Information Engineering in Support of Multilateral Joint Operational Interoperability

Éric Dorion, M. Sc.
Anne-Claire Boury-Brisset, Ph. D.
System of Systems Section,
Defence R&D Canada – Valcartier
2459, Pie XI North,
Val-Bélair, Québec, Canada, G3J 1X5
Tél: 418-844-4000 (4257)
Fax: 418-844-4538
Eric.Dorion@drdc-rddc.gc.ca
Anne-Claire.Boury-Brisset@drdc-rddc.gc.ca

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Abstract

In the information age era, there never has been a better time to reflect upon the fact that information in itself is something that has to be engineered. Since command and control is a cognitive process by which the commander gains situation awareness and proceeds to deliberated and co-ordinated action, one has to ask himself how raw data turns into actual information, and eventually knowledge that will trigger human understanding. Furthermore, the question arises as to how C4ISR system of systems can support this transformation process. Of course, this is no magic. Information systems do the only thing they are good at: Working on large amounts of data at incredible speed. This is where the human fails. However, data must be aggregated in such a way that it results in information that conveys *operational meaning* to the commander. This is where information technologies alone fail, miserably. The resulting information must capture the semantics of the commander's domain of interest, and this must exist prior the automated data transformation process.

The exercise of capturing the semantics of a certain business domain (the nouns, verbs, adjectives, etc.) along with its usage guidance (business rules) can be referred to as *information engineering* or *ontology engineering*. Conducting information engineering activities comes in support of the definition of *ontologies*. By definition, an ontology is an explicit formal specification of how to represent the objects, concepts and other entities that are assumed to exist in some area of interest and the relationships that hold among them.

Broadly speaking, interoperability can be achieved for systems that sit on top of a single common ontology, or for systems that sit on top of distinct ontologies provided with a means of translation between the crossing domains. An example of the first approach is the *Multilateral Interoperability Programme* (MIP) that provides a common ontology-oriented solution consisting of the *Command and Control Information Exchange Data Model* (C2IEDM), supporting land-focused joint military operations. In the next 2-year phase, its focus will expand to full-blown joint military operations. As for the latter, Defence R&D Canada – Valcartier is currently working on an interoperability solution between the Canadian Land Forces Command System

(LFCS) and the United States Global Command and Control System (GCCS). Both systems are built upon distinct ontologies and rely on a proper translation mechanism to achieve operational interoperability. This paper describes the information engineering process (ontological engineering) that must take place in order to successfully achieve both interoperability solutions.

Introduction

The current conduct of military affairs prescribes the formation of coalitions to achieve missions. The geopolitical context of today and the globalisation of communications, notably, force us to think of the world as a global village. The well-known "butterfly effect" example borrowed from the chaos theory is ever more important as the butterfly flap is so much more effectively propagated throughout the world than it was years ago. Because of that, military organisations do no longer operate in isolation. They must operate in coalitions, politically-wise and operationally-wise. Also, since information operations are a cornerstone for the effective realisation of military operations, reliance upon information systems to gather, organise, provide decision aids and disseminate information is increasing. Therefore, increased collaboration between national systems to support coalition operations is necessary. We refer to this kind of collaboration as *systems interoperability*. This collaboration scheme, to be comprehensive, must be subdivided into several levels, one of which is the establishment of a common basis for the semantic concepts that will be shared between the systems. This paper relates the authors' experience in systems interoperability at the semantics level, following 2 techniques to achieve interoperability: The first being the establishment of a common shared ontology that will be used by all participants who want to participate in the coalition. This is what the Multilateral Interoperability Programme (MIP) is currently defining with its MIP solution. The second technique is to operate a translation between the shared semantic concepts that are comprised in 2 distinct ontologies. In this case, a translation between the Command and Control Information Exchange Data Model (C2IEDM) [1] and the Over-The-Horizon Targeting GOLD (OTH-T-GOLD) [2] will be illustrated. In either case, it will be shown that interoperability can be achieved only if semantic elements are common to both systems domains.

