Inference rules for RDF(S) and OWL in N3Logic

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Abstract—This paper presents inference rules for Resource Description Framework (RDF), RDF Schema (RDFS) and Web Ontology Language (OWL). Our formalization is based on Notation3 Logic, which extended RDF by logical symbols and created Semantic Web logic for deductive RDF graph stores. We also propose OWL-P that is a lightweight formalism of OWL and supports soft inferences by omitting complex language constructs.

I. INTRODUCTION

Resource Description Framework (RDF) is a general method for conceptual description or modeling of information that is implemented in web resources. RDF Schema (RDFS) extends RDF to classes providing basic elements for the description of vocabularies. OWL adds more vocabulary for describing properties and classes i.e. relations between classes, cardinality, and richer typing of properties. Unfortunately, OWL has high worst-case complexity results for key inference problems. To overcome this problem we propose a lightweight OWL profile called OWL-P.

A rule is perhaps one of the most understandable notion in computer science. It consists of the condition and the conclusion. If some condition that is checkable in some dataset holds, then the conclusion is processed. In the same way RDF(S) and OWL entailments work.

The paper is constructed according to sections. Section II presents RDF and Notation3 Logic concepts. In Section III we present inference rules for RDF, RDFS and OWL in N3Logic. Section IV is devoted to related work. The paper ends with conclusions.

II. PRELIMINARIES

The RDF data model rests on the concept of creating web-resource statements in the form of subject-predicate-object expressions, which in the RDF terminology, are referred to as triples (or statements).

An RDF triple comprises a subject, a predicate, and an object. In [28], the meaning of subject, predicate and object is explained. The subject denotes a resource, the object fills the value of the relation, the predicate refers to the resource’s characteristics or aspects and expresses a subject – object relationship. The predicate denotes a binary relation, also known as a property.

Following [28], we provide definitions of RDF triples below.

Definition 1 (RDF triple). Assume that \( \mathcal{I} \) is the set of all Internationalized Resource Identifier (IRI) references, \( \mathcal{B} \) (an infinite) set of blank nodes, \( \mathcal{L} \) the set of literals. An RDF triple \( t \) is defined as a triple \( t = \langle s, p, o \rangle \) where \( s \in \mathcal{I} \cup \mathcal{B} \) is called the subject, \( p \in \mathcal{I} \) is called the predicate and \( o \in \mathcal{I} \cup \mathcal{B} \cup \mathcal{L} \) is called the object.

The elemental constituents of the RDF data model are RDF terms that can be used in reference to resources: anything with identity. The set of RDF terms is divided into three disjoint subsets: IRIs, literals, and blank nodes.

Definition 2 (IRIs). IRIs serve as global identifiers that can be used to identify any resource.

Definition 3 (Literals). Literals are a set of lexical values. It can be a set of plain strings, such as "Apple", optionally with an associated language tag, such as "Apple"@en.

Remark 1. In RDF 1.1 literals comprise a lexical string and a dataype, such as "1""http://www.w3.org/2001/XMLSchema#int.

Remark 2. In literals dataypes are identified by IRIs, where RDF borrows many of the datatypes defined in XML Schema 1.1 [26].

Definition 4 (Blank nodes). Blank nodes are defined as existential variables used to denote the existence of some resource for which an IRI or literal is not given.

Remark 3. Blank nodes are inconstant or stable identifiers and are in all cases locally scoped to the RDF store or the RDF file.

A collection of RDF triples intrinsically represents a labeled directed multigraph. The nodes are the subjects and objects of their triples. RDF is often referred to as being graph structured data where each \( \langle s, p, o \rangle \) triple can be interpreted as an edge \( s \xrightarrow{p} o \).

Definition 5 (RDF graph). Let \( O = \mathcal{I} \cup \mathcal{B} \cup \mathcal{L} \) and \( S = \mathcal{I} \cup \mathcal{B} \), then \( G \subseteq S \times \mathcal{I} \times O \) is a finite subset of RDF triples, which is called RDF graph.

On the other hand, in the Semantic Web environment there is a Notation3 format, which offers a new human-readable serialization of RDF model but it also extended RDF by logical symbols and created a new Semantic Web logic called Notation3 Logic (N3Logic). Following [21], we provide definitions of N3Logic below.

Definition 6 (N3Logic alphabet). A N3Logic alphabet \( A_{N3} \) consists of the following disjoint classes of symbols:
1) a set $I$ of IRI symbols beginning with < and ending with >,
2) a set $L$ of literals beginning and ending with ",
3) a set $V$ of variables, $V = B \cup V_U$, where $B$ is a set of existential variables (blank nodes in RDF-sense) start with _, and $V_U$ is a set of universal variables start with ?,
4) brackets (, ),
5) a logical implication $\Rightarrow$,
6) a period ..,
7) a period @false.

