pseudo-schemas

The XML syntax of RIF-PRD is specified for each component as a pseudo-schema, as part of the description of the component. The pseudo-schemas use BNF-style conventions for attributes and elements: "?" denotes optionality (i.e. zero or one occurrences), "\*" denotes zero or more occurrences, "+" one or more occurrences, "[" and "]" are used to form groups, and "|" represents choice. Attributes are conventionally assigned a value which corresponds to their type, as defined in the normative schema. Elements are conventionally assigned a value which is the name of the syntactic class of their content, as defined in the normative schema.

```
<!-- sample pseudo-schema -->
  <defined_element
    required_attribute_of_type_string="xs:string"
    optional_attribute_of_type_int="xs:int"? >
    <required_element />
    <optional_element />?
    <one_or_more_of_these_elements />+
    [ <choice_1 /> | <choice_2 /> ]*
  </defined_element>
```

### 8.1.3 Syntactic components

Three kinds of syntactic components are used to specify RIF-PRD:

- **Abstract classes** are defined only by their subclasses: they are not visible in the XML markup and can be thought of as extension points. In this document, abstract constructs will be denoted with all-uppercase names;

- **Concrete classes** have a concrete definition, and they are associated with specific XML markup. In this document, concrete constructs will be denoted with CamelCase names with leading capital letter;
- **Properties**, or *roles*, define how two classes relate to each other. They have concrete definitions and are associated with specific XML markup. In this document, properties will be denoted with camelCase names with leading lowercase letter.

## 8.2 Conditions

This section specifies the XML constructs that are used in RIF-PRD to serialize [condition formulas](#).

### 8.2.1 TERM

The `TERM` class of constructs is used to serialize [terms](#), be they [simple terms](#), that is, constants and variables; lists; or [positional terms](#), the latter being, per the definition of a [well-formed formula](#), representations of externally defined functions.

As an abstract class, `TERM` is not associated with specific XML markup in RIF-PRD instance documents.

[ *Const* | *Var* | *List* | *External* ]

#### 8.2.1.1 Const

In RIF, the `Const` element is used to serialize a [constant](#).

The `Const` element has a required `type` attribute and an optional `xml:lang` attribute:

- The value of the `type` attribute is the identifier of the `Const` symbol space. It must be a `rif:iri`;
- The `xml:lang` attribute, as defined by [2.12 Language Identification of XML 1.0](#) or its successor specifications in the W3C recommendation track, is optionally used to identify the language for the presentation of the `Const` to the user. It is allowed only in association with constants of the type `rif:text`. A compliant implementation **MUST** ignore the `xml:lang` attribute if the type of the `Const` is not `rif:text`.

The content of the `Const` element is the constant's literal, which can be any Unicode character string.

```
<Const type=rif:iri [xml:lang=xsd:language]? >
  Any Unicode string
</Const>
```

**Example 8.1.**

a. A constant with built-in type `xsd:integer` and value 2,000:

```
<Const type="xsd:integer">2000</Const>
```

b. The `Customer` class, in the [running example](#), is identified by a constant of type `rif:iri`, in the namespace `http://example.com/2009/prd2#`:

```
<Const type="rif:iri">
  http://example.com/2009/prd2#Customer
</Const>
```

c. A constant with non built-in type `xsd:int` and value 123:

```
<Const type="xsd:int">123</Const>
```

**8.2.1.2 Var**

In RIF, the `Var` element is used to serialize a [variable](#).

The content of the `Var` element is the variable's name, serialized as an Unicode character string.

```
<Var> any Unicode string </Var>
```

**8.2.1.3 List**

In RIF, the `List` element is used to serialize a [list](#).

The `List` element contains either zero or more `TERMS` (without variables) that serialise the elements of the list. The order of the sub-elements is significant and **MUST** be preserved.

```
<List>
  GROUNDTERM*
</List>
```

**Example 8.2.**

```
<List>
  <Const type="xsd:string"> New </Const>
  <Const type="xsd:string"> Bronze </Const>
  <Const type="xsd:string"> Silver </Const>
  <Const type="xsd:string"> Gold </Const>
</List>
```

#### 8.2.1.4 External

As a `TERM`, the `External` element is used to serialize a [positional term](#). In RIF-PRD, a positional term represents always a call to an externally defined function, e.g. a built-in, a user-defined function, a query to an external data source, etc.

The `External` element contains one `content` element, which in turn contains one `Expr` element that contains one `op` element, followed zero or one `args` element:

- The `External` and the `content` elements ensure compatibility with the RIF Basic Logic Dialect [\[RIF-BLD\]](#) that allows non-evaluated (that is, logic) functions to be serialized using an `Expr` element alone;
- The content of the `op` element must be a `Const`. When the `External` is a `TERM`, the content of the `op` element serializes a constant symbol of type `rif:iri` that must uniquely identify the external defined function to be applied to the `args` `TERMS`;
- The optional `args` element contains one or more constructs from the `TERM` abstract class. The `args` element is used to serialize the arguments of a [positional term](#). The order of the `args` sub-elements is, therefore, significant and **MUST** be preserved. This is emphasized by the required value "yes" of the attribute `rif:ordered`.

```
<External>
  <content>
    <Expr>
      <op> Const </op>
      <args rif:ordered="yes"> TERM+ </args>?
    </Expr>
  </content>
</External>
```

**Example 8.3.** The example shows one way to serialize, in RIF-PRD, the product of a variable named `?value` and the `xsd:decimal` value 0.9, where the operation conforms to the specification of the built-in [func:numeric-multiply](#), as specified in [\[RIF-DTB\]](#).

RIF built-in functions are associated with the namespace <http://www.w3.org/2007/rif-builtin-function#>.

```
<External>
  <content>
    <Expr>
      <op> <Const type="rif:iri"> http://www.w3.org/2007/rif-builtin-fun
      <args rif:ordered="yes">
        <Var> ?value </Var>
        <Const type="xsd:decimal"> 0.9 </Const>
```



```

        </args>
      </Expr>
    </content>
  </External>

```

## 8.2.2 ATOMIC

The `ATOMIC` class is used to serialize [atomic formulas](#): positional atoms, equality, membership and subclass atomic formulas, frame atomic formulas and externally defined atomic formulas.

As an abstract class, `ATOMIC` is not associated with specific XML markup in RIF-PRD instance documents.

```
[ Atom | Equal | Member | Subclass | Frame | External ]
```

### 8.2.2.1 Atom

In RIF, the `Atom` element is used to serialize a [positional atomic formula](#).

The `Atom` element contains one `op` element, followed by zero or one `args` element:

- The content of the `op` element must be a `Const`. It serializes the predicate symbol (the name of a relation);
- The optional `args` element contains one or more constructs from the `TERM` abstract class. The `args` element is used to serialize the arguments of a [positional atomic formula](#). The order of the `arg`'s sub-elements is, therefore, significant and MUST be preserved. This is emphasized by the required value "yes" of the attribute `ordered`.

```

<Atom>
  <op> Const </op>
  <args ordered="yes"> TERM+ </args>?
</Atom>

```

**Example 8.4.** The example shows the RIF XML serialization of the positional atom `ex1:gold(?customer)`, where the predicate symbol `gold` is defined in the example namespace `http://example.com/2009/prd2#`.

```

<Atom>
  <op>
    <Const type="rif:iri">
      http://example.com/2009/prd2#gold
    </Const>
  </op>
  <args ordered="yes">

```

```

    <Var> ?customer </Var>
  </args>
</Atom>

```

### 8.2.2.2 Equal

In RIF, the `Equal` element is used to serialize [equality atomic formulas](#).

The `Equal` element must contain one `left` sub-element and one `right` sub-element. The content of the `left` and `right` elements must be a construct from the `TERM` abstract class, that serialize the terms of the equality. The order of the sub-elements is not significant.

```

<Equal>
  <left> TERM </left>
  <right> TERM </right>
</Equal>

```

### 8.2.2.3 Member

In RIF, the `Member` element is used to serialize [membership atomic formulas](#).

