Combining Ontologies in Settings with Multiple Agents

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Abstract. Combining knowledge and beliefs of autonomous peers in distributed settings, is a major challenge. In this talk we consider agents that combine their ontologies and reason jointly with their coupled knowledge using the E-SHIQ representation framework. We motivate the need for a representation framework that allows agents to combine their knowledge in different ways, maintaining the subjectivity of their own knowledge and beliefs, and to reason collaboratively, constructing a tableau that is distributed among them. The talk presents the $E-\mathcal{SHIQ}$ representation framework and the tableau reasoning algorithm. It presents the implications to the modularization of ontologies for efficient reasoning, implications to coordinating agents' subjective beliefs, as well as challenges for reasoning with ontologies in open and dynamic multi-agent systems.

1 Combining Ontologies with $E-\mathcal{SHIQ}$

To combine knowledge and beliefs of autonomous agents in open and inherently distributed settings, we need special formalisms that take into account the complementarity and heterogeneity of knowledge in multiple interconnected contexts. Agents may have different, subjective beliefs concerning "bridging" heterogeneity and coupling their knowledge with the knowledge of others. The subjectivity of beliefs plays an important role in such a setting, as agents may inherently (i.e. due to restrictions of their task environment) have different views of the knowledge possessed by others, or they may not agree on the way they may jointly shape knowledge.

On the other hand, large ontologies need to be dismantled so as to be evolved, engineered and used effectively during reasoning. The process of taking an ontology to possibly interdependent ontology units is called ontology modularization, and specifically, ontology partitioning. Each such unit, or module, provides a specific context for performing ontology maintenance, evolution and reasoning tasks, at scales and complexity that are smaller than that of the initial ontology. Therefore, in open and inherently distributed settings (for performing either ontology maintenance, evolution or reasoning tasks), several such ontology modules may co-exist in connection with each other. Formally, it is required that any axiom that is expressed using terms in the signature of a module and it is entailed by the ontology must be entailed by the module, and vise-versa. The partitioning task requires that the union of all the modules, together with the set of correspondences/relations between modules, is semantically equivalent to the original ontology. This later property imposes hard restrictions to the modularization task: Indeed, to maintain it, a method must do this with respect to the expressiveness of the language used for specifying correspondences/relations between modules' elements, to the local (per ontology module) interpretation of constructs, and to the restrictions imposed by the setting where modules are deployed.

The expressivity of knowledge representation frameworks for combining knowledge in multiple contexts, and the efficiency of distributed reasoning processes, depend on the language(s) used for expressing local knowledge and on the language used for connecting different contexts.

While our main goal is to provide a rich representation framework for combining and reasoning with distinct ontology units in open, heterogeneous and inherently distributed settings, we propose the $E-\mathcal{SHIQ}$ representation framework and a distributed tableau algorithm [1] [2].

The representation framework $E-\mathcal{SHIQ}$:

- Supports subjective concept-to-concept correspondences between concepts in different ontology units.
- In conjunction to subjective concept-to-concept correspondences, $E-\mathcal{SHIQ}$ supports relating individuals in different units via link relations, as well as via subjective individual correspondence relations. While correspondence relations represent equalities between individuals, from the subjective point of view of a specific unit, link relations may relate individuals in different units via domain-specific relations.
- Supports distributed reasoning by combining local reasoning chunks in a peer-to-peer fashion. Each reasoning peer with a specific ontology unit holds a part of a distributed tableau, which corresponds to a distributed model.
- Finally, $E-\mathcal{SHIQ}$ inherently supports subsumption propagation between ontologies, supporting reasoning with concept-to-concept correspondences in conjunction to link relations between ontologies.

2 Constructing $E-\mathcal{SHIQ}$ distributed knowledge bases via modularization

To distribute knowledge among different agents, we need to partition monolithic ontologies to possibly interconnected modules. In this part of the talk we describe efforts towards constructing $E-\mathcal{SHIQ}$ distributed knowledge bases by modularizing ontologies: Our aim is to make ontology units as much self-contained and independent from others as possible, so as to increase the efficiency of the reasoning process. We discuss the flexibility offered by $E-\mathcal{SHIQ}$ itself, and different modularization options available (a first attempt towards this problem has been reported in [3]).

3 Challenges towards reasoning with multiple ontologies

Towards reasoning with ontology units in open and dynamic settings with multiple agents, this talk presents and discusses the following major challenges:

Reaching Agreements to correspondences: Agents in inherently distributed and open settings can not be assumed to share an agreed ontology of their common task environment. To interact effectively, these agents need to establish semantic correspondences between their ontology elements. As already pointed out, the correspondences computed by two agents may differ due to (a) different mapping methods used, to (b) different information one makes available to the other, or (c) restrictions imposed by their task environment. Although semantic coordination methods have already been proposed for the computation of subjective correspondences between agents, we need methods for communities, groups and arbitrarily formed networks of interconnected agents to reach semantic agreements on subjective ontology elements' correspondences [4].

Exploitation of ontology units in open and dynamic settings: In open settings where agents may enter or leave the system at will, we need agents to dynamically combine their knowledge and re-organize themselves, so as to form groups that can serve specific information needs successfully. There are several issues that need to be addressed here: Agents (a) must share information about their potential partners and must learn the capabilities, effectiveness, trustworthiness etc. of their peers, (b) must locate the potential partners, and (c) must decide for the "best" groups to be formed in an ad-hoc manner, towards serving the specific information needs. Reaching complete and optimal solutions in such a setting is a hard problem: we discuss the computation of approximate solutions [5].

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