**Remark 4.** Notation3 allows to abbreviate IRIs by using prefixes. Instead of writing &lt;http://example.com&gt;, we can write ex:..

**Remark 5.** Each IRI, variable and literal is an expression.

**Remark 6.** $\{f\}$ is an expression called formula.

**Remark 7.** $e_1 \Rightarrow e_2$ is a formula called implication.

In Notation3 literals, IRIs, variables or even formula expressions can be subjects, objects or predicates.

**III. Inference rules**

In this section, we introduce inference rules for RDF, RDFS and OWL. Inference rules connected with RDF(S) and OWL are basis of the deductive RDF graph stores.

**Definition 7** (Deductive RDF graph store). A deductive RDF graph store is an entity which remembers RDF triples and can generate new ones under certain conditions through deduction or inference. It can answer queries about the combined given and inferred triples.

**A. RDF and RDFS**

In Table I we present patterns which hold by RDF and RDFS entailments. All rules are tested in reasoning engines such as FuXi and cwm.

**B. OWL**

In Table II we analyze existing proposals for different OWL2 profiles: RDFS++ [11], L2 [6], RDF 3.0/OWLPrime [10], OWLSIF/pD+ [27], OWL-LD [7] and OWL-RL [20]. We check which terms are most commonly used and propose a new version of OWL 2 called OWL-P. We also considered time complexity for detecting a required rule application and frequently used vocabulary terms in our corpus. The snapshot (Table III) is built by [13] and use seeds from [24].

This profile of OWL2 is simpler that OWL-RL. It drops support for restriction and cardinality classes, class relationships and list-based axioms. In the Table IV, Table V and we present inference rules of OWL-P.

**IV. Related Work**

One of the most important general purpose logic programming language is Prolog [21]. It is declarative, which means that the program logic is declared in terms of relations, represented as facts and rules. Yet another declarative language is Datalog [5], which is syntactically a subset of Prolog. Apart from the Notation3, there are other rule-based inference engines formats for the Semantic Web, such as: FOL-RuleML [8], SWRL [12], RIF [14], R-DEVICE [3], TRIPLE [25], Jena rule [7] and SPIN [17].

FOL-RuleML (First-order Logic Rule Markup Language) [8] is a rule language for expressing first-order logic for the web. It is a sublanguage of RuleML [9]. In FOL-RuleML each of rules consists of a set of statements called an atom. The atom is a form which consists of objects which are individuals or variables, and a relation between them.

SWRL (Semantic Web Rule Language) [12] is based on OWL [21] and Unary/Binary Datalog RuleML, which sublanguage of the RuleML. It extends the set of OWL axioms to

**TABLE III**

| Vocabulary terms used in LOD snapshot 2015 |
|-------------------------------------------|
| owl:AllDifferent                          |
| owl:AllDisjointClasses                    |
| owl:AllDisjointProperties                 |
| owl:allValuesFrom                         |
| owl:assertionProperty                     |
| owl:AsymmetricProperty                    |
| owl:cardinality                           |
| owl:complementOf                          |
| owl:DatatypeProperty                      |
| owl:differentFrom                         |
| owl:disjointUnionOf                       |
| owl:disjointWith                          |
| owl:equivalentClass                       |
| owl:equivalentProperty                    |
| owl:FunctionalProperty                    |
| owl:hasKey                                |
| owl:hasSelf                               |
| owl:hasValue                              |
| owl:intersectionOf                        |
| owl:InverseFunctionalProperty             |
| owl:inverseOf                             |
| owl:IrreflexiveProperty                   |
| owl:maxCardinality                        |
| owl:minCardinality                        |
| owl:ObjectProperty                        |
| owl:oneOf                                 |
| owl:propertyChainAxiom                    |
| owl:propertyDisjointWith                  |
| owl:qualifiedCardinality                  |
| owl:qualifiedMaxCardinality               |
| owl:qualifiedMinCardinality               |
| owl:sameAs                                |
| owl:someValuesFrom                        |
| owl:sourceIndividual                      |
| owl:SymmetricProperty                     |
| owl:targetIndividual                      |
| owl:targetValue                           |
| owl:TransitiveProperty                    |
| owl:unionOf                               |
| rdfs:domain                               |
| rdfs:range                                |
| rdfs:subClassOf                           |
| rdfs:subPropertyOf                        |

