Semantic Technologies and Enhanced Situation Awareness

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Abstract—S*ituation awareness is a critical element of military decision superiority in a wide variety of operational contexts. Improved situation awareness can benefit operational effectiveness by facilitating the planning process, improving the quality and timeliness of decisions, and providing better feedback about the strategic and tactical consequences of military actions. The military coalition environment presents a number of challenges to situation awareness research; not only in terms of the technical approaches used to enhance situation awareness, but also in terms of the models and conceptual frameworks used to analyse situation awareness. This paper outlines an approach to enhancing situation awareness that is grounded in the use of Semantic Web technologies. We describe the challenges to both individual and team situation awareness presented by coalition military environments, and we discuss ways in which semantic technologies might be used to address these challenges. We suggest that an approach featuring domain ontologies, reasoning capabilities, semantic queries and semantic integration techniques provides the basis for an integrated framework for improving situation awareness in military coalition contexts. We provide an example of our approach in the form of the InfoGlue framework for adaptive, context-aware information retrieval.*

1. INTRODUCTION

In recent years there has been a growing appreciation of the importance of situation awareness (SA) to operator competence in a variety of complex task domains, including aviation (e.g. [1]), nuclear power plant management (e.g. [2]) and medical decision making [3]. SA is also a recognized as critical ingredient of operational effectiveness in military contexts [4-6]. Even when the operational context is not directly adversarial, as is the case in most humanitarian and peace-keeping operations, the awareness operators have of the temporal unfolding of events in a situation, and their understanding of the implications of those events for both ongoing activities and future plans, is clearly a critical element in the effectiveness and adaptability of a military force.

The attempt to deliver enhanced situation awareness, particularly in coalition contexts, faces a number of challenges. Firstly, military operators must deal with the inherent heterogeneity and distributed nature of information content. Information may be contained in multiple formats (e.g. images, video, unstructured text, XML) and will often be distributed across multiple data repositories or nodes of an information network. Situation awareness ultimately depends on an ability to deal with this heterogeneity - to aggregate, integrate and process task-relevant information in ways that support decision-making in an operationally-effective manner [see 7]. A second challenge concerns the task-variant information needs and requirements of those engaged in military problem-solving activities (e.g. individual human agents or hybrid teams comprising both human and software agents). The key problem here is that contemporary military engagements often subtend multiple operations (e.g. armed conflict, peace-keeping and humanitarian relief), and sometimes these operations may be combined to a greater or lesser extent in the same mission context – a feature epitomized by the notion of the three-block war [8]. When rapid goal switching is mandated by changing operational commitments then different subsets of information will need to be dynamically integrated or aggregated to support changing situation awareness requirements. A third challenge to enhanced situation awareness concerns the notorious problem of information overload. While the advent of network-enabled capabilities (NEC) [9] and the growth of the Internet as a medium for information dissemination provides opportunities for enhanced SA, they also present some problems in terms of the sheer volume of information that is available. There is a danger in these cases that task-relevant information processing may be swamped by masses of largely irrelevant information content. One resolution of this problem is to filter incoming information streams based on the task-variant knowledge and information requirements of different information consumers. However, this still necessitates a means to represent information requirements and dynamically adjust information retrieval processes to suit rapidly changing problem-solving goals.

This paper outlines an approach to enhanced SA that is grounded in the use of Semantic Web technologies. We describe the challenges to both individual and team situation awareness presented by coalition military environments, and we propose ways in which semantic technologies might be used to address these challenges. The InfoGlue framework (see Section 4) is presented as a specific example of a framework that embraces semantic technologies in order to support goal-relevant information processing. We suggest that an approach featuring domain ontologies, reasoning capabilities, semantic queries and semantic integration techniques provides the basis for an integrated framework for improving situation awareness in military coalition contexts.

