



A New Web Ontology Language for Context Representation and Reasoning

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ABSTRACT

Contextual representation and reasoning are an open issue of the semantic web. Although long parties have practically limited local treatment of context representation for the semantic web, a rich and vast consensus has yet to be reached about the encoding, particularly for reasoning about contextual knowledge. This paper presents OWLC: a contextual two-dimensional web ontology language. Using the first dimension, we can reason about context-dependent classes, properties, and axioms, while using the second dimension, we can reason about knowledge of contexts considered formal objects, as proposed by McCarthy [20]. We demonstrate how strong modeling and reasoning with OWLC can be through a real-world scenario arising from the domain of digital humanity. The Ferdinand de Saussure [15] use case is used for its naturally contextual and at the same time complex nature, making it possible to bring out many issues in context representation and reasoning.

Keywords: Web Ontology Language, Context Representation, Reasoning, Semantics, Context-dependent classes

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1. Introduction

The representation of context-dependent knowledge in the Semantic Web (SW) is a crucial issue. Several

paradigms have been proposed with the aim of adding context awareness in to the SW; ranging from practical RDF graph design patterns [23] [13] to theoretical works on extending description logic languages with contextual constructs and axioms [5] [18]. In this work, we present a novel approach as a combination of a formally defined theory and a practical implementation of contextual reasoning with OWL.

Before starting, let's clarify what do we mean by contexts and contextual reasoning. We consider that triples can be enriched with two-types of contexts: i) validity contexts which enhance the meaning of a fact such as the temporal validity. The fact itself is not sufficiently clear without validity contexts ii) additional contexts which add to the fact without interfering with its meaning such as the provenance of the triple. A statement where both contexts are given is the following: Saussure lived in Geneva between 1857 and 1876 as mentioned by Wikipedia, where 1857-1876 represents the validity context (more precisely the validity time) and Wikipedia is the provenance considered as an additional context. Based on that, we define contextual reasoning as the process of deriving new contextual knowledge from existing ones. The kernel of this process is reasoning on contexts themselves in order to boost the propagation of contextual knowledge.

For all this, we propose OWL^C , a contextual two-dimensional web ontology language that is an extension of the classical OWL. OWL^C [1] [4] was designed in the two-dimensions style [17] in the purpose of 1) avoiding the conflict when modeling contexts and context-dependent knowledge 2) avoiding adding an additional cost in the complexity of reasoning because the cost is already hidden in the shift from one-dimensional to two-dimensional semantics. Furthermore, the design of OWL^C was inspired by problems we encountered in practical scenarios in digital humanities. Therefore, we chose to test its usability over the SNSF1 project of Ferdinand de Saussure [3], which is sufficiently complex and paradigmatic to contain different aspects of context-dependent knowledge.

The remainder of the paper has been organized as follows: in section 2, we present the Ferdinand De Saussure (FDS) use case. In section 3, we go through the literature review of contextual knowledge representation and reasoning. In section 4 and 5, we present a contextual extension of OWL: OWL^C . We discuss also the different types of reasoning that can be performed. Furthermore, we demonstrate the usability of OWL^C by applying it to a historical scenario in section 6. Finally, we summarize our results in section 7.

2. Motivation: the Case of Ferdinand de Saussure (FDS)

Ferdinand de Saussure (1857 – 1913) is considered as a “formidable linguist” [15], first of all for his works in general linguistics, as well for his contributions in the rather more exclusive field of comparative grammar. However, Saussure published very little. For instance, he never published the theory he developed in the course of general linguistics he taught three times and which is considered as the work of his life. It is on the basis of lecture notes of his students that the book *Course in General Linguistics* (*Cours de Linguistique générale* CLG) was published in 1916. The legacy of Saussure is fortunately not limited to these monographs but includes a fund of about 50,000 handwritten pages² deposited in libraries of Geneva (Bibliothèque de Genève), Paris and Harvard. All these pages were photographed using a high definition digital camera. These manuscripts are of primordial importance for the Saussurean scholars (Saussureans for short). Their study is considered as the only mean to

