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"Application of Semantic Technologies in Network Based Defence"

Collaborative Technologies for Network-Centric Operations

Bjørn Jervell Hansen

Norwegian Defence Research Establishment (FFI)

P o Box 25; NO-2027 Kjeller, Norway

+47 63 80 70 88

bjorn-jervell.hansen@ffi.no

Application of Semantic Technologies in Network Based Defence

Abstract

Semantic technologies can be described as technologies that provide tools and methods to build more adaptive and flexible software by separating the meaning of the information at hand from the source code and the information itself. Examples of such technologies include Semantic Web standards like RDF, OWL, and SPARQL. In a Norwegian Defence Research Establishment (FFI) activity, semantic technologies are studied in order to evaluate how they can be utilised in military applications. Of special interest is their use in providing flexible services within the information infrastructure in the forthcoming Norwegian Network Based Defence (NBD).

NBD is the Norwegian adaptation of Network Centric Warfare, and is based upon utilising more extensive information sharing than what is currently being conducted in order to achieve improved shared situational awareness. This in turn is predicted to contribute to increased military effectiveness. An information infrastructure is necessary to implement NBD, and this paper presents our thoughts on how semantic technologies might contribute to solve several challenges in this infrastructure. The challenges considered are handling of flexible services, integrating and analysing information from heterogeneous sources, and information overload. The outcome of a conducted proof-of-concept experiment with semantic information integration is also presented.

Keywords: Semantic Technologies, Semantic Web, Network Based Defence, Information Integration, Information Overload, Dynamic Services

Introduction

Network Based Defence (NBD) is the Norwegian adaption of Network Centric Warfare (NCW) (Alberts et al. 1999) and thus also related to the NATO Network Enabled Capability (NNEC) (Bartolomasi et al. 2005). NBD is based upon utilising more extensive information sharing than what is currently being conducted in order to achieve improved shared situational awareness among the users. This can then contribute to an increased tempo in the execution of command and operations, increased fighting capabilities, increased survival, self synchronisation, and information superiority. All this is in the end predicted to contribute to increased military effectiveness.

An information infrastructure (INI) is needed to support NBD, and there are large

ongoing efforts in the Norwegian Defence connected to INI development. The Norwegian Defence Research Establishment (FFI) also has activities in support of this development, and one of these activities is evaluating semantic technologies in light of the needs originating from NBD.

Semantic technologies can be described as technologies that provide tools and methods to build more adaptive and flexible software by separating the meaning of the information at hand from the source code and the information itself. Examples of such technologies include Semantic Web standards like RDF, OWL, and SPARQL.

The goal of this paper is to contribute to the understanding of how semantic technologies can be beneficial also in the military domain. In order to achieve this, we will take a closer look at how we believe semantic technologies can contribute to solve some of the challenges introduced by, or amplified by, NBD. These challenges are related to finding the relevant information in a timely fashion, integrating and analysing information from various sources, and finding the relevant information in large information sets.

The paper is organised as follows: We start by presenting some of the challenges we foresee with the introduction of NBD. We then present semantic technologies with an emphasis on what we have labelled core semantic technologies, before we present our thoughts on how to utilise semantic technologies to help solve the presented challenges. A proof-of-concept experiment on semantic information integration is then presented, before we conclude the paper.

Network Based Defence Challenges

The implementation of NBD in the Norwegian Defence will lead to several challenges. Some are introduced by NBD, while others are already present but will be amplified by NBD. In this paper we concentrate on four of these challenges: Connecting to information sources in a flexible way, information integration, information analysis, and the risk of information overload.

Connecting to Information Sources in a Flexible Way

From a technological point of view, NBD is in essence based on an INI allowing military units to discover and connect to information sources in a flexible way. This flexibility is fundamental, as it is envisioned that units operating according to NBD will greatly benefit from being able to connect to emerging, unanticipated information sources during a mission. The information sources can for example

be other military units, databases, sensors, documents, etc. This constitutes the first challenge introduced by NBD that we will consider here.