2. Situation Awareness

2.1. Definition

Since its original conception, numerous definitions of SA have been proposed. The definition of SA is complicated by the ambiguity surrounding both the terms 'situation' and 'awareness'. Does awareness, for example, necessarily entail conscious awareness[1], and, if so then how should conscious awareness be defined? The most widely cited definition of SA is that proposed by Mica Endsley [11, 12]:

> "Situation awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." [12, p. 36]

Endsley claims that SA is a 'state-of-knowledge' that needs to be distinguished from the processes that are used to achieve that state. The processes that contribute to SA, she argues, should properly be characterized as situation assessment, rather than SA. This distinction between SA as a state of knowledge and the processes that contribute to situation awareness has caused considerable confusion in the literature, and not everyone shares Endsley's state-based view [see 13]. While state-based accounts tend to emphasize the events, systems, objects and entities that comprise the situation picture, process-oriented accounts tend to emphasize the cognitive processes on which SA depends.

Differences in the way SA is defined contribute to differences in the approaches used to enhance SA. If SA is a state then one should aim to isolate those elements of the situation picture that are critical to task performance and optimize the accessibility of those elements for end-user processing. On the other hand, if SA depends on a set of processes that are not an intrinsic part of a SA as a state, but on which SA depends, it becomes important to specify what processes are essential to SA. SA improvement, in these cases, will depend on changes in the operation of these processes to improve their potential to enhance SA.

Our approach tends to favour state-based approaches to situation awareness; however we feel that the state/process duality that has dominated SA research may be largely

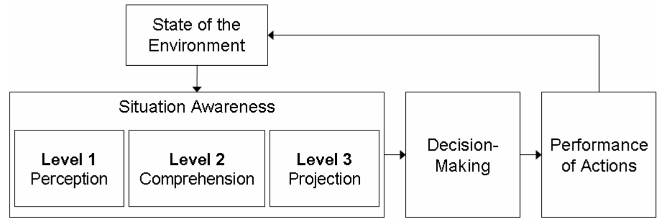

Figure 1: Endsley's model of situation awareness

unwarranted. Firstly, state-based approaches often seem to make reference to cognitive functions or processes as part of their operational definitions. Endsley's definition is, in fact, no exception here in terms of the emphasis it places on the processes of perception, comprehension and projection. Secondly, we regard the debate about state-based vs. process-based approaches as somewhat akin to the debate about conscious experience, particularly visual consciousness [14]. While it might seem appropriate to cast such phenomena in terms of particular states, e.g. brain states, O'Regan and Noë [14] instead argue that such experiences are essentially the result of an active process – a process of detecting the contingencies that exist between motor output and sensory input. We suggest that a theoretical account of SA may be somewhat similar in the sense that SA should legitimately be regarded as both a state and a process, and, as such attempts to enhance situation awareness need to consider both state-based and process-oriented approaches.

2.2. Situation Awareness Models

In addition to providing what is probably the most widely cited definition of SA, Endlsley has also provided what is, in all likelihood, the most comprehensive model of SA. Endsley's 'tripartite' model (see Figure 1) describes situation awareness in terms of three levels:

1. Level 1 SA - Perception - involves the perception of different elements (e.g. aircraft, terrain, etc.) in the environment as well as their characteristics (e.g. size, colour, location, etc.)

2. Level 2 SA – Comprehension – involves the comprehension of the significance associated with perceived elements in the environment.

3. Level 3 SA – Projection – involves the ability to anticipate the actions of elements and predict future states of the environment.

Extended versions of the model [15] incorporate a consideration of the role of limited attention and working memory, mental models and schemas, pattern matching and critical cues, ties between situation awareness and automatic action selection, categorization, data-driven and goal-driven processes, expectations and dynamic goal selection. While Endsley's model is not the only model of situation awareness [see 13], it is by far the most comprehensive available. We believe the model can prove useful in terms of identifying challenges for situation awareness research and we thus reference elements of the model as part of our

[1] Croft et al [10] have argued that the role of awareness in SA is overstated and that definitions should aim to take account of implicit or tacit knowledge.

