An Ontology for Specifying and Parsing Knowledge Representations Structures and Notations

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Abstract: In its introduction, this article gives a short state of the art about ontologies of knowledge representation languages (KRLs) and the problems caused by i) the lack of relations between these ontologies, and ii) the lack of ontologies about notations (concrete syntaxes). For programmers, these are the difficulties of importing, exporting or translating between KRLs; for end-users, the difficulties of adapting, extending or mixing notations. To show how these problems can be solved, this article first shows how concepts of the main KRL standards can be aligned and organized. Then, it shows how this KRL model ontology can be re-used and completed by a notation ontology. Based on these two ontologies, KRLs models and notations - and thereby parsing and generation - can be specified in a concise way that even KRL end-users can adapt. The article gives representative examples. For these ontologies or specifications, a concise KRL notation is introduced and used. However, the presented approach is independent of any notation and model that has at least OWL-2 expressiveness. Thus, the results can easily be replicated. A Web address for the full specification of the two ontologies, and for a knowledge server to test or use them, is also given.

1 INTRODUCTION

Various language models are used for knowledge representation, retrieval and exploitation. For each model (abstract syntax) there are also many possible notations (concrete syntaxes). Creating a parser or an export procedure for each knowledge representation language (*KRL; one model and/or one notation*) is time-consuming. Specifying the automatic translation of knowledge (representations) from one KRL to another is difficult, especially without some shared ontology of these KRLs, hence without formal semantic relations between their components. Learning and understanding a KRL is also difficult for a person. These are therefore also difficulties for knowledge sharing. For a knowledge provider, not being able to adapt a KRL notation, is also limiting.

There have been many works for partially addressing these problems, except for the last one which requires the use of a KRL notation ontology to enable any significant adaptation.

An early major work was KIF (Knowledge Interchange Format) (Genesereth and Fikes, 1992), a 1st-order logic based KRL - with a 2nd-order notation - to which most KRLs could be translated to and formalized with. Many were. To ease this, the Ontolingua "ontology server or shared repository" (Farquhar *et al.*, 1997) provided a well formalized KRL model ontology. E.g., it included a formalization of frame-based language concepts in KIF (concepts similar to those of OWL).

Later, with the popularization of MOF (the Meta-Object Facility of the OMG: Object Management Group), XML and then RDF, many language models or ontologies were created in these three languages. These were often simple lists of KRL components and their structural relations. Indeed, MOF, XML and RDF do not permit to fully *define* KRL components and hence relate all of them as in Ontolingua. They still permit to declare and use a set of KRL components that corresponds to a certain logics with well studied properties. Thus, the W3C provided the different language ontologies of the OWL family (OWL 2, 2009). With RIF-FLD, it also provided an expressive and extensible "Framework for Logic Dialects" (RIF-FLD, 2013). ANSI provided CL

(Common Logic, 2007), a "framework for a family of logic-based languages" restricted to 1st-order logic. The OMG created a "Conceptual package" along with an ontology for the "Semantics of Business Vocabulary and Business Rules" (SBVR, 2008).

These standards (RDF+OWL+RIF-FLD, CL and MOF+SBVR) have similar or complementary components. They are declared in their respective XML schemas but, to our knowledge, no ontology semantically relates them nor to concepts in Onto-lingua. However, within the scope of each of these standards, there are works on translating between models or ontologies. E.g., the W3C specifies ways to re-use RDF and OWL knowledge in RIF.

Model translation is often only a part of knowledge translation or (re-)presentation. Indeed, there are many existing or potential notations for KRL models and, so far, unlike some KRL models, no notation was represented by an ontology. Thus, no notation could be adapted or extended by their users, except very partially via a system of macros such as the one usable with the C programming language. A different parser and generator also had to be built for each notation, except for XML-based notations (e.g, RDF/XML: RDF in XML). The W3C proposes XSLT for specifying syntactic translations between XML based notations. It also proposes GRDDL for specifying where a software agent can find "algorithms (typically represented in XSLT)" to convert a structure or notation to RDF/XML. Conversely, there are some style-sheet based transformation languages and ontologies for specifying how RDF abstract structures can be *presented*, e.g., in a certain order, in bold, in a pop-up window, etc. : Xenon (Quan, 2005), Fresnel (Bizer *et al.*, 2006), OWL-PL (Brophy and Heflin, 2009) and SPARQL Template (Corby *et al.*, 2014). With these tools or the approach behind these tools, each modification to a notation requires a new template or style-sheet, and parsing is not addressed.

Supporting knowledge import/export/translation in a generic way requires specifying KRLs with respect to a KRL model ontology and a KRL notation ontology. This article presents such ontologies and gives examples of their use. To do so in a sufficiently concise and readable way, Section 2 first introduces FL, a concise and "visually structured" notation. Then, using FL, it shows how the main concepts of RIF-FLD, CL and SBVR can be related, defined and generalized to create the above cited two ontologies. This work required many readings of the specifications and grammars of RIF-FLD since they leave their underlying ontology implicit. Section 3 shows how the models and grammar of KRLs - and thereby their parsing, presentation and translation - can be specified based on these two ontologies. CSS-like presentation based on syntactic or semantic features could also be similarly specified but this is outside the scope of this article.

The generic approach we propose to solve the initially listed problems is independent of any notation and any model that has at least OWL 2 expressiveness. This article focuses on presenting the main ideas of the approach. The whole ontologies and model+notation specifications of various KRLs, as well as a Web server interface to test or use them, are available at http://www.webkb.org/KRLs/. This interface is similar to Google Translate except that the input and output languages are KRLs and, instead of KRL names, KRL specifications can also be given.

2 LANGUAGE ELEMENTS

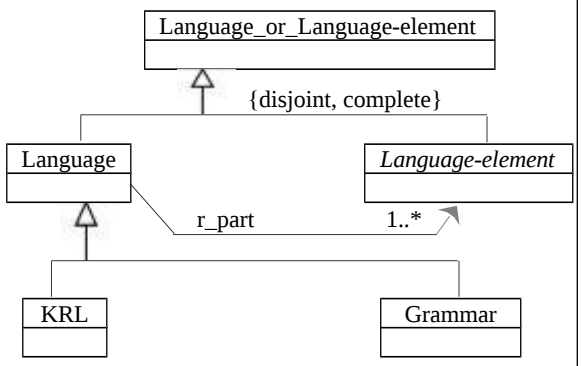
To allow the display and understanding of its numerous required illustrations, this article needs a concise and intuitive notation for KRLs of OWL-like expressiveness. Unfortunately, graphical notations are not concise enough and common notations such as those of the W3C are not sufficiently concise and "structured" enough. Here, "structured" means that all direct or indirect relations from an object can be (re-)presented into a unique tree-like statement so that the various inter-relations can readily be seen. Table 1 illustrates this by representing the same statement in five notations: FL then UML, Turtle (or Notation3), OWL Manchester notation and OWL Functional-style. The way to read the content for FL is explained and *given in italics* within a paragraph following the table.