The `Member` element contains two required sub-elements:

- the `instance` elements must be a construct from the `TERM` abstract class that serializes the reference to the object;
- the `class` element must be a construct from the `TERM` abstract class that serializes the reference to the class.

```

<Member>
  <instance> TERM </instance>
  <class> TERM </class>
</Member>

```

**Example 8.5.** The example shows the RIF XML serialization of class membership atom that tests whether a variable named `?customer` belongs to a class identified by the name `Customer` in the namespace `http://example.com/2009/prd2#`

```

<Member>
  <instance> <Var> ?customer </Var> </instance>
  <class>
    <Const type="rif:iri">
      http://example.com/2009/prd2#Customer
    </Const>
  </class>
</Member>

```

#### 8.2.2.4 Subclass

In RIF, the `Subclass` element is used to serialize [subclass atomic formulas](#).

The `Subclass` element contains two required sub-elements:

- the `sub` element must be a construct from the `TERM` abstract class that serializes the reference to the sub-class;
- the `super` elements must be a construct from the `TERM` abstract class that serializes the reference to the super-class.

```
<Subclass>
  <sub> TERM </sub>
  <super> TERM </super>
</Subclass>
```

#### 8.2.2.5 Frame

In RIF, the `Frame` element is used to serialize [frame atomic formulas](#).

Accordingly, a `Frame` element must contain:

- an `object` element, that contains an element of the `TERM` abstract class that serializes the reference to the frame's object;
- zero to many `slot` elements, serializing an attribute-value pair as a pair of elements of the `TERM` abstract class, the first one that serializes the name of the attribute (or property); the second that serializes the attribute's value. The order of the `slot`'s sub-elements is significant and **MUST** be preserved. This is emphasized by the required value "yes" of the required attribute `rif:ordered`.

```
<Frame>
  <object> TERM </object>
  <slot rif:ordered="yes"> TERM TERM </slot>*
</Frame>
```

**Example 8.6.** The example shows the RIF XML serialization of an expression that states that the object denoted by the variable `?customer` has the value denoted by the string "Gold" for the property identified by the symbol `status` that is defined in the example namespace `http://example.com/2009/prd2#`

```
<Frame>
  <object> <Var> ?customer </Var> </object>
  <slot rif:ordered="yes">
    <Const type="rif:iri">
      http://example.com/2009/prd2#status
```

```

    </Const>
    <Const type="xsd:string" > Gold </Const>
  </slot>
</Frame>

```

#### 8.2.2.6 External

In RIF-PRD, the `External` element is also used to serialize an [externally defined atomic formula](#), in addition to [serializing externally defined functions](#).

When it is an `ATOMIC` (as opposed to a `TERM`; that is, in particular, when it appears in a place where an `ATOMIC` is expected, and not a `TERM`), the `External` element contains one `content` element that contains one `Atom` element. The `Atom` element serializes the [externally defined atom](#) properly said:

The `op Const` in the `Atom` element must be a symbol of type `rif:iri` that must uniquely identify the externally defined predicate to be applied to the `args TERMS`.

```

<External>
  <content>
    Atom
  </content>
</External>

```

**Example 8.7.** The example below shows the RIF XML serialization of an externally defined atomic formula that tests whether the value denoted by the variable named `?value` is greater than or equal to the integer value 2000, where the test is intended to behave like the built-in predicate [pred:numeric-greater-than-or-equal](#) as specified in [\[RIF-DTB\]](#):

RIF built-in predicates are associated with the namespace <http://www.w3.org/2007/rif-builtin-predicate#>.

```

<External>
  <content>
    <Atom>
      <op> <Const type="rif:iri"> http://www.w3.org/2007/rif-builtin-pre
      <args rif:ordered="yes">
        <Var> ?value </Var>
        <Const type="xsd:integer"> 2000 </Const>
      </args>
    </Atom>
  </content>
</External>

```

### 8.2.3 FORMULA

The `FORMULA` class is used to serialize [condition formulas](#), that is, atomic formulas, conjunctions, disjunctions, negations and existentials.

As an abstract class, `FORMULA` is not associated with specific XML markup in RIF-PRD instance documents.

```
[ ATOMIC | And | Or | INeg | Exists ]
```

#### 8.2.3.1 ATOMIC

An [atomic formula](#) is serialized using a single `ATOMIC` statement. See specification of [ATOMIC](#), above.

#### 8.2.3.2 And

A [conjunction](#) is serialized using the `And` element.

The `And` element contains zero or more `formula` sub-elements, each containing an element of the `FORMULA` group, that serializes one of the conjuncts.

```
<And>
  <formula> FORMULA </formula>*
</And>
```

#### 8.2.3.3 Or

A [disjunction](#) is serialized using the `Or` element.

The `Or` element contains zero or more `formula` sub-elements, each containing an element of the `FORMULA` group, that serializes one of the disjuncts.

```
<Or>
  <formula> FORMULA </formula>*
</Or>
```

#### 8.2.3.4 INeg

The kind of [negation](#) that is used in RIF-PRD is serialized using the `INeg` element.

The `Negate` element contains exactly one `formula` sub-element. The `formula` element contains an element of the `FORMULA` group, that serializes the negated statement.

```

<INeg>
  <formula> FORMULA </formula>
</INeg>

```

### 8.2.3.5 Exists

An [existentially quantified formula](#) is serialized using the `Exists` element.

The `Exists` element contains:

- one or more `declare` sub-elements, each containing one `Var` element that serializes one of the existentially quantified variables;
- exactly one required `formula` sub-element that contains an element from the `FORMULA` abstract class, that serializes the formula in the scope of the quantifier.

```

<Exists>
  <declare> Var </declare>+
  <formula> FORMULA </formula>
</Exists>

```

**Example 8.8.** The example shows the RIF XML serialization of a condition on the existence of a value greater than or equal to 2.000, in the Gold rule of the `{{#sec-running-example|running example}}`, as represented in [example 4.2](#).

```

<Exists>
  <declare> <Var> ?value </Var> </declare>
  <formula>
    <And>
      <Frame>
        <object> <Var> ?shoppingCart </Var> </object>
        <slot rif:ordered="yes">
          <Const type="rif:iri">
            http://example.com/2009/prd2#value
          </Const>
          <Var> ?value </Var>
        </slot>
      </Frame>
      <External>
        <content>
          <Atom>
            <op> <Const type="rif:iri"> http://www.w3.org/2007/rif-bu
            <args rif:ordered="yes">
              <Var> ?value </Var>
              <Const type="xsd:integer"> 2000 </Const>
            </args>
          </Atom>
        </content>
      </External>
    </And>
  </formula>

```

```

        </External>
      </And>
    </formula>
  </Exists>

```

## 8.3 Actions

This section specifies the XML syntax that is used to serialize the action part of a rule supported by RIF-PRD.

### 8.3.1 ATOMIC\_ACTION

The `ATOMIC_ACTION` class of elements is used to serialize the atomic actions: *assert*, *retract*, *modify* and *execute*.

As an abstract class, `ATOMIC_ACTION` is not associated with specific XML markup in RIF-PRD instance documents.

```
[ Assert | Retract | Modify | Execute ]
```

#### 8.3.1.1 Assert

An [atomic assertion action](#) is serialized using the `Assert` element.

The `Assert` element has one `target` sub-element that contains an `Atom`, a `Frame` or a `Member` element that represents the target of the action.

```

<Assert>
  <target> [ Atom | Frame | Member ] </target>
</Assert>

```

#### 8.3.1.2 Retract

The `Retract` construct is used to serialize [retract atomic actions](#).

The `Retract` element has one `target` sub-element that contains an `Atom`, a `Frame`, or a `TERM` construct that represents the target of the action.

```

<Retract>
  <target> [ Atom | Frame | TERM ] </target>
</Retract>

```

### 8.3.1.3 Modify

An [atomic modification](#) is serialized using the `Modify` element.

The `Modify` element has one `target` sub-element that contains one `Frame` that represents the target of the action.

```
<Modify>
  <target> Frame </target>
</Modify>
```

**Example 8.9.** The example shows the RIF XML representation of the action that updates the status of a customer, in the Gold rule, in the [running example](#), as represented in [example 4.2](#).

*Modify( ?customer[status->"Gold"] )*

```
<Modify>
  <target>
    <Frame>
      <object>
        <Var> ?customer </Var>
      </object>
      <slot rif:ordered="yes">
        <Const type="rif:iri"> http://example.com/2009/prd2#status </Const>
        <Const type="xsd:string"> Gold </Const>
      </slot>
    </Frame>
  </target>
</Modify>
```

### 8.3.1.4 Execute

The [execution of an externally defined action](#) is serialized using the `Execute` element.

