OWL^{C}: A Contextual Two-Dimensional Web Ontology Language

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Abstract

Representing and reasoning on contexts is an open problem in the semantic web. Despite the fact that context representation has for a long time been treated locally by semantic web practitioners, a recognized and widely accepted consensus regarding the way of encoding and particularly reasoning on contextual knowledge has not yet been reached by far. In this paper, we present OWL^{C}: a contextual two-dimensional web ontology language. Using the first dimension, we can reason on contexts-dependent classes, properties, and axioms and using the second dimension, we can reason on knowledge about contexts which we consider formal objects, as proposed by McCarthy [20]. We demonstrate the modeling strength and reasoning capabilities of OWL^{C} with a practical scenario from the digital humanity domain. We chose the Ferdinand de Saussure [15] use case in virtue of its inherent contextual nature, as well as its notable complexity which allows us to highlight many issues connected with contextual knowledge representation and reasoning.

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1 Introduction

The representation of context-dependant knowledge in the Semantic Web (SW) is a crucial issue. Several paradigms have been proposed with the aim of adding context awareness into 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.

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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 SNSF[1] 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 pages[2] 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 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.

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[1] `http://www.snf.ch/en/Pages/default.aspx`

[2] which have been (and still) transcribed

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 $(\langle N_C, N_R, N_I\rangle, \langle N_{KC}, N_{KR}, N_{KI}\rangle)$ 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:

$$(1857, \mathit{wikipedia}) : \mathit{LivedIn}(\mathit{Saussure}, \mathit{Geneva})$$

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 context[3].

The axioms of the contexts language are formulas:

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

where A $\in N_{KC}$, B $\in N_{KC}$, C $\in N_{KC}$, 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 $\langle N_C, N_R, N_I \rangle$. For Example:

  $$Human(Saussure)^4$$

- an expression of the form $K : \phi$, where K is either an individual context name (in N_{KI}) or a concept expression over the context signature $\langle N_{KC}, N_{KR}, N_{KI} \rangle$. 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 ($C \sqsubseteq D$, $C \equiv D$, $C\ disjoint\ D$)

     $$\mathit{1969} : CanVote \sqsubseteq \mathit{Aged21orMore}$$

     states that the axiom $CanVote \sqsubseteq \mathit{Aged21orMore}$ holds in the temporal context $\mathit{1969}$.

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

[4] We 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.

Table 1 OWL 2 DL$^{C}_{core}$ direct model theoretic semantics.

Abstract Syntax	CDL syntax	Semantics (Interpretation in context k)
IntersectionOf(C_1 ... C_n)	$C_1 \sqcap ... \sqcap C_n$	$C_1^{\mathcal{I}[k]} \cap ... \cap C_n^{\mathcal{I}[k]}$
UnionOf(C_1 ... C_n))	$C_1 \sqcup ... \sqcup C_n$	$C_1^{\mathcal{I}[k]} \cup ... \cup C_n^{\mathcal{I}[k]}$
ComplementOf(C)	$\neg C$	$(\neg C)^{\mathcal{I}[k]} = \Delta^{\mathcal{I}[k]} \setminus C^{I[k]}$
R SomeValuesFrom(C)	$\exists(R.C)$	$x \mid \exists y : (x, y) \in (R)^{\mathcal{I}[k]} and \quad y \in (C)^{\mathcal{I}[k]}$
R AllValuesFrom(C)	$\forall(R.C)$	$x \mid \forall y : (x, y) \in (R)^{\mathcal{I}[k]} \rightarrow y \in (C)^{\mathcal{I}[k]}$
OneOf(a$_1$ ...a$_n$)	a$_1$ ... a$_n$	$(a_1)^{\mathcal{I}[k]}, ..., (a_n)^{\mathcal{I}[k]}$

2. a role axiom ($R \sqsubseteq S$, $functional(R)$, $transitive(R)$, $\ldots$)