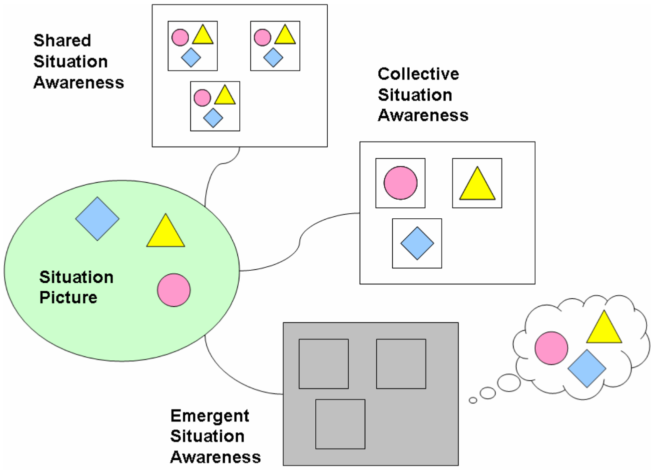

Figure 2: Types of team situation awareness

discussion about the challenges for situation awareness presented by coalition military environments (see Section 3).

2.3. Team Situation Awareness

While SA research has typically focused on the cognitive processes and the mental representations held by individual human operators, the notion of team SA (TSA) has recently attracted considerable interest. TSA is defined by Endsley as 'the degree to which every team member possesses the SA required for his or her responsibilities' [16, p. 39] and it is assumed to encompass the notion of shared SA (SSA), which typically refers to the degree to which team members have the same SA or understand a situation in the same way [17].

While most studies of TSA have centred on the notion of SSA we argue that a number of additional forms of TSA are possible within collaborative (human and hybrid) team environments (see Figure 2). These include:

1. **Shared Situation Awareness:** in this form of SA all team members have a common awareness or understanding of a situation. Each member essentially seeks to represent all aspects of a situation.

2. **Collective Situation Awareness:** collective SA is characterized by a situation in which each team member has awareness of a limited aspect of the total situation picture. No one team member has awareness of the total situation relevant to the task in which the team is engaged; rather each member focuses on one particular element or aspect of the situation – they each possess localized as opposed to global SA. In collective SA, as opposed to emergent SA (see below), it is assumed that all situation-relevant information is collectively represented by team members. Team goals are realized by patterns of communication and collaboration between the members of a team, and collectively the team has adequate SA to adaptively coordinate team-level behaviour in order to ensure the accomplishment of team goals. The awareness that each team member has of the situation may be distinct, but more likely it will be overlapping: each team member will share at least part of their understanding of the situation with another team member. Some degree of overlap or redundancy may be necessary for the purposes of communication, collaboration or cross-checking purposes.

3. **Emergent Situation Awareness:** in some team situations it seems possible to propose a third form of TSA. In this case, it may not make sense to talk of the team elements as possessing *any* level of situation awareness. One may encounter this situation in contexts where task performance is distributed across multiple nodes of an information processing network, each of which possesses relatively little representational potential. In hybrid agent teams, for example, we encounter a situation wherein some team elements may be simple software agents to which the ascription of psychological constructs or processes, such as SA, may not seem entirely appropriate. Nevertheless, we suggest that it does, in some cases at least, make sense to talk of the team as a whole as possessing global SA. Inasmuch as ensembles of relatively simple agents are able to collaboratively coordinate their behaviours to meet specific team-level objectives and deal adaptively with the exigencies of the external situation in realizing these goals, we suggest that SA (in these contexts) is an emergent property of distributed, collaborative problem solving activity.