The `Execute` element has one `target` sub-element that contains an `Atom`, that represents the externally defined action to be executed.

The `op Const` in the [Atom element](#) must be a symbol of type `rif:iri` that must uniquely identify the [externally defined action](#) to be applied to the `args TERMS`.

```
<Execute>
  <target> Atom </target>
</Execute>
```



**Example 8.10.** The example shows the RIF XML serialization of the message printing action, in the *</t>Unknoww status<i>*, in the [running example](#), using the [act:print](#) action built-in.

The namespace for RIF-PRD action built-ins is <http://www.w3.org/2007/rif-builtin-action#>.

```

<Execute>
  <target>
    <Atom>
      <op>
        <Constant type="rif:iri"> http://www.w3.org/2007/rif-builtin-action#
      </op>
      <args rif:ordered="yes">
        <External>
          <content>
            <Expr>
              <op>
                <Constant type="rif:iri"> http://www.w3.org/2007/rif-builtin-action#
              </op>
              <args rif:ordered="yes">
                <Const type="xsd:string"> New customer: </Const>
                ?customer
              </args>
            </Expr>
          </content>
        </External>
      </args>
    </Atom>
  </target>
</Execute>

```

### 8.3.2 ACTION\_BLOCK

The ACTION\_BLOCK class of constructs is used to represent the [conclusion, or action part, of a production rule](#) serialized using RIF-PRD.

If action variables are declared in the action part of a rule, or if some atomic actions are not assertions, the conclusion must be serialized as a full [action block](#), using the Do element. However, simple action blocks that contain only one or more assert actions SHOULD be serialized like the conclusions of logic rules using [RIF-Core](#) or [RIF-BLD](#), that is, as a single asserted Atom or Frame, or as a conjunction of the asserted facts, using the And element.

In the latter case, to conform with the [definition of an action block well-formedness](#), the formulas that serialize the individual conjuncts MUST be atomic Atoms and/or Frames.

As an abstract class, `ACTION_BLOCK` is not associated with specific XML markup in RIF-PRD instance documents.

```
[ Do | And | Atom | Frame ]
```

#### 8.3.2.1 *New*

The `New` element is used to serialize the construct used to create a new frame identifier, in an [action variable declaration](#).

The `New` element is always empty.

```
<New />
```

#### 8.3.2.2 *Do*

An [action block](#) is serialized using the `Do` element.

A `Do` element contains:

- zero or more `actionVar` sub-elements, each of them used to serialize one [action variable declaration](#). Accordingly, an `actionVar` element must contain a `Var` sub-element, that serializes the declared variable; followed by the serialization of an [action variable binding](#), that assigns an initial value to the declared variable, that is: either a `frame` or the empty element `New`;
- one `actions` sub-element that serializes the sequence of atomic actions in the action block, and that contains, accordingly, a sequence of one or more sub-elements of the `ATOMIC_ACTION` class. The order of the atomic actions is significant, and the order **MUST** be preserved, as emphasized by the required `rif:ordered="yes"` attribute.

```
<Do>
  <actionVar rif:ordered="yes">
    Var
    [ New | Frame ]
  </actionVar>*
  <actions rif:ordered="yes">
    ATOMIC_ACTION+
  </actions>
</Do>
```

**Example 8.11.** The example shows the RIF XML serialization of an action block that asserts that a customer gets a new \$5 voucher.

```

<Do>
  <actionVar rif:ordered="yes">
    <Var>?voucher</Var>
    <New />
  </actionVar>
  <actions rif:ordered="yes">
    <Assert>
      <target>
        <Member>
          <instance><Var>?voucher</Var></instance>
          <class>
            <Const type="rif:iri">http://example.com/2009/prd2#Vouche
          </class>
          </Member>
        </target>
      </Assert>
      <Assert>
        <target>
          <Frame>
            <object><Var>?voucher</Var></object>
            <slot rif:ordered="yes">
              <Const type="rif:iri">http://example.com/2009/prd2#value<
              <Const type="xsd:integer">5</Const>
            </slot>
          </Frame>
        </target>
      </Assert>
      <Assert>
        <target>
          <Frame>
            <object><Var>?customer</Var></object>
            <slot rif:ordered="yes">
              <Const type="rif:iri">http://example.com/2009/prd2#vouche
              <Var>?voucher</Var>
            </slot>
          </Frame>
        </target>
      </Assert>
    </actions>
  </Do>

```

## 8.4 Rules and Groups

This section specifies the XML constructs that are used, in RIR-PRD, to serialize [rules](#) and [groups](#).

### 8.4.1 RULE

In RIF-PRD, the `RULE` class of constructs is used to serialize [rules](#), that is, unconditional as well as conditional actions, or rules with bound variables.

As an abstract class, `RULE` is not associated with specific XML markup in RIF-PRD instance documents.

[ *Implies* | *Forall* | *ACTION\_BLOCK* ]

#### 8.4.1.1 ACTION\_BLOCK

An [unconditional action block](#) is serialized, in RIF-PRD XML, using the `ACTION_BLOCK` class of construct.

#### 8.4.1.2 Implies

[Conditional actions](#) are serialized, in RIF-PRD, using the XML element `Implies`.

The `Implies` element contains an `if` sub-element and a `then` sub-element:

- the required `if` element contains an element from the `FORMULA` class of constructs, that serializes the condition of the rule;
- the required `then` element contains one element from the `ACTION_BLOCK` class of constructs, that serializes its conclusion.

```
<Implies>
  <if> FORMULA </if>
  <then> ACTION_BLOCK </then>
</Implies>
```

#### 8.4.1.3 Forall

The `Forall` construct is used, in RIF-PRD, to represent [rules with bound variables](#).

The `Forall` element contains:

- one or more `declare` sub-elements, each containing one `Var` element that represents one of the declared rule variables;
- zero or more `pattern` sub-elements, each containing one element from the `FORMULA` group of constructs, that serializes one [binding pattern](#);
- exactly one `formula` sub-element that serializes the formula in the scope of the variables binding, and that contains an element of the `RULE` group.

```

<Forall>
  <declare> Var </declare>+
  <pattern> FORMULA </pattern>*
  <formula> RULE </formula>
</Forall>

```

**Example 8.12.** The example shows the rule variables declaration part of the Gold rule, from the [running example](#), as represented in [example 4.2](#).

```

<Forall>
  <declare><Var>?customer</Var></declare>
  <pattern>
    <And>
      <formula><Member> ... </Member></formula>
      <formula><Frame> ... </Frame></formula>
    </And>
  </pattern>
  <formula>
    <Forall>
      <declare><Var>?shoppingCart</Var></declare>
      <pattern><Member> ... </Member></pattern>
      <formula>
        <Implies> ... </Implies>
      </formula>
    </Forall>
  </formula>
</Forall>

```

#### 8.4.2 Group

The Group construct is used to serialize a [group](#).

The Group element has zero or one behavior sub-element and zero or more sentence sub-elements:

- the behavior element contains
  - zero or one ConflictResolution sub-element that contains exactly one IRI. The IRI identifies the conflict resolution strategy that is associated with the Group;
  - zero or one Priority sub-element that contains exactly one signed integer between -10,000 and 10,000. The integer associates a priority with the Group's sentences;
- a sentence element contains either a Group element or an element of the RULE abstract class of constructs.

```

<Group>
  <behavior>

```

```

        <ConflictResolution> xsd:anyURI </ConflictResolution>?
        <Priority> -10,000 ≤ xsd:int ≤ 10,000 </Priority>?
    </behavior>?
    <sentence> [ RULE | Group ] </sentence>*
</Group>

```

## 8.5 Document and directives

### 8.5.1 Import

The `Import` directive is used to serialize the reference to an RDF graph or an OWL ontology to be combined with a RIF document. The `Import` directive is inherited from [\[RIF-Core\]](#). Its abstract syntax and its semantics are specified in [\[RIF-RDF+OWL\]](#).