Information Integration

The second challenge we identify is the integration of the information from all these sources. There is little reason to believe that the different pieces of information will be on compatible formats, let alone on the same format. Here it is worth to notice that this challenge is not introduced by NBD - it is already present - but with more information sources becoming available the challenge is amplified.

Information Analysis

During the important process of situation analysis, military users analyse the available information in order to make sense of the situation that generated the information.

The analysis is predominantly a manual process. This means that with all the new information becoming available in an NBD, the process runs the risk of becoming increasingly difficult and error-prone.

As was the case with information integration, this challenge is not introduced by NBD, but is amplified due to the increasing number of information sources becoming available.

Risk of Information Overload

Being able to discover and connect to information sources in a flexible way and integrate and analyse this information, the next challenge, and the last to be discussed here, will be to provide users with means to find the information relevant to his or her situation and overcome information overload. Once again, this challenge is already a present, but we envision it to be amplified due to the extensive information sharing that is fundamental to NBD.

Semantic Technologies

In our work, we use the following definition of semantic technologies: Semantic Technologies are software technologies that exploit the meaning of the information at hand and involve the use of an explicit knowledge model (Hansen

et al. 2007).

Examples of technologies that, given the right context, can be considered semantic technologies are ontologies, rule engines, inference engines, and agents.

What makes semantic technologies different from traditional information technologies is that with semantic technologies the meaning (semantics) of the data is explicitly represented in semantic models separately from the data itself and the program logic. Further, this explicit representation can be handled by computers, making it possible for computers to share and work with the semantics with minimal, and in some cases no, human intervention. The way the semantic models are linked to the software also means that they can be exchanged for other semantic models at run-time, providing the resulting software with a flexibility unattainable using traditional information technologies.

The Semantic Web and its related activities, are among the strongest drivers for semantic technology development at the moment. The Semantic Web is a vision presented in (Berners-Lee et al. 2001) that is based on evolving the current World Wide Web from today's web of documents to a web of data accessible to computers as well as to people. To be able to attain this, the web content has to be annotated according to ontologies. That way both the data residing on web pages that currently are only understandable to humans and data residing on other medias (like databases, electronic calendars etc.) can be made computer-processable and thus more accessible and reusable.

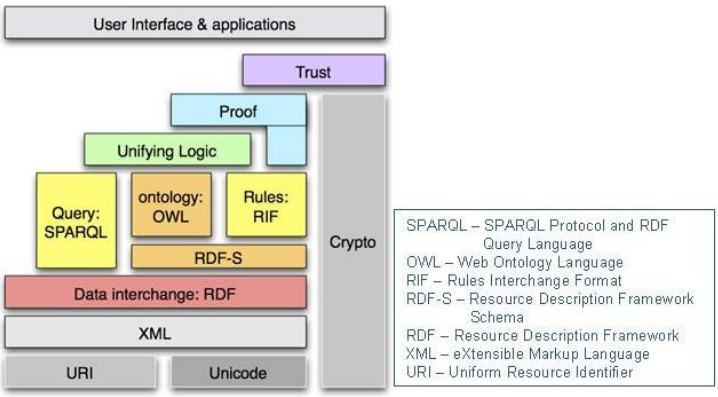


Figure 1. The Semantic Web Layer Cake

The main contributer to technologies for realising the Semantic Web is the World Wide Web Consortium (W3C). The W3C's prediction of the technology needs for realising the Semantic Web is often illustrated by the Semantic Web Layer Cake, shown in Figure 1.

In our view it is worth to notice that the use of Semantic Web technologies and standards proposed by W3C is not restricted to being used only in connection with the whole World Wide Web. They can also be used within and between enterprises and large organisations. This is true independently of the success of the Semantic Web as such, and makes the W3C technologies interesting also in the military domain. In the FFI activity it has been decided to focus on the semantic technologies introduced through the W3C due to the availability and maturity of these technologies.

