

Using a Military Information Ontology to Build Semantic Architecture Models for Airspace Systems¹

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Abstract—In this paper, we present a Military Information Ontology (MilInfo) that has been developed to be used as a foundation for semantic architecture models for airspace systems. The military ontology is intended to be used by system architects working in the DoDAF framework, possibly using case tools. 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 MilInfo ontology is intended to support specification and querying of several aspects of military information, including content, significance, source, quality, analysis and constraints. To avoid reinventing the wheel, concepts from existing ontologies were adopted, notably the OpenCyc ontology.

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1. INTRODUCTION

In this paper, the authors present a Military Information Ontology that has been developed to be used as a foundation for semantic architecture models for airspace systems. Specifically, we will use it to power applications to improve the development of system architectures and plans for unmanned aircraft systems, such as semantic consistency checking. 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 ontology is intended to be used by system architects working in the U.S. Department of Defense Architecture Framework (DoDAF), possibly using case

tools. These users may develop a number of complementary ontologies 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 Military Information Ontology is viewed as a core component with wide application to many such architectures

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

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are provided whenever necessary using Protégé mechanisms and XSLT translations.

The MilInfo ontology is 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?)
- Constraints (e.g., which agents are permitted to have access to the information).

In order to avoid reinventing the wheel, we studied a number of top-level ontologies that contain the concept of information, and adopted several concepts from the OpenCyc ontology [5], for example the distinction between an “information bearing object” (e.g. a book or report) and the abstract information it contains. This allows us to state, for instance, that several physical copies of a book contain the same abstract information, or that different reports contain the same abstract information.

2. DEFINING MILITARY 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. In the modern era, since Napoleon, that importance has increased. Specialized intelligence and reconnaissance services were established to gather information about enemies. Headquarters staff organizations evolved and expanded to gather information about the status and disposition of friendly forces. Signal Corps and other communications services emerged to move information to and from military organizations. And, in all these areas, specialized technology was developed to aid in the processing of an increasing flood of military information.

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, information seems to be at the heart of all military activities; it pervades the military doctrinal landscape and provides a dominant theme for success in everything from training and logistics to combat operations.

This primacy is recognized in terms such as “Information Warfare” [1] and “Information Superiority” [1]. The United States Joint Chiefs of Staff, for example, list “Information Operations”, defined as “actions taken to affect adversary information and information systems while defending one’s own information and information systems,” as one of thirteen basic military operations for U.S. forces [2]. Moreover, 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.

In the development of modern military theory, information occupies center stage. It is, for example, essential to the basic doctrine of Network-Centric War, which dominates current American military thinking. According to the Secretary of Defense, Office of Force Transformation, implementing Network Centric Warfare “as the theory of war for the information age and the organizing principle for national military planning and joint concepts, capabilities, and systems” is one of its top five goals.[3]

David Alberts, lead author of Network [4], defines the concept 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, [Network-Centric Warfare] translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace.” [4]

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.

The official military definition, for example, illustrates a fundamental ambiguity in the conventional understanding of the term. Joint Publication 1-02 defines information as:

“1. Facts, data, or instructions in any medium or form. 2. The meaning that a human assigns to data by means of the known conventions used in their representation.” [1]

From this kind of definition, it is not clear whether the object of a particular information operation is, or ought to

be, an abstract idea or a concrete document that contains a representation of an idea. Furthermore, there is very little description of the things that comprise information and how they are related. Nor is there much to indicate how information might be evaluated or used. Moreover, if there is no common model that illuminates and specifies these notions, it will be difficult to discuss them, complicated to communicate them, and exceedingly difficult to create information systems that interoperate.

3. A MILITARY INFORMATION ONTOLOGY

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.

One intended use of the ontology is in the description of UAV Enterprise Architectures. An Enterprise Architecture is defined as an architecture of one or more systems situated in a domain of operation. The form of the supported Enterprise Architecture description is indicated in the Department of Defense Architecture Framework (DoDAF). This is an emerging DoD standard that is a required design artifact for all new systems that are to be acquired by the U.S. Department of Defense.

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. [6]

Secondly, a range of rigorous ontology development methodologies, such as OntoClean, [7] and classifiers, such as Racer [8], FaCT, [9] 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-cycle maintenance and system interoperability, from such an engineering approach, appear to be possible. [10]

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.