The `Import` directive contains:

- exactly one `location` sub-element, that contains an IRI, that serializes the location of the RDF or OWL document to be combined with the RIF document;
- zero or one `profile` sub-element, that contains an IRI. The admitted values for that constant and their semantics are listed in the section Profiles of Imports, in [\[RIF-RDF+OWL\]](#).

```

<Import>
  <location> xsd:anyURI </location>
  <profile> xsd:anyURI </profile>?
</Import>

```

### 8.5.2 Document

The `Document` is the root element of any RIF-PRD instance document.

The `Document` contains zero or more `directive` sub-elements, each containing an `Import` directive, and zero or one `payload` sub-element, that must contain a `Group` element.

```

<Document>
  <directive> Import </Import>*
  <payload> Group </payload>?
</Document>

```

The semantics of a document that imports RDF and/or OWL documents is specified in [\[RIF-RDF+OWL\]](#) and [\[RIF-BLD\]](#). The semantics of a document that does not import other documents is the semantics of the rule set that is serialised by the `Group` in the document's `payload` sub-element, if any.

An example of a complete RIF-PRD XML instance document representing the [running example rule set](#) is presented in [Appendix: Complete RIF-PRD XML example](#).

## 8.6 Constructs carrying no semantics

### 8.6.1 Annotation

Annotations can be associated with any concrete class element in RIF-PRD: those are the elements with a CamelCase tagname starting with an upper-case character:

```
CLASSELT = [ TERM | ATOMIC | FORMULA | ATOMIC_ACTION | ACTION_BLOCK | ... ]
```

An identifier can be associated to any instance element of the abstract `CLASSELT` class of constructs, as an optional `id` sub-element that **MUST** contain a `Const` of type `rif:local` or `rif:iri`.

Annotations can be included in any instance of a concrete class element using the `meta` sub-element.

The `Frame` construct is used to serialize annotations: the content of the `Frame`'s `object` sub-element identifies the object to which the annotation is associated:, and the `Frame`'s `slots` represent the annotation properly said as property-value pairs.

If all the annotations are related to the same object, the `meta` element can contain a single `Frame` sub-element. If annotations related to several different objects need be serialized, the `meta` role element can contain an `And` element with zero or more `formula` sub-elements, each containing one `Frame` element, that serializes the annotations relative to one identified object.

```
<any concrete element in CLASSELT>
  <id> Const </id>?
  <meta>
    [ Frame
      |
      <And>
        <formula> Frame </formula>*
      </And>
    ]
  </meta>?
  other CLASSELT content
</any concrete element in CLASSELT>
```

Notice that the content of the `meta` sub-element of an instance of a RIF-PRD class element is not necessarily associated to that same instance element: only the

content of the `object` sub-element of the `Frame` that represents the annotations specifies what the annotations are about, not where it is included in the instance RIF document.

It is suggested to use Dublin Core, RDFS, and OWL properties for annotations, along the lines of <http://www.w3.org/TR/owl-ref/#Annotations> -- specifically `owl:versionInfo`, `rdfs:label`, `rdfs:comment`, `rdfs:seeAlso`, `rdfs:isDefinedBy`, `dc:creator`, `dc:description`, `dc:date`, and `foaf:maker`.

**Example 8.13.** The example shows the structure of the document that contains the [running example rule set](#), as represented in [example 4.2](#), including annotations such as rule set and rule names.

```

<Document>
  <payload>
    <Group>
      <id><Const type="rif:iri">http://example.com/2009/prd2#CheckoutRuleSe
      <meta>
        <Frame>
          <object><Const type="rif:iri">http://example.com/2009/prd2#Checko
          <slot rif:ordered="yes">
            <Const type="rif:iri">http://dublincore.org/documents/dcmi-name
            <Const type="xsd:string">W3C RIF WG</Const>
          </slot>
          <slot>
            <Const type="rif:iri">http://dublincore.org/documents/dcmi-name
            <Const type="xsd:string">Running example rule set from the RIF-
          </slot>
        </Frame>
      </meta>
      <behavior> ... </behavior>
      <sentence>
        <Group>
          <id><Const type="rif:iri">http://example.com/2009/prd2#GoldRule</
          <behavior> ... </behavior>
          <sentence><Forall> ... </Forall></sentence>
        </Group>
      </sentence>
      <sentence>
        <Group>
          <id><Const type="rif:iri">http://example.com/2009/prd2#DiscountRu
          <sentence><Forall> ... </Forall></sentence>
        </Group>
      </sentence>
    </Group>
  </payload>
</Document>

```



## 9 Presentation syntax

To make it easier to read, a non-normative, lightweight notation was introduced to complement the mathematical English specification of the abstract syntax and the semantics of RIF-PRD. This section specifies a presentation syntax for RIF-PRD, that extends that notation. The presentation syntax is not normative. However, it may help implementers by providing a more succinct overview of RIF-PRD syntax.

The EBNF for the RIF-PRD presentation syntax is given as follows. For convenience of reading we show the entire EBNF in its four parts (rules, conditions, actions, and annotations).

### Rule Language:

```

Document      ::= IRIMETA? 'Document' '(' Base? Prefix* Import* Group? ')'
Base          ::= 'Base' '(' ANGLEBRACKKIRI ')'
Prefix       ::= 'Prefix' '(' Name ANGLEBRACKKIRI ')'
Import       ::= IRIMETA? 'Import' '(' LOCATOR PROFILE? ')'
Group        ::= IRIMETA? 'Group' Strategy? Priority? '(' (RULE | Group
Strategy     ::= Const
Priority      ::= Const
RULE         ::= (IRIMETA? 'Forall' Var+ ' such that ' FORMULA* '(' RU
CLAUSE       ::= Implies | ACTION_BLOCK
Implies      ::= IRIMETA? 'If' FORMULA 'Then' ACTION_BLOCK
LOCATOR      ::= ANGLEBRACKKIRI
PROFILE      ::= ANGLEBRACKKIRI

```

### Action Language:

```

ATOMIC_ACTION ::= IRIMETA? (Assert | Retract | Modify | Execute )
Assert        ::= 'Assert' '(' Atom | Frame | Member ')'
Retract       ::= 'Retract' '(' ( Atom | Frame | Var | Const ) ')'
Modify        ::= 'Modify' '(' Frame ')'
Execute       ::= 'Execute' '(' Atom ')'
ACTION_BLOCK  ::= IRIMETA? ('Do (' (IRIMETA? Var (Frame | 'New()'))* ATO
                'And (' (Atom | Frame)* ')') | Atom | Frame)

```

### Condition Language:

```

FORMULA      ::= IRIMETA? 'And' '(' FORMULA* ')') |
                IRIMETA? 'Or' '(' FORMULA* ')') |
                IRIMETA? 'Exists' Var+ '(' FORMULA ')') |
                ATOMIC |
                IRIMETA? NEGATEDFORMULA |
                IRIMETA? Equal |
                IRIMETA? Member |
                IRIMETA? Subclass |
                IRIMETA? 'External' '(' Atom ')'

```

```

ATOMIC          ::= IRIMETA? (Atom | Frame)
Atom            ::= UNITERM
UNITERM        ::= Const '(' (TERM* ')'
GROUNDUNITERM  ::= Const '(' (GROUNDTERM* ')'
NEGATEDFORMULA ::= 'Not' '(' FORMULA ')' | 'INeg' '(' FORMULA ')'
Equal          ::= TERM '=' TERM
Member        ::= TERM '#' TERM
Subclass      ::= TERM '##' TERM
Frame         ::= TERM '[' (TERM '->' TERM)* ']'
TERM          ::= IRIMETA? (Const | Var | List | 'External' '(' Expr ')')
GROUNDTERM    ::= IRIMETA? (Const | List | 'External' '(' Expr '(' GRO
Expr          ::= UNITERM
List          ::= 'List' '(' GROUNDTERM* ')'
Const        ::= '"' UNICODESTRING '^' SYMSPACE | CONSTSHORT
Name         ::= UNICODESTRING
Var          ::= '?' UNICODESTRING
SYMSPACE     ::= ANGLEBRACKIRI | CURIE

```

**Annotations:**

```

IRIMETA          ::= '(*' IRICONST? (Frame | 'And' '(' Frame* ')')? '*'

```

A NEGATEDFORMULA can be written using either *Not* or *INeg*. *INeg* is short for *inflationary negation* and is preferred over 'Not' to avoid ambiguity about the semantics of the negation.