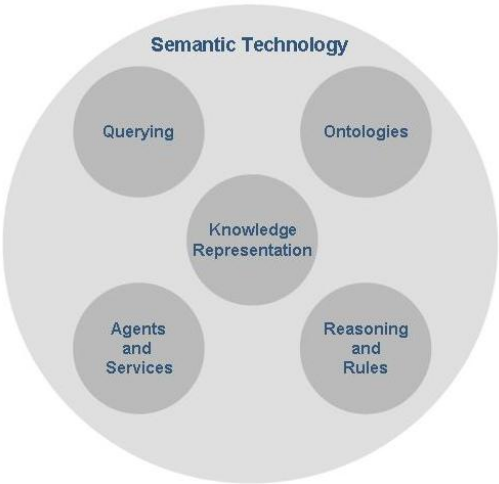


Figure 2. The five core technologies

During our research on semantic technologies, five core technologies, illustrated in Figure 2, have been identified and will now be described.

Knowledge Representation

Knowledge representation aims at representing and storing knowledge in a formal way, thus making the knowledge accessible to computers. By basing the knowledge representation language on formal logic, the computers can also infer new knowledge from an existing body of knowledge.

There exist several formalisms for representing knowledge, but one recent knowledge representation formalism important for representing knowledge in large networks like the Web is W3C's graph-based Resource Description Framework (RDF) (W3C 2004*c*).

Ontologies

Ontologies are explicit and formal semantic models of a domain of interest, and are usually defined as *a formal, explicit specification of a shared conceptualisation* (Studer et al. 1998). This means than in an ontology, the concepts of the domain and the relations between them are defined in a formal way.

Ontologies can be linkable, and is thus well suited to support a modular way to re-use existing models to create larger models. This is illustrated in Figure 3 taken from the gene ontology project (Stephens et al. 2006), where several local ontologies are linked together.

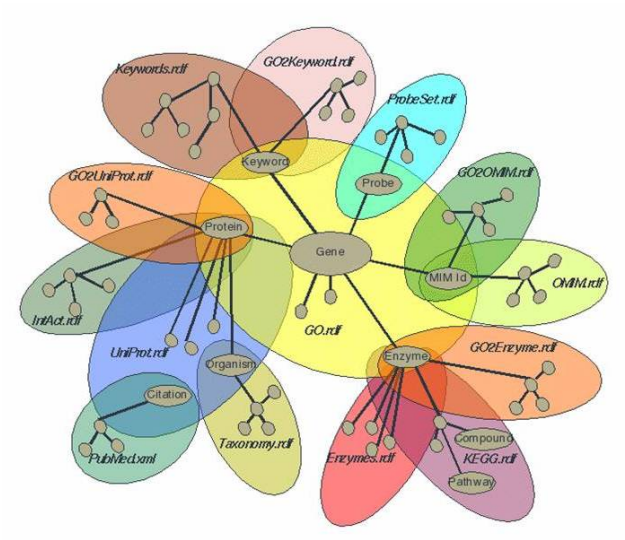


Figure 3. Linking several ontologies to create one large, modular semantic model

One of the most important ontology specification languages today is W3C's Web Ontology Language (OWL) (W3C 2004*b*) which is based on Description Logics (Baader et al. 2003).

Querying

Querying is a fundamental way of collecting information from information systems. In systems based on semantic technologies, the information is typically represented using knowledge representation formalisms and stored in a knowledge base. Using the W3C query language and protocol for querying RDF, SPARQL (W3C 2007*c*) it is possible to query RDF-based knowledge bases in a way similar to querying relational databases using SQL.

Reasoning and Rules

Reasoning is an important feature of semantic technologies as it represents a way to infer new knowledge based on existing knowledge. The inference process is, when considered in a semantic technology context, based on a set of rules. These rules are either the axioms of the ontology that specifies the knowledge, custom rules provided by a user, or both. In the latter case the reasoning is often called hybrid reasoning.

User-defined rules are used in addition to the ontology axioms for expressivity reasons. The ontology axioms often provide somewhat limited expressivity due to the need to keep key inference problems decidable.

