Using Ontologies to Build Web Service-based Architecture for Airspace Systems

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In this paper, we present an architecture for operating unnamed aerial vehicles (UAVs) that leverages a group of Military Information Ontologies (MilInfo) to semantically specify and compose information services. The ontologies were developed in the Web Ontology Language (OWL), a W3C standard, and edited in Protégé/OWL, an open source tool that is a de facto standard for OWL ontology creation. Since the UAV domain is concerned chiefly with information gathering tasks, the ontologies cover a wide range of content including definitions of information in general (and military information in particular), organizations, and communications. The ontologies are intended to support specification and querying of several aspects of military information, including content, significance, source, quality, analysis and constraints.

Introduction

As the ability to generate and store large quantities of information expands dramatically, the need to publish, subscribe and evaluate this data is also expanding. Today's military has transformed itself to an information based fighting force and the need for semantically rich data has become readily apparent.

The Military Information Ontologies (MilInfo) discussed in this article are intended to be used by system architects working in the U.S. Department of Defense Architecture Framework (DoDAF) to provide a logically consistent domain model to be used as a foundation for multiple, related enterprise architectures. The domain model serves as both a repository of re-usable components and the conceptual foundation that promotes coherence and interoperability among the architecture models.

The ontology itself was developed in the Web Ontology Language (OWL), a W3C standard, and edited in Protégé/OWL, an open source tool that is a de facto standard for ontology creation. The use of OWL as a knowledge representation language is intended to bring added expressiveness compared to, e.g., representations in UML or RDF. Translations to UML and other languages are provided whenever necessary using Protégé mechanisms and XSLT translations.

The MilInfo ontologies are intended to support specification and querying of the following aspects of military information: Content (e.g., to what topic does the information pertain?); Significance (e.g., who needs/ uses the information?); Composition (e.g., of what "parts" is the information composed?); Source (what agency or system is the source of the information?); Quality (e.g., how accurate is the information?); Analysis (e.g., is the information inspectable?) and Constraints (e.g., which agents are permitted to have access to the information).

In addition, a complementary Information Services ontology has been (is being) developed to describe Services, related to information, that a notional UAV might provide to an *ad hoc* "Community of Interest" to support dynamic "self-synchronization."

Future air systems must be adaptable in flight, able to participate in a dynamic assembly of component systems, and responsive to a wide range of command structures driven by "effects-based" planning objectives that are continually evaluated and refined in "mission time". Above all, it demands that they be interoperable with all other systems in the network.

Interoperablity, in Network Centric Operations, is much more than an ability to communicate and exchange data with other systems. It implies a systemic ability to identify, request, provide and apply information and services to and from other agencies in the network. A service can be anything from simple data processing to particular combat actions. Thus, services provide the "operational" aspect of Network Centric Operations. This kind of interoperability implies considerable machine-to-machine communication as well as machine-to-human communication and a degree of machine "intelligence" to realize the full potential of Network Centric Operations.

Self synchronization of military forces in a complex, highly dynamic combat environment will ultimately depend on a combination of highly trained persons and competent, automated systems that provide those humans with good, timely, and more importantly, adaptable, support in a wide range of potential situations. In general, that kind of support implies a considerable degree of automated machine-machine interaction that requires very little human input and that is sensitive to the context of the situation. We are developing prototype technologies that provide that type of support in a realistic combat a simulation environment that will allow engineers and analysts to explore, analyze and validate a wide range of Network Centric Operations concepts and requirements for systems to support those concepts.

A set of representative Unmanned Air Vehicles are implemented as "Peer Objects" in a peer-to-peer simulation framework. Each of the objects contains a model of the Services it provides, , represented in OWL-S and developed in the Protégé OWl-S plugin. A Service may be an information service or a combat service, such as “ReconnoiterFixedTarget”, “FindMobileTarget”, AttackMobilTarget, “MonitorAirSpace”, etc. The Service Model includes dynamic constraints (e.g. sensor modes, fuel-state, time-on-station, mission-priority, etc.) as well as a set of high-level tactics and maneuvers that may be employed by that particular Object.

Uses for Military Information Ontologies

The Military Information Ontology attempts to create such a model and to formalize certain core concepts related to information in the domain of military operations and specify them to the degree that they may be made “machine readable” by knowledge based systems. In particular it focused on the domain of unmanned air vehicles (UAV) and intended to support three related activities in that domain.

We believe that such architecture models can and should be based on domain models derived from a complementary collection of related ontologies. To facilitate use in standard CASE tools, domain ontologies, modeled in the OWL DL language, can be translated to the XML model interchange language, XMI using XSLT transforms. The XMI files can then be imported in any UML CASE tool to create UML class diagrams of the domain model. The UML class diagram then forms the basis for constructing specific UAV architectures.

Basing UAV architectures on formal domain ontologies serves several important purposes. In the first place the description logic formalism supports a rich, comprehensive representation of key aspects of the domain and lends precision to a computationally decidable architecture model. [3]

Secondly, a range of rigorous ontology development methodologies, such as OntoClean, [4] and classifiers, such as Racer [5] and other tools are available to verify and complete domain ontologies. The application of these tools and methods results in a logically sound model that provides a layer of quality assurance at the foundation of the architecture and improves confidence in the final product.