Definition of *Interoperability*

The term *interoperability* being widely in use and defined in several ways, this paper will focus on the US Joint Publication 1-02 definition, where *interoperability* is:

> *"The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together."* [3]

The *Levels of Information Systems Interoperability (LISI)* [4] provides a 5-level hierarchy for interoperability focused on 4 attributes. The *PAID* attributes (Procedures, Applications, Infrastructure and Data) form the orthogonal aspects vectors that qualify systems interoperability while the 5-level hierarchy, ranging from *isolated* to *enterprise,* qualify the degree of achieved interoperability. The fact that one of the four attributes is *Data* shows the importance that semantics play in the interoperability scheme.

The NATO C3 Technical Architecture [5] also defines a hierarchy of interoperability degrees, ranging from *unstructured data exchange* to *seamless sharing of information*. This hierarchy is refined into sub-degrees representing functional derivatives of the four interoperability degrees. In this sense, the MIP solution aims at achieving interoperability degree 2.h (Structured Data Exchange/Data Object Exchange) for its human-interpretable information exchange mechanism and degree 4.a (Seamless Sharing of Information/Common Information Exchange) for its systems-interpretable information exchange mechanism. OTH-T-GOLD, as a message text format (MTF) allows for interoperability degree 2.h.

It would seem that attaining higher levels of interoperability (either from LISI's or NC3TA's perspective) is desirable. In fact, lower levels may very well address the operational needs for systems interoperability. Since also that higher levels require more money and effort to achieve, one has to carefully weigh the pros and cons of adopting the interoperability "nirvana" while in fact the "right" level depends on the *operational concept* over-arching the need for interoperability. The operational concept is the actual driving force for defining the level of interoperability needed between systems. This principle becomes a prime factor for information engineering, either when defining a shared common ontology (e.g. the C2IEDM) or when translating between 2 ontologies.

Ontologies: definition and role

Ontologies have received increasing interest in computer science and information systems. They explicitly encode a shared understanding of a domain that can be communicated between people and application programs [6]. According to Gruber [7], an ontology is « *an explicit specification of a shared conceptualisation* ». That means that it formally specifies the entities that exist in some area of knowledge and relationships that hold among them. It is shared in that it represents consensual knowledge of a community of agents that adhere to the definitions.

In the literature, ontologies range from controlled vocabularies to highly expressive domain models [8]: integrated data dictionaries designed for human understanding, taxonomies organizing concepts of a domain into inheritance hierarchies, structured data models suitable for data management, and finally highly expressive computational ontologies. Within this ontology spectrum, a *controlled vocabulary* is a finite set of terms with unambiguous definitions. A *taxonomy* is a collection of controlled vocabulary terms organized into a hierarchical structure, the terms being linked by generalization-specialization relations. A *thesaurus* is a networked collection of controlled vocabulary terms, where the relations between terms in thesaurus hierarchy are interpreted as narrower-broader relations. *Conceptual models* (e.g. database model) are also part of the spectrum but usually concern a restricted domain and are built for specific applications. Ontologies add more expressiveness in the specification of relationships between concepts. Formal ontologies use a representation language to specify properties and constraints of concepts that can be exploited for automated reasoning (inferencing).

In our perspective, an ontology, as a conceptualisation of a domain, explicitly captures the semantics of the entities in that domain. It comprises the definition of concepts, their properties, attributes, relations, as well as constraints and axioms that constrain the meaning of the concepts (disambiguation). It formally specifies the meaning of the concepts in order to make domain assumptions explicit and prevent errors in data interpretation. An important aspect in the ontology development process is to explicitly establish relationships that exist between concepts. De facto relationships between concepts in ontologies include relations that link a concept with more specific concepts (*is-a/subsume* relation) and relations that link a complex object to its constituents (*part-of/contains* relation). Any variety of relations that exist among entities should be specified, for example causal, functional dependencies, or temporal relations.

