Context and Ontologies: Contextual Indexing of Ontological Expressions

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Abstract

This paper discusses aspects of context as applied to ontologies. In particular, we note some formalizations of context that have been applied to ontologies such as Menzel (1999) and Akman & Surov (1996, 1997), that have largely been framed in terms of theories such as Situation Theory (Barwise & Perry, 1983) which originated in natural language semantics. We also mention the notion of labeled deduction (Gabbay, 1996) and speculate on its prospective use in the contextualizing of ontologies. The latter can be viewed as a mechanism for annotating ontological assertions and proofs with contextual information about provenance, security, strength/confidence of assertion, and aspects of policy. Labeled deduction correlates one or more logics, with one logic addressing the primary assertion or inference step and another logic addressing the label or annotation of that assertion or inference step.

The Need for Contexts for Ontologies

In recent years, ontologies have been proposed as models which represent the common, shared semantics of domains or subject areas (see Guarino (1998), Guarino, Welty, Smith (2001), Guarino, Varzi, Vieu (2004)). Domain-spanning middle and upper ontologies (Semy et al, 2004; IEEE SUO) have also been proposed, the better to situate and align domain ontologies by axiomatizing common semantics shared by nearly every domain, and allowing those domains to inherit the common semantics. The emerging Semantic Web (Daconta, Obrst, Smith, 2003; Berners-Lee et al, 2001) has more recently defined knowledge representation language standards such as RDF/S, OWL, and extensions of these including Semantic Web Rule Language (SWRL) and OWL-FOL, a first-order logic extension of OWL.

An increasingly important issue in the use of ontologies and the Semantic Web is that of context, i.e., 1) how should an ontology be interpreted in specific, changing contexts, and 2) how can ontologies incorporate the notion of context? Contexts here can be considered specific views of domains, dependent on the user, organization, etc., and their needs and intents.

Increasingly, the notion of context with respect to ontology needs to be addressed. Is a context embedded within a given ontology (where the ontology is viewed as a theory or set of logical theories about a domain)? Is a context with respect to an ontology, i.e., with respect to a particular interpretation of a theory or set of theories, and thus outside the ontology as theory, leading us to view a context as encapsulating ontologies and changing the interpretations of those ontologies in this context as opposed to that context? Is a context a *first-class citizen* of the logic of the ontology? Is it a *microtheory* ala Cyc (Blair et al, 1992), meaning a portion of the (monolithic) ontology that is separable from other microtheories, and thus with respect to those possibly containing contradictory assertions? Should hybrid logics and reasoning methods, as for example discussed in Audemard et al (2002) and Giunchiglia et al (2000), be used?

In the Semantic Web, ontologies expressed in OWL, possibly using SWRL and other extensions, have annotations – annotations on the classes, properties, and instances, but also on the ontologies. These annotations can carry information about the construct, possibly its security, version, provenance, strength or confidence of belief, etc. Currently, these annotations are non-symbolic and uninterpreted, in fact, uninterpretable under the current semantics of OWL. Inference engines that work on OWL ontologies can provide whatever interpretation they desire to these annotations. Similarly, reification in RDF is a statement S2 about a statement S1: a triple along the lines of S2: <john, states, S1>. The truth of S2 cannot be determined; there is no semantics for reification in RDF, only a syntax which a given inference engine is free to semantically interpret as it will. This is problematic, insofar as reification in RDF is used to capture belief information, in particular.

The general problem is therefore: if you make statements about statements or annotate statements with statements in ontology languages, should these be semantically interpreted, and if so, how? In general, statements about statements are formally representable only in second-order logic (however, reification in RDF is first-order). Can these annotations also act as context determiners, and if so how? Because these annotations begin to look like indices in a context structure, i.e., guiding the interpretation of the assertion (or inference step) so annotated, how do we deal with them? How might we formalize context and its interaction with the logical assertions of ontologies? We assert in this paper that these annotations indeed create a context for the interpretation of ontologies. Is this the only notion of context? No, but it may be that the mechanisms for the multiple notions of context are similar or, in fact, the same.

Furthermore, there is overlap here with the evolving notion of *policy*, especially with respect to Semantic Web ontologies. *Policy* we take as really an aspect of formal pragmatics, as opposed to just the base formal semantics, i.e., policy involves how the semantics should be interpreted in a given context, with the policy theory (ontology) ensuring the correct intent of the policy for a given semantic interpretation, and thereby ensuring the correct usage of the given semantics as expressed in the ontology/ies of the site or enterprise that has propounded the policy.

Formalization of Context for Ontologies

Traditional formalizations of context such as McCarthy (1987, 1991, 1993), Guha (1991), McCarthy & Buvač (1997) and the related notion of *microtheory* in Cyc (Blair, et al, 1992; Lenat & Guha, 1990; Lenat, 1998) introduced the notion of *ist(c, p),* i.e., a proposition *p* is true (ist) in a given context *c*, a so-called lifting axiom (of a proposition's truth value from one context to another). As Menzel (1999) points out, these formalizations, including that of Akman & Surav (1996, 1998), propose a so-called "subjective conception" of context, meaning one which defines contexts as sets of propositions, i.e., as theories related via an entailment relation, and typically as a set of beliefs of a person or agent – hence, *subjective*. Menzel (1999), however, proposes an "objective conception" of context, a shared context among agents that views the truth of a proposition not as a logical relation (such as entailment) between the proposition of a context and other propositions, but instead as a correspondence relation between the proposition and the world – hence, *objective*.