$$DecentralizedCountry : hasLocalPowerIn \sqsubseteq electedLocallyIn$$

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 $\mathcal{M} = (\mathcal{I}, \mathcal{J})$ where $\mathcal{I} = (\Delta, \cdot^{\mathcal{I}[\cdot]})$ is the core interpretation, $\mathcal{J} = (\Omega, \cdot^{\mathcal{J}})$ is the context interpretation, and $\Delta \cap \Omega = \emptyset$. $\cdot^{\mathcal{I}[\cdot]}$ is a family of interpretation functions, one for each context $k \in \Omega$. $.^{\mathcal{J}}$ 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$^{C}_{core}$ basic class constructors. We only consider contextual interpretations that satisfy the *rigid designator hypothesis* [19], i.e. $i^{\mathcal{I}[k]} = i^{\mathcal{I}[k']}$ for any individual $i \in N_I$, $k \in \Omega$, 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 $\forall k \in K^{\mathcal{J}} : C^{\mathcal{I}[k]} \subseteq D^{\mathcal{I}[k]}$, where $C \in N_C$ and $D \in N_C$
- $\mathcal{M} \models K : R \sqsubseteq S$ iff $\forall k \in K^{\mathcal{J}} : R^{\mathcal{I}[k]} \subseteq S^{\mathcal{I}[k]}$, where $R \in N_R$ and $S \in N_R$
- $M \models K : C(a)$ iff $\forall k \in K^{\mathcal{J}} : C(a)^{\mathcal{I}(k)}$, where $C \in N_C$ and $a \in N_I$
- $M \models K : R(a, b)$ iff $\forall k \in K^{\mathcal{J}} : R(a, b)^{\mathcal{I}(k)}$, 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, $K^{\mathcal{J}}$ designates the singleton $\{k^{\mathcal{J}}\}$ 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:

- $\langle AsianCountry \rangle \, Professor$: the individuals that belong to the class $Professor$ in some context of type $xAsianCountry$.

- $[EuropeanCountry]Professor$: the individuals that belong to the class $Professor$ in all contexts of type $EuropeanCountry$.
- $\{Switzerland\}Professor$: the individuals that belong to the class $Professor$ in *Switzerland*.

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

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

5 Reasoning with OWL^C

Inspired from OWL 2 RL[5], 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 $k_1, \ldots, k_m$ 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.

$Professor \sqsubseteq hasColleague$ **only** $Professor$
$1904 : Professor(Ferdinand)$
$1904 : hasColleague(Ferdinand, Robert)$
$1880 : hasColleague(Ferdinand, Clara)$
entails $1904 : Professor(Robert)$ but not $1880 : Professor(Clara)$.

Explicit contextual reasoning

When the TBox axioms explicitly refer to contexts. From
$FranceBefore1944 : CanVote \sqsubseteq Man$

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

Table 3 OWL^C: Entailment rules for the core language.

	IF	**THEN**
cls-com $\neg C$	T(?c_1, owl:complementOf, ?c_2) Q(?x, rdf:type, ?c_1, ?k) Q(?x, rdf:type, ?c_2, ?k)	false
cls-int1 $C \sqcap D$	T(?c, owl:intersectionOf, ?x) LIST[?x, ?c_1, ..., ?c_n] Q(?y, rdf:type, ?c_1, ?k) Q(?y, rdf:type, ?c_2, ?k) ... Q(?y, rdf:type, ?c_n, ?k)	Q(?y, rdf:type, ?c, ?k)
cls-int2 $C \sqcap D$	T(?c, owl:intersectionOf, ?x) LIST[?x, ?c_1, ..., ?c_n] Q(?y, rdf:type, ?c, ?k)	Q(?y, rdf:type, ?c_1, ?k) Q(?y, rdf:type, ?c_2, ?k) ... Q(?y, rdf:type, ?c_n, ?k)
cls-uni $C \sqcup D$	T(?c, owl:unionOf, ?x) LIST[?x, ?c_1, ..., ?c_n] Q(?y, rdf:type, ?c_i, ?k)	Q(?y, rdf:type, ?c, ?k)
cls-svf1-1 $\exists R.C$	T(?x, owl:someValuesFrom, ?y) T(?x, owl:onProperty, ?p) Q(?u, ?p, ?v, ?k) Q(?v, rdf:type, ?y, ?k)	Q(?u, rdf:type, ?x, ?k)
cls-svf1-2 $\exists R.C$	T(?x, owl:someValuesFrom, ?y) T(?x, owl:onProperty, ?p) T(?u, ?p, ?v) Q(?v, rdf:type, ?y, ?k)	Q(?u, rdf:type, ?x, ?k)
cls-svf1-3 $\exists R.C$	T(?x, owl:someValuesFrom, ?y) T(?x, owl:onProperty, ?p) Q(?u, ?p, ?v, ?k) T(?v, rdf:type, ?y)	Q(?u, rdf:type, ?x, ?k)
cls-avf-1 $\forall R.C$	T(?x, owl:allValuesFrom, ?y) T(?x, owl:onProperty, ?p) Q(?u, rdf:type, ?x, ?k) Q(?u, ?p, ?v, ?k)	Q(?v, rdf:type, ?y, ?k)
cls-avf-2 $\forall R.C$	T(?x, owl:allValuesFrom, ?y) T(?x, owl:onProperty, ?p) Q(?u, rdf:type, ?x, ?k) T(?u, ?p, ?v)	Q(?v, rdf:type, ?y, ?k)
cls-avf-3 $\forall R.C$	T(?x, owl:allValuesFrom, ?y) T(?x, owl:onProperty, ?p) Q(?u, rdf:type, ?x, ?k) Q(?u, ?p, ?v, ?k)	T(?v, rdf:type, ?y)