Due to their formal, expressive and shared properties, ontologies constitute domain models that can be reused across applications, facilitating knowledge sharing and reuse. Moreover, ontologies facilitate semantics information integration and interoperability between heterogeneous sources at a high level of abstraction. They can also be exploited to index and access semi-structured information sources. They facilitate information retrieval over collections of heterogeneous and distributed information sources.

Finally, some critical issues to be considered regarding ontological engineering are the cost of developing and maintaining ontologies, and the fact that ontologies should be extensible and evolve over time.

In reaching for systems interoperability, 2 solutions are possible at the semantics level:

1) A single shared common set of semantic elements is defined, so that disparate systems that are built upon it achieve semantics interoperability at once.
2) A translation mechanism between 2 (or more) ontologies is defined so that minimal semantics interoperability is achieved.

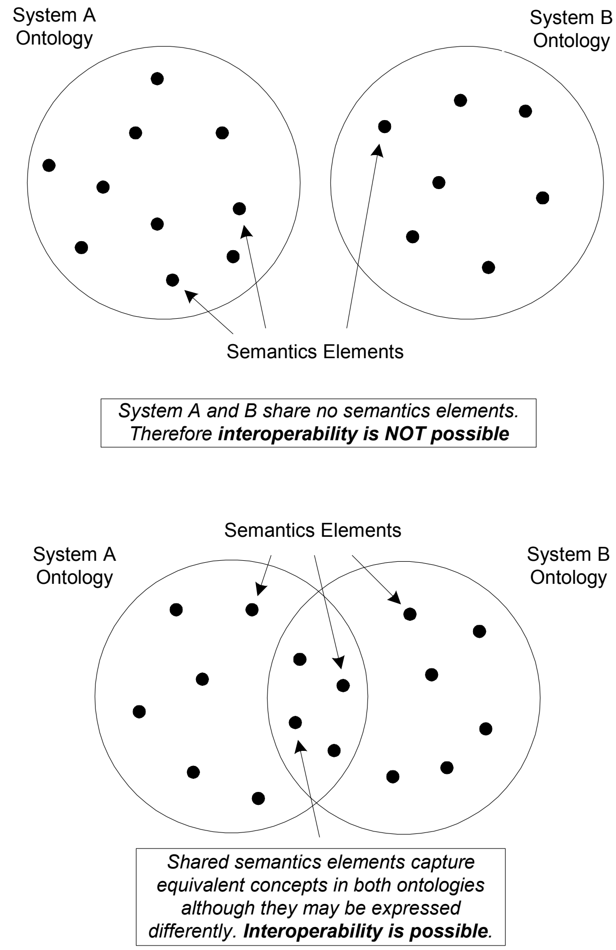

Figure 1: Semantic-level Interoperability

Semantic-level Interoperability

It is argued that interoperability at the semantics level is not always possible. Figure 1 shows an illustration of this as 2 systems can only interoperate if they share some of the semantic elements their distinct ontologies capture. The shared elements may be expressed differently but they nonetheless have to exist in both ontologies. Consequently, the need for operational interoperability (e.g. Navy systems interoperating with Land force systems) requires that the semantics of the information to be exchanged exist in both domains. Whether the means to express the semantics are the same or different does not change the need for the concept to exist in both worlds. The military realm offers a strong context around which the semantics of different domains (air, navy, land, joint) often overlap. The semantics overlap is the actual region where one can seize the opportunity to make 2 systems talk to each other at the same semantics level.

The question arises then as to what degree of semantic overlapping is required to achieve interoperability between 2 systems. The answer lies in the specification of the operational need for interoperability. Military interoperability occurs when different services (air, navy, land, joint) in a combined fashion and also in the international context (coalition). The reason for this is that each of these entities develops C2 systems that suit their specific needs. Conducting combined and coalition operations give a strong context about the information that must be exchange between partners. This in turn conditions the semantic elements that must exist in each stakeholder's ontologies. Therefore, the operational context will always be the driving force and rationale for systems interoperability.