Specification of user-defined rules is, however, not supported by OWL, but have to be specified using other means. There currently exists no dominant standard for specifying user-defined rules, but examples of formalisms that can be used alongside OWL include the Semantic Web Rules Language (SWRL)(Horrocks et al. 2005), Rule Markup Language (RuleML) (Boley et al. 2001), and the recent W3C initiative Rules Interchange Format (RIF)(W3C 2007*a*).

An important feature regarding reasoning in the context of semantic technologies is the ability to create generic reasoners that can do automatic reasoning with a wide range of applications. Several such reasoners exist, for example Racer (Haarslev & Moller 2001), FaCT++ (Tsarkov & Horrocks 2006), KAON2 (Motik & Sattler 2006), and Pellet (Sirin et al. 2007).

Agents and Services

The use of agents is a central concept in the Semantic Web. Agents are software components able to take advantage of computer-readable elements in information and services, and in this context they are considered to be autonomous (able to make decisions on behalf of a user), proactive (able to take the initiative when appropriate), and social (able to cooperate with other agents).

Representing agents as Web Services is advantageous, as the Web Service architecture is an interesting platform on which to build executable Multi-Agent Systems (MAS). In (Walton 2007) three approaches for constructing MAS using the Web Service architecture are outlined.

Web Services that are enriched with semantic service descriptions are called Semantic Web Services. There exist several initiatives focusing on how to represent Semantic Web Services, the main initiatives being: Web Ontology Language

- Services (OWL-S) (W3C 2004*a*), Web Service Modelling Ontology (WSMO) (Roman et al. 2005), Semantic Web Services Framework (SWSF) (W3C 2005), and Semantic Annotations for WSDL (SAWSDL) (W3C 2007*b*).

Semantic Technologies Applied to the Network Based Defence Challenges

Semantic technologies provide several interesting capabilities, some of which have the potential to address the previously presented challenges.

In general, we feel that semantic technologies can contribute in at least four stages:

1. Making more information source available to the participants
2. Integrating the information from these sources
3. Contribute to the analysis of the integrated information
4. Overcoming information overload by helping the users to find the most relevant information.

These stages are somewhat related. Stage 1 means that more information will have to be integrated (stage 2), and analysed (stage 3), and this will in its turn mean that the amount of information the user has to relate to is larger than before (stage 4).

Making More Information Sources Available

The use of a service-oriented architecture (SOA) is recommended for the NATO Network Enabled Capability (NNEC) (Bartolomasi et al. 2005) in order to provide a loose coupling between services and thus the flexibility NNEC needs.

We feel that the same recommendation can be made for NBD. Treating the information sources like services in a SOA makes it possible to connect information sources and users (clients) in a flexible way: The information sources announce their presence, and the users can search for the sources, often relying on a service registry.

There exist several methods for implementing a SOA, many of which rely on a service registry where services can register and clients discover the services it needs. This provides, at least in principle, a loose coupling between the services and the clients: The client does not need to know about the service in advance in

order to use it, and the service does not have to know anything about the clients that are going to use it.

Semantic technologies can improve SOA by improving the service descriptions. Basing these descriptions on ontologies makes it possible for computers to handle the descriptions automatically and opens up the possibility of doing reasoning on the descriptions. This can contribute to automating fundamental SOA processes like service discovery, service invocation, service composition, and negotiations between services and clients. A SOA with these capabilities is called a semantic SOA.

As an example of what is expected, we will take a look at service discovery. When the service descriptions are based on ontologies, instead of matching a service to a request using strings (e.g. a client searching for a "sensor" while the only available sensor service is labelled "radar" will not find the radar service), the matching can be done on concepts and the relations between concepts. The discovery process is in this case often called matchmaking. Using the small example provided above, the client searching for a "sensor" can be linked to the "radar" service if the ontology points out that a radar is a subclass of a sensor assuming that we have an intelligent service registry with matchmaking abilities. Equivalent services labelled with different, but synonymous, labels can be handled correspondingly.