The last notation is "positional relation" based. The first four are graph-based notations: they are composed of concept nodes and relation nodes. These textual graph-based notations are frame-based. A frame is a statement composed of a first "object" (alias "node": individual or type, quantified or not) and several links associated to it (links from/to other objects). In this article, "link" refers to an instance of a "binary relation type". In OWL, such a type is instance of "owl:Property" (in FL: owl#Property). What is not an individual is a type: relation type or concept type (an instance of owl#Class in OWL).

In this article, the default namespace is for the types we introduce. The names of a concept type or individual that we introduce is a nominal expression beginning by an uppercase letter. The name of a relation type we introduce begins by "r_" (or "rc_" if this is a type of link with destination a concrete term). Thus, names not following these conventions and not prefixed by a namespace are KRL keywords.

Table 1: The same statement - or set of statements (here, a set of relations about Language_or_Language-element) - in five different notations: FL, UML, Turtle, OWL Manchester, OWL Functional-Style. In all other tables, FL will be used.

```
Language_or_Language-element   //below: links defining it
  = exclusion
    { (Language   r_part:  1..* Language_element,
                      >    KRL    Grammar  )
      Language_element
    };
//Notes. ">" is an abbreviation for the "subtype" link (as in
//  some other notations). "<" is its inverse.  "exclusion{...}"
//  specifies a union of disjoint types.  If "T = exclusion{...}"
//  this is one subtype partition of T.  If "T > exclusion{...}"
//  this is not a partition (or it is an "incomplete" one).  A ","
//  separates 2  links of different types.  For consecutive links
//  of the same type, this type needs not  be repeated and the
//  destinations are only separated by one or several spaces.
```




```
:Language_or_Language-element   owl:equivalentClass
     [ rdf:type   owl:Class;
       owl:unionOf  ( :Language  :Language_element )  ].
[ ] rdf:type  owl:AllDisjointClasses; //→no shared instance
    owl:members  ( :Language  :Language_element ).
Language  rdfs:subClassOf   [a owl:Restriction;
   owl:onProperty  : r_part;
   owl:minQualifiedCardinality "1"^^xsd:nonNegativeInteger;
   owl:onClass  Language_element ].
KRL  rdfs:subClassOf  :Language.
Grammar  rdfs:subClassOf  :Language.
```

```
Class:  Language_or_Language-element
    EquivalentTo:  Language or Language-element
DisjointClasses:  Language, Language-element
Class: Language EquivalentTo:
                          r_part  min 1 Language_element
Class: KRL  SubClassOf:  Language
Class: Grammar  SubClassOf:  Language
```

```
EquivalentClasses( :Language_or_Language-element
       ObjectUnionOf( :Language  Language-element) )
DisjointClasses(: Language :Language_element)
EquivalentClasses( :Language
 ObjectMinCardinality(1 :r_part  :Language_element) )
SubClassOf (:KRL  : Language)
SubClassOf (:Grammar  : Language)
```

Within nominal expressions, '_' and '-" are used for separating words. When both are used, '-' connects words that are more closely associated.

Since nouns are used for the introduced types, the common convention for reading links in graph-based KRLs can be used: links of the form "X R: Y" can be read "X has for R Y". If "of" is used for reversing the direction of a link, the form "X R of: Y" can be read "X is the R of Y". In FL, if a link is not a subtype link (or another "link from a type"), the first node is quantified and its default quantifier is "any", the "forall" quantifier for definitions (in other words, the type in the first node is defined by this link). Links with the same first node may quantify it differently. Indeed, in FL, the quantifiers of the source node and destination node of each link may also be specified in its relation node or in its destination node. This permits FL to gather any number of statements into a unique visually connected graph. However, in this article, the quantifier for the first node is always "any" and left *implicit*. A destination node can also be source of links if they are encapsulated within parenthesis. Thus, given all this and the notes at the end of the FL content in Table 1, its first six lines can be read: "*The type Language_or_Language-element is equivalent to its subtype partition composed of Language_element and Language, and any instance of Language has for (r_)part at least 1 instance of Language_element. This last type has for subtypes (at least) KRL and Grammar*". The other tables of this article can now be read (any new keyword will be explained, most often via a comment next to it). In these tables, bold characters are only for highlighting important types and for readability purposes.

Table 2 shows how types for KRL models and notations can be organized and inter-related. E.g., RIF-FLD includes RIF-BLD, both are part of the RIF family of models, and both have a Presentation Syntax ("PS") and an XML linearization.

Table 3 relates Language_element and some of its direct subtypes to important top-level types, thus adding precisions to these subtypes. Such a specification is missing in RIF-FLD but is well detailed in SBVR. This is why Table 3 includes many top-level SBVR types, although indirectly: *the types with names in italics* are still types that *we introduce* but they *have the same names as types in SBVR* and are equal to them or slight generalizations of them. This approach is for readability reasons and flexibility: if the SBVR authors disagree with our interpretation of their types, only some links to SBVR types will have to be changed, not our ontology. As illustrated by Table 3, to complement and organize types from other ontologies, ours had to include many new types.

Table 2: Examples of relations between KRLs.

```
KRL r_part: 1..* Language_element,
 > exclusion { KRL_notation KRL_model },
 r_grammar_head_element_type: Grouped_phrases;

KRL_notation
 > (S-expression_based_notation > LISP_based_KIF)
   (Function-like_based_notation
     > (RIF_PS > RIF-FLD_PS  RIF-BLD_PS) )
   (Graph-based_notation
     > (Markup_language_based_notation
         > (XML_based_notation
             > (RIF_XML > RIF-FLD_XML) )
       (Frame_based_notation > FL JSON-LD Turtle) ) );

KRL_model
 > (First-order-logic_with_sets_and_meta-statements
     > (KIF_model r_model_type of: LISP-based_KIF),
     r_part: 1..* First-order-logic )
   (First-order-logic > (CL r_model_type of: CLIF) )
   (RIF > (RIF-FLD r_model_type of: RIF-FLD_PS,
                   r_part: RIF-BLD )
          (RIF-BLD r_model_type of: RIF-FLD_PS) )
   (Graph-based_model
     > (JSON-LD_model r_model_type of: JSON-LD)
       (RDF r_part: 1..* JSON-LD_model,
            r_model_type of: JSON-LD RDF/XML),
       (Frame_model_with_closed_world_assumption
         > F-Logic_classic_model )
       (Frame_model_with_open_world_assumption
         > (Description_logic_model > OWL_model) ) );

OWL_model
 > (OWL1_model > OWL-Lite OWL-DL OWL1-Full)
   (OWL2_model > OWL2_EL OWL2 -RL OWL2-Full),
 r_part: 1..* (OWL1-Full r_part: 1..* RDF 1..* OWL-DL )
        1..* (OWL2-Full r_part: 1..* OWL2_EL
                                1..* OW-2_RL ) );
```

In RIF-FLD, depending on the context, the word "term" has different meanings. In our ontologies, *Gterm* generalizes all these meanings of "term": it is identical to Language_element and sbvr#Expression. In RIF-FLD, an "individual term" is an abstract term that is not a Phrase (see Table 3), although it may refer to one. Individual_gTerm - or, simply "Iterm" - generalizes this notion to concrete terms too. This distinction was very useful to organize types of language elements, especially those from the implicit ontology of RIF-FLD (this framework uses different vocabulary lists, including one for signatures; in our ontology, all these terms are inter-related). In this context, "individual" does not refer to "something that is not a type". Since an Iterm may refer to a Phrase, an Iterm identifier may be a Phrase identifier. Thus, Table 3 uses the construct "near_exclusion" instead of "exclusion".