Attempts to enhance TSA need to consider of patterns of communication and coordination between the elements of a team as well as the factors that militate against a common understanding of situation-specific information items. Given the unique role played by inter-agent communication and coordination in TSA, any attempts to enhance TSA need to consider the inter-personal relationships between team members. In general, it will not be sufficient to assume that just because the SA of individual team members is enhanced that overall TSA will be improved. Among the factors that may militate against TSA are social and organizational factors [18], and these need to be carefully considered in the effort to enhance TSA. Cultural factors can also influence the understanding team members have of situation-specific information items, so aspects of the cultural context are particularly important for TSA enhancement in multi-national coalition contexts.

3. Challenges of the Coalition Military Environment

The coalition military environment presents a number of challenges to enhanced situation awareness. This section presents an analysis of some factors that may undermine both individual and team-level SA.

3.1. Information Quantity

As discussed in the introduction (see Section 1), the quantity of information made available by both sensor systems and large-scale communication networks threatens to undermine SA because of the difficulty of locating and monitoring task-relevant information. Information quantity tends to compromise Level 1 SA in Endsley's model (the level of perceptual processing) because it becomes difficult to selectively process those elements of the information environment that directly contribute to awareness of a situation. Another problem is that information quantity may exceed the limited processing potential of individuals or teams – this is the notorious problem of information overload.

One solution to the problem of information quantity lies in an ability to rapidly identify relevant information via advanced search and retrieval processes; another relates to the ability to adaptively filter incoming information streams with respect to the information requirements of end-user agents. Semantic technologies provide a potential solution strategy here: ontologies provide a basis for representing the semantic referents of information resources thereby facilitating the search and retrieval process, while semantic queries provide a mechanism for filtering incoming information streams with respect to task-relevant information processing goals (semantic queries also enable a user to selectively retrieve and display particular types of information content based on their task-variant information needs and requirements).

3.2. Information Accessibility

Information exploitation in military contexts is further complicated by the nature of the communication network environment. Mobile, wireless and *ad-hoc* networks are likely to be a common feature of future military coalition environments, and they promise to enhance the ability of forces to disseminate information in a manner that suits changing mission requirements. Nevertheless, such networks are not without their potential problems in terms of shared situation understanding and TSA. One problem is that time-variant changes in network connectivity can result in the differential availability of nodes and their associated information resources. This can contribute to a confusing situation picture because query results executed from one location in the network need not coincide with the results of the same query executed elsewhere [19]. Moreover, the same query may return different results at different times based on the physical distribution of knowledge resources and the extent of intervening changes in network topology. Figure 3 illustrates the connectivity of two networks at different points in time. If information content is distributed across all nodes in these networks then a query that executes in a highly connected context (A) will not necessarily return the same query results in a situation where some network elements have become temporarily isolated (see B), perhaps as a result of the physical displacement of some mobile elements. These disparities with respect to the results of query execution may lead to a confusing situation picture in

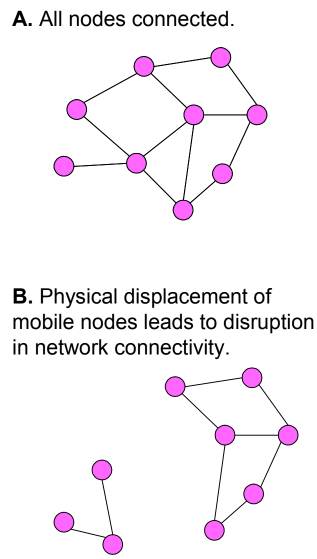

Figure 3: Changes in network topology

which TSA is undermined by virtue of the differential information content available to coalition elements based on their location in a network topology and the time at which they engage in query execution.