1. https://github.com/RDFLib/FuXi
2. http://www.w3.org/2000/10/sparql/doc/cwm.html
3. http://jena.apache.org/documentation/inference
### TABLE I

**Inference Rules for RDF and RDFS**

| Conditions | Conclusions |
|------------|-------------|
| (?S ?P ?O) | -> (?P rdf:type rdf:Property). |
| (7P rdfs:domain ?C. ?S ?P ?O) | -> (?S rdf:type ?C). |
| (7P rdfs:range ?C. ?S ?P ?O) | -> (?O rdf:type ?C). |
| (?S ?P ?O) | -> (?S rdf:type rdfs:Resource). |
| (?C rdf:type rdfs:Class) | -> (?C rdfs:subClassOf rdfs:Resource). |
| (?Q rdfs:subPropertyOf ?R. ?P rdfs:subPropertyOf ?Q) | -> (?P rdfs:subPropertyOf ?R). |
| (7Q rdfs:range ?C. ?S ?P ?O) | -> (?S rdf:type ?C). |
| (7Q rdfs:subPropertyOf ?R. ?S ?P ?O) | -> (?S 7R 7O). |
| (?Q rdf:type rdfs:Class) | -> (?Q rdf:type rdfs:Class). |
| (7A rdfs:subClassOf ?B. 7S rdf:type ?A) | -> (?S rdf:type ?B). |
| (7Q rdf:type rdfs:Class) | -> (?Q rdfs:subClassOf ?Q). |
| (7B rdfs:subClassOf ?C. ?A rdfs:subClassOf ?B) | -> (?A rdfs:subClassOf ?C). |
| (7X rdf:type rdfs:ContainerMembershipProperty) | -> (?X rdfs:subPropertyOf rdfs:member). |
| (7X rdf:type rdfs:Datatype) | -> (?X rdfs:subClassOf rdfs:Literal). |

### TABLE II

**Comparison of OWL Profiles**

|                  | OWL-P | RDFS++ | L2  | RDFS 3.0 | OWLPrime | OWLSIF | pD* | OWL-LD | OWL-RL |
|------------------|-------|--------|-----|----------|----------|--------|-----|--------|--------|
| owl:AllDifferent | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:AllDisjointClasses | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:AllDisjointProperties | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:allValuesFrom | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:assertionProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:AsymmetricProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:cardinality | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:complementOf | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:DatatypeProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:differentFrom | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:disjointUnionof | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:disjointWith | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:equivalentClass | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:equivalentProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:FunctionalProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:hasKey | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:hasSelf | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:hasValue | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:intersectionof | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:inverseFunctionalProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:inverseOf | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:IrreflexiveProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:maxCardinality | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:minCardinality | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:ObjectProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:oneOf | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:propertyChainAxiom | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:propertyDisjointWith | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:qualifiedCardinality | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:qualifiedMaxCardinality | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:qualifiedMinCardinality | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:sameAs | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:someValuesFrom | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:sourceIndividual | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:symmetricProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:targetIndividual | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:targetValue | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:transitiveProperty | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| owl:unionof | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| rdfs:domain | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| rdfs:range | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| rdfs:subClassOf | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
| rdfs:subPropertyOf | ☑     | ☑      | ☑   | ☑        | ☑        | ☑      | ☑   | ☑      | ☑      |
**TABLE IV**
Inference rules for OWL-P properties

| Conditions                                      | Conclusions                                      |
|------------------------------------------------|--------------------------------------------------|
| `{?S ?P ?O} => {?S owl:sameAs ?S. ?P owl:sameAs ?P. ?O owl:sameAs ?O}` |                                                   |
| `{?S owl:sameAs ?S} => {?S owl:sameAs ?S}`                  |                                                   |
| `{?Q owl:sameAs ?T. ?R owl:sameAs ?P} => {?Q owl:sameAs ?T. ?R owl:sameAs ?P}` |                                                   |
| `{?S owl:sameAs ?S2. ?S ?P ?O} => {?S2 ?P ?O}`                |                                                   |
| `{?O owl:sameAs ?O2. ?S ?P ?O} => {?S ?P ?O2}`                |                                                   |
| `{?P rdf:type owl:FunctionalProperty. ?Q ?P ?R} => {?P rdf:type owl:FunctionalProperty. ?Q ?P ?R}` |                                                   |
| `{?P rdf:type owl:InverseFunctionalProperty. ?Q ?P ?R} => {?P rdf:type owl:InverseFunctionalProperty. ?Q ?P ?R}` |                                                   |
| `{?P rdf:type owl:IrreflexiveProperty. ?Q ?P ?Q} => {?false}` |                                                   |
| `{?P rdf:type owl:SymmetricProperty. ?Q ?P ?R} => {?Q ?P ?R}` |                                                   |
| `{?P rdf:type owl:AsymmetricProperty. ?Q ?P ?R} => {?false}` |                                                   |
| `{?P rdf:type owl:TransitiveProperty. ?Q ?P ?R. ?R ?P ?S} => {?false}` |                                                   |
| `{?P1 owl:equivalentProperty ?P2. ?Q ?P1 ?R} => {?false}` |                                                   |
| `{?P1 owl:propertyDisjointWith ?P2. ?Q ?P1 ?R. ?Q ?P2 ?R} => {?false}` |                                                   |
| `{?P1 owl:inverseOf ?P2 . ?Q ?P2 ?R} => {?false}` |                                                   |