This "correspondence" relation is interesting in a number of ways, including its apparent correlation to the notion of *compatibility* of contexts developed in the *local model semantics* of Giunchiglia & Ghidini (1998), Giunchiglia & Bouquet (1997, 1998), and related to Obrst et al (1999a-b). In addition, of course, it acts as a refinement of the *accessibility* relation between worlds in possible worlds semantics (and which, however, is usually taken to be an entailment relation), which is why Menzel (1999) proposes the use of Situation Theory (Barwise & Perry, 1983), which explicitly intends to establish more granular formal contexts in natural language semantics than the usual notion of possible worlds, i.e., situations. Situation theory and a similar theory, Discourse Representation Theory (Kamp & Reyle, 1993), attempt to extend the original focus of natural language semantics from the sentence to the discourse level, including the formal pragmatics of language. Stalnaker (1998) is also relevant here.

Recently, there has been research addressing ontologies and contexts with respect to Semantic Web ontology languages such as OWL. In particular, Bouquet et al (2004) build on Giunchiglia & Ghidini (1998), and extend OWL to include contexts, as Context-OWL or C-OWL, in which mappings among ontologies are first class citizens in their own right, represented independently of the ontologies they link.

Contextual Indexing of Ontological Expressions

One prospective accommodation of contexts to ontologies involves the notion of labeled deduction (Gabbay, 1996; Basin et al, 2000). In labeled deduction, multiple logics are correlated. In some natural language processing usage of labeled deduction, the formal syntax of an expression is correlated with its formal semantics (Finger et al, 1997; Kempson, 1996; Moortgat, 1999).

Some examples from formal linguistics may help illustrate how labeled deductive systems (LDS) work. In Figure 1 (from Gabbay & Kempson, 1992; adapted from Kempson, 1996, p. 569), the Modus Ponens (MP) proof structure contains units of the form label-plus-formula, e.g., **α:P,** with α labeling the formula **P** (with **P, Q** ranging over logical types **e, t, e→t** – roughly, type entity, type truth value, and functional type entity to truth value, respectively). In this example, the conclusion **β(α):Q** signifies the function application of β on α in the label of the formula **Q**. In this natural language parsing application (using the Curry-Howard isomorphism of types as formulae), words are labels on their types, and successive Modus Ponens applications build up a semantic interpretation of a sentence via simultaneous function applications on the labels.

$$\frac{\alpha{:}P \qquad \beta{:}P \rightarrow Q}{\beta(\alpha){:}Q}$$

Figure 1. Labelled Deductive System: Modus Ponens

In Figure 2 (Kempson, 1996, p. 574), a rule of →Introduction is given, where the label builds a

Assume:	**α:P** **…** **β(α):Q**
λx β(x): P → Q	

Figure 2. Labelled Deductive System: →Introduction

λ-abstraction which records where the assumption has been retracted. Such a representation might be used for ellipsis in natural language discourse, where the resulting lambda term can be then be bound to another premise.

In other more typical logical usages, an assertion or inference step is annotated with other logical information, so that multiple logics exist and act over the same expression. For each primary logical assertion or deductive step, annotations exist. These annotations (labels) are themselves symbolically interpreted according to the logic they are expressions of, at each step in the primary assertion or deductive step. Typically, the annotations are expressed in simpler logics than the primary assertion/deductive step. Consider a very simple example, where the label of each formula in the MP proof above is just $\mathbf{t_1}$, designating a specific time at which the formula is true. From $\mathbf{t_1{:}P}$, $\mathbf{t_1{:}P \rightarrow Q}$, one concludes $\mathbf{t_1{:}Q}$. The effect is therefore that the most computationally resource-intensive deduction using the logical assertions drives the inference, with the annotations (expressing security, strength of belief, provenance information) represented in less expressive and therefore more efficiently executed logics (typically propositional logics, some of which can be implemented in bit-vector operations). The result is that a Modus Ponens proof can simultaneously cause the composition of security and/or belief-confidence annotations according to simpler logics, and propagate the annotations through the ontological space.

Labeled deduction, therefore, may be a mechanism by which contexts expressed as indices representing security, belief, provenance, and other policy (formal pragmatic) determinants may influence the interpretation of ontological (semantic) expressions. For example, Rasga et al (2002) with regard to modal logic, discusses using a labeled formula $\mathbf{x{:}\varphi}$ which means that φ holds at world $\mathbf{x}$ in the underlying Kripke structure (model), and then defining rules which separately and simultaneously work on the labels and the formulae. Blackburn (1999, 2000) *internalizes* labeled deduction by moving its methods from the (external) metalanguage to the object language (propositional modal logic) by introducing as labels **i** *nominals*, each of which is true at exactly one state in the model. So a formula with a nominal label "**i:** φ will be true at any state in a model iff φ is true at the state that **i** labels" (Blackburn, 2000, p. 137-138). The resulting logic is a hybrid logic with two sorts: propositions and nominals.

In this short paper, we can only suggest the possible use of labeled deduction for contextual indexing of ontological expressions. For example, one might consider a very simple system for a security context, where individual propositions (facts or assertions in an ontology) and ontology rules are labeled with their respective security classifications. The resulting system (using MP) might look as in Figure 3.

α:P
β:P → Q

(α * β):Q

where (α * β) is defined as (α, β elements of a poset and ≥ is a partial ordering):
i. $(\alpha * \beta) = \alpha$ if $\alpha \geq \beta$
ii. $(\alpha * \beta) = \beta$ if $\beta > \alpha$

Figure 3. LDS MP: Security Labels + Ontology Expressions

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