Strategies for dealing with this particular challenge may include the replication of information content so as to introduce redundancy into the network; however, a somewhat more intelligent approach may be provided by data charging mechanisms [20]. Data charging emphasizes the use of intelligent forward caching mechanisms to pull or push relevant data to mobile devices during periods of high connectivity in order to preserve user access to task-relevant information content during periods of network disconnection. The main challenge with data charging concerns the identification and representation of factors that influence the selection of *relevant* information. Factors such as problem-solving goals, information requirements, trust ratings (there may be little point in downloading distrusted information), access history (we may infer needs or preferences based on past patterns of information access), the features of the mobile display device (there is no point in downloading information to a display device if the device cannot subsequently display that information to the user) and the profile of the end user may all contribute to adaptive data charging mechanisms [21]. Semantic technologies might prove useful here in terms of an ability to represent information requirements and the contextual factors that drive adaptive information retrieval processes. Semantic queries could, for example, provide a mechanism for defining information requirements that drive data charging processes.

3.3. Information Heterogeneity

Information content is increasingly available in a variety of diverse forms, such as unstructured textual data, images and audio feeds. Such heterogeneity creates problems for situation awareness because situation-relevant information may be distributed across multiple resources and not all resources may be equally amenable to automated information fusion processes. The problem of information heterogeneity primarily affects Level 1 and Level 2 SA within Endsley's model: the ability to perceptually access relevant information content may be difficult if information is not presented in the right form; in addition, it may be difficult to comprehend and understand a situation if the operator is required to fuse information from multiple, disparate information resources.

Semantic technologies can assist with the problem of information heterogeneity in a variety of ways. Firstly, strategies for semantically-enabled data fusion have been explored in a number of studies [22-27], including those undertaken as part of the ITA [28]. Moreover the annotation of multimedia content can facilitate the alignment of semantic meta-data annotations with multimedia content at the featural/sub-featural level [29, 30], and this can serve as an important adjunct to information retrieval, integration and aggregation .

3.4. Goal Switching

Contemporary military operations are often complicated by the need to undertake multiple, disparate missions within the same theatre-of-operations. The challenge to situation awareness in these contexts is how to detect and represent changing problem-solving goals against the backdrop of dynamic, and often conflicting, operational commitments. When rapid goal switching is mandated by changing operational commitments then different subsets of information will need to be dynamically integrated or aggregated to support changing situation awareness requirements. Semantic integration techniques are important here, as are semantic queries that reflect and represent end-user information requirements. In terms of semantic integration we advocate an approach that emphasizes the dynamic integration and alignment of ontology components based on the nature of the problem-solving context (e.g. the task or goal at hand) [19]. In essence this approach eschews the idea of large-scale, global ontology alignment independent of task context; rather it countenances the idea that ontologies (or relevant sub-components thereof) should be dynamically aligned to reflect goal and task-relevant processing. Such capabilities rely on effective mechanisms to represent the epistemic requirements of tasks, and to prune larger ontologies in light of these requirements, i.e. to extract just those elements that are relevant for current problem-solving activity. The development of automated semantic integration processes that can support this process is a key technical challenge for situation awareness, and current approaches often require considerable degrees of manual intervention. Another challenge relates to the ability to detect and represent aspects of the problem-solving context, e.g. a change in task context or problem-solving goal. Efforts to develop solutions to this problem often necessitate careful analysis of the user's task context (e.g. via the use of goal-directed hierarchical task analysis, for example) as well as user-centred approaches to user interface design [7]

3.5. Cultural Differences

According to Endsley's model, SA involves far more that simply perceiving information in the environment; it also emphasizes the importance of comprehending the *meaning* of information in an integrated form, especially in terms of being able to understand the implications of the current situation in terms of future projected states. Such an understanding is arguably of critical significance in making operationally and strategically-effective decisions, but the process of comprehension is complicated by the vagaries of cultural difference. Firstly, situation-relevant information may be interpreted differently in different cultures and this may cause a situation to be perceived in different ways, especially in terms of the projection of current situation states into the future. Secondly, cultural differences may interfere with communication and collaboration processes (based on differences in non-verbal communication, for example) that undermine information sharing and information exchange (as discussed in 2.3, communication is a key element of TSA). Thirdly, culture introduces potential semantic differences between the meaning of particular terms and phrases. This can result in misunderstanding when the information content of messages utilizes culture-specific vocabulary elements. Command intent, for example, expresses the objectives and intentions of a commander, but cultural differences may militate against consensual interpretations of this intent. Terms that are semantically ambiguous across cultural contexts can lead to misunderstanding and confusion between coalition partners.

