

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 Ontolingua. 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.

<pre> Language_or_Language-element //below: links defining it = exclusion { (Language r_part: 1..* Language_element, > KRL Grammar) Language_element }; </pre> <p>//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.</p>
<pre> classDiagram class Language_or_Language_element class Language class Language_element class KRL class Grammar Language_or_Language_element < -- Language Language_or_Language_element < -- Language_element Language < -- KRL Language < -- Grammar Language --> "1..*" Language_element : r_part Language_or_Language_element .. Language_element : {disjoint, complete} </pre>
<pre> :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. </pre>
<pre> 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 </pre>
<pre> 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) </pre>

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 r_model_type of: JSON-LD,
  > JSON-LD_model
  (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
> (OWL-1_model > OWL-Lite OWL-DL OWL-1-Full)
  (OWL-2_model > OWL-2_EL OWL-RL OWL-2-Full),
  r_part: 1..* (OWL-1-Full r_part: 1..* RDF,
    r_part: 1..* OWL-DL )
  1..* (OWL-2-Full r_part: 1..* OWL-2_EL );
  
```

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
{ (Referable_gTerm //e.g., via a variable
  r_annotation: 0..* Annotation, //referable -> linkable
  > (Gterm_that_cannot_be_annotated_without_link
  r_annotation: 0 Annotation ) )
  Non-referable_gTerm //e.g., a predefined term
  };
  
```

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 `Item`, 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.

<pre> Language_element 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 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_part //below are examples of its subtypes > (r_relation_parameter > (r_link_parameter > (r_link_source > rdfs#domain) (r_link_destination > rdfs#range))) r_function_parameter r_phrase_part > rdf#subject rdf#object; r_operator > rdf#predicate; //just an example //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 returns 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 an 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]); </pre>
--

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).

<pre> Phrase < ^(Gterm r_operator: 1 (Relation_type > (owl#Property r_instance: r_binary_relation)), r_result: 1 (Truth_value r_instance: True False Indeterminate_truth-value/*for example*/)), > (Phrase_that_is_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-conjunction])) (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-DocmentLocator_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 > <i>Positional_formula</i> <i>Formula_with_named_arguments</i> > cl#Sentence Phrase_of_a_grammar, = 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 } exclusion { <i>Composite_formula</i> Atomic_formula_or_reference_to_formula }), //see Table 7 > <i>Termula</i>, //parameter for a function or atomic_formula; its subtypes are not listed in this article }); </pre>
<pre> //with the next subtype of r_part, the source ?x has some parts of type ?pt but no <i>other</i> 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 give 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)); </pre>

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,.[1 Type],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,.[1 Type],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,.[1 Type],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).

<pre> <i>Individual_gTerm</i> //the expression "Individual term" comes from RIF-FLD = near_exclusion { (Individual_concrete_term //see next sub-sections for details > Concrete-term_for_constant_or_name Lexical-grammar_character-set Concrete_list-like_term Concrete_list-like_term (String > (Delimited_string > Delimited_Unicode_string)) Character) (<i>Individual_abstract_term</i> > (Abstract_individual_gTerm_that_is_not_referable_in_RIF-FLD > exclusion { (Operator_that_is_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 Fterm_or_variable, 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_that_is_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 Relation-or-Function_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 //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: 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: 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)))); </pre>

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 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.

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 3
    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 10: Important links from Grammar_element, followed by an example of grammar head rule.

<pre>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)</pre>
<pre>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);</pre>

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 is 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).

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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