Realising the first prototype of the Semantic Interoperability Logical Framework

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Abstract

Increased focus on multi-functional and multi-national operations brings new requirements to today's and tomorrow's military command and control systems. In such contexts, the Swedish Armed Forces as well as other nations' armed forces need to interact intensely with each other and with civilian organizations. Thus the need for information exchange between heterogeneous systems that are owned and designed by different organizations has radically increased. It is therefore of great importance that future command and control systems are developed with flexibility in mind, in order to be able to adapt to different situations in which the need to exchange information between heterogeneous systems exists. Semantic heterogeneity is a particularly challenging form of heterogeneity which occurs when there is disagreement regarding the meaning, interpretation and intent of information or when information is described in different ways in two different systems.

Within NATO, semantic interoperability (SI) has been identified as a core capability for future command and control systems. An effort to address this need, called Semantic Interoperability Logical Framework (SILF) was initiated by a NATO research group IST-075 and is currently under development within a follow-on group IST-094. SILF includes tool and methodology support for harmonising data/information models on a semantic level, as well as mediators to translate between heterogeneous abstractions. The framework builds on a knowledge-based approach utilizing emerging semantic technologies, such as ontologies. However, SILF has never been prototyped in an implementation manner. The Swedish Defense Research Agency (FOI) has since 2007, in a parallel project and in cooperation with NATO's

former as well as current research groups in this field (IST-075 and IST-094), worked to clarify the concept of semantic interoperability, to build skills in this area, and to propose solutions for this problem. In this paper we will show how the Semantic Interoperability Project at FOI, commissioned by the Swedish Armed Forces, has realised the first prototype of the SILF, point out some pitfalls and state some conclusions. By taking the first steps towards an implementation of SILF, we believe that the Logical in the Semantic Interoperability Logical Framework, i.e. the L in the SILF, can be dropped. Thereby the FOI version of the SILF is hereafter referred as SIF.

1. The Problem

The ongoing globalization poses new challenges for military operations. In particular, it has become much more common to carry out activities together with other nations' civil and military organizations, i.e. to interoperate in multinational and multifunctional contexts. In order to cooperate efficiently, it is necessary for different organizations to exchange information between their command and control (C2), management and information systems (IS), i.e., to be interoperable. It is therefore essential to develop future IS that can adapt to different types of situations in which the information exchange needs are not known in advance. A prerequisite for an improved interoperability between IS of different organizations is to create standards, methods and tools which can align different terminology, and facilitate translation of data between heterogeneous systems.

The core problem is that the traditional means of exchanging information between heterogeneous systems do not guarantee that the intended meaning of information (the semantics) is preserved. To ensure that meaning is preserved, we need shared terminologies (ontologies); every message between communicating actors may then include references to one or several ontologies according to which the message should be interpreted. Common representation of semantics through ontologies represents one important step towards information interoperability.

2. Semantic Interoperability

NATO's primary research group in this field, NATO RTO IST-094, has defined Semantic Interoperability as *the ability of two or more computerized systems to exchange information for a specific task and have the meaning of that information accurately and automatically interpreted by the receiving system, in light of the task to be performed* [1].

Hence, two actors that are semantically interoperable can not only exchange information, but can also interpret and understand the intended meaning of the information in a common way. This is a key issue in the interaction between groups that do not share common frames of reference acquired through a common culture or through education. Support for semantic interoperability is therefore a prerequisite for the ability to participate in international operations with allied forces.

One way to achieve semantic interoperability between two systems is to align the ontologies of those systems. Ontologies have more recently become recognized as an emerging mechanism for dealing with semantic interoperability of Information Systems (cf. [2]). Ontology alignment is the result of an ontology matching process which is the task of determining correspondences between the concepts of different ontologies. Ontology matching and alignment are required when two heterogeneous systems want to harmonise their ontologies in order to achieve semantic interoperability. This process of harmonising two different ontologies is known as ontology reconciliation.

3. SIF - Semantic Interoperability Framework

Before we go through the development of our first prototype of the SIF in the next section, we will in this section briefly describe the SIF, its main components and functions as well as its assumptions and conditions. As we try to keep our description of SIF as a concept to the level that is adequate to understand the prototype development and not deeper, the interested reader who seeks for deeper details is referred to the Final Report of the NATO task group IST-075 [3].