4. BORROWING THE WHEEL: USING 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 OpenCyc², SUMO, Omega and SENSUS.

² <http://www.opencyc.org>

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. Below we discuss some of the key concepts we borrowed from OpenCyc, and the consequences they have for the MillInfo ontology

Abstract Information versus Information Bearing Object

OpenCyc proposes a fundamental difference between AbstractInformation as content and information as an InformationBearingObject (e.g. a document). An InformationBearingObject contains information but is not per se information.

For example, a Database-AbstractContent is “abstract repositories of information rather than as physical storage devices. A database generally has some means of accessing data from structured records, frames or relational structures, using some query language.” While a Database-Physical is “a collection of information bearing objects (IBOs); a subset of StructuredInformationSource. Each element of Database-Physical is an IBO that stores many pieces of information, organized for easy scanning and access. Typically, a data base involves one or more formatted data record schemes, together with some device for searching and retrieving data. Note that, as an IBO, a Database-Physical is some particular, tangible copy of a database. To refer to the abstract 'content' of a database, use Database-AbstractContent.” [5]

AbstractInformation is (at its most elemental) propositions. The encoding of AbstractInformation depends on a context (of use). Think of expressing the same idea two different ways depending on who is your audience.

An InformationBearingObject contains information encoded into a format. English is a format, so is XML. Formats (languages) can be natural or artificial. A type of InformationBearingObject is a dataset, another is a document.

In general, most properties of information are really properties of the AbstractInformation. For example, the scope (spatial, temporal, topical, and situational) of the information does not depend on its specific manifestation – if you copy a document, the scope of its information does not change.

We therefore decided to continue this distinction and create a concept called MilitaryInformation which is a type of AbstractInformation, and a concept MilitaryInformationbearingObject which is a specialization of InformationBearingObject. The reason to call the specialization of AbstractInformation MilitaryInformation (instead of MilitaryAbstractInformation) is that we found out most relevant types of military information we discussed really refer to the AbstractInformation, not the InformationBearingObject.

For example, how should we define military plans, orders, requests, reports and pictures? Military plans, orders, and requests are clearly abstract information (they can be realized into many different InformationBearingObjects, e.g. electronic and printed versions). These are the majority of types we needed to define so far. Military pictures are one exception, in that we frequently want to talk about the physical realization (e.g. the picture file acquired by a UAV) more than the abstract picture it contains (although that is meaningful as well). Reports (and manuals, etc.) have a dual character: sometimes we mean the physical printed copy distributed (an IBO), sometimes the report content (AbstractInformation).

Figure 1 shows a screenshot of Protégé with the Military Information Ontology loaded. The class tree on the left side shows some types of Military Information and highlights MilitaryPlan. Notice that MilitaryPlan appears twice, as a subtype of MilitaryInformation and as a subtype of Plan (which in turn is a type of AbstractInformation). This shows how Protégé (and indeed the OWL representation behind it) are able to represent multiple inheritance between classes, and how important that is in the Military Information Ontology