Finally the potential for the application of Model Drive Architecture (MDA) and similar techniques to software system development is attractive. For example the creation of a top level Computation Independent Models (CIM), from the domain models is straightforward. This CIM can seed the extension – perhaps translation - of the architecture to the full scale design and development of UAV software systems using the Model Driven Architecture, or some similar approach. Significant benefits in development efficiency, life-cyle maintenance and system interoperability, from such an engineering approach, appear to be possible. [6]

A second intended use is in the application of a number of emerging semantic web, knowledge-based tools to what will be (when other, related ontologies have been developed) a knowledge-based architecture. The potential for using intelligent design and program management tools, and a wide variety of automated machine-to-machine interaction across distributed development teams is likely to improve and extend the value and lifetime of the architecture itself. It might, for example, allow a “stakeholder” at some not-to-distant time to “ask” the architecture a question such as “What is the schedule risk of adopting this new technology?” and to receive a relatively succinct and meaningful reply to the question. Likewise, it could allow an aeronautical engineer to “ask” the architecture questions like “What is affected if we change the shape of the fuselage?” and to expect a reasonable and reliable answer that includes the effects on propulsion, avionics and all related disciplines.

A third intended use of the model is seen in the actual development of knowledge bases for UAV knowledge-based systems that acquire, analyze, appreciate, disseminate and otherwise use military information. UAVs are expected to quickly evolve into intelligent robotic systems that will automatically communicate and inter-operate with other manned and unmanned intelligent systems to accomplish their assigned tasks. A common set of domain ontologies, shared by many of these same systems should greatly improve the level and quality of interaction. So, objects that are of the “Target” class in the architecture are, perhaps with further specification, also objects of type “Target” in the actual UAV knowledge base Then class of weapons and behaviors that are employed against them in the architecture model are, probably with additional refinement, found as weapon and behavior types in the UAV knowledge base.

What is Information?

Information has long been recognized as a valuable supporting aspect of military operations. It has long been viewed as important to the physical objects and the effective application of physical force in military contests. However, the last decade has seen a qualitative change in the way the military views information. Information itself has become a central focus of military operations. Information is now understood to be both an object of the military contest and a means of achieving one’s goals in that contest. Indeed, this privileged position is recognized in terms such as “Information Warfare” [1] and “Information Superiority” [1]. All the U.S. Armed Services have recently developed doctrine and specialized organizations to conduct Information Operations, and this trend appears to be mirrored in the Armed Forces most nations around the world.

Yet, despite the increased emphasis on military information, there is little discussion of exactly what constitutes “information”. Unfortunately, the notion of information is widely applied in the world at large, and that broad application introduces vagueness and ambiguity and that potentially confuses discourse and, in particular, complicates the development of automated systems that operate on particular types of information.

Borrowing from the OpenCyc Ontology

In creating an ontology of something as fundamental as Information, an important concern is to avoid reinventing the wheel. A common strategy in accomplishing that goal is to use a *top-level ontology.* Existing top-level ontologies include OpenCyc [1], SUMO, and Omega. We studied a number of these top-level ontologies that contain the concept of information or something similar. Our goal as not to import the whole top-level ontology but rather to understand the different perspectives on that concept. Of the available top-level ontologies, the one that proved to contain the most relevant conceptual distinctions is the OpenCyc ontology.

The most important conceptual distinction we adopted from OpenCyc is that between AbstractInformation as content and information and an InformationBearingObject (e.g. a document). An InformationBearingObject contains information but is not per se information. This is critical to enable, for example, a distinction between a Database-AbstractContent (an abstract repository of information) and a Database-Physical ("a collection of information bearing objects […] that store many pieces of information, organized for easy scanning and access) [2].

Another group of classes we used from OpenCyc is related to events that create or manipulate information. These events are critical in representing knowledge about the quality and origin of information, which is intrinsically dependent of such events. Types of events related to Information are information creation, access, modification and transfer events. For example, an author is someone who participated in an IBOCreation event. The same AbstractInformation may originate from two different authors, and authorship may be established by several events (e.g. the original creation and subsequent modification events).

An important set of lessons learned gives respect to the use of OpenCyc. We have found in this effort that it is very important to make the right distinctions upfront, and keep a certain rigor and care with key definitions to avoid potential problems in the form of unintended inferences and ontological relationships. On the positive side, the OpenCyc ontology contained several key conceptualizations we needed. This increased the quality of the Military Information ontology and sped up the development process. At the same time, we had trouble importing only the distinctions, as classes in the OpenCyc ontology are highly interrelated.

References

[1] U.S. DoD Joint Publication 1-02 "Department of Defense Dictionary of Military and Associated Terms", http://www.dtic.mil/doctrine, April 12, 2001, (As amended through 9 June 2004)

[2] OpenCyc Documentation, available at http://www.opencyc.org

[3] OWL Web Ontology Language Guide, availabile at http://www.w3.org/TR/2004/REC-owl-guide-20040210/#Owl-Varieties

[4] "Evaluating Ontological Decisions with OntoClean", Communications of the ACM, Febrary 2003, vol 45, No. 2, p. 61, Guarino, Nicola and Welty, Christopher

[5] Racer System Description, available at http://www.sts.tu-harburg.de/~r.f.moeller/racer/

[6] MDA Executive Overview available at http://www.omg.org/mda/executive_overview.htm