In order to ensure semantic interoperability between heterogeneous systems, an architecture is needed which includes a party-wise set of common ontologies between communicating parties. Such is always implied by actors who exchange messages (otherwise communication is impossible), but in this architecture it is made explicit. This allows each message between communicating parties to be provided with references to one or more of the ontologies according to which the message should be interpreted. SIF is a high level view of such an architecture that supports semantic interoperability among heterogeneous information systems. In terms of features, SIF is a middleware that performs interoperability in a communication medium and not as part of the communicating systems. SIF applies means of knowledge-based systems, using ontologies, for mediation purposes.

Assumptions and Conditions

The application of SIF assumes that the lower levels of interoperability have already been achieved between the concerned systems. This means that the systems are connected (physical interoperability is established) and that they can exchange data in such a way that automatic data processing is possible (syntactic interoperability is also established). It also assumes that semantic descriptions of systems can be obtained in some way. These descriptions can more or less automatically be (partly) derived from systems, but in order to achieve the necessary quality of the descriptions the process normally requires human intervention.

It is important to note that the starting point for SIF is that existing systems have a need to share information in order to be able to interact in some kind of coalition. This must also be done without claiming major changes to the systems, and without any requirements of knowing the other systems' intention beforehand. Nations will unlikely change their C2 systems in order to be able to interact with other nations. Nor is it likely that they want to adapt their C2 systems every time a new nation will integrate. The optimum for each C2 system is to "talk and listen" in their own language. In addition, the general situation is that of a sender creating a message without knowing in advance who the receiver will be.

Main components and functions

The basic idea of SIF is to foster the use of a semantic description of all of the information to be exchanged and then take advantage of a number of existing and emerging semantic technologies, mainly ontologies, to improve interoperability. Figure 1 shows an overall view of SIF which can be described as follows. SIF mediates an exchange of information between systems A and B, which do not necessarily know each other. Furthermore, the assumption is that the systems information structures are different and therefore the exchange of information cannot happen painlessly. This means that to make the communicated information correctly interpreted in accordance with the semantics of system B a transformation is required for all information that system A communicates. A number of ontology operations take place in order to define and produce the rules necessary for these transformations. Input to these ontology operations and transformations are not only semantic descriptions of systems A and B, but also references to potential shared concepts and definitions which will exist in the "Common Ground" (CG).

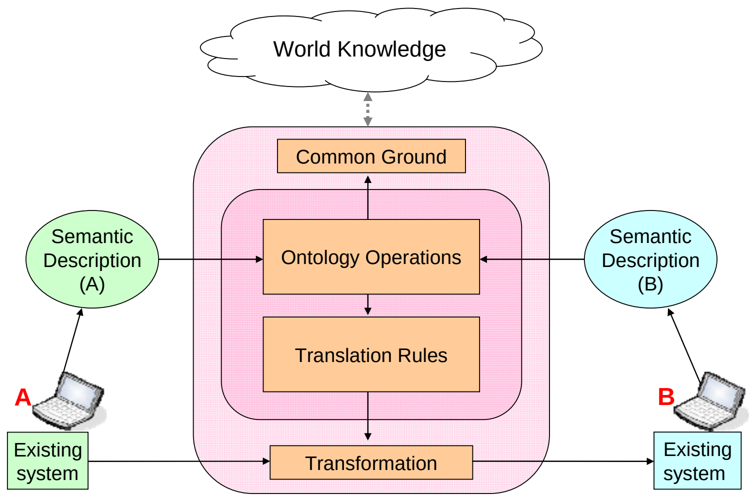

Figure 1: An overall view of SIF.

The most important components of SIF according to Figure 1 are as follows. The main purpose of *Common Ground* (CG) is to provide knowledge resources that will serve as common references for the *semantic descriptions* supplied by independent systems, in order to produce accurate ontology mappings. The idea here is that a portion of "all knowledge" available in the world, either exist or can be made available in machine-readable form. If this available machine-readable knowledge proves to be useful, reliable and validated for military use, it can be placed in CG to support SIFs ontological activities. An ontology manager within SIF provides services for *ontology operations* that identify similar concepts across ontologies and otherwise harmonise and align ontologies. *Translation rules* are the output of the mappings between concepts in system A's and B's ontologies, their Semantic Descriptions and the Common Ground. *Transformation* is used to convert a message from a form which was suitable for system A into a form which is appropriate for system B. It is important to note that the structure of the message is converted without loss of semantics.

The major functionality of SIF is to facilitate the exchange of messages (information) by the help of the above described components. The information exchange is orchestrated into a number of stages, which we have defined as the life-cycle process of SIF, namely Semantic Interoperability Development and Execution Process (SIDEP).