Information Manipulation Events

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

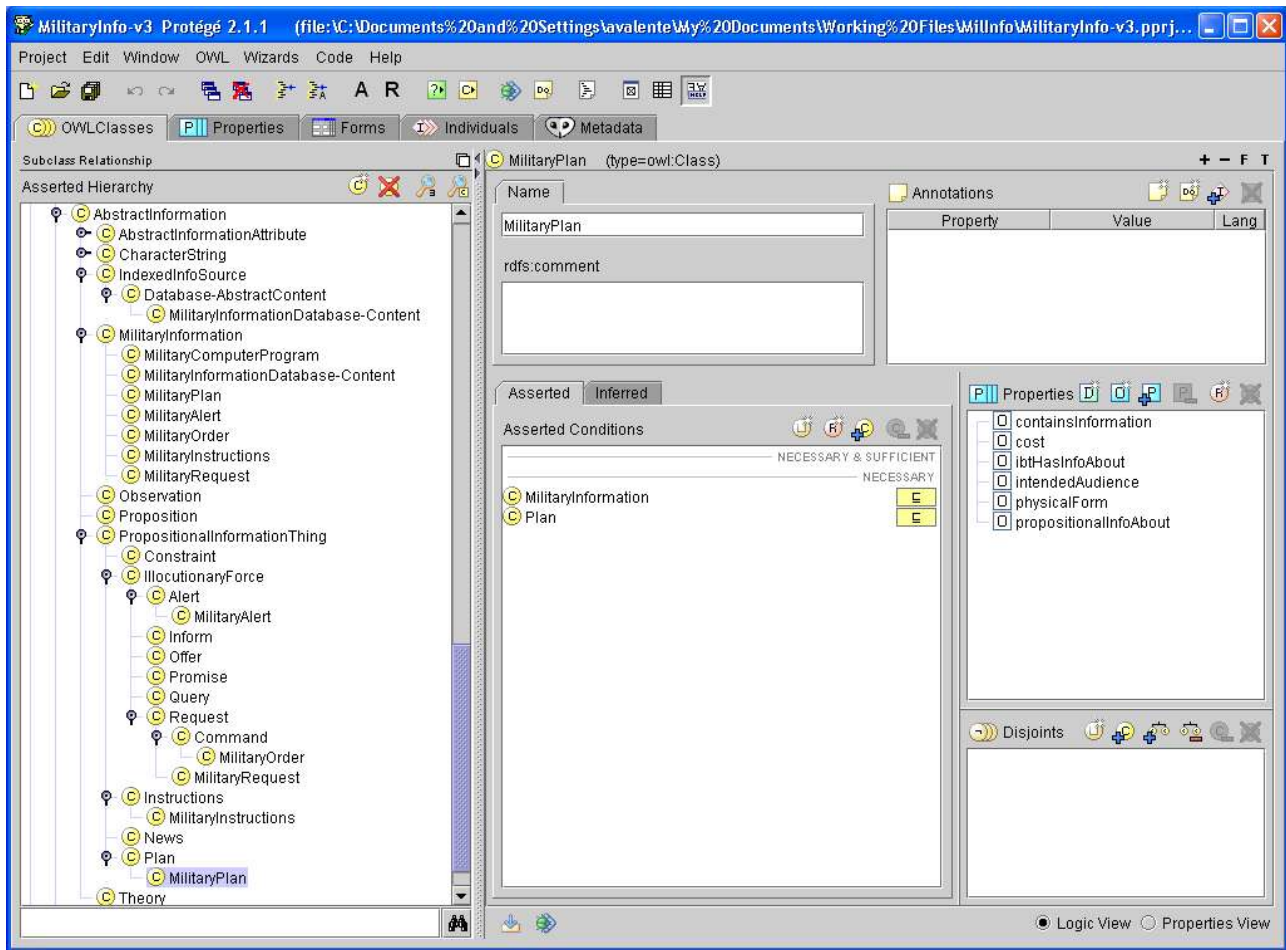


Figure 1: Screenshot of Protégé showing part of the Military Information Ontology.

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).

There are different types of InformationTransferEvents. Information can be moved from a source to a destination through a medium. There is a difference between a move that reconstructs an InformationBearingObject at the destination (e.g. transfer a file) and a move that changes the format. You can also have both at the same time – e.g. translate between two languages and save the results into a new file.

5. REQUIREMENTS FOR MILINFO

The requirements for any ontology can be defined in three dimensions. First, requirements can be defined in terms of the "sentences" it needs to support. Since an ontology is at the very least a vocabulary, one way to define its scope is to specify the sentences one intends to build using it, that is, what ideas must it to allow a user to say or express.

Second, requirements can be defined in terms of a number of questions or queries it needs to be able to express and

answer. Here, an ontology is viewed as a basis for representing information that will be queried, and therefore this specifies what questions it needs to understand and answer.

Third, requirements can be defined in terms of the tasks the ontology is intended to automate or support. Here we use the perspective of an ontology as an artifact that is used to perform tasks. Requirements thus specify what tasks it is supposed to perform (or help perform), and by whom. For example, ontologies can be used for translation, automated reasoning, visualization, constraint checking, etc.

Below, we will detail the requirements for MilInfo in the questions dimension.

Question Requirements

Below are example questions that we used as requirements for each of the question areas.

Questions about Content

- (1) What type [category] of information is it?
- (2) To what [topic, object] does the information pertain?

- (3) What knowledge does it contain? What type of abstract information are we dealing [opinions, hypothesis, observations]?
- (4) What is the level of detail [granularity] in the information?
- (5) What is the scope [spatial, temporal, topical, and situational] of the information? (In practice, this means the granularity of the “aboutness”, the object the information is about.)