Table 3: Situating Language_element w.r.t. other types (note: names in italics come from SBVR).

```
Thing = owl#Thing, r_identifier: 0..* Individual_gTerm,
 = exclusion
   { (Situation = exclusion{State Process},
       r_description: 0..* Phrase )
     (Entity //thing that can be involved in a situation
       > exclusion
         { Spatial_entity //e.g., Square, Physical_Entity
           (Non-spatial_entity //e.g., Justice, Attribute, ...
             > (Description_content = Meaning,
                 > Proposition Question
                   (Concept > Noun_concept //e.g., types
                                (Verb_concept = Fact_type) ) )
               (Description_container > (File > RDF_file))
               (Description_instrument
                 > (Language_or_Language-element
                     = exclusion
                       { (Language > KRL Grammar,
                           r_part: 1..* Language_element )
                         Language_element //see below
                       } ) ) )
         } ) };

Language_element = Gterm Expression,
 r_representation of: 1 Meaning,
 > near_exclusion //String is both abstract and concrete
   { (Representation > Statement,
       rc_type: Concrete_term )
     (Concrete_term > (Expression > Text),
       > (Concrete_iTerm < Iterm) ) //see Table 7
   }
   near_exclusion //a reference to a phrase is an Iterm
   { (Phrase > Statement Definition Frame) //Tables 5-6
     (Individual_gTerm = Iterm, //see Table 7
       > Place_holder, r_identifier of: 1 Thing )
   }
   near_exclusion { Positional_gTerm Frame
                    Gterm_with_named_arguments }
   near_exclusion //subtyping these types is KRL dependent
   { Non-referable_gTerm //e.g., a predefined term
     (Referable_gTerm //via constant/variable/function/phrase
       r_variable: 0..* Variable, r_result of: 1..* Function,
       r_annotation: 0..* Annotation, //referable→linkable
       > (Gterm_that_cannot_be_annotated_without_link
           r_annotation: 0 Annotation ) Termula )
   };
```

This construct has no formal meaning (it does not set exclusion links). It is only useful for readability purposes. Table 3 also uses it to group and distinguish types for abstract and concrete terms. Indeed, a (character) string may be seen by some persons as being both abstract and concrete. Our ontology must be compatible with such visions when they come at no cost.

RIF-FLD distinguishes three types of generic structures for a Gterm that is a function or a phrase. We

dropped their RIF-related restrictions and named them Positional_gTerm, Gterm_with_named_arguments and Frame. Table 1 gave examples for positional and frame terms. A term with named arguments is similar to a frame except that, as in object-oriented languages, local attribute names are used instead of link types (types are global). It could be argued that a same term could be presented in any of these three forms and hence that these three distinctions should rather be syntactic. However, the authors of RIF-FLD have not formalized the equivalence/correspondence between i) "classes and properties" ("interpreted as sets and binary relations") and ii) "unary and binary predicates", *in order to have* a "uniform syntax for the RIF component of both RIF-OWL 2 DL and RIF-RDF/OWL 2 Full combinations" (RIF-FLD-OWL, 2013). According to this vision, each person re-using ontologies must decide if, for its applications, stating such an equivalence is interesting or not. RIF rules or a macro language such as OPPL can certainly be used for such structural translations (Šváb-Zamazal *et al.*, 2012). However, to avoid imposing this exercise to most users of our KRL model ontology, and to avoid limiting its use for specifying KRLs, it formalizes relations between a frame and a Conjunction_of_links_from_a_same_source (this is done in the last 15 lines of Table 6 plus the 3 lines related to Half-link in Table 7; reminder: a link is - or can also be seen as - a binary relation).

We found that a small number of link types are sufficient for defining a structure for abstract terms and specifying their related concrete terms. Table 4 lists and explains the main link types. They can be seen as a representation and *extension* of the signature system of RIF-FLD. The ideas are that 1) every composite term can be decomposed into a (possibly implicit) operator (e.g., a predicate, a quantifier, a connective, a collection type) and a list of parameters (alias, "parts"), and 2) many non-binary relations can be specified as links to a collection of terms. Table 5 and the subsequent tables use the link types of Table 4 directly or via functions which are shortcuts for specifying such links. This is highlighted via bold characters in those tables. The end of Table 4 specified one of these functions. In the tables 5 to 7, which illustrate the organization of subtypes of Phrase and Iterm, this function is used to define certain abstract terms as links and hence enable to store them or present them as such when necessary.

Some of such links are used for both abstract and concrete terms. E.g., rc_operator_name is often also associated to an abstract term for specifying a default name for its operator. If no such link is specified or if "" is given as destination, the operator type name (without its namespace identifier) is used as default operator name.