4. SIDEP

We have designed SIDEP as the process of preparing and executing a semantic interoperability task between two or more C2 systems.

SIDEP guides the life-cycle of a semantic interoperability task initiated by task initiator and involving at least two actors. The process consists of four phases Preparation, Configuration, Operation and Post-Operation. Every phase is a distinct sub-process, having a strict position in the phase sequence. Every phase includes one or more activities, which are executed within an order. Activities are considered to be implemented as the services of SIF. A service can be internal to SIF, or external, when consumed by an actor participating in a semantic interoperability task. Every service has input and/or output, which capture acquired and produced artefacts respectively.

In Figure2, the four major SIDEP phases are depicted, together with containing activities.

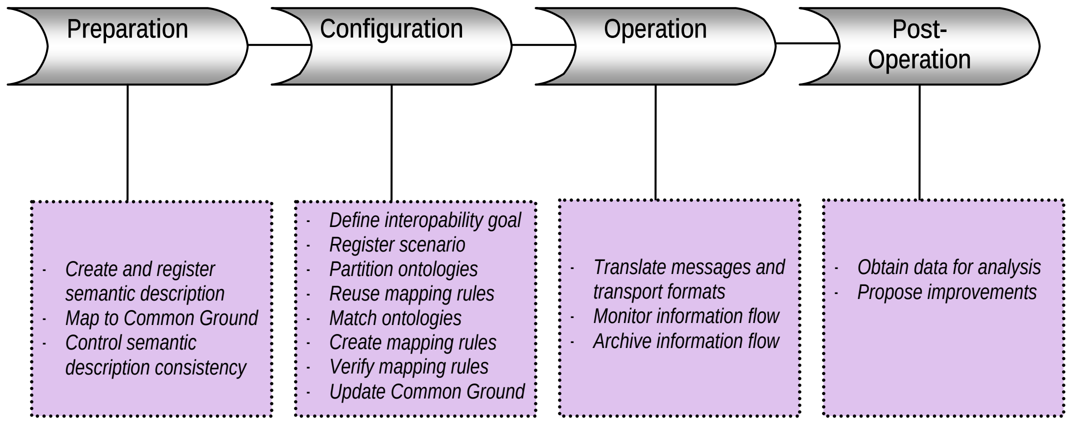

Figure 2: SIDEP phases and activities.

The Preparation is an "off-line" phase, where the military organizations accommodate their system by new capabilities required for knowledge based semantic interoperability according to SIF. When a certain operation and the goal for it have been specified, the Configuration phase will start to harmonise the semantic descriptions of the heterogeneous participating systems in the operation. The Operation phase is the only online phase from a military perspective where the configuration is completed and the SI tasks are executed with the support of SIF realizing the message exchanges between the involved systems. The last phase, Post-Operation, concerns analysis and evaluation of the results to be able to propose improvements for future uses. For more details on the responsibility of each of the phases we refer to [14].

In what follows, we will illustrate the implementation of the prototype of the semantic interoperability framework (SIF) and its life-cycle (SIDEP) on a case study example.

5. SIF case study

In this section we describe our SIF case study. The scenario is as follows. An Automatic Identification System (AIS) communicates with a JC3IEDM-compatible receiver by way of a message broker middleware (figure 3 below). The sender and receiver are thus syntactically interoperable. However, the receiver does not understand the AIS messages and simply puts them in an error log.

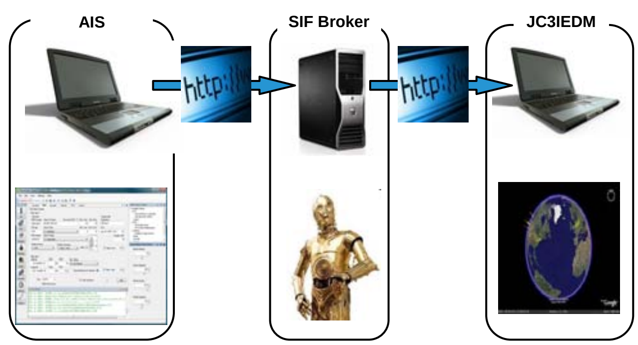

Figure 3: SIF case study.

Systems

The scenario involves three systems: an AIS sender, a broker middleware and a JC3IEDM-compatible receiver.

System A – AIS. The sending system (A) is an Automatic Identification System (AIS). Such systems are used by ships to identify themselves by broadcasting AIS messages containing information about the ship such as position, speed, bearing and type of ship.