Questions about Significance/Function

- (1) How important is the information with respect to the goal or agent it is tied to?
- (2) Who needs/ uses the information?
- (3) What action [process, decision] does it imply?
- (4) What are the [measurable] effects of not having the information [at the threshold quality level]?
- (5) How does it affect [support, motivate, initiate, constrain] the implied action?
- (6) Is the information “operational” [i.e. can it be readily adapted to purpose]?
- (7) Is the information available to all [essential] users/clients?

Questions about Source

- (1) What agency has provided/produced the information?
- (2) What system is the source of the information?
- (3) What is the relation of the source to the subject [focus] of the information?
- (4) How many sources contributed to the compilation of the information?

Questions about Quality

- (1) How reliable [trustworthy] is the information? How reliable must it be?
- (2) How accurate is the information? How accurate must it be?
- (3) How current is the information? How current must it be?
- (4) How timely is the information? How timely must it be?
- (5) How complete is the information? How complete must it be?
- (6) How secure is the information? How secure must it be?

- (7) What is the value of the information

Questions about Analysis

- (1) Is the information inspectable?
- (2) How is the value of the information measured?
- (3) Is the quality of the information verifiable?
- (4) Is the effect of the information traceable?
- (5) Can the quality of the information be improved?
- (6) Can the value of the information be increased?
- (7) How is the information known to be trustworthy? = Is it verifiable?

Questions about Constraints and Assumptions

- (1) Which agents are permitted to have access to information of a particular type? (Relevant for information security).
- (2) What authority must be associated with command information to make it effective [for an agent of a particular type]?
- (3) By what means is the information propagated?

6. USES FOR THE MILINFO ONTOLOGY

The military is making the transformation into the information age of warfare. This is one of the greatest revolutions in military affairs since Napoleonic times according to some. It is a direct result of the combination of Moore’s Law and Metcalf’s Law. This phenomenon is captured in the book series by Dave Alberts, et. al. capturing the power of network-centric warfare culminating in the book “Power to the Edge”. In the series, the authors examine the performance differences between netted and non-netted system to adapt, to project power and to be able to deal with asymmetric warfare such as the Global War on Terrorism [3].

The drive for more information and the ability to produce great quantities of information naturally lead one to the path of organization of data, rapid processing of information and publishing information down directly to the warfighter. As the ability of the military to generate information expands rapidly, the same forces that have driving the internet to examine ontologies as a way of providing richness in the data for ease of retrieval. As an example, the developer of a new UAV that collects information on possible terrorists can have many sensors on board, all producing data but not necessarily information. By using ontologies (military ontology for example) and tagging the data with other information (like where, when, what mission, why the data was generated and cross correlating the data, a natural

richness will be provided to the people with the right access and need to know..

To ensure interoperability, the military requires a disciplined enterprise architecture approach for its systems. This approach to a military ontology follows the DoD Architecture Framework Ver.1 UML approach to a military UAV system of systems, so that the system engineers and designers will have more visibility into the top level uses of the vehicle in the network centric environment. They will then be able to design a more rich information system by the use of a disciplined approach to the military ontology.

7. CONCLUSIONS

In this paper, we discussed the motivation, use, requirements and contents of a Military Information Ontology.

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.

The Military Information Ontology is being developed with several other “sister” ontologies, for example one for Military Communications and another for Military Organizations. The initial development is kept separate at this point, and we envision an integration process to occur in the near future.

We are just starting to apply the ontology and look forward to reporting these results in a future article.

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BIOGRAPHY

Andre Valente, Ph.D. is the founder and CEO of Knowledge Systems Ventures. He is also a research scientist at the Information Sciences Institute at the University of Southern California. He has seventeen years of experience and expertise in knowledge- systems and knowledge management. He has researched, designed and built knowledge systems and architectures for several companies in the Internet Media, Manufacturing, Aerospace and Defense industries. Dr. Valente received a Ph.D. degree in Computer Science from the University of Amsterdam and an M.B.A. degree from the University of Southern California. He has published three books and more than 60 articles on knowledge management and knowledge engineering.

Douglas Holmes is co-founder and Senior Partner of Java Professionals. In the past nineteen years, he has lead and participated in numerous knowledge-based programs for DARPA and other research agencies, as well as commercial applications in the petroleum and other sectors. He is currently developing architecture models in the military unmanned systems domain. He also has over twenty years experience as an Air Force Fighter Pilot and Fighter Weapons School Instructor. Mr. Holmes has a B.S. In Mathematics and Basic Sciences from the U.S. Air Force Academy and a M.S. in Management Information Systems from Golden Gate University.

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