¹<http://www.snf.ch/en/Pages/default.aspx>

²which have been (and still) transcribed

reach a better understanding of Saussure's ideas. As of today, only 5,000 manuscripts of the 50'000 pages have been transcribed. One of the major problems of Saussureans is to understand the content of the manuscripts and this is due to the following contextual problem:

- **Authorship as a context:** transcripts of manuscripts come from various sources. Their authorship is of major importance for Saussurians given the level of confidence that they attribute to each source.
- **Time as a context:** for the majority of the manuscripts, we know neither their date nor their place of writing. This, of course, complicates the establishment of a clear sequence of ideas on Saussure's work.
- **Terminology as a context:** in [10], the author showed that the terminology used by Saussure varies over time or writing purpose. He eventually identified more than a dozen different terminologies in Saussure's work. Therefore, the terminology can also be considered as a context. Indeed it is essential to precisely understand the meaning of each specific manuscript.

3. Related Works

In 2001, the authors of [12] introduced the idea of locality and compatibility where reasoning is considered mainly local and uses only part of what is potentially available. In 2003, [7] introduced the concept of distributed description logics where binary relations describe the correspondences between contexts. However, the coordination between a pair of ontologies can only happen with the use of bridge rules. C-OWL [8] was introduced in the same year. The idea behind is to localize the content of ontologies and to allow for explicit mappings via bridge rules. In 2004, a new concept called E-connections [18] emerged: ontologies are interconnected by defining new links between individuals belonging to distinct ontologies. One major disadvantage is that it does not allow concepts to be subsumed by concepts of another ontology, which limits the expressiveness of the language. Then, in 2006, the authors of [5] attempted to extend description logics with new constructs with relative success. In 2011, a proposition was argued to use a two dimensional-description logics [17]. Results showed that this approach does not necessarily increase the computational complexity of reasoning. Another work, [16], proposed a framework for contextual knowledge representation and reasoning (*CKR*) based on current *RDF(S)* standards. However, the expressiveness of the formalism is restricted to *RDFS* and there are no axioms that make it possible to explicitly use the relationships between contexts to deduce new facts or to deal with contradictions between contexts. In 2012, [9] argues that treating contexts in the semantic web needs more advanced means, such that contexts should be explicitly presented and logically treated...

On the other hand, many attempts to find a solution to the syntactic restriction of RDF binary relations emerged. Two approaches were proposed:

(a) Extending the Data Model and/or the Semantics of RDF:

The triple data structure could be extended by adding a fourth element to each triple, which is intended to express the context [11] of a set of triples [14] [21].

(b) Using Design Patterns: It Could be Categorized Along Three Axes:

- The contextual index *co* is attached to the statement $R(a, b)$ and thus $R(a, b)$ holds for *co* such as *RDF*

reification [6]. This method is not supported in DL reasoning.

- The contextual index co is attached to the relation $R(a, b, co)$ [2] [3]. One advantage is being able to talk about assertions as (reifying) individuals.
- The contextual index co is attached to the object terms $R(a@co, b@co)$ where co is the contextual-slice of a and b [22]. This method introduces many contextualized individuals which cause objects proliferation.

4. OWL 2 DL^C : A Two-Dimensional Web Ontology Language for Contexts

OWL 2 DL was designed to support the existing description logic business segment and has desirable computational properties for reasoning systems. In this section, we introduce an extension of OWL 2 DL for contexts, that we call OWL 2 DL^C . The semantics are based on the semantics of the two-dimensional description logic [17]. OWL 2 DL^C_{core} is the first dimension. It is used to represent contextual object knowledge such as contextual classes, contextual properties and contextual axioms. OWL 2 $DL^C_{context}$ is the second dimension. It is used to represent contexts which are considered as first class citizens.

Formally speaking, an OWL 2 DL^C signature (or vocabulary) is a pair of DL signatures $(\langle N_C, N_R, N_P \rangle, \langle N_{KC}, N_{KR}, N_{KI} \rangle)$ where:

- N_C (resp. N_{KC}) is a set of domain (resp. context) concept names,
- N_R (N_{KR}) is a set of domain (context) role names,
- N_I (N_{KI}) is a set of domain (context) individuals names.