In our scenario the system A contains an AIS simulator *NemaStudio* from SailSoft, and our own developed AIS adapter. With this simulator we can create multiple fictive ships, setup their individual traffic properties (bearing, speed etc) and simulate the routes by sending AIS messages calculated according to the settings. To be able to serialize and transmit AIS messages we developed an AIS adapter that catches the sampled messages and convert them into RDF-triplets [4].

System B – JC3IEDM. The receiving system B implements the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM) [5] with the aim to simulate a command and control center which uses an earth browser to visualize vessels on a map.

The system is developed as a web application with a RESTful [6] service interface for the incoming messages (RDF-triplets). A message handler updates a semantic information model from which a query engine reads out information and updates a KML-file [7]. The Earth browser frequently pulls information from this file to display on the screen.

SIF Broker. Systems A and B communicate by way of the SIF Broker, a message broker middleware with a translation functionality. A broker administrator configures what translation service the broker will call. The default translation service simply echoes the message, i.e., does not modify the message.

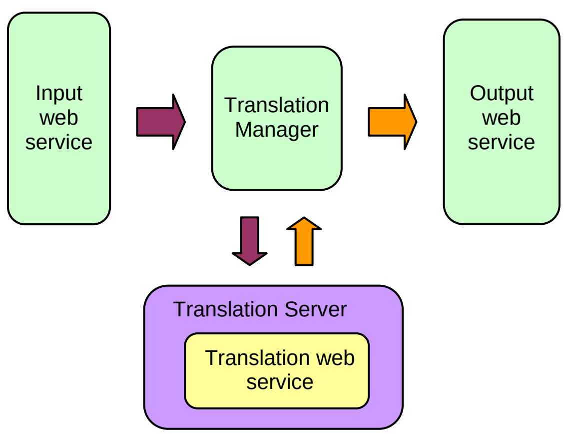

Figure 4: SIF Broker.

In the design of the SIF Broker we took a service oriented approach (SOA) [8]. SIF Broker offers a service where messages from the AIS system are uploaded to. The messages are then transmitted to a chosen translation service. The result is then dispatched to the destination service. The motivation of the SOA approach is the very low coupling it offers, and in longer term the simplicity for real systems to interact with the SIF Broker. In fact, it is possible to directly call the translation service from other message brokers, not just the SIF Broker developed here.

The implementation of SIF Broker follows message oriented middleware for point-to-point communication with additional dispatching to a translation service. The interaction between the systems is done over HTTP using RESTful services. In this way SIF Broker opens an interface for the sending system which simply posts a file to an URL residing in the SIF Broker domain. In the same manner the translation service and the JC3IEDM are offering RESTful APIs to communicate over HTTP with SIF Broker.

Development of the translation service following SIDEP

Initially, system B does not understand the messages coming from system A and simply puts the messages received in an error log; a message translation is needed. Accordingly, we use SIDEP to develop a RESTful translation service that the broker middleware may call before dispatching messages.

Preparation phase. In the preparation phase, two ontologies are created using Topbraid Composer [9], one for the sending AIS system and another for the receiving JC3IEDM-compatible system.

Configuration phase. In the configuration phase, entities from the AIS ontology are matched with corresponding entities in the JC3IEDM ontology with the help of semi-automatic matching tools, e.g. OntoConto [10] (described below). Based on the entity matches, we write SPARQL [11] rules that translate messages expressed in the AIS ontology to messages expressed in the JC3IEDM ontology. The SPARQL translation rules are created using the visual mapping tool SPINmap [9] in TopBraid Composer. Finally, the translation rules are (automatically) compiled in Topbraid Composer into a RESTful translation service.

Operation phase. During the operation phase, the RESTful translation service constructed during the configuration phase is called by the broker middleware that mediates between systems A and B.

Post-operation phase. We did not perform any post-operation analysis during this case study. The case study was set up to explore only the first three SIDEP phases.

Ontology tools

The RESTful translation service was developed using Topquadrant's Topbraid Composer [9] extended with OntoConto [10], an open source Eclipse [12] plugin released as part of the NEON Toolkit 2.3.1 [13] – the plugin had to be adapted to work within TopBraid Composer. OntoConto visualises ontology alignments and offers functionality to edit, store, load and automatically generate alignments. In Figure 5 two ontologies are displayed side by side, and alignments are visualised as arcs connecting elements from these two ontologies. The user generates a new alignment by selecting a matching algorithm from a dropdown menu offering various matching algorithms.