The RIF-PRD presentation syntax does not commit to any particular vocabulary and permits arbitrary Unicode strings in constant symbols, argument names, and variables. Constant symbols can have this form: "UNICODESTRING"^^SYMSPACE, where SYMSPACE is an ANGLEBRACKIRI or CURIE that represents the identifier of the symbol space of the constant, and UNICODESTRING is a Unicode string from the lexical space of that symbol space. ANGLEBRACKIRI and CURIE are defined in Section [Shortcuts for Constants in RIF's Presentation Syntax](#) of [RIF-DTB]. Constant symbols can also have several shortcut forms, which are represented by the non-terminal CONSTSHORT. These shortcuts are also defined in the same section of [RIF-DTB]. One of them is the CURIE shortcut, which is extensively used in the examples in this document. Names are Unicode character sequences. Variables are composed of UNICODESTRING symbols prefixed with a ?-sign.

**Example 7.1.** Here is the transcription, in the RIF-PRD presentation syntax, of the complete RIF-PRD document corresponding to the [running example](#):

```

Document (
  Prefix( ex1 <http://example.com/2009/prd2> )
  (* ex1:CheckoutRuleset *)
  Group rif:forwardChaining (

```

```

(* ex1:GoldRule *)
Group 10 (
  Forall ?customer such that (And( ?customer # ex1:Customer
                                   ?customer[status->"Silver"] ))
    (Forall ?shoppingCart such that (?customer[shoppingCart->?shoppingCart]
    (If Exists ?value (And( ?shoppingCart[value->?value]
                           pred:numeric-greater-than-or-equal(?value
    Then Do( Modify( ?customer[status->"Gold"] ) ) ) ) ) ) )

(* ex1:DiscountRule *)
Group (
  Forall ?customer such that (And( ?customer # ex1:Customer ) )
  (If Or( ?customer[status->"Silver"]
         ?customer[status->"Gold"] )
  Then Do( (?s ?customer[shoppingCart->?s])
          (?v ?s[value->?v])
          Modify( ?s[value->func:numeric-multiply(?v 0.95)] ) ) ) )

(* ex1:NewCustomerAndWidgetRule *)
Group
  Forall ?customer such that (And( ?customer # ex1:Customer
                                   ?customer[status->"New"] ) )
  (If Exists ?shoppingCart ?item
    ( And ( ?customer[shoppingCart->?shoppingCart]
           ?shoppingCart[containsItem->?item]
           ?item # ex1:Widget ) ) )
  Then Do( (?s ?customer[shoppingCart->?s])
          (?val ?s[value->?val])
          (?voucher ?customer[voucher->?voucher])
          Retract( ?customer[voucher->?voucher] )
          Retract( ?voucher )
          Modify( ?s[value->func:numeric-multiply(?val 0.90)] ) ) )

(* ex1:UnknownStatusRule *)
Group (
  Forall ?customer such that ( ?customer # ex1:Customer )
  (If Not(Exists ?status
    (And( ?customer[status->?status]
          External(pred:list-contains(List("New", "Bronze
  Then Do( Execute( act:print(func:concat("New customer: " ?customer)
          Assert( ?customer[status->"New"] ) ) ) ) ) )
) □

```

## 10 References

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## 11 Appendix: Model-theoretic semantics of RIF-PRD condition formulas

This appendix provides an alternative specification of the [Semantics of condition formulas](#), and it is also normative.

This alternative specification is provided for the convenience of the reader, for compatibility with other RIF specifications, such as [\[RIF-DTB\]](#) and [\[RIF-RDF+OWL\]](#), and to make explicit the interoperability with RIF logic dialects, in particular [\[RIF-Core\]](#) and [\[RIF-BLD\]](#).

## 11.1 Semantic structures

The key concept in a model-theoretic semantics of a logic language is the notion of a semantic structure [Enderton01, Mendelson97].

**Definition (Semantic structure).** A *semantic structure*,  $I$ , is a tuple of the form  $\langle TV, DTS, D, D_{ind}, D_{func}, I_C, I_V, I_{list}, I_{tail}, I_P, I_{frame}, I_{sub}, I_{isa}, I_{=}, I_{external}, I_{truth} \rangle$ . Here  $D$  is a non-empty set of elements called the *Herbrand domain* of  $I$ , that is, the set of all ground terms which can be formed by using the elements of  $Const$ .  $D_{ind}$ ,  $D_{func}$  are nonempty subsets of  $D$ .  $D_{ind}$  is used to interpret the elements of  $Const$  that are individuals and  $D_{func}$  is used to interpret the elements of  $Const$  that are function symbols.  $Const$  denotes the set of all constant symbols and  $Var$  the set of all variable symbols.  $TV$  denotes the set of truth values that the semantic structure uses and  $DTS$  is a set of identifiers for primitive datatypes (please refer to Section [Datatypes](#) of RIF data types and builtins [[RIF-DTB](#)] for the semantics of datatypes).

As far as the assignment of a standard meaning to formulas in the RIF-PRD condition language is concerned, the set  $TV$  of truth values consists of just two values, **t** and **f**.

The other components of  $I$  are *total* mappings defined as follows:

1.  $I_C$  maps  $Const$  to  $D$ .

This mapping interprets constant symbols. In addition:

- If a constant,  $c \in Const$ , is an *individual* then it is required that  $I_C(c) \in D_{ind}$ .
- If  $c \in Const$ , is a *function symbol* then it is required that  $I_C(c) \in D_{func}$ .

2.  $I_V$  maps  $Var$  to  $D_{ind}$ .

This mapping interprets variable symbols.

3.  $I_{list}$  and  $I_{tail}$  are used to interpret lists. They are mappings of the following form:

- $I_{list} : D_{ind}^* \rightarrow D_{ind}$
- $I_{tail} : D_{ind}^+ \times D_{ind} \rightarrow D_{ind}$

In addition, these mappings are required to satisfy the following conditions:

- $I_{list}$  is an injective one-to-one function.
- $I_{list}(D_{ind})$  is disjoint from the value spaces of all data types in  $DTS$ .
- $I_{tail}(a_1, \dots, a_k, I_{list}(a_{k+1}, \dots, a_{k+m})) = I_{list}(a_1, \dots, a_k, a_{k+1}, \dots, a_{k+m})$ .

Note that the last condition above restricts  $I_{tail}$  only when its last argument is in  $I_{list}(D_{ind})$ , the image of  $I_{list}$ . If the last argument of  $I_{tail}$  is not in  $I_{list}(D_{ind})$ , then the list is malformed and there are no restrictions on the value of  $I_{tail}$  except that it must be in  $D_{ind}$ .

4.  $I_P$  maps  $D$  to functions  $D^*_{ind} \rightarrow D$  (here  $D^*_{ind}$  is a set of all sequences of any finite length over the domain  $D_{ind}$ ).

This mapping interprets positional terms atoms.

5.  $I_{frame}$  maps  $D_{ind}$  to total functions of the form  $SetOfFiniteBags(D_{ind} \times D_{ind}) \rightarrow D$ .

This mapping interprets frame terms. An argument,  $d \in D_{ind}$ , to  $I_{frame}$  represents an object and the finite bag  $\{ \langle a_1, v_1 \rangle, \dots, \langle a_k, v_k \rangle \}$  represents a bag of attribute-value pairs for  $d$ . We will see shortly how  $I_{frame}$  is used to determine the truth valuation of frame terms.

Bags (multi-sets) are used here because the order of the attribute/value pairs in a frame is immaterial and pairs may repeat. Such repetitions arise naturally when variables are instantiated with constants. For instance,  $o[?A \rightarrow ?B \ ?C \rightarrow ?D]$  becomes  $o[a \rightarrow b \ a \rightarrow b]$  if variables  $?A$  and  $?C$  are instantiated with the symbol  $a$  while  $?B$  and  $?D$  are instantiated with  $b$ . (We shall see later that  $o[a \rightarrow b \ a \rightarrow b]$  is equivalent to  $o[a \rightarrow b]$ .)

6.  $I_{sub}$  gives meaning to the subclass relationship. It is a mapping of the form  $D_{ind} \times D_{ind} \rightarrow D$ .