Organising information sources as services in a SOA seems like a promising way to achieve the flexibility needed in an INI. But this is probably not enough. We envision that more automation is needed to achieve the goals of NBD, automation that possibly can be achieved by exploiting the semantic service descriptions of semantic SOA. Moreover, as semantic SOA is envisioned to promote an even looser coupling of services than is the case with regular SOA, it can be seen as a way to support a higher degree of collaboration between parties that are able to represent themselves as services.

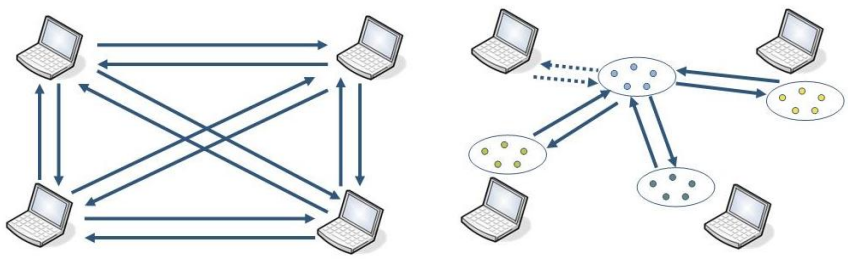
Integrating the Information

The main idea of semantic information integration is to exploit the fact that ontologies can be linked together to create a huge, modular model. Instead of making the integration of information encoded according to different formats on a term-to-term-basis, the format ontologies can be linked together. This is solving the (semantic) mismatch between the different formats at the semantic level: The elements being linked are the ontology concepts and not just the terms. As ontologies are formal, reasoning and rules can assist in doing the actual integration. An experiment in which this technique was used, is described in the next section of the

paper.

The biggest problem with the classical approach of relating the terms in the different formats point-to-point is scalability. In the worst case this approach can result in an exponential growth of integrations needed in the number of formats to integrate between. This is commonly known as the n^2 problem, and is illustrated in Figure 4(a).

Semantic information integration, on the other hand, has the advantage that it can represent a linear growth in the number of integrations needed to be carried out. This is illustrated in Figure 4(b). Semantic information integration thus represents a more scalable way to integrate information from heterogeneous sources.



(a) (b)

Figure 4. Point-to-point (a) vs. centralised/federated (b) information integration

Semantic technologies can make the information integration scalable and flexible. This will be important in NBD as all systems will have to relate to more other systems than before due to the NBD goal of more extensive information exchange.

It is important to note that this way to integrate information from heterogeneous sources is interesting regardless of NBD. Even today, information integration is a huge challenge as the number of systems continue to grow.

Analysing the Information

The analysis considered in this context is situation analysis, defined in (Roy 2001) as *a process, the examination of a situation, its elements, and their relations, to provide and maintain a product, i.e., a state of [situation awareness], for the decision maker*. The information is analysed to allow the military user to make sense of the situation that generated the information.

Situation analysis is covered by what is often labelled high-level data fusion, or information fusion, according to the Joint Directors of Laboratories (JDL) data fusion model (Hall & McMullen 2004), a model widely used in military data

fusion.

Relations, like for example `is-threatened-by`, `can-observe`, etc., are essential to situation analysis, as the focus is no longer solely on what is being observed and where it is, but on the relations between the units. An important aspect of these relations is that they are usually not directly observable. Thus in order to estimate them, one solution is to use user-defined rules as a basis to do reasoning. This can be seen as a way to emulate the manual process of looking for patterns in the information to make hypotheses about entity relationships. If the information is represented using ontologies, semantic technologies offer generic reasoners that should be able to infer these relations.

The highlighted parts of the following definition of situation assessment and impact assessment from (Steinberg & Bowman 2001), in our view further strengthens the tie between information fusion and semantic technologies, keeping in mind that semantic technologies can act as a basis for automatic reasoning: *Situation Assessment [..] is the estimation and prediction of entity states on the basis of* ***inferred relations*** *among entities, whereas Impact Assessment [..] is usually implemented as a prediction,* ***drawing particular kinds of inferences*** *from [Situation Assessment] associations.*

Overcoming Information Overload

Semantic search, i.e. the use of semantic technologies in search, looks promising as a way to enhance traditional search strategies. The main contribution from semantic technologies is the handling of concepts and relations. Every concept is related to other concepts in various manners, and by utilising these relationships semantic search has the potential to reduce ambiguity and give higher precision than traditional string-based search alone.