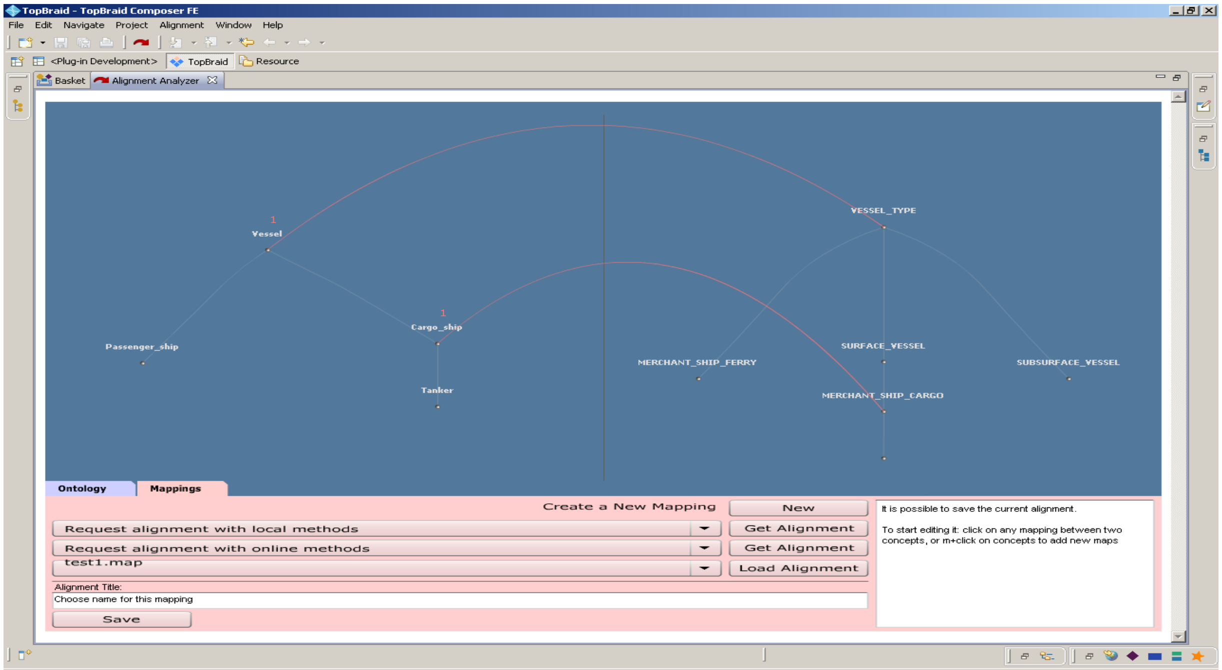

Figure 5: Screen shot of the OntoConto plugin in TopBraid Composer.

In addition to Tobraid Composer, we considered using several other ontology tools, among others OntoStudio from Ontoprise and the free, open-source platform Protégé. However, after an evaluation of the suitability we decided to implement our prototype in Topbraid.

Lessons learned

The first lesson learned in this study was that to create expressive ontologies from informal information models is non-trivial, but the result can be of great use. We ran the SIDEP process twice, first trying a light-weight approach to the preparation phase and subsequently a more heavy-weight approach. During the light-weight preparation phase, ontologies for systems A and B were (semi-automatically) extracted from the AIS message format and the JC3IEDM exchange format respectively; the result could perhaps be described as physical data models expressed in OWL since the two ontologies do not refer directly to the maritime domain but rather mirror the AIS and JC3IEDM message formats. During the more heavy-weight preparation phase, we (manually) mapped the respective ontologies to a common ground for the maritime domain. We found the matching tools helpful only after the more heavy-weight preparation phase.

The second lesson learned was that it can be far from trivial to transform matching results into translation rules expressed as SPARQL queries. While the visual mapping tool SPINmap removed the need for low-level SPARQL coding, constructing the (visual) translation rules based on matching results required considerable effort none the less.

6. Conclusions

Ontologies can be matched semi-automatically - more automatically the more accurate and detailed the ontologies are. Indeed, we found that extra effort put into the preparation phase resulted in a more automated configuration phase. In fact, we found that automated matching services provided useful matches during the configuration phase *only if* concepts in each ontology had been mapped to relevant concepts in the common ground (in our case, maritime concepts) during the earlier preparation phase.

Presently, matching result are manually compiled into translation rules in SIF, but visual mapping tools such as SPINmap can considerably reduce the need for tedious low-level coding.

Semantic technologies, tools and best practices are still young, but the conditions improve fast.

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