Table 4: Main links for defining a structure for abstract terms and specifying concrete terms.

```
Gterm   r_identifier_or_description of: 1 Thing,
  r_operator:  0..1 Operator , //Table 7
  r_part:  0..* Gterm,  //object parts or fct/relation arguments
  r_parts: 1 List,  //r_part destinations, sequentially ordered
  r_result: 1 Gterm, //e.g., a phrase has for r_result a boolean
  rc_type:  Concrete_term,  //rc_type is defined below
  r_variable: 0..* Variable,   r_result of: 1...* Function;

rc_link_to_concrete-term  //also often from a Concrete_term
     _[Gterm,Concrete_term]  //signature of this relation type
 >  rc_begin-mark   rc_separator   rc_end-mark
     rc_operator_begin_mark   rc_operator_end_mark
     rc_operator_name   rc_infix-operator_position
     rc_parts_begin-mark   rc_parts_separator
     rc_parts_end-mark  rc_annotation_position; //-1: before

r_gTerm_part   r_type: Transitive_relation_type,
  > (r_operator >  r_frame_source  rdf#predicate)
    (r_parameter = r_part,  //"r_part" used for concision
       > (r_link_parameter
            >  (r_link_source        >  rdfs#domain)
               (r_link_destination > rdfs#range) ) )
    (r_phrase_part > rdf#subject  rdf#object);

//r_parts permits to order the parts, this is sometimes
// needed for abstract terms and this also permits to give
// a default order for presentation purposes.
r_parts _[?e,?list]
  :=> [any  ^(Thing  r_member of: ?list)  r_part of: ?e];
r_parts _[?e,?list]
  :<= [any  ^(Thing  r_part of: ?e)  r_member of: ?list];

/* Notes:  in FL,  ":=' permits to give a full definition,
 ":=>"  gives only "necessary conditions",
 ":<=" gives only "sufficient conditions",
 "^(" and ")" delimit a  lambda-abstraction (a construct
       defining and returning a type; in OWL related KRLs,
       owl#Restriction can be used),
 "_(" and ")" delimit the parameters of a function call,
 "_[" and "]" delimit the parameters of a definition,
 ".[" and "]" delimit  the elements of a list,
 ".{" and "}" delimit the elements of a set.  */

rc_type _[?t,?rct] := [any ?t  rc_: 1..* ?rct];
//people who see concrete terms as specialisations of
// abstract terms can still state:
//    rc_type <  subtype;       rc_   r_type:  instance;

   //in the next function signature, the variables are untyped
f_link_type  _[ ?operatorName,  ?linkType,
                ?linkSourceType,  ?linkDestinationType ]
 :=  ^(Link   rc_operator_name: ?operatorName,
          r_operator: ?linkType,  r_result: 1 Truth_value,
          r_link_source: 1 ?linkSourceType,
          r_link_destination: 1 ?linkDestination,
          r_parts: .[ ?linkSource ?linkDestination] );
```

Table 5: Important top-level types of phrases (first row); a way to restrict this general model for KRLs (2nd row)
(note: names in italics come from RIF-FLD, names in bold italics are used in RIF-FLD signatures, bold is for highlighting).

```
Phrase < ^(Gterm  r_operator: 1  (Operator_type  > (owl#Property  r_instance: r_binary_relation ) ),
                  r_result: 1 (Truth_value  r_instance:  True  False  Indeterminate_truth-value/*for example*/ ) ),
 > (Phrase_not_referable_in_RIF-FLD   //hence, phrase that cannot have an annotation in RIF-FLD
     > (Annotation  >  cl#Comment ,  //"cl#' prefixes terms from Common Logics
         > (Formal_annotation  > (RIF_annotation  r_parts: .[0..1 Constant, 0..1 Frame_or_Frame-conjuction]) )
       (Annotating_phrase =  f_link_type_("",r_annotation,Gterm,Annotation))
       Module_directive    Attribute  ),
 = exclusion
   { (Modularizing_phrase
      > (Phrases =  Grouped_phrases,   r_part: 0..* Phrase,  > cl#Text,   //Phrases is the head element of a KRL grammar
         > (Module   >  cl#Module  cl#NamedText,
            > (Document   r_part:  0..1 Document_Directive   0..1 Phrases),
            r_part: 0..1 (Module_parts_that_are_directives  <  Module,
                        >  (Module_header = f_link_type_("",r_header,Module, .[0..* Module_directive]) ) )
                    0..1 (Module_parts_that_are_not_directives = f_link_type_("Group",r_group,Module,.[0..* Phrases],
                        <  Module,   >  Module_body   Group_of_phrases ),
            r_parts: .[0..1 Module_header, 0..1 Module_body]  ) )
       (Module_directive = f_link_type_("",r_relation,Module,Thing),
         > (Module_name_directive = f_link_type_("Name",r_name,Module,Name) )
           (Excluded_Gterm-reference_directive = f_link_type_("",r_excluded_gTerm,Module,.[1..* Gterm_reference]) )
           (Document_directive
             > (Dialect_directive =  f_link_type_("Dialect",r_dialect,Module,Name))
               (Base_directive     =  f_link_type_("Base",r_base,Module,Document_locator))
               (Prefix_directive   =  f_link_type_("Prefix",r_prefix,Module,NamespaceShortcut-DocumentLocator_pair))
               (Import-or-module_directive  > cl#Importation,
                 > (Import_directive = f_link_type_("Import",r_imported-doc,Document,Imported_document_reference) )
                   (Remote_module = f_link_type_("Module",r_imported-module,Module,Remote_module_reference) )
               ) ) ) )
     (Non-modularizing_phrase   //this may include non-monotonic phrases: assertions, queries, removals
       > (Formula  >  Positional_formula   Formula_with_named_arguments    Phrase_of_a_grammar    cl#Sentence,
          = exclusion  //the 3 following distinctions come from KIF
            { (Definition = exclusion { Non_conservative_definition  Conservative_definition } )
              (Sentence  //fact in a world: formula assigned a truth-value in an interpretation
                >  Belief  //the fact that someone believes in a certain thing
                  Axiom ) //sentence assumed to be true, from/by which others are derived
              (Inference_rule> Production_rule) //like an implication but the conclusion is "true" only if/when the rule is fired
            }
            near_exclusion  { Composite_formula    Atomic_formula_or_reference_to_formula } ) ),   //see Table 7
        Termula_phrase )  //a termula is a RIF function/atomic_formula parameter; its subtypes  are not listed in this article
   };
```

```
    //with the next subtype of r_part, the source ?x has some parts of type ?pt but no other parts with type the genus of ?pt
r_only_such_part_of_that_type _[?x ?pt]  <  r_part _(?x ?pt),                    //this definition requires that relations of type
 := [?x  r_part:  1..* ?pt    0 ^(?t != ?pt,  < (?gpt  r_genus_supertype of: ?pt))];    // r_genus_supertype are set by definitions

//Thanks to this link type,  our general model for KRLs and the default presentation associated to its abstract terms,
//  KRLs can be defined in a very concise way.  Below are examples for some abstract terms of some KRLs.
//  The next section gives examples for some concrete terms of some KRLs.  For the Triplet_notation, nothing else is required.

RIF   r_only_such_part_of_that_type:   //any model of the RIF family has for part terms defined by the following lambdas:
 ^(Gterm_that_can_be_annotated_without_link > Phrase)   ^(Grouped_phrases  r_part: 0..* Document)
 ^(Quantification >  Classic_quantification)    ^(Frame > Minimal_frame)    ^(Collection > List)
 ^(Delimited_string > Delimited_Unicode_string);  //in RIF, the only "delimited strings" are "delimited Unicode strings"

RIF-BLD   r_only_such_part_of_that_type:    ^(Rule_conclusion > rif-bld#Formula)     //these are just two examples,
 ^(Rule_premise  >  Connective_phrase_on_atomic_formulas   Conjunction_phrase);    //  RIF-BLD has other restrictions

Triplet_notation = ^(KRL r_only_such_part_of_that_type:  ^(Phrase > Link)  ^(Individual_gTerm > Constant_or_variable) );
```