The operator  $\#\#$  is required to be transitive, i.e.,  $c_1 \#\# c_2$  and  $c_2 \#\# c_3$  must imply  $c_1 \#\# c_3$ . This is ensured by a restriction in [Section Interpretation of condition formulas](#);

7.  $I_{isa}$  gives meaning to class membership. It is a mapping of the form  $D_{ind} \times D_{ind} \rightarrow D$ .

The relationships  $\#$  and  $\#\#$  are required to have the usual property that all members of a subclass are also members of the superclass, i.e.,  $o \# c_1$  and  $c_1 \#\# s_1$  must imply  $o \# s_1$ . This is ensured by a restriction in [Section Interpretation of condition formulas](#);

8.  $I_=$  is a mapping of the form  $D_{ind} \times D_{ind} \rightarrow D$ .

It gives meaning to the equality operator.

9.  $I_{truth}$  is a mapping of the form  $D \rightarrow TV$ .

It is used to define truth valuation for formulas.

10.  $I_{\text{external}}$  is a mapping from the coherent set of schemas for externally defined functions to total functions  $D^* \rightarrow D$ . For each external schema  $\sigma = (?X_1 \dots ?X_n; \tau)$  in the [coherent set of external schemas](#) associated with the language,  $I_{\text{external}}(\sigma)$  is a function of the form  $D^n \rightarrow D$ .

For every external schema,  $\sigma$ , associated with the language,  $I_{\text{external}}(\sigma)$  is assumed to be specified externally in some document (hence the name *external schema*). In particular, if  $\sigma$  is a schema of a RIF built-in predicate, function or action,  $I_{\text{external}}(\sigma)$  is specified so that:

- If  $\sigma$  is a schema of a built-in function then  $I_{\text{external}}(\sigma)$  must be the function defined in [\[RIF-DTB\]](#);
- If  $\sigma$  is a schema of a built-in predicate then  $I_{\text{truth}} \circ (I_{\text{external}}(\sigma))$  (the composition of  $I_{\text{truth}}$  and  $I_{\text{external}}(\sigma)$ , a truth-valued function) must be as specified in [\[RIF-DTB\]](#);
- If  $\sigma$  is a schema of a built-in action then  $I_{\text{truth}} \circ (I_{\text{external}}(\sigma))$  (the composition of  $I_{\text{truth}}$  and  $I_{\text{external}}(\sigma)$ , a truth-valued function) must be as specified in the [section Built-in actions](#) in this document.

For convenience, we also define the following mapping  $I$  from terms to  $D$ :

- $I(k) = I_C(k)$ , if  $k$  is a symbol in `Const`;
- $I(?v) = I_V(?v)$ , if  $?v$  is a variable in `Var`;
- For list terms, the mapping is defined as follows:
  - $I(\text{List}(\ )) = I_{\text{list}}(\langle \rangle)$ . Here  $\langle \rangle$  denotes an empty list of elements of  $D_{\text{ind}}$ . (Note that the domain of  $I_{\text{list}}$  is  $D_{\text{ind}}^*$ , so  $D_{\text{ind}}^0$  is an empty list of elements of  $D_{\text{ind}}$ .)
  - $I(\text{List}(t_1 \dots t_n)) = I_{\text{list}}(I(t_1), \dots, I(t_n))$ , if  $n > 0$ .
  - $I(\text{List}(t_1 \dots t_n | t)) = I_{\text{tail}}(I(t_1), \dots, I(t_n), I(t))$ , if  $n > 0$ .
- $I(p(t_1 \dots t_n)) = I_P(I(p))(I(t_1), \dots, I(t_n))$ ;
- $I(o[a_1 \rightarrow v_1 \dots a_k \rightarrow v_k]) = I_{\text{frame}}(I(o))(\{ \langle I(a_1), I(v_1) \rangle, \dots, \langle I(a_n), I(v_n) \rangle \})$   
Here  $\{ \dots \}$  denotes a bag of attribute/value pairs.
- $I(c1 \# c2) = I_{\text{sub}}(I(c1), I(c2))$ ;
- $I(o \# c) = I_{\text{isa}}(I(o), I(c))$ ;
- $I(x=y) = I_{=} (I(x), I(y))$ ;
- $I(\text{External}(t)) = I_{\text{external}}(\sigma)(I(s_1), \dots, I(s_n))$ , if  $t$  is an instance of the external schema  $\sigma = (?X_1 \dots ?X_n; \tau)$  by substitution  $?X_1/s_1 \dots ?X_n/s_n$ .

Note that, by definition, `External(t)` is well-formed only if  $t$  is an instance of an external schema. Furthermore, by the [definition of coherent sets of external schemas](#),  $t$  can be an instance of at most one such schema, so  $I(\text{External}(t))$  is well-defined.

**The effect of datatypes.** The set **DTS** must include the datatypes described in Section [Primitive Datatypes](#) of RIF data types and builtins [\[RIF-DTB\]](#).

The datatype identifiers in **DTS** impose the following restrictions. Given  $dt \in \mathbf{DTS}$ , let  $LS_{dt}$  denote the lexical space of  $dt$ ,  $VS_{dt}$  denote its value space, and  $L_{dt}: LS_{dt}$



→  $VS_{dt}$  the lexical-to-value-space mapping (for the definitions of these concepts, see Section [Primitive Datatypes](#) of RIF data types and builtins [\[RIF-DTB\]](#). Then the following must hold:

- $VS_{dt} \subseteq D_{ind}$ ; and
- For each constant " $lit$ "<sup>dt</sup> such that  $lit \in LS_{dt}$ ,  $I_C("lit"$ <sup>dt</sup>) =  $L_{dt}(lit)$ .

That is,  $I_C$  must map the constants of a datatype  $dt$  in accordance with  $L_{dt}$ .

RIF-PRD does not impose restrictions on  $I_C$  for constants in symbol spaces that are not datatypes included in **DTS**. □

## 11.2 Interpretation of condition formulas

This section defines how a semantic structure,  $I$ , determines the truth value  $TVal_I(\varphi)$  of a condition formula,  $\varphi$ .

We define a mapping,  $TVal_I$ , from the set of all condition formulas to **TV**. Note that the definition implies that  $TVal_I(\varphi)$  is defined *only if* the set **DTS** of the datatypes of  $I$  includes all the datatypes mentioned in  $\varphi$  and  $I_{external}$  is defined on all externally defined functions and predicates in  $\varphi$ .

**Definition (Truth valuation).** *Truth valuation* for well-formed condition formulas in RIF-PRD is determined using the following function, denoted  $TVal_I$ :

- *Positional atomic formulas:*  $TVal_I(r(t_1 \dots t_n)) = I_{truth}(I(r(t_1 \dots t_n)))$ ;
- *Equality:*  $TVal_I(x = y) = I_{truth}(I(x = y))$ .  
To ensure that equality has precisely the expected properties, it is required that:
  - $I_{truth}(I(x = y)) = \mathbf{t}$  if  $I(x) = I(y)$  and that  $I_{truth}(I(x = y)) = \mathbf{f}$  otherwise. This is tantamount to saying that  $TVal_I(x = y) = \mathbf{t}$  iff  $I(x) = I(y)$ ;
- *Subclass:*  $TVal_I(sc \## c1) = I_{truth}(I(sc \## c1))$ .  
To ensure that the operator  $\##$  is transitive, i.e.,  $c1 \## c2$  and  $c2 \## c3$  imply  $c1 \## c3$ , the following is required:
  - For all  $c1, c2, c3 \in D$ , if  $TVal_I(c1 \## c2) = TVal_I(c2 \## c3) = \mathbf{t}$  then  $TVal_I(c1 \## c3) = \mathbf{t}$ ;
- *Membership:*  $TVal_I(o \# c1) = I_{truth}(I(o \# c1))$ .  
To ensure that all members of a subclass are also members of the superclass, i.e.,  $o \# c1$  and  $c1 \## scl$  implies  $o \# scl$ , the following is required:
  - For all  $o, c1, scl \in D$ , if  $TVal_I(o \# c1) = TVal_I(c1 \## scl) = \mathbf{t}$  then  $TVal_I(o \# scl) = \mathbf{t}$ ;
- *Frame:*  $TVal_I(o[a_1 \rightarrow v_1 \dots a_k \rightarrow v_k]) = I_{truth}(I(o[a_1 \rightarrow v_1 \dots a_k \rightarrow v_k]))$ .

