Evolving Use of Distributed Semantics to Achieve Net-centricity

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Abstract

For the US Department of Defense (DoD)'s efforts to achieve net-centricity, more intelligent ways of handling information must be pursued, in particular using machine-interpretable semantic models, i.e., ontologies. One approach, which we've adopted in current and emerging research projects, is to combine Semantic Web technologies with logic programming, thereby utilizing standards-based ontologies and rules and yet ensuring that the runtime automated reasoning over these is efficient. In this paper, we discuss our current Semantic Environment for Enterprise Reasoning (SEER) architecture, which combines an Enterprise Service Bus (ESB) with our Semantic Web Ontologies and Rules for Interoperability with Efficient Reasoning (SWORIER) system. SWORIER converts OWL ontologies and SWRL rules into logic programming, thereby enabling efficient runtime reasoning using Prolog. We also briefly discuss potential enhancements to such an environment, including the use of constraint logic, meta-reasoning, and hybrid logic.

Introduction

For years, the US Department of Defense (DoD) has wrestled with using the vast amount of data at its disposal to make rapid and effective decisions. Although automated information systems have increased in size and power and exponentially increased the volume of available data, the problem has only increased [5, 15]. A more intelligent way of handling the enormous volume of data is clearly needed. By "intelligent" we mean data that is semantically interpretable by machines allowing for automated reasoning to assist human decision makers. The data will by its nature be distributed, since DoD has thousands of systems and networks all contributing to the info-space, and centralizing everything into a single system is impossible. Furthermore, the nature of DoD operations tends to enforce a need for distributed information systems. Recently the DoD has developed its vision for net-centric operations, wherein data is discovered and shared across a wide variety of users. Elements of this vision include tagged data sources and discovery services that enable data to be automatically discovered and used by machines, creating more intelligent networks. The work of defining the structure of this data falls to so-called Communities of Interest (COIs) [6] who are a collection of representatives from different organizations that have an interest in the creation or use of the data in the community's domain and making it more shareable. As the collective technical proficiency of these COIs increases, the more they will embrace the use of Semantic Web technology (ontologies, logical inferencing) to power much of the intelligence.

MITRE currently has several initiatives demonstrating the effectiveness of using Semantic Web technology to aid the DoD in managing its information and making better decisions. Among these is an effort to express system behavior in ontologies (using OWL) and rules (using SWRL [14]), and translate this into a logic programming environment for efficient automated reasoning to maintain situational awareness and notify human decision makers when certain conditions exist [18, 19, 20, 21]. This kind of approach combining Semantic Web technology with logic programming is now recognized as potentially very effective and has led to a strong research thread loosely characterized as Description Logic Programming [10, 13, 22, 23], though there are variants employing Answer Set Programming [1, 2, 12], which we hope to investigate immediately. Furthermore, our current approach uses an Enterprise Service Bus (ESB) to transport data between applications, which allows for a wide variety of data to be flexibly and easily accessed (we observe that in general, ESBs can be considered modern incarnations of blackboard systems in AI [7]). This makes it necessary for semantic models to be created in order to combine the data, but the efforts are worth the cost, as this approach will prove superior to older network based paradigms in terms of increased flexibility, better data sharing and re-use, faster information assimilation, and ultimately better decisions.

Net-centricity

The DoD defines Net-centricity as "an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision-makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization. In essence, (Net-centricity) translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace." [16] It entails making information available to users not previously anticipated when the system that produces that information was first designed. Achieving Net-centricity requires standards and formats for describing data – the five recommended products being a glossary, a conceptual model, a semantic model, business rules, and a list of authoritative data sources [6]. COIs have the responsibility to produce these. Although not specifically required to create ontologies to represent their data, COIs are increasingly creating more of these in order to promote better semantic interoperability. As more ontologies are created more machine-to-machine interaction becomes possible. One drawback to this, however, is that as the number of ontologies increases, it raises the need for having more and better ontology mapping or semantic brokering. We characterize this paradigm as requiring "distributed semantics", where the semantics of disparate parts of the enterprise are modeled as ontologies with rules, distinct ontologies need to be mapped, and multiple reasoning engines need to interact.