4.1 The contexts language: OWL 2 $DL^C_{context}$ Contexts are Considered as Formal Objects [20] and are of Two Types:

- **Validity contexts:** are contexts that can affect the fact itself either by enhancing its meaning, or by limiting its meaning to a given context. Fluents [23] are a typical example of validity contexts (i.e. a fluent is a temporal property whose object is subject to change over time).
- **Additional contexts:** supplement a fact with additional elements that do not modify its meaning. As a result, the fact is more precisely described with the additional context, but sufficiently clear without it. A typical example is the publication context which provide information about the provenance of the triple as a reference in order to support the claim.
- A context type is usually characterized by a set of dimensions that describe it to a certain level of approximation. For instance, a validity context could be composed of many dimensions, such as the temporal validity, the spatial validity, etc. For example:

(1857, wikipedia) : LivedIn(Saussure, Geneva)

³In this case the individual context names N_{KI} is the cartesian product $N_{KI} \times N_{KI}$ of a set of temporal contexts and a set of provenance contexts.

states that Saussure lived in Geneva during 1857 as mentioned in Wikipedia. 1857 is the temporal dimension of the validity context and Wikipedia is the provenance dimension considered as an additional context³.

The axioms of the contexts language are formulas:

$$A \subseteq B \mid C(a)$$

where $A \in N_{KC}$, $B \in N_{KC}$, $C \in N_{KI}$, $a \in N_{KI}$.

4.2 The core language: OWL 2 DL^{C_{core}}

An axiom expression of the core language is either:

- A DL axiom expression on the core signature $\langle N_C, N_R, N_I \rangle$ i. For Example: *Human(Saussure)*⁴
- An expression of the form: $\kappa : \phi$, where κ is either an individual context name (in N_{KI}) or a concept expression over the context signature $\langle N_{KC}, N_{KR}, N_{KI} \rangle$ i. Such an expression states that the axiom ϕ holds in the specified context or in all contexts of the specified context concept. ϕ can be:

1. A concept axiom ($C \sqsubseteq D$, $C \equiv D$, C disjoint D)

1969 : *CanVote* \sqsubseteq *Aged21orMore*

states that the axiom *CanVote* \sqsubseteq *Aged 21 or More* holds in the temporal context 1969

Abstract Syntax	CDL syntax	Semantics (Interpretation in context k)
IntersectionOf ($C_1 \dots C_n$)	$C_1 \sqcap \dots \sqcap C_n$	$C_1^{I[k]} \cap \dots \cap C_n^{I[k]}$
UnionOf ($C_1 \dots C_n$)	$C_1 \sqcup \dots \sqcup C_n$	$C_1^{I[k]} \cup \dots \cup C_n^{I[k]}$
R ComplementOf (C)	$\neg C$	$(\neg C)^{I[k]} = \Delta^{I[k]} \setminus C^{I[k]}$
R Some Values From (C)	$\exists(R.C)$	$x \mid \exists y : (x, y) \in (R)^{I[k]} \text{ and } y \in (C)^{I[k]}$
All Values From(C)	$\forall(R.C)$	$x \mid \forall y : (x, y) \in (R)^{I[k]} \rightarrow y \in (C)^{I[k]}$
OneOf ($a_1 \dots a_n$)	$a_1 \dots a_n$	$(a_1)^{I[k]}, \dots, (a_n)^{I[k]}$

Table 1. OWL 2 DL^{C_{core}} direct model theoretic semantics

2. A role axiom ($R \sqsubseteq S$, *functional* (R), *transitive*(R), . . .) *Decentralized Country*: has Local Power *In* \sqsubseteq *electedLocallyIn*

⁴We consider non contextual (standard) DL axioms as contextual axioms that are valid in all validity contexts. Therefore an expression of the form $C \sqsubseteq D$ is in fact an abbreviation for $\top^{VC} : C \sqsubseteq D$ where \top^{VC} is the top context concept whose interpretation contains all the validity contexts of Ω .

states that in decentralized countries (contexts), a person with local power in a region had necessarily been locally elected in that region.

3. A class or role assertion $(C(a), R(a, b))$ defined on the core signature with contextual concept and role expressions

1857: Professor(Saussure) which states that Saussure was a professor during 1857.