Since the bag of attribute/value pairs represents the conjunctions of all the pairs, the following is required, if  $k > 0$ :

- $TVal_I(\circ[a_1 \rightarrow v_1 \dots a_k \rightarrow v_k]) = \mathbf{t}$  if and only if  $TVal_I(\circ[a_1 \rightarrow v_1]) = \dots = TVal_I(\circ[a_k \rightarrow v_k]) = \mathbf{t}$ ;
- **Externally defined atomic formula:**  $TVal_I(\text{External}(t)) = \mathbf{t}$  iff  $\mathbf{t}$  is an atomic formula that is an instance of the external schema  $\sigma = (?X_1 \dots ?X_n; \tau)$  by substitution  $?X_1/s_1 \dots ?X_n/s_n$ .

Note that, by definition,  $\text{External}(t)$  is well-formed only if  $t$  is an instance of an external schema. Furthermore, by the [definition of coherent sets of external schemas](#),  $t$  can be an instance of at most one such schema, so  $I(\text{External}(t))$  is well-defined;

- **Conjunction:**  $TVal_I(\text{And}(c_1 \dots c_n)) = \mathbf{t}$  if and only if  $TVal_I(c_1) = \dots = TVal_I(c_n) = \mathbf{t}$ . Otherwise,  $TVal_I(\text{And}(c_1 \dots c_n)) = \mathbf{f}$ .  
The empty conjunction is treated as a tautology, so  $TVal_I(\text{And}()) = \mathbf{t}$ ;
- **Disjunction:**  $TVal_I(\text{Or}(c_1 \dots c_n)) = \mathbf{f}$  if and only if  $TVal_I(c_1) = \dots = TVal_I(c_n) = \mathbf{f}$ . Otherwise,  $TVal_I(\text{Or}(c_1 \dots c_n)) = \mathbf{t}$ .  
The empty disjunction is treated as a contradiction, so  $TVal_I(\text{Or}()) = \mathbf{f}$ ;
- **Negation:**  $TVal_I(\text{Not}(c)) = \mathbf{f}$  if and only if  $TVal_I(c) = \mathbf{t}$ . Otherwise,  $TVal_I(\text{Not}(c)) = \mathbf{t}$ ;
- **Existence:**  $TVal_I(\text{Exists } ?v_1 \dots ?v_n (\varphi)) = \mathbf{t}$  if and only if for some  $I^*$ , described below,  $TVal_{I^*}(\varphi) = \mathbf{t}$ .

Here  $I^*$  is a semantic structure of the form  $\langle TV, DTS, D, D_{\text{ind}}, D_{\text{pred}}, IC, I^*_V, IP, I_{\text{frame}}, I_{\text{NP}}, I_{\text{sub}}, I_{\text{isa}}, I, I_{\text{external}}, I_{\text{truth}} \rangle$ , which is exactly like  $I$ , except that the mapping  $I^*_V$ , is used instead of  $I_V$ .  $I^*_V$  is defined to coincide with  $I_V$  on all variables except, possibly, on  $?v_1, \dots, ?v_n$ .  $\square$

### 11.3 Condition satisfaction

We define, now, what it means for a *state of the fact base* to satisfy a condition formula. The satisfaction of condition formulas in a state of the fact base provides formal underpinning to the operational semantics of rule sets interchanged using RIF-PRD.

**Definition (Models).** A semantic structure  $I$  is a **model** of a condition formula,  $\varphi$ , written as  $I \models \varphi$ , iff  $TVal_I(\varphi) = \mathbf{t}$ .  $\square$

**Definition (Herbrand interpretation).** Given a non-empty set of constants,  $\text{Const}$ , the *Herbrand domain* is the set of all the ground terms that can be formed using the elements of  $\text{Const}$ , and the *Herbrand base* is the set of all the well-formed ground atomic formulas that can be formed with the elements in the Herbrand domain.

A semantic structure,  $I$ , is a **Herbrand interpretation**, if the set of all the ground formulas which are true with respect to  $I$  (that is, of which  $I$  is a model), is a subset of the corresponding Herbrand base,  $B_I$ .  $\square$

In RIF-PRD, the semantics of condition formulas is defined with respect to semantic structures where the domain,  $\mathcal{D}$  is the Herbrand domain that is determined by the set of all the constants,  $\text{Const}$ ; that is, with respect to Herbrand interpretations.

**Definition (State of the fact base).** To every Herbrand interpretation  $I$ , we associate a **state of the fact base**,  $w_I$ , that is represented by the subset of the Herbrand base that contains all the ground atomic formulas of which  $I$  is a model; or, equivalently, by the conjunction of all these ground atomic formulas.  $\square$

**Definition (Condition satisfaction).** A RIF-PRD condition formula  $\varphi$  is **satisfied** in a state of the fact base,  $w_I$ , if and only if  $I$  is a model of  $\varphi$ .  $\square$

At the syntactic level, the interpretation of the variables by a valuation function  $\mathcal{V}$  is realized by a [substitution](#). As a consequence, a ground substitution  $\sigma$  [matches](#) a condition formula  $\psi$  to a set of ground atomic formulas  $\Phi$  if and only if  $\sigma$  realizes the valuation function  $\mathcal{V}$  of a semantics structure  $I$  that is a model of  $\psi$  and  $\Phi$  is a representation of a state of the fact base,  $w_I$  (as defined [above](#)), that is associated to  $I$ ; that is, if and only if  $\psi$  is satisfied in  $w_I$  (as defined [above](#)).

This provides the formal link between the [satisfaction of a condition formula](#), as defined above, and a [matching substitution](#), and, followingly, between the alternative definitions of a state of facts and the satisfaction of a condition, here and in [section Semantics of condition formulas](#).

## 12 Appendix: XML schema

The RIF PRD XML Schema is defined as a redefinition of the [RIF Core XML Schema](#).

XML schemas for the RIF-PRD sublanguages are defined below and are also available [here](#) with additional examples.

```
<?xml version="1.0" encoding="UTF-8"?>

<xs:schema
  targetNamespace="http://www.w3.org/2007/rif#"
  xmlns:xs="http://www.w3.org/2001/XMLSchema"
  xmlns="http://www.w3.org/2007/rif#"
  elementFormDefault="qualified">

<!-- ===== -->
<!-- RIF PRD Rule Language -->
<!-- ===== -->
```

```

<!-- Redefine some elements in the Core rule language -->

<xs:redefine schemaLocation="CoreRule.xsd">

  <!-- Group      ::= IRIMETA? 'Group' Name? '(' (RULE | Group)* ')' -->
  <xs:group name="Group.content">
    <xs:sequence>
      <xs:group ref="IRIMETA" minOccurs="0" maxOccurs="1"/>
      <!-- Adds behavior to Group -->
      <xs:element ref="behavior" minOccurs="0" maxOccurs="1"/>
      <xs:element ref="sentence" minOccurs="0" maxOccurs="unbounded"/>
    </xs:sequence>
  </xs:group>

  <!-- RULE      ::= (IRIMETA? 'Forall' Var+ ' such that ' FORMULA* ' (
  <xs:group name="Forall.content">
    <xs:sequence>
      <xs:group ref="IRIMETA" minOccurs="0" maxOccurs="1"/>
      <xs:element ref="declare" minOccurs="1" maxOccurs="unbounded"/>
      <!-- Adds pattern to Forall -->
      <xs:element ref="pattern" minOccurs="1" maxOccurs="unbounded"/>
      <!-- different from formula in And, Or and Exists -->
      <xs:element name="formula">
        <xs:complexType>
          <xs:group ref="CLAUSE"/>
        </xs:complexType>
      </xs:element>
    </xs:sequence>
  </xs:group>

  <!-- Implies   ::= IRIMETA? 'If' FORMULA 'Then' ACTION_BLOCK -->
  <xs:group name="then.content">
    <xs:choice>
      <xs:group ref="ACTION_BLOCK"/>
    </xs:choice>
  </xs:group>

</xs:redefine>

<!-- ===== -->
<!-- RIF PRD Condition Language -->
<!-- ===== -->

<!-- Redefine some elements in the Core Conditions -->

<xs:redefine schemaLocation="CoreCond.xsd">