The Multilateral Interoperability Programme

The goal of the MIP is:

> *"to achieve international interoperability of Command and Control Information Systems (C2IS) at all levels from corps to the lowest appropriate level, in order to support multinational, combined and joint operations and the advancement of digitisation in the international arena, including NATO."* [9]

For the past years, the MIP community has been working on the establishment of its MIP solution that is two-fold:

1) Capturing the semantics of the coalition land force operations and the relationships between the semantic elements of the battlefield. This resulted in the creation of the C2IEDM and derived artefacts, leading to the definition of the coalition land force ontology-oriented solution.
2) An information exchange mechanism (IEM) that would enable the information flow between systems.

To achieve this, the MIP always counted on a strong definition of the operational concepts for land operations (Figure 1Figure 2). The MIP Operational Working Group (OWG) gathers Subject Matter Experts (SMEs) and defines the Information Exchange Requirements (IERs) needed to conduct land operations. These are then decomposed into Information Content Elements (ICEs), like molecules broken into atoms of information. The ICEs are then mapped against the C2IEDM. This process is necessary to prevent duplication of semantic elements within the model. The C2IEDM is then enriched with business rules and constraints expressed in natural language that prevent the wrongful utilisation of the semantic elements. The data model in itself cannot express all the constraints that must be met to ensure semantic integrity. It must be augmented with documentation that describes all possible and forbidden relationships that can occur between semantic elements. This is why the C2IEDM always come with its main documentation and annexes [1]. Therefore, the data model by itself does not constitute a *formal* ontology. However, the data model augmented with its documentation form a comprehensive informal ontology as it tries to capture every semantic aspects of its domain of interest. Generally, the MIP data modellers try to render every possible aspect of the C2IEDM as explicit as possible so that a systems developer can use it as a comprehensive ontology-oriented solution.