Semantic technologies could provide a potential solution strategy to some of the problems posed by cultural differences. Firstly, ontologies could provide a mechanism for making the meaning of information items explicit with respect to culture-agnostic frames of reference, e.g. a global, culture-oriented ontology for coalition operations. In addition, ontologies could provide the substrate for transformation processes that convert culture-specific representations of information content into formats that are optimized for consumption by another cultural group. For example, command intent may be translated into a variety of forms based on the cultural affiliation of the intended recipient. Fourthly, reasoning capabilities can assist end users with respect to the prediction of future states of the world by representing predictive contingencies in the domain of interest. These capabilities may or not may reflect culture-specific biases when it comes to causal models, but they nevertheless provide a means for exploring the temporal evolution of a situation in either a culture-agnostic or culture-specific manner.

4. INFOGLUE: A FRAMEWORK FOR CONTEXT-AWARE INFORMATION RETRIEVAL

Having outlined some of the challenges for SA presented by the coalition military environment we now present a framework for context-aware information retrieval that is grounded in the use of semantic technologies, such as

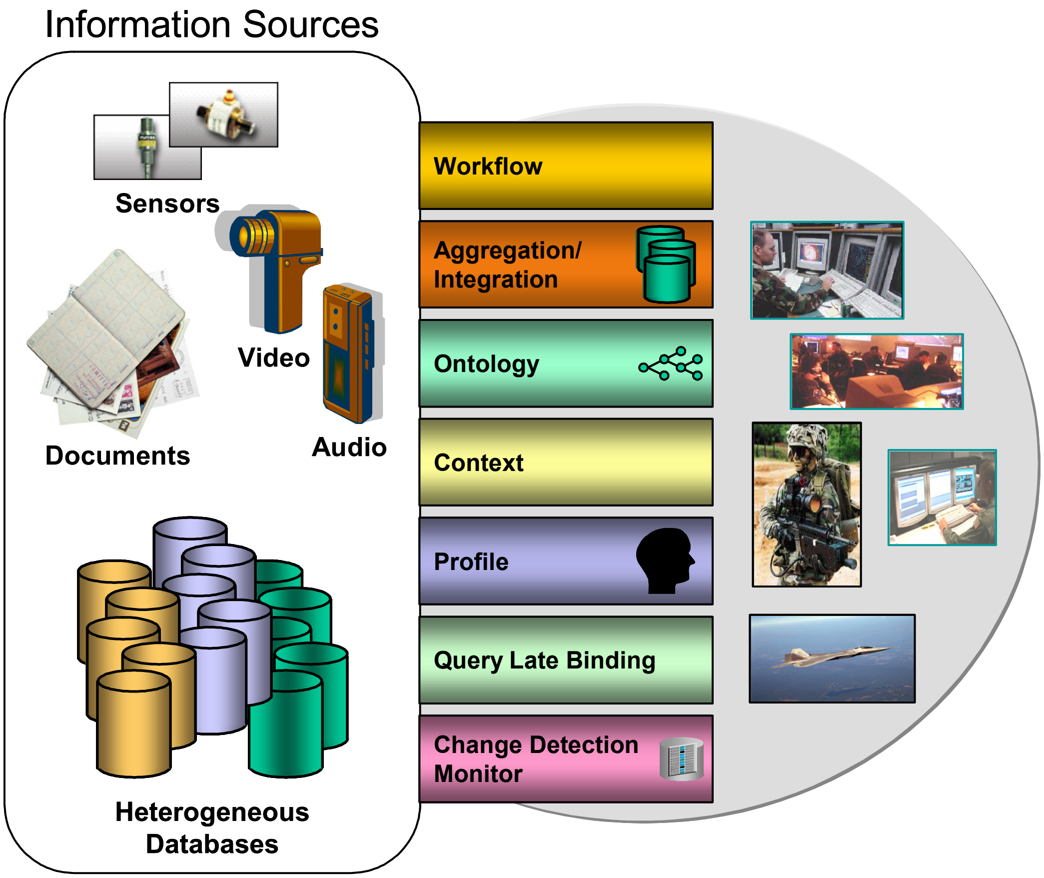

Figure 4: Major components of the InfoGlue framework

domain ontologies, semantic queries and semantic integration techniques. This framework provides an example of the type of technical approach we advocate in terms of building systems for enhanced situation awareness and it forms one of the initial outcomes of our research within the ITA. The framework we present (known as InfoGlue) is an integrated framework to support context-aware information retrieval from multiple heterogeneous information sources [31]. At the heart of the approach is the notion that information retrieval mechanisms should reflect a user's information requirements, and that such requirements are often influenced by a host of contextual factors associated with the problem-solving environment.

The InfoGlue framework (see Figure 4) is organized around five key concepts:

- **Workflow.** Of all the factors that influence information requirements, the task context is probably the most important. A process model can be used to align information retrieval mechanisms with task-variant information requirements, thereby facilitating the retrieval of task-relevant information. Modelling of the task context is recognized as a critical step in many knowledge engineering and business process improvement approaches (e.g. [32]), and the InfoGlue framework is no exception in this respect.