SEER and SWORIER

We have developed a system called SWORIER (Semantic Web Ontologies and Rules for Interoperability with Efficient Reasoning) [18, 19, 20] which converts ontological and instance information, along with SWRL expressed rules, into Prolog to enable efficient automated reasoning over them. The ontologies, their knowledge bases (KB), and rules are translated into Prolog clauses via XSLT (Extensible Stylesheet Language Transformations). Once created, the Prolog KB can then be accessed via an ESB and have data from several sources routed into it in the form of logical assertions, and its output can be transformed into whatever format is needed for additional processing or display, such as KML for Google Earth™, email, or chat. The entire architecture that includes SWORIER we call SEER (Semantic Environment for Enterprise Reasoning). Figure 1 shows the SEER architecture that includes the ESB, the SWORIER KB (using Amzi™ Prolog), and various sources.

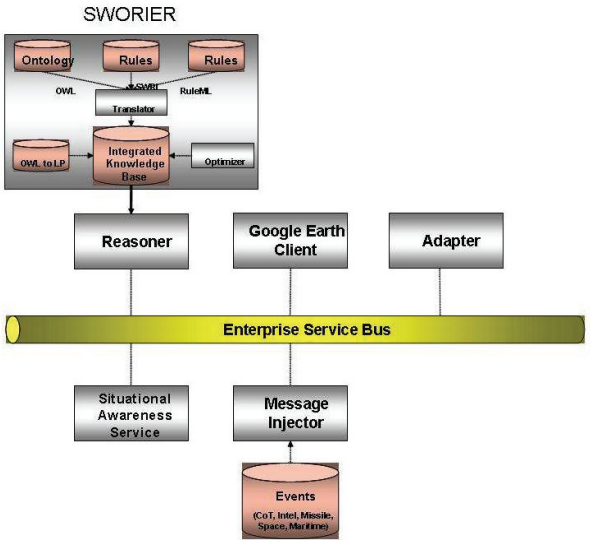

Figure 1. SEER Architecture with SWORIER

Our initial research focused on a military command and control domain with a supply convoy moving through an unsecured area. We developed five ontologies (modularizing the main classes in distinct ontologies) in OWL, with accompanying rules in the Semantic Web Rule Language (SWRL).

- *TheaterObject: to describe objects in the battlefield and reports about them.*
- *RegionOfInterest: to describe regions of interest on the battlefield.*
- *Convoy: to describe the convoy, its mission, components.*
- *Convoy Route: to describe routes the convoy might take.*
- *ConditionsAndAlert: to model how the KB builds, resulting in conditions and alerts that affect the convoy.*

TheaterObject is the class of entities that represent objects in theater. Some types of TheaterObjects include MilitaryUnit, Sniper, RoadObstacle, Facility. TheaterObjects have a location, and may have a speed, heading, and combatIntent, among other features. The property combatIntent is used to represent whether an object in theater is friendly, hostile or unknown.

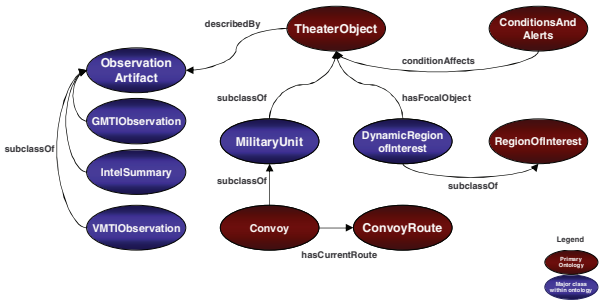

Figure 2. High level Ontology Design

The ontologies are displayed schematically in Figure 2.

