Knowledge Extraction for Multi-Agent System Communication

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1 AIM AND INTRODUCTION

This research focuses on applying and implementing known knowledge extraction techniques in the area of description logics (DL) to communication in multi-agent systems (MAS) consisting of agents that store their knowledge in ontologies. Such agents need methods to communicate the knowledge stored in their ontologies in a way that can be understood by other agents. An obvious prerequisite for such communication to take place is some sort of common signature between the ontologies of the agents. Establishing a common signature commonly referred to as *ontology alignment* and is not trivial in practice. There is a lot of research and implementation of ontology alignment specialised for agent communication. One approach to constructing alignments is learning mappings through examples. This approach assumes a closed world of the agents and relies on the agents exchanging positive and negative examples of concepts they wish to align. This is the employed process in efforts such as [Afsharchi et al. 2013; Van Diggelen et al. 2007]. Other examples of ontology alignment in the context of agent communication include [Laera et al. 2007; Mascardi et al. 2011; Payne and Tamma 2014].

Ontologies are knowledge bases consisting of logical statements called *axioms*. This comes with the advantage that a set of logical axioms can entail knowledge that is not explicitly stated by the axioms: lots of information can be implicit. As a consequence, when communicating, agents must take into account the implicit knowledge contained in their expertise. Assuming a common signature is established between two communicating agents, the agents still require methods to extract specific knowledge from their ontologies that go beyond sending a list of axioms. Agents require methods to extract both explicit and implicit knowledge from their ontologies in a way that can be communicated to another agent if the need arises.

2 A PROPOSAL

This research aims to investigate, implement, and evaluate *knowledge extraction* methods for agent communication that can build upon a common signature established ontology alignment techniques: we are interested in developing knowledge extraction techniques for agent communication that already *assume the existence of a common signature*. The preliminary observations of the research are as follows: (i) Knowledge extraction is an important component of agent-based systems applied to information/knowledge domains. (ii) Knowledge extraction techniques can be implemented using existing methods and tools such as *uniform interpolation* and *modularity* but practical implementations will need to be developed for agent-based systems. (iii) Knowledge extraction techniques can mitigate some recognised agent communication issues.

There are several existing techniques in the DL literature that can be used to extract knowledge from ontologies that can be adapted for agent communication. Knowledge extraction can be useful in situations where the expertise of the agent is accumulated by the agent itself (as can very much likely be the case in contexts where agents are applied to *ontology learning* [Maedche and Staab 2004]) and is seemingly obscure to external users or agents: knowledge extraction can be used by an expert agent to help foreign entities (such as other agents or humans) navigate its knowledge in small doses. For example agents can leverage knowledge extraction to extract topic-specific subjects of their expertise perhaps in response to queries from other agents or human users. This will add a layer of flexibility to communication for the agents.

Speech acts [Finin et al. 1994; Searle et al. 1980] and corresponding communication protocols encapsulating knowledge extraction are needed to effectively capture knowledge extraction techniques for agent communication. This will broaden the application range of MASs in information and knowledge management domains.

3 EXISTING KNOWLEDGE EXTRACITON TECHNIQUES

We provide an overview of some existing methods that can be used to reshape agents knowledge represented using ontologies.

3.1 Modularity

Given a large ontology, a useful task is for its users to be able to generate *topic-specific* subjects of the ontologies. For example, given an ontology such as SNOMED CT [Donnelly 2006], a medical practitioner may only be interested in knowledge about the respiratory system, i.e., they only need a subject of SNOMED CT that encapsulates all knowledge related to the respiratory system. Such a subject is called a *module*. There are several approaches to computing modules with different properties and varying support [Del Vescovo et al. 2010; Grau et al. 2008; Jiménez-Ruiz et al. 2008; Parsia et al. 2009; Sattler et al. 2009]. Most approaches favour *locality-based modules* because they can be computed efficiently and provide strong logical guarantees [Sattler et al. 2009]. To compute a module, a user provides a subset signature Σ of the ontology's signature that describes their topic of interest, a set of axioms capturing all knowledge entailed by the ontology relative to Σ is then computed as the module.

Communication protocols for agents that adopt modularity would enable agents to leverage modularity to extract and communicate specific portions of their knowledge. In practice, the signature of modules are usually bigger than the input signature provided, and this is a strength in scenarios where the constraints on the input signature is loose and all information relating to the input signature. However, when where there are strict constraints on the input signature, this can be a disadvantage. Consider an agent who desires

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to extract the exact knowledge entailed by an exact signature under it's given ontology. The agent may compute this knowledge by computing a module, but with less precision: axioms of the module may contain symbols that are not in the signature provided by the agent, and as a result, the agent may find it difficult to use the module.