As an example of how semantic search can enhance traditional search, consider a search on the term "Fridtjof Nansen" - a famous Norwegian polar explorer but also the name of the new class of Norwegian frigates. With traditional search a user has no way to specify explicitly which of the Fridtjof Nansens s/he is searching for. With semantic search, ontologies give a user a way to specify this.

Information navigation is another technique made possible by semantic technologies that can help users overcoming information overload when they face all the new information made available through the extensive information sharing in NBD. Once again the explicit representation of concepts and their relations in ontologies is the key. The idea is to browse through the information along the relations specified in the ontology. This can be thought of as the same kind of

browsing as is done on the World Wide Web by following hyperlinks. One immediate benefit of this is that once a user has hit upon a concept of interest, related concept will only be one relation away. To continue the Fridtjof Nansen example, a user can navigate from a 'Frigate' concept to 'Fridtjof Nansen' if the latter is encoded in an ontology to be a specification of the former. Further, as a 'Frigate' 'Fridtjof Nansen' can have sister ships. By following a 'sister ship' relation, a user has easy access also to Fridtjof Nansen's sister ships should that be of interest.

Both these techniques made possible by semantic technologies are ways to help a user find the information relevant to his or her situation more easily when they face the large information sets. And the large information sets will probably become even larger when units operate according to NBD.

Ontologies as the Common Denominator in the Application of Semantic Technologies

There is a cost related to the development of ontologies, but the development is inevitable as ontologies are fundamental to the use of semantic technologies. However, it is worth to note that the use of semantic technologies for several capabilities, like for example the capabilities outlined in the preceding subsections, facilitates reuse of ontologies and also mappings. That way an ontology developed to support semantic service descriptions can also be used to support semantic information integration, information fusion, semantic search, and information navigation.

Experiment: Semantic Information Integration

The experiment was conducted during the NATO Coalition Warrior Interoperability Demonstration (CWID) 2007 at Lillehammer, Norway, and the motivation was to investigate semantic technologies used for integrating information from heterogeneous information sources.

The experiment dealt with translating between two data formats using semantic information integration. The two formats in question were NATO Friendly Force Information (NFFI) (Malewicz 2006) and an FFI specific data format. Both were XML Schema-defined formats regarding track information.

The integration strategy was to create an ontology for each of the formats and define mappings between the two ontologies through the use of a mapping ontology, illustrated in Figure 5. The semantic modeling tool TopBraid Composer (TopQuadrant 2008) was used to create ontologies for both formats from the XML

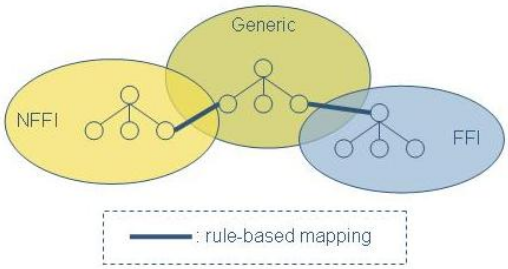


Figure 5. The NFFI and FFI ontologies mapped together through a generic mapping ontology

Schemas, while the mappings were defined as rules.

The whole format translation process is shown in Figure 6, and involves the following steps (the numbering also refers to the figure):

1. An NFFI XML message is received
2. The message is validated against the NFFI XML Schema
3. The information contents of the message is transformed to RDF triples using eXtensible Stylesheet Language Transformations (XSLT)
4. The RDF triples are added to the knowledge base
5. New RDF triples are inferred in the knowledge base according to the mapping rules
6. RDF triples representing the information on the FFI format are extracted from the knowledge base using SPARQL
7. The RDF triples are transformed to XML using XSLT
8. The FFI XML message is validated using the FFI XML Schema
9. An FFI XML message is returned

The software created to perform the actual transformation was totally model independent. In other words: The same software can in principle perform a transformation between any formats given the appropriate ontologies, ontology mapping rules, and XSLT scripts. In our view, this can be considered as a proof of concept regarding the ability of semantic technologies to contribute to flexible software.

