Logics for the Semantic Web

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Abstract. Logic clearly has a role to play in the development of the Semantic Web, most obviously in the model-theoretic formalization of semantics to allow for automated reasoning. But logic can do more than provide model-theoretic underpinnings for the Web. We believe the Semantic Web will evolve to accommodate many kinds of reasoning, based on a variety of logics. We discuss how different logics' languages, axioms, and inference rules can support different kinds of reasoning. Our position is that the research being done on using multiple logics for different kinds of reasoning should be exploited by the Semantic Web community.

1. Overview

Popular expositions of the Semantic Web often stress that *semantic* in this context means "machine processable" or "machine understandable" [1,18]. But the data on the Web are already being processed and in some sense understood by machines. So there must be something more to this notion of *semantic*. This something more is usually taken to be logical (model-theoretic) semantics. We accept the utility of model theory [11,15,16] in providing a formal semantics for the Web. But the emphasis on model-theoretic foundations tends to overlook an interesting possibility: that the Semantic Web might evolve to support many kinds of reasoning and so will need to employ a variety of different logics. The focus on general model-theoretic foundations for the Semantic Web hides important differences among logics that are relevant for different kinds of reasoning.

For example, on certain occasions we may need to reason about what might possibly be the case (e.g., "Is this document possibly related to that one?"). On other occasions we may be interested in a different sort of question (e.g., "Is every *Research Paper* also a *Document*?"). In both cases, a particular logical syntax can be used to govern the formal deductive steps, and an appropriate model theory can be used to formalize the semantics. But whereas the logic used in the first case might be designed specifically to reason about possibility, the logic used in the second case might be designed specifically to reason about subsumption. Thus, different logics would be used for different kinds of reasoning.

The questions of how to use different logics to support different styles of reasoning are being actively investigated within the logic community [2,3,4,5,6]. Recently, similar issues have been taken up by researchers more closely affiliated with the Semantic Web [9,14]. Our position is that the research being done on using multiple logics for different kinds of reasoning should be exploited by the Semantic Web community.

2. Many logics

Model-theoretic semantics allows us to analyze “the validity of inference processes" [9], which in turn paves the way for automated reasoning, widely considered to be *the* major goal of the

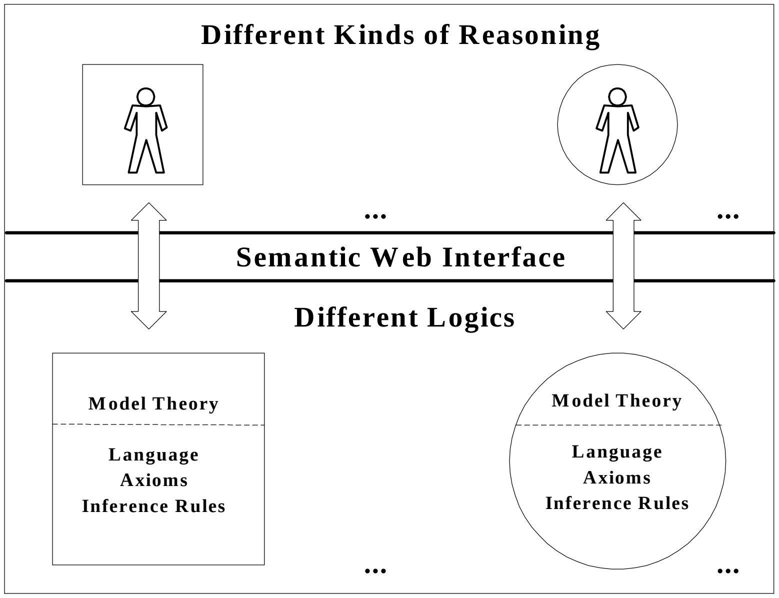

Figure 1 - Different Logics for Different Kinds of Reasoning

Semantic Web. But a model-theoretic foundation for automated reasoning on the Web is only one part of a larger picture (Figure 1). The more interesting parts of this picture come into view once we consider that different kinds of reasoning require different kinds of logical support. Then we can view logic not as a single monolithic foundation for machine-processable semantics, but rather as a collection of different reasoning systems constructed for particular purposes.

3. How Logics Differ

We consider a *logic* to consist of a syntax (or deductive system [8]) and an appropriate semantics (or model theory). We follow the exposition of Epstein [4] to highlight how differences in the language, axioms, or inference rules of a logic support different kinds of reasoning. According to Epstein, "What we pay attention to in reasoning determines which logic is appropriate." He elaborates: "Each logic, other than classical logic, is based on some aspect of propositions in addition to form and truth-value; different aspects give rise to different structural conditions on the semantics, yielding a spectrum of semantics" [4].

For instance, one aspect of reasoning deemed important by the creators of the Ontology Inference Layer (OIL) is the ability to verify that one concept or class subsumes another [12]. This aspect of reasoning is reflected in OIL's language by the use of *concept* as an important primitive [12]. The choice of *concepts* as primitives in OIL's language, along with their role in reasoning about subsumption, demonstrates the connection between the elements of a logic (more specifically, the elements of a logic's language) and the reasoning purposes to which the logic is put.

But reasoning about subsumption is only one of many conceivable purposes for which one might use the Semantic Web. For instance, to reason about what might possibly be the case, it may be useful to employ a modal logic, which adds to the language of classical propositional logic specific modal operators dealing with possibility and necessity, and which also modifies the axioms and inference rules of propositional logic [7,13].

These are just two examples to suggest some of the relevant issues. As people recognize the appropriateness of other kinds of reasoning on the Semantic Web, many issues dealing with multiple semantics will arise and will deserve a more thorough treatment.

4. Conclusion

The Semantic Web will need to employ multiple logics to support a variety a reasoning tasks. The current focus on model-theoretic semantics overlooks the potential benefits of using multiple logics to support multiple kinds reasoning on the Web. The Semantic Web community can benefit by exploiting the research done in the logic community concerning the use of multiple logics for different reasoning tasks.

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