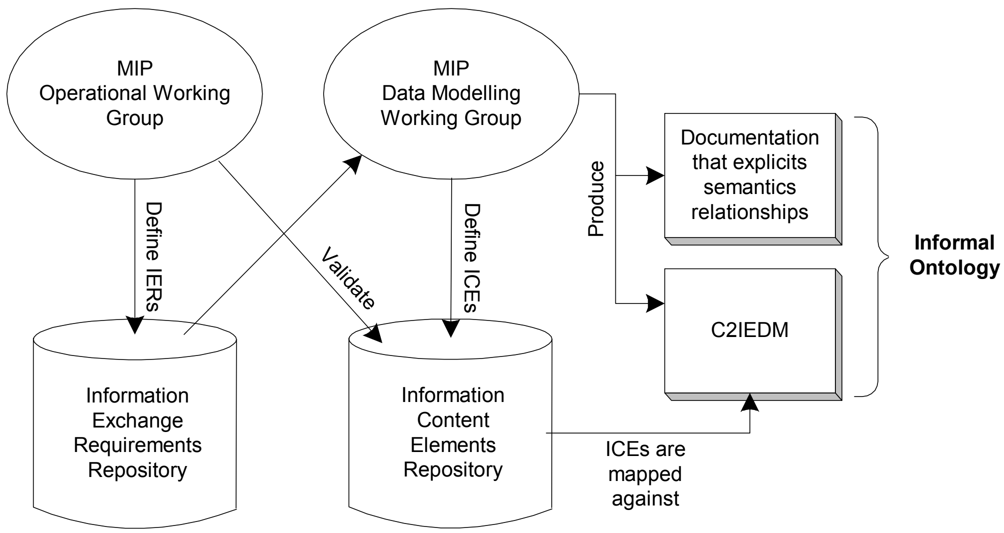

Figure 2: Information Exchange Requirements Process

Mapping the OTH-T-GOLD and the C2IEDM

While it is desirable to have every systems sit on top of the same ontology, and also to have every military stakeholders to agree upon the same set of semantic concepts, it is not always economically feasible to systems that are currently fielded. Therefore, the fallback solution is to try to build a piece of code that will translate semantic concepts from one ontology to another. Defence R&D Canada - Valcartier is working on an interoperability solution between the US Global Command and Control System (GCCS) and the Canadian Land Forces Command and Control Information System (LFC2IS). GCCS uses OTH-T-GOLD as a means of interoperability between its own workstations and LFC2IS sits directly on top of the MIP solution (C2IEDM and IEM).

Operational Concept

We previously mentioned that the first step was to identify the operational concept. Indeed, recognizing the operational concept as the driving force that prompts interoperability is the key and allows the definition of the information exchange requirements. In this exercise, the idea was for the land force to be able to inform the navy about its own land units information and to get in return information about the navy ships information (tracks). The operational concept is to gain shared awareness about mutual owned information (land vs navy) so that missions would be conducted with a degree of synchrony that was before only possible through human intervention.

Information Exchange Requirements

An analysis of both OTH-T-GOLD and C2IEDM revealed a number of sets, attributes, fields and values that would convey the information needed to support the operational concept. For example, the XCTC message in OTH-T-GOLD would be the main vehicle for navy information to the land component while several attributes of the C2IEDM would fill a JUNIT and JPOS so that land information would populate the navy system. It is a very long and fastidious exercise, but a necessary one to align semantic elements of both ontologies.

Semantics Loss and Bi-directional Information Exchange

We know that for interoperability to be possible, both ontologies must comprise some semantic elements that they must share. However, information elements that are used to express these semantic elements may differ, and sometimes they differ significantly. For example, both OTH-T-GOLD and C2IEDM are capable of expressing aircraft types. However, the need for details about aircraft types differs from the land component to the navy component. A "Mig 29" in OTH-T-GOLD maps to a "fixed wing fighter" in the C2IEDM. However, a "fixed wing fighter" in the C2IEDM corresponds to multiple values of the OTH-T-GOLD, not only to "Mig-29". These information elements cannot be exchanged back and forth between the systems. Therefore, the mapping must occur between information elements that are detailed enough to "nourish" the generic information elements, provided that the semantics necessary to support the operational concept is still conveyed between the systems. We define this as an "acceptable semantics loss". This is not that different from the jpg image file format, where loss of information is accepted to result in smaller files while the image still conveys the same information to the eye. This also demonstrates that information elements pushed to another system and pulled back are transformed in the process. In other words, bi-directional information exchange is often impossible to realize. Does this mean that bi-directional interoperability is impossible? No! The nature of information exchanged between systems can be asymmetric. In fact, this asymmetry is desirable as it prevents this kind of problem. Of course, this again should not contravene with the operational concept. In our example, it made sense since land information belongs to the land system while navy information belongs to the navy system. It was never a question whether land information should come from the navy system and vice-versa. In other words, one-directional information exchange supported bi-directional interoperability for this operational concept. One who attempts this kind of interoperability exercise should bear in mind that semantics loss almost always arises in the process, so it is better to clarify which system bears the "master" information. Otherwise, it may lead to major troubles.

Conclusion

Achieving systems interoperability requires that there is sufficient semantic overlap between systems' respective ontologies. This paper described the steps necessary to realize semantics interoperability either by adopting one and only one ontology or by designing a means to migrate from one ontology to another. These steps were labelled as *information engineering*. Information engineering aspects, characteristics and particularities were illustrated for both approaches. In either case, reaching for systems interoperability makes sense only if it supports an operational concept for the exchange of information. Keeping this in mind, the development of a single shared ontology will stabilize as soon as the operational concept is supported. The same applies to the harmonization of 2 distinct ontologies: A partial mapping constitutes a success if the over-arching operational concept's goal is met.

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