A contextual interpretation is a pair of interpretations $\mathcal{M} = (I, J)$ where $I = (\Delta, \cdot^I[\cdot])$ is the core interpretation, $J = (\Omega, \cdot^J[\cdot])$ is the context interpretation, and $\Delta \cap \Omega = \emptyset$. $\cdot^I[\cdot]$ is a family of interpretation functions, one for each context $k \in \Omega$. \cdot^J is the (non-contextual) interpretation function of every context in the context language. The interpretation of the class constructors of the core language is straightforward. Table 1 contains the OWL frame like abstract syntax, the contextual description logic syntax (CDL) and the direct model theoretic semantics of OWL_{core}^C basic class constructors. We only consider contextual interpretations that satisfy the *rigid designator hypothesis* [19], i.e. $i^{I[k]} = i^{I[k']}$ for any individual $i \in N_p$, $k \in \Omega$, and $k' \in \Omega$.

A contextual axiom $K : \phi$ is satisfied by an interpretation \mathcal{M} if in every context k that belongs to the interpretation of K , the interpretation in k of the concepts, roles and individuals that appear in ϕ satisfy the axiom condition

- $\mathcal{M} \models K : C \sqsubseteq D$ iff $\forall k \in K^J : C^{I[k]} \subseteq D^{I[k]}$, where $C \in N_c$ and $D \in N_c$
- $\mathcal{M} \models K : R \sqsubseteq S$ iff $\forall k \in K^J : R^{I[k]} \subseteq S^{I[k]}$, where $R \in N_r$ and $S \in N_r$
- $\mathcal{M} \models K : C(a)$ iff $\forall k \in K^J : C(a)^{I(k)}$, where $C \in N_c$ and $a \in N_i$
- $\mathcal{M} \models K : R(a, b)$ iff $\forall k \in K^J : R(a, b)^{I(k)}$, where $R \in N_r$, $a \in N_i$ and $b \in N_i$

(if K is not a concept expression but a context individual name k , K^J designates the singleton $\{k^J\}$ in the above expressions).

4.3 The Interaction Between the Core and Context Language

The interaction between the two languages is done using special operators. We introduce, in table 2, the OWL frame-like abstract syntax and the semantics of these contexts-based concept forming operators. Examples:

- **$\langle \text{Asian Country} \rangle$ Professor** The individuals that belong to the class Professor in some context of type x AsianCountry.
- **$[\text{European Country}]$ Professor** The individuals that belong to the class Professor in all contexts of type EuropeanCountry.
- **$\{\text{Switzerland}\}$ Professor** The individuals that belong to the class Professor in Switzerland.

Abstract Syntax	CDL	Semantics
ConceptValuesFromSomeContext (C [K])	$\langle K \rangle C$	$x \in \Delta \mid \exists y \in K^J : x \in C^{I[y]}$
ConceptValuesFromAllContext (C [K])	$[K]C$	$x \in \Delta \mid \forall y \in K^J \rightarrow x \in C^{I[y]}$
ConceptValuesFromThisContext (C [k])	$\{k\} C$	$x \in \Delta \mid x \in C^{I[k]}$
PropertyValuesFromSomeContext (R [K])	$\langle K \rangle R$	$(x, z) \in \Delta \times \Delta \mid \exists y \in K^J : (x, z) \in R^{I[y]}$
PropertyValuesFromAllContext (R [K])	$[K]R$	$(x, z) \in \Delta \times \Delta \mid \forall y \in K^J : (x, z) \in R^{I[y]}$
PropertyValuesFromThisContext (R [k])	$\{k\} R$	$(x, z) \in \Delta \times \Delta \mid (x, z) \in R^{I[k]}$

Table 2. Semantics of the contexts-based concept forming operators

5. Reasoning with OWL^c

Inspired from OWL 2 RL⁵, OWL^c is considered as a profile aimed at applications that require scalable reasoning without sacrificing too much expressive power. This is achieved by restricting the use of constructs to a certain syntactic position, similarly to OWL 2 RL.