3.2 Uniform Interpolation

Uniform interpolation [Koopmann and Schmidt 2015; Lutz and Wolter 2011] eliminates symbols from an ontology while preserving logical entailments in the remaining symbols of the ontology. Uniform interpolation may be intuitively thought of as summarising the knowledge entailed by an ontology with respect to a given subset signature of the ontology. Given an ontology O and a subset Σ of the signature of O, let $sig()$ be a function that returns the signature from an axiom or set of axioms and let $\mathcal{V}$ denote a uniform interpolant relative to O. For every axiom α such that $O \models \alpha$ and $sig(\alpha) \subseteq \Sigma$, $\mathcal{V} \models \alpha$ and $sig(\mathcal{V}) \subseteq \Sigma$. An intuitive way of thinking about uniform interpolation is that given an ontology O and a subset signature Σ of O a uniform interpolant is an ontology describing how all the symbols Σ are related in O. Unlike modularity, the signature of a uniform interpolant does not exceed the input signature, thus, uniform interpolation can be seen as a more precise knowledge extraction tool. However, uniform interpolation also has its downsides, for example, not all uniform interpolants can be expressed in standardised DLs [Koopmann and Schmidt 2015], additionally, for expressive DLs such as $\mathcal{SHROIQ}(\mathcal{D})$, no uniform interpolation are known.

We are interested in the utility of knowledge extraction tools using uniform interpolation for agent communication where the requirements on communication are strict e.g when the communicated content cannot exceed the common signature between the agents or when there is some sensitive information an agent's ontology that must not be communicated. This will require investigation into how uniform interpolation can be integrated into agent communication including the necessary communication protocols and speech acts.

While knowledge extraction tools like uniform interpolation and modularity have strengths and applications in agent communication, there are other knowledge sharing scenarios in which tools like modularity and uniform interpolation may not suffice. For example, an agent may be interested in describing a concept in its ontology with respect to the common signature shared with another agent, in such situations, neither modularity nor uniform interpolation would suffice. There are other well established logic-based knowledge extraction tools that help accomplish this, covered in the next subsections.

3.3 Weakest Sufficient and Strongest Necessary Conditions

Weakest sufficient conditions (WSCs) and strongest necessary conditions (SNCs) [Doherty et al. 2001; Lin 2001; Wernhard 2014] are fundamental tools used for *knowledge approximation* in logic. Given an ontology, one may be interested in approximating knowledge to a lesser signature of the knowledge base such as with the cases of communicating agents and summarising ontologies described above and can be achieved using WSCs/SNCs. For example, given a logical formula X expressed in some knowledge base or ontology, one may be interested in expressing X is a subset signature Σ that may allow for more efficient reasoning. A sufficient condition of X expressed in Σ is a lower[1] approximation of X and a necessary condition of X expressed in Σ is an upper approximation of X.

Incorporating WSCs/SNCs into agent communication will enable agents to reason about concepts like causality, premises, and consequences for *specific* concepts in their respective ontologies: unlike the approaches mentioned earlier WSCs and SNCs can help agents describe certain concepts in their ontologies w.r.t a specified subset signature such as the common signature between communicating agents. For example, consider a MAS that manages and troubleshoots components of a large and complex system such as a car or space shuttle. Imagine an agent A_{g1} that has expertise on error codes and their relation to components across the entire system and another agent A_{g2} whose expertise is on a sub-section of the system. A_{g2} may be troubleshooting an error code #EC185 and may want to know how #EC185 might be related to specific components represented using a signature Σ in its sub-section, thus needing to communicate with A_{g1}. This knowledge may be implicit in agent A_{g1}'s ontology, however, A_{g1} may leverage WSCs and SNCs to find how #EC185 is related to the components specified by Σ.

3.4 Craig Interpolation and Beth Definability

A logic has the Beth definability property if concepts (predicates) that are implicitly defined can also be explicitly defined within ontologies built using the language of the logic. Simply put, a concept C is implicitly definable with respect to a signature Σ and ontology O if there is some concept D such that the signature of D is a subset of Σ, $O \models C \equiv D$, and $C \equiv D$ is not present as an axiom in O, i.e, it is not obvious from the axioms in O that $C \equiv D$, hence $C \equiv D$ is *implicit*; the definition $C \equiv D$ is said to be an *explicit* definition of C w.r.t Σ under O. Several DLs have been shown to have the Beth Definability property including $\mathcal{ALC}$ and $\mathcal{ALCO}$. For these logics, the relationship between Beth Definability and Craig Interpolation is that if a concept is implicitly definable, an explicit definition can be extracted using Craig Interpolation. Theoretical results of Craig Interpolation for DL have been provided in [Ten Cate et al. 2006, 2013], however practical implementations do not exist.

Our preliminary investigation suggests that WSCs/SNCs can be used as alternatives to Craig Interpolation to compute definitions. It is important investigate and evaluate how agents may compute and exchange definitions. Definition mechanisms will be useful to communicating agents in situations where there are strict requirements on the common signature.

4 CONCLUSION

We have proposed the integration of well-known knowledge extraction techniques into agent communication. This will improve flexibility in communication and broaden the range of applications for to MASs using ontologies such as [Klapiscak and Bordini 2008; Mascardi et al. 2011].

[1] "Upper" or "Lower" w.r.t an ordering of implication, subsumption or logical entailment

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