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

	IF	**THEN**
cxt-svf ($\langle K\rangle\, D$)	T(?e, owl^c : onClass, ?d) T(?e, owl^c : inSomeContextOf, ?k) Q(?x, rdf:type, ?d, ?y) T(?y, rdf:type, ?k)	T(?x, rdf:type, ?e)
cxt-avf ($[K]D$)	T(?e, owl^c : onClass, ?d) T(?e, owl^c : inAllContextOf, ?k) T(?x, rdf:type, ?e) Q(?x, rdf:type, ?d, ?y)	T(?y, rdf:type, ?k)
cxt-ov ($\{K\}\, D$)	T(?e, owl^c : onClass, ?d) T(?e, owl^c : inThisContext, ?k) Q(?x, rdf:type, ?e)	Q(?x, rdf:type, ?d, ?k)

$FranceBefore1944 : CanVote(Alejandro)$
$FranceIn1989 : CanVote(Andros)$
we can infer $FranceBefore1944 : Man(Alejandro)$ but not $FranceIn1989 : Man(Andros)$ (where $FranceBefore1944$ and $FranceIn1989$ 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
$\langle PastPresidentialTerm\rangle President \sqsubseteq FormerPresident$
1933-1945 : $President(Roosvelt)$
$PastPresidentialTerm$(1933-1944)
entails $FormerPresident(Roosvelt)$

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.

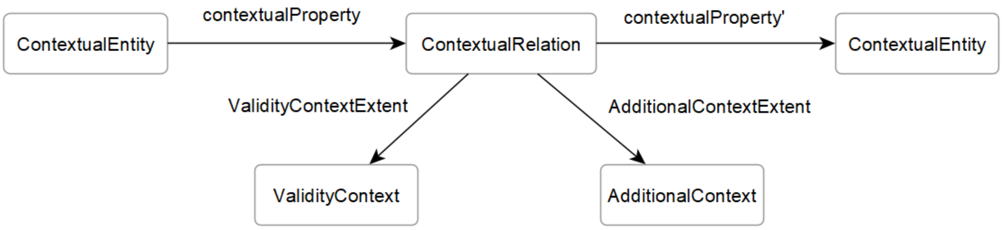

Figure 1 Contexts in RDF.

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 Gate[6], we extracted name entities and relations from transcriptions. Time and provenance were then added to the contextual relations. Knowledge was also enriched with Wikidata[7]. We have 1032 persons. We have also shown in [2] that the FDS project contains a lot of fluent[8] relations among them: relations between persons (colleagues, studentOf, professor, spouseOf, husbandOf, educatedAt, etc.).

6.3 Representing FDS with OWL^C

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 OWL^C 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 OWL^C to RDF, we implicitly used the standard

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[6] `https://gate.ac.uk/projects.html`

[7] `https://www.wikidata.org/wiki/Wikidata`

[8] a 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)

mapping of OWL to RDF[9]. For instance, the mapping of the axiom:

$$(1904, UniversityOfGeneva) : Colleague(Saussure, Paolo)$$

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

```
:Saussure   cp:colleagueOf          :x.
:x          cp1:colleagueOf         :Ascoli.
:x          rdf:type                :contextualRelation.
:x          :during                 :"1889"^^xsd:date.
:x          :location               :UniversityOfGeneva.
:during     rdfs:subPropertyOf      owlc:validityContextExtent
:location   rdfs:subPropertyOf      owlc: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.
- `owlc` 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 $\langle C \rangle D$ and universal operators [C]D, we designed the *owlc:contextRestriction* 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 *owlc:onClass* (*owl:onProperty*)
2. The type of the restriction: in case of a universal (resp. existential) restriction , *owlc:inAllContextOf* (*owlc:inSomeContextOf*) should be used.

If

$$[EuropeanCountries]FamousLinguist$$

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