In the original version of OWL-2 RL, the rules are given as universally quantified first order implications over a ternary predicate T . This predicate represents a generalization of *RDF* triples thus, $T(s, p, o)$ represents a generalized *RDF* triple with the subject s , predicate p , and the object o . Variables in the implications are preceded with a question mark. To include the notion of contexts, we introduce a quaternary predicate $Q(s, p, o, k)$ where s is the subject, p is the predicate, o is the object and k is the context for which the predicate holds. If the ontology has multiple context dimensions (e.g. time and provenance) k must be understood as k_1, \dots, k_m and hence Q as an $m + 3$ -ary predicate.

We can distinguish two types of object reasoning: explicit and implicit.

Implicit Contextual Reasoning

When the TBox axioms is declared as in normal OWL but the ABox is contextual.

Professor \sqsubseteq has Colleague only Professor
 1904 : Professor(Ferdinand)
 1904 : has Colleague (Ferdinand,Robert)
 1880 : has Colleague (Ferdinand,Clara)
 entails 1904: Professor (Robert) but not 1880 : Professor (Clara).

Explicit Contextual Reasoning

When the TBox axioms explicitly refer to contexts. From

FranceBefore1944 : CanVte \sqsubseteq Man

⁵https://www.w3.org/TR/owl2-profiles/#Feature_Overview_3

	IF	THEN
cls-com $\neg C$	$T(?c, \text{owl:complement Of}, ?c_2)$ $Q(?x, \text{rdf:type}, ?c_1, ?k)$ $Q(?x, \text{rdf:type}, ?c_2, ?k)$	false
cls-int1 $C \sqcap D$	$T(?c, \text{owl:intersection Of}, ?x)$ $\text{LIST}[?x, ?c_1, \dots, ?c_n]$ $Q(?y, \text{rdf:type}, ?c_1, ?k)$ $Q(?y, \text{rdf:type}, ?c_2, ?k)$ $Q(?y, \text{rdf:type}, ?c_n, ?k)$	$Q(?y, \text{rdf:type}, ?c, ?k)$
cls-int2 $C \sqcup D$	$T(?c, \text{owl:intersection Of}, ?x)$ $\text{LIST}[?x, ?c_1, \dots, ?c_n]$ $Q(?y, \text{rdf:type}, ?c, ?k)$	$Q(?y, \text{rdf:type}, ?c_1, ?k)$ $Q(?y, \text{rdf:type}, ?c_2, ?k)$ $Q(?y, \text{rdf:type}, ?c_n, ?k)$
cls-uni $\exists R.C$	$T(?c, \text{owl:union Of}, ?x)$ $\text{LIST}[?x, ?c_1, \dots, ?c_n]$ $Q(?y, \text{rdf:type}, ?c_i, ?k)$	$Q(?y, \text{rdf:type}, ?c, ?k)$
cls-svf 1-1 $\exists R.C$	$T(?x, \text{owl:some Values From}, ?y)$ $T(?x, \text{owl:on Property}, ?p)$ $Q(?u, ?p, ?v, ?k)$ $Q(?v, \text{rdf:type}, ?y, ?k)$	$Q(?u, \text{rdf:type}, ?x, ?k)$
cls-svf 1-2 $\exists R.C$	$T(?x, \text{owl:some Values From}, ?y)$ $T(?x, \text{owl:on Property}, ?p)$ $T(?u, ?p, ?v)$ $Q(?v, \text{rdf:type}, ?y, ?k)$	$Q(?u, \text{rdf:type}, ?x, ?k)$
cls-svf 1-3 $\exists R.C$	$T(?x, \text{owl:some Values From}, ?y)$ $T(?x, \text{owl:on Property}, ?p)$ $Q(?u, ?p, ?v, ?k)$ $T(?v, \text{rdf:type}, ?y)$	$Q(?u, \text{rdf:type}, ?x, ?k)$
cls-avf-1 $\forall R.C$	$T(?x, \text{owl:all Values From}, ?y)$ $T(?x, \text{owl:onProperty}, ?p)$ $Q(?u, \text{rdf:type}, ?x, ?k)$ $Q(?u, ?p, ?v, ?k)$	$Q(?v, \text{rdf:type}, ?y, ?k)$
cls-avf-2 $\forall R.C$	$T(?x, \text{owl:allValuesFrom}, ?y)$ $T(?x, \text{owl:onProperty}, ?p)$ $Q(?u, \text{rdf:type}, ?x, ?k)$ $T(?u, ?p, ?v)$	$Q(?v, \text{rdf:type}, ?y, ?k)$
cls-avf-3 $\forall R.C$	$T(?x, \text{owl:all Values From}, ?y)$ $T(?x, \text{owl:onProperty}, ?p)$ $Q(?u, \text{rdf:type}, ?x, ?k)$ $Q(?u, ?p, ?v, ?k)$	$T(?v, \text{rdf:type}, ?y)$