```

```

<!-- FORMULA          ::= IRIMETA? 'And' '(' FORMULA* ')' |
                        IRIMETA? 'Or' '(' FORMULA* ')' |
                        IRIMETA? 'Exists' Var+ '(' FORMULA ')' |
                        ATOMIC |
                        IRIMETA? NEGATEDFORMULA |
                        IRIMETA? Equal |
                        IRIMETA? Member |
                        IRIMETA? Subclass |
                        IRIMETA? 'External' '(' Atom ')' -->
<xs:group name="FORMULA">
  <xs:choice>
    <xs:group ref="FORMULA"/>
    <xs:group ref="NEGATEDFORMULA"/>
    <xs:element ref="Subclass"/>
  </xs:choice>
</xs:group>

</xs:redefine>

<!-- Additional elements to the Core Condition schema          -->

<!-- Subclass          ::= TERM '##' TERM -->
<xs:element name="Subclass">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="sub">
        <xs:complexType>
          <xs:group ref="TERM" minOccurs="1" maxOccurs="1"/>
        </xs:complexType>
      </xs:element>
      <xs:element name="super">
        <xs:complexType>
          <xs:group ref="TERM" minOccurs="1" maxOccurs="1"/>
        </xs:complexType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>

<!-- NEGATEDFORMULA   ::= 'Not' '(' FORMULA ')' | 'INeg' '(' FORMUL
('INeg' should always be preferred to 'Not' is there is the risk of an

<xs:group name="NEGATEDFORMULA">
  <!--
    NEGATEDFORMULA     ::= 'INeg' '(' FORMULA ')'
  -->

```

```

    <xs:sequence>
      <xs:element ref="INeg"/>
    </xs:sequence>
  </xs:group>

<!-- 'INeg' '(' FORMULA ')' -->
<xs:element name="INeg">
  <xs:complexType>
    <xs:sequence>
      <xs:group ref="IRIMETA" minOccurs="0" maxOccurs="1"/>
      <xs:element ref="formula" minOccurs="0" maxOccurs="1"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>

<!-- Additional elements to the Core rule schema -->

  <xs:element name="behavior">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="ConflictResolution" minOccurs="0" maxOccurs="1" type="x" />
        <xs:element name="Priority" minOccurs="0" maxOccurs="1" type="x" />
      </xs:sequence>
    </xs:complexType>
  </xs:element>

  <xs:element name="pattern">
    <xs:complexType>
      <xs:sequence>
        <xs:group ref="FORMULA"/>
      </xs:sequence>
    </xs:complexType>
  </xs:element>

<!-- ===== -->
<!-- RIF PRD Action Language -->
<!-- ===== -->

<!-- ACTION_BLOCK ::= IRIMETA? ('Do (' (Var (Frame | 'New'))* ATOMIC_AC
      'And (' (Atom | Frame)* ')') | Atom | Frame) -->

  <xs:group name="ACTION_BLOCK">
    <xs:sequence>

```

```

    <xs:group ref="IRIMETA" minOccurs="0" maxOccurs="1"/>
    <xs:choice>
      <xs:element ref="Do"/>
      <xs:element ref="And"/>
      <xs:element ref="Atom"/>
      <xs:element ref="Frame"/>
    </xs:choice>
  </xs:sequence>
</xs:group>

<!-- 'Do (' (IRIMETA? Var (Frame | 'New'))* ATOMIC_ACTION+ ' )' -->
<xs:element name="Do">
  <xs:complexType>
    <xs:sequence>
      <xs:element ref="actionVar" minOccurs="0" maxOccurs="unbounded"/>
      <xs:element ref="actions" minOccurs="1" maxOccurs="1"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>

<xs:element name="actionVar">
  <xs:complexType>
    <xs:sequence>
      <xs:group ref="IRIMETA" minOccurs="0" maxOccurs="1"/>
      <xs:element name="Var" minOccurs="1" maxOccurs="1"/>
      <xs:element name="ACTIONVARIABLEDECLARATION" minOccurs="1" maxOccurs="1"/>
    </xs:sequence>
    <xs:attribute name="ordered" type="xs:string" fixed="yes"/>
  </xs:complexType>
</xs:element>

<xs:element name="actions">
  <xs:complexType>
    <xs:sequence>
      <xs:group ref="ATOMIC_ACTION" minOccurs="1" maxOccurs="1"/>
    </xs:sequence>
    <xs:attribute name="ordered" type="xs:string" fixed="yes"/>
  </xs:complexType>
</xs:element>

<!-- The New element is always empty. -->
<xs:element name="New">
</xs:element>

<xs:group name="ACTIONVARIABLEDECLARATION">
  <xs:choice>
    <xs:element ref="New"/>
    <xs:element ref="Frame"/>
  </xs:choice>
</xs:group>

```

```

    </xs:choice>
  </xs:group>

  <!-- ATOMIC_ACTION ::= IRIMETA? (Assert | Retract | Modify | Execute )
  <xs:group name="ATOMIC_ACTION">
    <xs:sequence>
      <xs:group ref="IRIMETA" minOccurs="0" maxOccurs="1"/>
      <xs:choice>
        <xs:element ref="Assert"/>
        <xs:element ref="Retract"/>
        <xs:element ref="Modify"/>
        <xs:element ref="Execute"/>
      </xs:choice>
    </xs:sequence>
  </xs:group>

  <!-- Assert ::= 'Assert' '(' Atom | Frame | Member ') '-->
  <xs:element name="Assert">
    <xs:complexType>
      <xs:choice>
        <xs:element name="target" minOccurs="1" maxOccurs="1">
          <xs:complexType>
            <xs:choice>
              <xs:element ref="Atom"/>
              <xs:element ref="Frame"/>
              <xs:element ref="Member"/>
            </xs:choice>
          </xs:complexType>
        </xs:element>
      </xs:choice>
    </xs:complexType>
  </xs:element>

  <!-- Retract ::= 'Retract' '(' ( Atom | Frame | Var | Const ) ') '
  <xs:element name="Retract">
    <xs:complexType>
      <xs:choice>
        <xs:element name="target" minOccurs="1" maxOccurs="1">
          <xs:complexType>
            <xs:choice>
              <xs:element ref="Atom"/>
              <xs:element ref="Frame"/>
              <xs:group ref="TERM"/>
            </xs:choice>
          </xs:complexType>
        </xs:element>
      </xs:choice>
    </xs:complexType>
  </xs:element>

```



```

</xs:element>

<!-- Modify      ::= 'Modify'  '(' Frame ') '-->
<xs:element name="Modify">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="target" minOccurs="1" maxOccurs="1">
        <xs:complexType>
          <xs:choice>
            <xs:element ref="Frame"/>
          </xs:choice>
        </xs:complexType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>

<!-- Execute      ::= 'Execute'  '(' Atom ') '-->
<xs:element name="Execute">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="target" minOccurs="1" maxOccurs="1">
        <xs:complexType>
          <xs:choice>
            <xs:element ref="Atom"/>
          </xs:choice>
        </xs:complexType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>

</xs:schema>

```

## 13 Appendix: Complete RIF-PRD XML example

TBD

```

<Document>
  <payload>
    <Group>
      <id><Const type="rif:iri">http://example.com/2009/prd2#CheckoutRuleSe
      <meta>
        <Frame>
          <object><Const type="rif:iri">http://example.com/2009/prd2#Checko

```

```

    <slot rif:ordered="yes">
      <Const type="rif:iri">http://dublincore.org/documents/dcmi-name
      <Const type="xsd:string">W3C RIF WG</Const>
    </slot>
    <slot>
      <Const type="rif:iri">http://dublincore.org/documents/dcmi-name
      <Const type="xsd:string">Running example rule set from the RIF-
    </slot>
  </Frame>
</meta>
<behavior>
  <ConflictResolution>rif:forwardChaining</ConflictResolution>
</behavior>
<sentence>
  <Group>
    <id><Const type="rif:iri">http://example.com/2009/prd2#GoldRule</
    <behavior>
      <Priority> 10 </Priority>
    </behavior>
    <sentence><Forall> ... </Forall></sentence>
  </Group>
</sentence>
<sentence>
  <Group>
    <id><Const type="rif:iri">http://example.com/2009/prd2#DiscountRu
    <sentence><Forall> ... </Forall></sentence>
  </Group>
</sentence>
</Group>
</payload>
</Document>

```