Table 6: Important types of formulas and connections between frames, links and positional formulas
(note: names in italics come from RIF-FLD, names in bold italics are used in RIF-FLD signatures, bold is for highlighting).

```
Composite_formula =  f_relation_type_("",r_relation,.[1..* Formula]),  // => r_part: 1..* Formula
 > exclusion
   { (Formula_connective   r_operator_type:  1 connective_operator,   >  cl#Boolean_sentence,
       > exclusion
         { (Connective_phrase_with_1_argument  = f_relation_type_("",r_unary_relation,.[1..* Formula]),
            > (Negating_formula=exclusion{(Symmetric_negating_formula = f_relation_type_("Not",r_not,.[1..* Formula]))
                                           (Negation-as-failure_formula = f_relation_type_("Naf",r_naf,.[1..* Formula]))
                                          }))
           (Connective_phrase_with_2_arguments  = f_relation_type_("",r_binary_relation,.[1..* Formula]),
            >  (Rule = f_relation_type_(":-",r_rule_implication,.[1..* Formula]),
                 = exclusion{  (Inference_rule     > Production_rule)   (Logical_rule <  Sentence, > Logical_implication) }
                   exclusion{  (Implication_only > Production_rule)   (Logical_equivalence r_operator: r_equivalence) },
                 r_part:  1 (Rule_premise < Formula)   1 (Rule_conclusion < Formula)  ) )
           (Variable-n-ary_connective_phrase = f_relation_type_("",r_variable-ary_relation,.[1..* Formula]),
            >  exclusion { (Disjunction_phrase = f_relation_type_("Or",r_or,.[1..* Formula]))
                           (Conjunction_phrase = f_relation_type_("And",r_and,.[1..* Formula]),
                             > (Conjunction_of_links = f_relation_type_("And",r_and,Link),
                                 > Frame_as_conjunction_of_links_from_a_same_source ) )   } )
         } )
     (Quantification = f_quantification_type_("",Quantifier,.[1 Type],Constant-or-variable,Formula),
       > (Classic_quantification = f_quantification_type_("",Quantifier,.[],Variable,Formula) )   //no guard, no constant
          exclusion
          { (Universal_quantification = f_quantification_type_("Forall",q_forall,.[1 Type],Constant_or_variable,Formula),
              > (Classic_universal_quantification = f_quantification_type_("Forall",q_forall,.[],Variable,Formula) ) )
            (Existential_quantification = f_quantification_type_("Exists",q_exists,.[1 Type],Constant_or_variable,Formula),
              > (Classic_existential_quantification  = f_quantification_type_("Exists",q_exists,.[],Variable,Formula) ) )   } )
   };

Atomic_formula_or_reference_to_formula
 > exclusion { (Formula_reference  //this is also an Individual_gTerm
                 > exclusion { Variable_for_a_formula       Reference_to_formula_in_remote_module  //with the same KRL
                               Reference_to_externally_defined_formula } )   //not in a module and not with the same KRL
               (Atomic_formula
                 > { Constant_for_a_formula
                     (Atomic_formula_that_is_not_a_constant
                       > near_exclusion   //possible shared subtypes: subclass_or_equal, link
                         { (Positional-or-name-based_formula    r_operator: 1 Termula,   >  cl#Atomic_sentence,
                             > exclusion { (Positional_formula  r_part: 1..* Termula)
                                           (Name-based_formula  r_part: 1..* Name-Termula_pair) } )
                           (Equality_formula = f_link_type_("=",r_equal,Termula,Termula),  >  cl#Equation)
                           (Class-membership = f_link_type_("#",r_type,Termula,Termula) )
                           (Subclass_formula = f_link_type_("##",r_supertype,Termula,Termula) )
                           (Frame = (Frame_as_conjunction_of_links_from_a_same_source  ?f
                                       r_frame_head: 1 Termula ?fh,    r_part: (1..* Link  r_link_source: ?fh) )
                                    (Frame_as_head_and_half-links_from_head  ?f
                                       r_operator: (1 Termula ?fh  r_frame_head of: ?f),
                                       r_part: (1..* Half_link  r_link_source: ?fh),
                                       > (Minimal_frame  r_part: 1..* Minimal_half-link) ) )
                         } )
                         (Binary_atomic_formula_that_is_not_a_constant
                          > (Link  =  (Link_as_positional_formula  < Positional_formula,
                                       <  f_link_type_("",r_binary_relation_type,Termula,Termula),
                                       r_part of: (1 Frame ?f  r_frame_head: 1 Termula ?fh),   r_link_source: ?fh )
                                      (Link_as_frame_part   r_part of: (1 Frame ?f  r_frame_head: 1 Termula ?fh),
                                       r_operator: ?fh,   r_link_source: ?fh,   r_link_destination: 1 Termula ?ld,
                                       r_part: (1 Half_link   r_link_source: ?fh,   r_operator: ?fh,  r_parts: ?ld )  ) ) )
                     } )  };
```