Table 3. OWL^c Entailment rules for the core language

	IF	THEN
cxt-svf ($\langle K \rangle D$)	$T(?e, owl^c : \text{on Class}, ?d)$ $T(?e, owl^c : \text{in Some Context Of}, ?k)$ $Q(?x, rdf: \text{type}, ?d, ?y)$ $T(?y, rdf: \text{type}, ?k)$	$T(?x, rdf: \text{type}, ?e)$
cxt-avf ($[K] D$)	$T(?e, owl^c : \text{on Class}, ?d)$ $T(?e, owl^c : \text{in All Context Of}, ?k)$ $T(?x, rdf: \text{type}, ?e)$ $Q(?x, rdf: \text{type}, ?d, ?y)$	$T(?y, rdf: \text{type}, ?k)$
cxt-ov ($\{K\} D$)	$T(?e, owl^c : \text{on Class}, ?d)$ $T(?e, owl^c : \text{in This Context}, ?k)$ $Q(?x, rdf: \text{type}, ?e)$	$Q(?x, rdf: \text{type}, ?d, ?k)$

Table 4. OWL^c entailment rules for the context-based concept forming operators

France Before 1944 : Can Vote (Alejandro)

France In 1989 : Can Vote (Andros)

we can infer France Before 1944 : Man (Alejandro) but not France In 1989 : Man (Andros)

(where France Before 1944 and France In 1989 are the contexts in use).

Interaction between OWL^c_{core} and OWL^c_{context}

The rules presented in this section let us do the interaction between the two languages. Syntactic restrictions are applied to the new constructors: an existential contextual restriction ($\langle C \rangle D$), ($\langle C \rangle R$) may only appear in the left-hand side of a subclass axiom, whereas a universal contextual restriction ($[C] D$, $[C] R$) may only appear in the right-hand side. Due to space limitations, we show only some of these rules in table 4.

An example of the existential rule is as follows: a former president is someone who has been president in the past

$\langle \text{Past Presidential Term} \rangle \text{President} \sqsubseteq \text{Former President}$

1933-1945 : President (Roosevelt)

Past Presidential Term (1933-1944)

entails Former President (Roosevelt)

6. OWL^c in Practice

Since OWL^c was created to deal with practical problems, we chose to evaluate it on a real use case: the SNSF project of Ferdinand de Saussure (FDS). Therefore, in this section, we explain the methodology to follow from the choice of contexts to reasoning. First, we start by defining the contexts dimensions to be used. In addition, we describe the process we followed to extract contextual knowledge from the Saussurian texts. Then, we discuss the problems we encountered while encoding the model in RDF. Finally, we propose a practical implementation of contextual reasoning.

6.1 How to Choose Your Context Dimensions?

When talking about the implementation of contextual reasoning, some questions always arise such as: how do you decide what should be a context and what shouldn't? Is there a list of predefined contexts dimensions, you choose from? etc. According to your target, you choose your dimensions. In the case of the FDS project, we are interested in reasoning about time and provenance. Therefore, we choose the validity time and provenance as our dimensions.