```
_:x    rdf:type             owlc:ContextRestriction .
_:x    owlc:onClass         :FamousLinguist .
_:x    owlc:inAllContextOf  :EuropeanCountries.
```

6.4 Reasoning in FDS with OWL^C

One characteristics of the contextual rules is that they generates new objects of type ContextualRelation. 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 TopBraid Composer[11]:

---

[9] https://www.w3.org/TR/owl2-mapping-to-rdf/

[4] http://spinrdf.org

[11] https://www.topquadrant.com/tools/ide-topbraid-composer-maestro-edition/

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

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 where 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 $[t, end\ ofconsidered\ period]$.

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 $[t1...t2]$, we can infer that A knows B since $t1$.

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.

References

1 Sahar Aljalbout, Didier Buchs, and Gilles Falquet. Introducing Contextual Reasoning to the Semantic Web with OWL^C. In *Proceedings of the 24th International Conference on Conceptual Structures: ICCS*. Springer, 2019.

2 Sahar Aljalbout and Gilles Falquet. Un modèle pour la représentation des connaissances temporelles dans les documents historiques. In *IC 2017 : 28es Journées francophones d'Ingénierie des Connaissances (Proceedings of the 28th French Knowledge Engineering Conference), Caen, France, July 3-7, 2017.*, pages 145–150, 2017. URL: `https://hal.archives-ouvertes.fr/hal-01568018`.

3 Sahar Aljalbout and Gilles Falquet. A Semantic Model for Historical Manuscripts. *arXiv preprint*, 2018. `arXiv:1802.00295`.

4 Sahar Aljalbout, Gilles Falquet, and Didier Buchs. A Practical Implementation of Contextual Reasoning on the Semantic Web. In *Proceedings of the 10th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management - Volume 2: KEOD,*, pages 255–262. INSTICC, SciTePress, 2018.

5 Djamal Benslimane, Ahmed Arara, Gilles Falquet, Zakaria Maamar, Philippe Thiran, and Faiez Gargouri. Contextual ontologies. *Advances in Information Systems*, pages 168–176, 2006.

6 Tim Berners-Lee, James Hendler, Ora Lassila, et al. The semantic web. *Scientific american*, 284(5):28–37, 2001.

7 Alexander Borgida and Luciano Serafini. Distributed description logics: Assimilating information from peer sources. *J. Data Semantics*, 1:153–184, 2003.

8 Paolo Bouquet, Fausto Giunchiglia, Frank Van Harmelen, Luciano Serafini, and Heiner Stuckenschmidt. C-owl: Contextualizing ontologies. In *International Semantic Web Conference*, pages 164–179. Springer, 2003.

9 Loris Bozzato, Martin Homola, and Luciano Serafini. Context on the semantic web: Why and how. *ARCOE-12*, page 11, 2012.

10 Giuseppe Cosenza. *Tra terminologia e lessico: i percorsi di pensiero di F. de Saussure.* PhD thesis, University of Calabria, 2015.

11 Renata Dividino, Sergej Sizov, Steffen Staab, and Bernhard Schueler. Querying for provenance, trust, uncertainty and other meta knowledge in RDF. *Web Semantics: Science, Services and Agents on the World Wide Web*, 7(3):204–219, 2009.

12 Chiara Ghidini and Fausto Giunchiglia. Local Models Semantics, or contextual reasoning=locality+compatibility. *Artificial intelligence*, 127(2):221–259, 2001.

13 José M Giménez-García, Antoine Zimmermann, and Pierre Maret. NdFluents: An Ontology for Annotated Statements with Inference Preservation. In *European Semantic Web Conference*, pages 638–654. Springer, 2017.

14 Olaf Hartig and Bryan Thompson. Foundations of an alternative approach to reification in RDF. *arXiv preprint*, 2014. `arXiv:1406.3399`.

15 John E Joseph. *Saussure*. Oxford University Press, 2012.

16 Mathew Joseph and Luciano Serafini. Simple Reasoning for Contextualized RDF Knowledge. In *WoMO*, pages 79–93, 2011.

17 Szymon Klarman and Víctor Gutiérrez-Basulto. Two-Dimensional Description Logics for Context-Based Semantic Interoperability. In *AAAI*, 2011.

18 Oliver Kutz, Carsten Lutz, Frank Wolter, and Michael Zakharyaschev. E-connections of abstract description systems. *Artificial intelligence*, 156(1):1–73, 2004.

19 Joseph LaPorte. Rigid designators. *Philosophical Studies*, 130:321—336, 2006.

20 John McCarthy. Generality in artificial intelligence. *Communications of the ACM*, 30(12):1030–1035, 1987.

21 Vinh Nguyen, Olivier Bodenreider, and Amit Sheth. Don't like RDF reification?: making statements about statements using singleton property. In *Proceedings of the 23rd international conference on World wide web*, pages 759–770. ACM, 2014.

22 Chris Welty. Context slices: representing contexts in OWL. In *Proceedings of the 2nd International Conference on Ontology Patterns-Volume 671*, pages 59–60. CEUR-WS. org, 2010.

23 Chris Welty, Richard Fikes, and Selene Makarios. A reusable ontology for fluents in OWL. In *FOIS*, volume 150, pages 226–236, 2006.