include Horn-like rules. Logical operators and quantifications supports of SWRL are the same as in RuleML. Moreover, RuleML contents can be parts of SWRL content. Axioms may consist of OWL, RDF and rule axioms. A relation can be an IRI, a data range, an OWL property or a built-in relation. An object can be a variable, an individual, a literal value or a blank node.

**TABLE V**
Inference rules for OWL-P classes

| Conditions                                                                 | Conclusions                                      |
|---------------------------------------------------------------------------|--------------------------------------------------|
| `{?A owl:equivalentClass ?B . ?x rdf:type ?A} => {?x a ?B}`                |                                                   |
| `{?A owl:equivalentClass ?B . ?x rdf:type ?B} => {?x a ?A}`                |                                                   |
| `{?A owl:disjointWith ?B} => {?false}`                                     |                                                   |
| `{?C rdf:type owl:Class} => {?C rdfs:subClassOf ?C. ?C owl:Thing. ?C owl:equivalentClass ?C. ?C owl:equivalentClass ?C.} => {?false}` |                                                   |
| `{?A owl:equivalentClass ?B} => {?A rdfs:subClassOf ?B. ?B rdfs:subClassOf ?A}` |                                                   |
| `{?B rdfs:subClassOf ?A} => {?A owl:equivalentClass ?B}`                  |                                                   |
| `{?P rdf:type owl:ObjectProperty} => {?P rdfs:subPropertyOf ?P. ?P owl:equivalentProperty ?P.} => {?false}` |                                                   |
| `{?P rdf:type owl:DatatypeProperty} => {?P rdfs:subPropertyOf ?P. ?P owl:equivalentProperty ?P.} => {?false}` |                                                   |
| `{?B rdfs:subPropertyOf ?R. ?R rdfs:subPropertyOf ?P} => {?false}`      |                                                   |

RIF (Rule Interchange Format) [14] is a standard for exchanging rules among disparate systems. It focused on exchange rather than developing a single one-fits-all rule language. It can be separated into a number of parts, RIF-core [23] which is the common core of all RIF dialects, RIF-BLD (Basic Logic Dialect) [15] comprising basic dialects (i.e. Horn rules) for writing rules, RIF-PRD [13] (Production Rule Dialect) for representing production rules and RIF-DTB (Datatypes and Built-in Functions) [22] comprising a set of datatypes and built-in functions.

R-DEVICE [3] is a deductive rule language for reasoning about RDF data. In R-DEVICE resources are represented as objects and RDF properties are realized as multi-slots. It supports a second-order syntax, where variables can range over classes and properties. It provides a RuleML-like syntax.

TRIPLE [25] is an RDF rule (query, inference, and transformation) language, with a layered and modular nature. It is based on Horn Logic [11] and F-Logic [16]. Rules in TRIPLE are used for transient querying and cannot be used for defining and maintaining views.

SPIN (SPARQL Inferencing Notation) [17] is a constraint and SPARQL-based rule language for RDF. It can link class with queries to capture constraints and rules which describe the behavior of those classes. SPIN is also a method to represent queries as templates. It can represent SPARQL statement as RDF triples. That proposal allows to declare new SPARQL functions.

Jena rule is a rule format used only by inference engine in the Jena framework [19]. The rule language syntax is based on RDF. It uses the triple representation, which is similar to Notation3 except that a rule name can be specified in a rule. There are not any formula notation, and built-in functions are written in function terms.
V. CONCLUSIONS

This paper define how knowledge and logic might be handled on the Semantic Web environment. We present inference rules RDF, RDF Schema and OWL. All rules are tested in reasoning engines. Our formalization is based on Notation 3 Logic, which extended RDF by logical symbols and created a new Semantic Web logic. Moreover, we propose a lightweight OWL profile called OWL-P. Our proposed rule will be useful for deductive RDF graph stores.

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