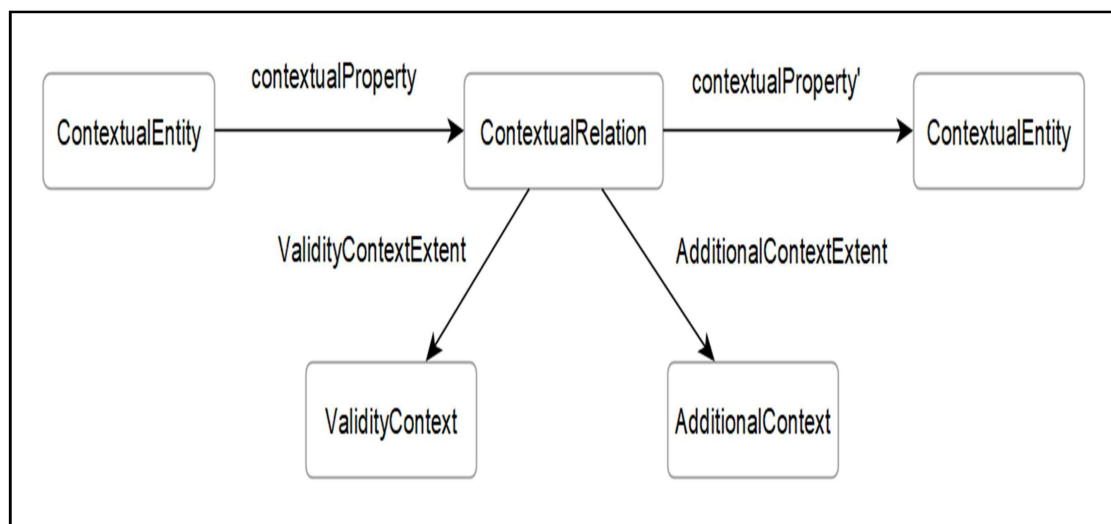


Figure 1. Contexts in RDF

In order to come up with a suitable range of dimensional values, we must consider the granularity of contexts. In our use case, the main focus is on the Saussurian network (persons he cites in his manuscripts, students, etc.) and events he participated too. Therefore, the data provenance will be the transcriptions from which the data was extracted. For the time dimension, the most granular value is a “year”.

6.2 Contextual knowledge Acquisition

The acquisition of contextual knowledge was the hardest phase of this project given the fact that: 1) the information is scattered in thousands of transcriptions 2) no general purpose natural language processing tool can extract accurately knowledge from text yet, in particular, contextual entities or more precisely n-ary relations (e.g. Saussure lived in Geneva in 1857). In many cases, information could be split over different sentences, so the problem can be hard and require “coreference resolution”. The simplest way was to use existing tools to find binary relations and then parse in the vicinity of the text to find contexts such as dates/years. In cooperation with a Saussurian linguist, we did the task semi-automatically. Using Gate6, we extracted name entities and relations from transcriptions. Time and provenance were then added to the contextual relations. Knowledge was also enriched with Wikidata⁷. We have 1032 persons. We have also shown in [2] that the FDS project contains a lot of fluent⁸ relations among them: relations between persons(colleagues, studentOf, professor, spouseOf, husbandOf, educatedAt, etc.).

⁶<https://gate.ac.uk/projects.html>

⁷<https://www.wikidata.org/wiki/Wikidata>

⁸a fluent is a relation whose object is subject to change over time (e.g Saussure lives in Geneva in 1860 but in Paris in 1882)

6.3 Representing FDS with OWLC

In this section, we explain how to encode the overall model in RDF. We start by presenting the contextual pattern we adopted and then we prove the correspondence between the OWLC formalization and the RDF based representation.

When it comes to encoding contexts in RDF, a lot of techniques are made available (check section 3). We chose to use the n-ary pattern we presented in [2] for its compactness and intuitiveness (figure 1). In order to map OWLC to RDF, we implicitly used the standard mapping of OWL to RDF9. For instance, the mapping of the axiom:

(1904, University of Geneva) : Colleague (Saussure, Paolo)

where (1904,University of Geneva) is the validity context composed of the validity time (1904) and the location (University of Geneva), is as follows:

:Saussure	cp:colleague of	:x.
:x	cp1:colleague of	:Ascoli.
:x	rdf:type	:contextualRelation.
:x	:during	:"1889"^^xsd:date.
:x	:location	:UniversityOfGeneva.
:during rdfs	:sub Property of owl	:validityContextExtent
:location rdfs	:sub Property of owl	:validityContextExtent

Where

- cp is used for the property linking the entity to the contextual relation.
- cp1 is used for the property linking the contextual relation to the object.
- owl refers to the vocabulary introduced by the contextual ontology.