Table 7: Important types of "individual terms" (terms that are not phrases except for those referring to phrases)
(note: names in italics come from RIF-FLD, names in bold italics are used in RIF-FLD signatures, bold is for highlighting).

```
Individual_gTerm  //the expression "Individual term" comes from RIF-FLD
 = near_exclusion
   { (Individual_concrete_term
       > Concrete-term_for_constant_or_name   Lexical-grammar_character-set   Concrete_list-like_term
         (String >  (Delimited_string > Delimited_Unicode_string))    Character  )
     (Individual_abstract_term
       > (Abstract_individual_gTerm_not_referable_in_RIF-FLD
           > exclusion
             { (Operator_not_referable_in_RIF-FLD  //predefined in RIF-FLD which does not rely on an ontology
                 > exclusion { Quantifier   Connective_operator   Aggregation-function_or_list_operator } )
               Symbol_space_identifier   //e.g., xs:decimal, rif:iri
               (Name-Termula_pair  r_parts: .[1 Name, 1 Termula])
               (Half_link  r_link_source: 1 Termula,  r_operator: 1 Link_type,  r_part: 1..* Link_destination,
                 > (Minimal_half-link  r_operator: 1 Link_type,  r_part: 1 Minimal_Link_destination) ),
               (Link_destination  r_parts: .[0..1 Cardinality, 1 Termula],  > (Minimal_link_destination  r_part: 1 Termula))
             } )
         Fterm_or_variable      Individual_abstract_term_of_a_grammar
         (Operator   r_type: Operator_type,   > r_relation  f_function  Operator_not_referable_in_RIF-FLD)
         (Symbol_space > rif#iri   rif#local   xs#string  xs#integer  xs#decimal  xs#double)  )
   };

Fterm_or_variable   //cl#Term_or_sequence_marquer,
 = exclusion
   { (Variable > Variable_for_a_formula)   //cl#Sequence_marquer
     (Fterm   //cl#Term
       > exclusion
         { (Gterm_reference > (Constant_gTerm = ^(Gterm r_operator: 0 Operator_type),
                                 = exclusion { Individual  //in the classic sense of "category that is not a type"
                                               (Predicate = Type,    //cl#predicate
                                                 >  rdfs#Class   (Literal_or_datatype > rdfs#Literal  rdfs#Datatype) ) } )
                            (Reference_to_external_gTerm >  Gterm_locator  Imported_document_reference /* ... */) )
           (Functional_term   r_operator: 1 (Function_type  <  Type),
             = exclusion { (Non-aggregate_functional_term = Expression)
                           (Aggregate_function_or_collection
                             > (Aggregate_function   r_operator: 1 Aggregation-function_operator ,
                                  r_parts: .[1 Aggregate_function_bound_list, 1 Formula] )
                               (Collection   r_operator: 1 Collection_type,   //e.g., rdfs#Container
                                 = exclusion { (Unordered_collection  > Set)
                                               (Ordered_collection
                                                 > (List  = f_function_type_("List",fd_list,.[1..* Ftermula]),
                                                      = exclusion { Closed_list   Open-list } ) ) } ) )
                       } ) } ) };

Concrete-term_for_constant_or_name   //just some examples to show that the same approach applies for concrete terms
> (Symbol-space_name   r_identifier of: 1..* Symbol_space,
    > exclusion  { (Symbol-space_name_via_bracketed_IRI   r_part: 1 IRI_reference )
                   (Symbol-space_name_via_compact_URI   r_part: 1 Compact_URI)  } )  //xs:decimal, rif:iri, ...
  (Variable_name  r_identifier of: 1..* Variable,  <  ^(f_string_type_("?","","")  r_part: 1 Undelimited_variable-name) )
  (Constant_concrete_term  r_identifier: 1..* Constant_gTerm,
   > (Constant_concrete_term_without_symbol-space
       > (Constant_IRI  r_part: 1 IRI_reference )
         (Constant_short-name_via_compact_URI  r_part: 1 Compact_URI)
         (Literal_or_datatype_concrete_term  r_identifier of: 1..* Literal_or_datatype,
           > (Double_quoted_string
               <  ^(f_string_type_("","","") r_part:  1..* f_character_type_with_escape_for_(Character,"\\","") ))
             (Numeric_literal  > (Positive_integer  <  ^(f_string_type_("+","","") r_part: 1..* Digit))
                                 (Negative_integer <  ^(f_string_type_("-","","") r_part: 1..* Digit)) ) ) ) );
```

3 PRESENTING AND PARSING

Table 8 lists major kinds of structured concrete terms and thus also the main presentation possibilities for structured abstract terms (see the 14 names in italics). Based on the five main categories for these concrete terms (see the names in bold and not in italics), it is easy to find the five categories of abstract terms they correspond to, even though such links are not shown in Table 8. We found that each of these concrete term types can be defined with only a few types of links, those that begin by "rc_" and that were listed in Table 4. We defined some functions to provide shortcuts for setting those links when defining a particular concrete term, e.g., fc_prefix-fct-like_type.

In our ontologies, links from a type do not specify that the given destination is the only one possible (to do so in FL, "=>" must be used instead of "':" after the link type name; in OWL-based models, owl#allValuesFrom can be used). Thus, such links represent "default" relationships: if a link from a type T specializes a link from a supertype of T, it overrides this inherited link. This is also true when the link type is functional (i.e., can have only one destination) and its destination for T does not specialize the destination for a supertype of T. The links beginning by "rc_" looks functional but are not: in FL, multiple destinations can be stated to indicate different presentation possibilities. However, by convention, such links override inherited links of the same types.

Table 8: Important types of structured concrete terms (except for strings) and definition of their default presentation.

```
Structured_concrete_term_that_is_not_a_string  //the examples in the comments below are in FL; with their delimiters a KRL
 > exclusion                                   // may have all these structures  and still only requires an LALR(1) parser
  { (List_cTerm  >  Enclosed_list_cTerm  /* e.g., .[A B C] */    Fct-like_list_cTerm  /* e.g., A ..[B C] */ )
    (Set_cTerm  >  Enclosed_set_cTerm  /* e.g., .{A B C} */    Fct-like_set_cTerm  /* e.g., A ..{B C} */ )
    (Positional_cTerm  //e.g., with operator "f" and parts/parameters A, B and C
      rc_operator-name: "",  rc_operator_begin_mark: "",  rc_operator_end_mark: "",   //link types listed in Table 4
      rc_parts_begin-mark: "(",  rc_parts_separator: "",  rc_parts_end-mark: ")",
      rc_infix-operator_position: 0,  //when different from 0, this indicates the operator position within the parts
      > exclusion { (Fct-like-cTerm
                      = exclusion { (Prefix_fct-like-cTerm  rc_parts_begin-mark: "_(")          //e.g.:  f _(A B C)
                                    (Postfix_fct-like-cTerm  rc_parts_begin-mark: "(_") } )     //e.g.:  (_ A B C)f
                    (List-like_fct_cTerm
                      = exclusion { (List-like_prefix-fct_cTerm  rc_parts_begin-mark: ".(")     //e.g.:  .(f A B C)
                                    (List-like_infix-fct_cTerm  rc_parts_begin-mark: "(.",
                                                                rc_operator_begin_mark: ".")   //e.g.:  (. A B .f  C)
                                    (List-like_postfix-fct_cTerm  rc_parts_begin-mark: "(..") } )  //e.g.:  (.. A B C f)
                  } )
    (Frame_cTerm  //e.g., for the example below, with operator the type "f" and with parts two half-links of type r1 and r2
      rc_operator-name: "",  rc_operator_begin_mark: "",  rc_operator_end_mark: "",
      rc_parts_begin-mark: "{",  rc_parts_separator: ",",  rc_parts_end-mark: "}",  //as in JSON-LD
      rc_parts: 1..* Half-link_cTerm,
      > exclusion { (Prefix_frame_cTerm  rc_parts_begin-mark: "_{")        //e.g.:  f_{ r1: A,   r2: B }
                    (List-like_frame_cTerm  rc_parts_begin-mark: "{.",
                      > List-like_prefix-frame_cTerm                       //e.g.:  {. f   r1: A,   r2: B}
                        List-like_infix-frame_cTerm )                      //e.g.:  {. r_id: f,  r1: A,   r2: B}
                    (Postfix_frame_cTerm rc_parts_begin-mark: "{_")       //e.g.:  {_  r1: A,  r2: B } f
                    Alternating-XML_cTerm  //Frame in the Alternating-XML style where concept nodes alternate
                  } )                                                     // with link nodes, as in RDF/XML
    Cterm_with_named_arguments  //quite rare in KRLs, hence not detailed in this article
  };

fc_prefix-fct-like_type _[?notationSet, ?operator_name, ?begin_mark, ?separator, ?end_mark]   //call examples are in Table 9
 :=  ^(Prefix_fct-like-cTerm  r_direct-or-indirect_part of: ?notationSet,   rc_operator-name: ?operator_name,
        rc_parts_begin_mark: ?begin_mark,  rc_parts_separator: ?separator,   rc_parts_end_mark: ?end_mark )

Phrase  //any phrase has at least these presentations in these 2 kinds of notations (see Table 2), e.g., in RIF-PS and RIF-XML:
  rc_type:  ^(fc_prefix-fct-like_type _(.{Function-like_based_notation},"","(","",")")  rc_annotation-position: -1)
            ^(fc_alternating-XML_type_(.{XML_based_notation},"") rc_annotation-position: 0 );

List  rc_type:  fc_list_type _( .{Notation}, "[", "," ,"]" );  //by default, in any notation, a list has for representation  a
 // comma separated list of element delimited by square brackets;   note that fc_list_type has no argument for an operator name
```

Table 8 shows how different kinds of "default presentations" can be represented in concise ways.