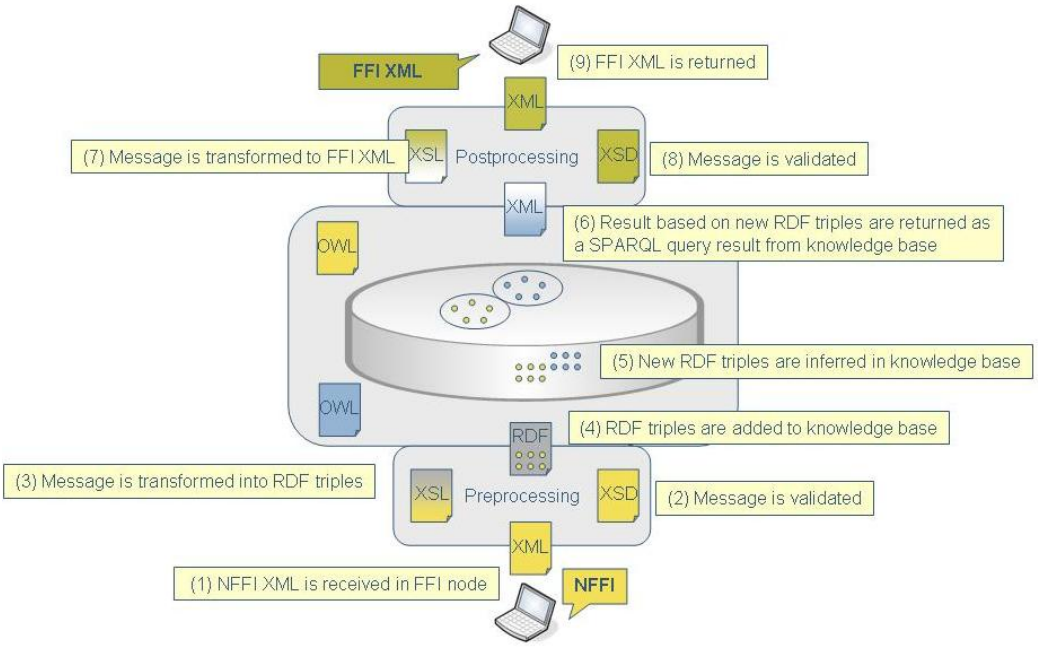


Figure 6. The translation process

The transformation part of the experiment was assessed as being successful, as the process outlined above gave the desired results. Some performance issues was experienced, in some cases the reasoning took in the order of minutes to complete on an ordinary, single-core laptop computer, but we expect this issue to be resolved with more powerful computers and more efficient reasoners.

Our experience also showed that much work is needed for modelling ontologies, creating the ontology mapping rules, and creating XSLT scripts. The upside of this, however, is that it is possible to reuse the output from these efforts.

More details on the experiment can be found in (Gagnes 2007).

Conclusion

With the development of an INI to support NBD, the Norwegian Defence will face several challenges. In this paper four important challenges have been elaborated upon: Connecting to information sources in a flexible way, integrating information from an increasing number of heterogeneous sources, analysing information, and handling information overload.

Our goal with this paper has been to contribute to the understanding of how semantic technologies can be beneficial also in the military domain. Thus, semantic technologies are introduced as tools to help solve these challenges, and of the many predicted capabilities of semantic technologies, we have focused on five capabilities as particularly interesting: Semantic SOA, semantic information integration, information fusion, semantic search, and information navigation.

In addition to this, the paper has presented a successful proof-of-concept experiment regarding semantic information integration.

Acknowledgements

This paper is to a large extent based on collaborative work on semantic technologies where my colleagues Tommy Gagnes, Rolf Rasmussen, Marianne Rustad, Geir Sletten, and Jonas Halvorsen have made substantial contributions. Tommy Gagnes also did most of the work in connection with the experiment presented in the paper.

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