The mapping of the context-based concept forming operators to RDF is more delicate. In order to represent the contextual existential $\langle CD \rangle$ and universal operators $[C]D$, we designed the owl:context Restriction similarly to owl:Restriction. A context restriction class should have exactly two triples linking the restriction to:

1. The class (resp. property) that the restriction applies on, using the new predicate owl: on Class (owl: on Property)
2. The type of the restriction: in case of a universal (resp. existential) restriction, owl: in All Context of (owl: in Some Context of) should be used.

⁹<https://www.w3.org/TR/owl2-mapping-to-rdf/>

If

[European Countries] Famous Linguist

represents the people who are considered as famous linguists in all european countries. The mapping is as follows:

```
_:x      rdf: type                owl:Context Restriction .
_:x      owl: on Class          :Famous Linguist .
_:x      owl: in All Context of :European Countries.
```

6.4 Reasoning in FDS with OWL^c

One characteristics of the contextual rules is that they generates new objects of type Contextual Relation. We choose to use SPIN[10]⁴ because it is flexible enough that you can pass parameters to them to customize their behavior. Then, they can be instantiated in any RDF or OWL ontology to add inference rules and constraint checks. Two types of rules were implemented using Top Braid Composer¹¹.

6.4.1 OWL^c Rules

Figure 2 shows the example of the cls-int rule encoded as a SPIN template. It declares that the assertion of the same individual in two classes, holding for the same context, generates an assertion for this individual in the intersection of those classes, but also for the same holding contexts. It is implemented using a SPARQL INSERT request and is composed of a spin : body and spin : constraint.

spin:body

```
INSERT{
?this    owl:representedBy      _:b0.
_:b0     a                        owl:ContextualRelation.
_:b0     a                        ?ClassIntersection.
_:b0     owl:validityContextExtent ?co.
}
WHERE{
?this    owl:representedBy      ?cr1.
?cr1     a                        owl:ContextualRelation.
?cr1     a                        ?FirstClass.
?cr1     owl:validityContextExtent ?co.
?this    owl:representedBy      ?cr2.
?cr2     a                        owl:ContextualRelation.
?cr2     a                        ?SecondClass.
?cr2     owl:validityContextExtent ?co.
FILTER NOT EXISTS{
?this    owl:representedBy      _:0.
_:0      a                        owl:ContextualRelation.
_:0      a                        ?ClassIntersection.
_:0      owl:validityContextExtent ?co.
}
}
```

⁴<http://spinrdf.org>

¹¹<https://www.topquadrant.com/tools/ide-topbraid-composer-maestro-edition/>

Spin:Constraint

Argument	arg:ClassIntersection	rdfs:Class
Argument	arg:FirstClass	rdfs:Class
Argument	arg:SecondClass	rdfs:Class

Notice that the classes are declared as spin:constraint. Notice also that the query contains a filter. The existence of the filter is of a major importance, because it guarantees that an existing triple is not generated again and again, whenever the rules are running.

6.4.2 Domain Rules

Domain rules were added to enable historical reasoning over the knowledge. They were created in collaboration with Saussurean experts. A typical rule is

If a manuscript M is a letter written by a scholar A to a scholar B at time t then we can infer that A is aware of B 's work at time t and thereafter, i.e in the time interval $[t, \text{end of considered period}]$.

For instance, from the fact that a manuscript M is written by a person A as a letter to a person B and the writing time of M is $[t_1...t_2]$, we can infer that A knows B since t_1 .

7. Conclusion

OWL^C is an extension of the web ontology language for contexts. It is completely embedded within the current Semantic Web standards. It builds on top of these standard formalisms and enhances them with the following aspects: (1) knowledge is organized in two layers: contextualized knowledge and knowledge about contexts (2) contexts can have many dimensions and are divided into validity context and additional context (3) reasoning can be performed explicitly or implicitly. We also described a modeling scenario from the domain of digital humanities, by which we demonstrate the features of OWL^C. The choice of this particular domain is due to its inherent contextual nature and sufficient complexity.

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