In a KRL that is perfectly regular with respect to a particular kind of abstract/concrete term - e.g, the concrete "operator based terms" (those that have an operator in our approach) - allows the terms of this kind to be (re-)presented in the same way. A perfectly regular KRL is then one which is perfectly regular for all the kinds of terms it allows. The "Triplet notation" is perfectly regular. To be so, a more expressive KRL would have to be fully based on an ontology and be Nth-order logic based. Since KIF re-uses the LISP notation, it is perfectly regular with respect to "operator based concrete terms" and "concrete terms for collections". Most KRLs have some *ad hoc* abstract and concrete terms. E.g., in RIF-XML the directives of a document are presented in different ways: some via links, some via XML attributes. In RIF-PS, they are presented as positional terms but not links. Thanks to the fact that our general model represents the directives both as parts and links (see Table 5), these RIF predefined directives can be represented within/via frames as well as via positional terms. The first part of Table 9 shows how *ad hoc* concrete terms of particular types of KRLs can be specified in a concise way. The approach used to do

Table 9: Ways to specify concrete terms for particular kinds of terms in particular notations, via our ontology.

```
//Thanks to the default values in our specifications for abstract and concrete terms, only the following lines are needed for
// defining the presentation in RIF-PS of the abstract terms shared by the  KRLs of the RIF family. For instance, the order and
// operator names of the directives of a document can be found in Table 5. Since these directives follow the default presentation
// for phrases in RIF-PS, nothing needs to be specified about them here. The abstract term restrictions can be specified here (as
// illustrated below for "Frame" or separately, as illustrated by the second part of Table 5.
RIF  r_only_such_part_of_that_type:    //because of the default values, there is no need for more than the next lines
 ^(Phrase  rc_type: fc_prefix-fct-like_type_(.{RIF-PS},"","(","",")") )  //by default, a phrase in RIF_PS follows this style
 ^(RIF_annotation  rc_type: fc_list_type_(.{RIF-PS},"(*","","*)"))   //this is overridden by some subtypes of Phrase, e.g., this one
 ^(Quantification_bound_list  rc_type: fc_list_type_(.{RIF-PS},"","",""))
 ^(Rule rc_type: fc-like_infix-fct_type_(.{RIF-PS},":-","","",""))
 ^(Externally_defined_term  rc_type: fc_prefix-fct-like_type_(.{RIF-PS},"External","(","",")"))
 ^(Equality_formula  rc_type: fc_list-like_infix-fct_type_(.{RIF-PS},"=","","",""))
 ^(Subclass_formula  rc_type: fc_list-like_infix-fct_type_(.{RIF-PS},"##","","",""))   //e.g., "?t1 ## ?t2";  in FL: "?t1 < ?t2"
 ^(Class-membership_formula  rc_type: fc_list-like_infix-fct_type_(.{RIF-PS},"#","","",""))
 ^(Frame > Minimal_frame,   rc_type: fc_infix_list-like_frame_type_(.{RIF-PS},"","[","","]") )   //abstract+concrete specification
 ^(Half_link rc_type: fc_half-link_type_(.{RIF-PS},"","","->","",""))
 ^(Name-Termula_pair  rc_type: fc_list_type_(.{RIF-PS},"","->","",""))
 ^(Open_list    rc_type: fc_prefix-fct-like_type_(.{RIF-PS},"List","(","|",")"))
 ^(Open-list_rest rc_type: fc_list_type_(.{RIF-PS},"","","",""))
 ^(Aggregate_function rc_type: fc_prefix-fct-like_type_(.{RIF-PS},"","{","|","}"))
 ^(Aggregate_function_bound_list rc_type: fc_fct-like_list_cTerm_(.{RIF-PS},"[","",]""));

RIF-FLD  r_only_such_part_of_that_type:    //only 1 example for RIF-XML: the concrete term for  Document  in RIF-FLD
  ^(Document  rc_type:  (1 fc_alternating-XML-cTerm_type_(.{RIF-XML},"Document")  rc_annotation-position: 0,
                                rc_XML-attribute_type:  r_dialect  xml#base  xml#prefix,  //the last two are predefined in XML
                                rc_XML-link_types: .[rif#directive rif#payload] ) );

JSON-LD_model  r_only_such_part_of_that_type: //the specifications of both the JSON-LD_model and the JSON-LD notation
 ^(Phrase rc_type:  fc_list-like_infix-frame_type_(.{JSON-LD},"","{",",",",","}"))                    // except for the concrete terms
 ^(Half_link rc_type: fc_half-link_type_(.{JSON-LD},"",":","",""))
 ^(Module_header rc_type: fc_list-like_infix-frame_type_(.{JSON-LD},"'@context:'","{",",",",","}"))
 ^(Module_body   rc_type: fc_list_type_(.{JSON-LD},"","",",",""))
 ^(Formula  >  ^(Minimal_frame  r_operator: 1 Constant_gTerm))   //only 1 destination per link
 ^(Fterm_or_variable >  Constant_or_set_or_closed_list)
 ^(Set  rc_type: fc_list_type_(.{JSON-LD},"[",",",",","]"))  //by default in JSON-LD (whereas in JSON, this would be for a list)
 ^(Closed_list  >  ^(Frame  r_part: 1 .[r_container, Closed_list],   //1st way to represent a list in JSON-LD
                                rc_type: fc_half-link_type_(.{JSON-LD},"","@container",":","@list","") )
                        ^(Frame  r_part: .[r_list, 1 Set],  rc_type: fc_half-link_type_(.{JSON-LD},"","@list",":","","") ) );  //2nd way
```

```
^(Thing ?t  rc_: (a Enclosed_list_cTerm ?c  r_KRL-set: ^?notationSet))                    //"^?" prefixes variables that are implicitly
  rc_parts: f_remove_empty_elements_in_list _( .[ (^?cb  rc_begin_mark of: ?c),        //  universally quantified
                                                                fc_r_parts_(?notationSet,(^?tp r_parts of: ?t),(^?cs rc_parts_separator of: ?c))
                                                                (^?cb  rc_end_mark of: ?c) ]  );
```

so for abstract terms (see the second part of Table 5) is here re-used. Thus, the abstract and concrete terms of a KRL - or a family of KRLs - can be specified at the same time. This enables organized specifications and thus eases the comparison of KRLs.