Figure 3 shows a sample output display on Google Earth™ of a convoy moving through hostile territory. The reasoner is able to infer that the convoy needs to change its route based on its location, its destination, and the presence of a sniper along its path. An ontology describes the types of things that are present in the convoy scenario and their semantics. Rules capture the behavior of the system in the presence of certain information, so for example, a rule might state that "If a convoy's region of interest (ROI – the circle around the convoy's icon) intersects with a sniper's ROI then recommend that the convoy find an alternate route."

Figure 3. Sample Graphical Output

We subsequently extended the scenario to encompass distinct rules of engagement (policies). We selected a weather event, a sandstorm, as the dynamic event that would trigger the swapping of rules sets. We identified a small set of behavior differences between rule sets; namely, different calculations of sizes of the Region of Interest around each Theater Object and different treatment and therefore different alerts of unknown movers. These were realistic differences in varying visibility situations. We then showed that, upon a sandstorm event, rule sets are swapped, effectively modifying behavior in real-time.

To accomplish this, we had to select an approach. There are many potential architectural options, which we cannot list here. We chose to build two independent rule sets, one to handle favorable visibility on the battlefield and one to handle poor visibility on the battlefield. By instantiating a different logic server for each rule set, each KB (ontologies, instances, rules) is ready to be swapped at any time, allowing us to change behavior instantly, whenever a real-time event is detected. The knowledge base available to both logic servers remains constant and synchronized as dynamic new instances are added; only the rules are distinct.

The Way Ahead

Several areas of improvement still lie ahead. Right now the ESB is a fairly "dumb" mechanism for moving data from one application to the next. As more semantic models come on line there is going to be an increased need for translating between them. Therefore, ESBs will need to evolve into having more of a "semantic broker" or mediator (mapping) role in order to let applications share data that originates from multiple models. An alternative is that a dedicated semantic broker (or a set of such) be attached to the ESB.

Also, the types of reasoning needed to support realistic operational needs is going to be varied and likely will surpass the capabilities of any single reasoner or reasoning system. In addition to traditional deductive logic, operational tasks may require constraint logic [8], modal and/or hybrid reasoning [11], including that supporting labelled deduction (LD) [9]. LD supports reasoning over symbolic annotations attached to ontological assertions. These annotations can represent provenance, belief, and security information, as displayed in Figure 4, in which the antecedent assertions of the Modus Ponens structure are annotated with α and β, respectively, yielding a function application β(α) annotated to the consequence [17].

$$\frac{\begin{array}{l}\alpha : P \\ \beta : P \rightarrow Q\end{array}}{\beta(\alpha) : Q}$$

Figure 4. Labelled Deductive System: Modus Ponens

Finally, probabilistic reasoning, fuzzy logic, or Bayesian belief networks that address uncertainty, and others may be necessary. It is quite likely that some type of "meta-reasoning" layer will be needed to adjudicate these tasks and pass them along to the appropriate reasoner (this could be combined with the Semantic Broker), yielding an architecture as in Figure 5. Some combinatorial or fusion reasoning will then be needed to synthesize the results. Ongoing research is needed to develop the theory and practice of how to best combine all of these.

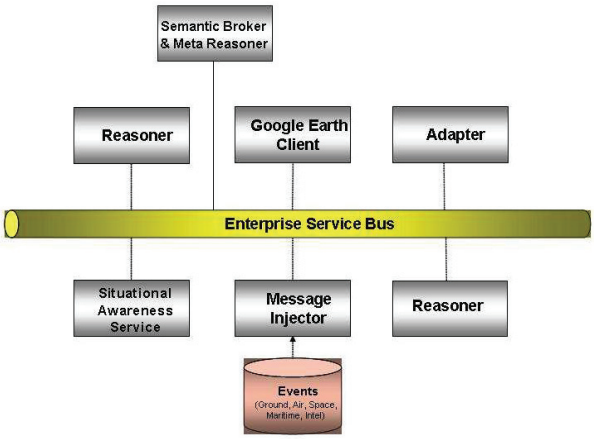

Figure 5. Architecture with Meta Reasoner

Acknowledgments

The views expressed in this paper are those of the authors alone and do not reflect the official policy or position of The MITRE Corporation.

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