The second part of Table 9 shows how an ordered list of concrete terms can be specified for a type of abstract term, given a type of presentation and a list of notation types. Since the function fc_r_parts is recursive and, in turn, uses such specifications (links of type rc_parts or, for non-structured terms, links of type rc_), the specified ordered list only contains strings. Finally, given the value of rc_separator between tokens in the considered notation (i.e., the kinds of space characters separating them), the kinds of strings that can be associated to this collected list are specified. Thus, the whole specification is fully declarative. However, for concrete term generation purposes, choices have to be made, e.g., about space indentation. In our system, this is implemented via generation functions (also included in our ontologies) which recursively navigate the abstract and concrete specifications to find the most precise relevant specifications. Since our system rejects the entering of ambiguous knowledge (e.g., different concrete term specifications for a same type of abstract term and the same type of notation), finding the most precise relevant specifications was easy to implement.

Specifying parsing rules and generating them - for a given abstract term and grammar notation - can be represented using the same techniques. The first part of Table 10 shows the beginning of an ontology for grammars. The second part shows an example of grammar rule (and its connection to a grammar but this part actually needs not be generated). Once the grammar rules are *generated* - in a way *similar to presentation generation* - the generation of *their presentation is then done exactly as for any other statement*, according to the given grammar notation.

Our ontologies can be represented with OWL-2 based KRLs. E.g., r_parts links with "lists with cardinalities" (e.g., .[0..1 Y, 1..* Z]) as destinations can be replaced by lists without cardinalities (e.g., .[Y, Z]) as long as r_part links are also used for specifying the cardinalities (e.g., X r_part: 0..1 Y, 1..* Z). Functions are not mandatory since their definitions can be expanded whenever they are called.

Replicating our work does not require details on the implementation of our system: our ontologies *are* the required *declarative code*. The used inference engine is irrelevant as long as it can handle the specifications. However, some readers might be interested to know that our translation server exploits the parser available at http://goldparser.org while its inference engine was implemented in Pascal Object (for portability purposes) and exploits tableaux decision procedures (Horrocks, 1997). This server and its inference engine have recently been designed by Logicells/GTH (http://www.mitechnologies.net/). This work on a generic approach for handling KRLs comes from the many problems encountered to handle various versions of FL and other KRLs in the knowledge sharing servers WebKB-1 (Martin and Eklund, 1999) and WebKB-2 (Martin, 2002, 2011).

Table 10: Important links from Grammar_element, followed by an example of grammar head rule.

```
Grammar_element    //currently, the specifications are mainly only for EBNF-like grammars and Lex&Yacc-like grammars
  r_part  of: 1..* Grammar,    //and conversely:    Grammar   r_part:   1..* Grammar_element;
  > exclusion
    { (Phrase_of_a_grammar  =  exclusion{Non-lexical-grammar_rule   Lexical-grammar_rule}, >  Head_grammar-rule )
      (Individual_gTerm_of_a_grammar = exclusion{  Lexical-grammar_individual-gTerm  //what Lex grammars handle
                                                   Non-lexical-grammar_individual-gTerm } ) };

Non-lexical-grammar_rule  =  NLG_rule,        //this is a beginning but the representation of the whole grammar is similar
  r_part:   1 NLG_rule_left-hand-side    1 NLG_expression     0..1 (Parsing_action_phrase < Phrase),
  rc_:  (1 fc_list_type_(.{W3C-EBNF,XBNF,Grammar},"","","")   //like fc_prefix-fct-like-cTerm_type but without operator
           rc_parts: .[NLG_rule_left-hand-side "::=" NLG_expression] )    //→"A::=B"  ("Grammar "→default presentation)
        (1 fc_list_type_(.{ISO-EBNF},"","","")
           rc_parts: .[NLG_rule_left-hand-side "=" NLG_expression] )     //→ "A = B" in ISO-EBNF
        (1 fc_list_type_(.{Yacc, Bison},"","","")
          rc_parts: .[NLG_rule_left-hand-side ":" NLG_expression] );   //→ "A : B" in Yacc or Bison (without parsing actions)
```

```
Grammar_for_RIF_FLD_in_RIF-PS  <  Grammar,   r_description of:  1..* (RIF-FLD < (KRL_model  r_part of: 1..* KRL)),
  r_part: 1 (fc_NLG_rule_type_( .{RIF-PS},  "RIF-FLD_document",  .[ 0..1 Annotation  "Document"  "("
                                  0..1 Dialect_directive   0..1 Base_directive   0..* Prefix_directive   0..* Import_directive
                                                  0..*  Remote_module_directive 0..1 Group  ")"  ]
                             )  <   Head_grammar-rule );
```

4 CONCLUSIONS

One contribution of this article is a generic model for structured abstract or concrete terms. It is simple: only a few types of links and a few distinctions (Tables 4 and 8). This operator+parameters based model permits to define terms in a concise and flexible way, and thus also their presentation and parsing.

A second contribution is the design of a KRL model ontology by representing, aligning and extending various KRL models, and defining their elements via the above cited few links, as illustrated by Tables 3 and 5-7. Thus, the merged models are also easier to re-use.

A third one is the design of a KRL notation ontology - to our knowledge, the first one - based on the above two cited contributions, as illustrated by Tables 8-10.

These three contributions permit to solve or reduce the problems listed in the introduction: KRL syntactic translations, KRL parser implementation, dynamic extension of notations, etc. Thus, they provide an ontology-based concise alternative to the use of XML as a meta-language for easily creating KRLs following KRL ontologies. Therefore, this also complements GRDDL and can be seen as a new research avenue. This avenue is important given the frequent need for applications to i) integrate or easily import and export from/to an ever growing number of models and syntaxes (XML-based or not), and ii) let the users parameter these processes.

Previous attempts (by the first author of this article) based on directly extending EBNF - or directly representing or generating concrete terms in a KRL or transformation language - required much lengthier specifications that were also more difficult to re-use.

Besides its translation server, the Logicells/GTH company will use this work in its applications for them to i) collect and aggregate KRs from the knowledge bases they exploit, and ii) enable end-users to adapt the input and output formats they wish to use or see. The goal behind these two points is to make these applications - and the ones they relate - more (re-)usable, flexible, robust and inter-operable.

One theme of our future work on this approach will be the *generation of parsing actions in parsing rules*, given an implementation "data model". A second theme will be the representation and integration of more models and notations for KRLs as well as *query languages and programming languages*. A third theme will be the extension of our notation ontology into a *presentation ontology* with concepts from style-sheets and, more generally, user interfaces.

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