- **Information Aggregation and Integration.** Information is often stored in heterogeneous systems, and an information integration mechanism is therefore required to provide a semantically-uniform interface as the basis for query execution and data transformation processes. Design principles for situation awareness also mandate that relevant information is aggregated in a manner that supports goal-relevant processing. As such, data aggregation mechanisms that retrieve information from multiple sources and combine this information in the context of integrated displays are an essential element of the InfoGlue framework.

- **Ontologies.** Domain ontologies play a key role in the InfoGlue framework. Their main function is to enable enhanced knowledge management services, such as semantic search, text mining and document classification. They also provide a semantically-enriched substrate for information integration processes in the sense that the schemas of local information repositories can be aligned with the elements of an enterprise-level ontology.

- **Context.** The notion of 'context' within the InfoGlue framework targets aspects of the problem-solving environment that are not subsumed by the notions of 'workflow' and 'user profile'.

- **User Profile.** A user profile within the InfoGlue framework is an ontology fragment that describes a user's characteristics in relation to information consumption. It can include descriptions of a user's skills, interests and security classification and presentational prerequisites. It can also provide a medium for representing information about preferences for particular information sources, some of which maybe linked to culture-specific trust evaluations.

InfoGlue supports the exploitation of heterogeneous systems by relying on semantic mapping and semantic integration techniques. Mappings are first established between the schemas of specific information repositories and the elements of a global domain ontology. The mappings, once established, support a process of query rewriting wherein a semantic query expressed against the global ontology can be rewritten to match the schemas of specific source repositories. The modified query can then be executed by the query engine of specialized Commercial-Off-The-Shelf (COTS) Enterprise Information Integration (EII) systems, which retrieve information from multiple repositories. The use of COTS EII systems, in this case, capitalizes on the distributed query optimization capabilities provided by COTS products

5. CONCLUSION

This paper has emphasized a technical approach to enhancing SA that is grounded in the use of Semantic Web technologies. Military coalition environments present a number of challenges for SA and we have sought to describe these challenges with respect to conceptual frameworks for both individual and team-level SA. The definitions and frameworks originally devised for SA were largely developed in the context of single operator or small team environments and it is by no means clear, at this point, whether such notions are wholly applicable to the situation one sees in large-scale military coalitions. We suspect, in fact, that current SA models and definitions are inadequate in terms of capturing the phenomena of situation awareness in team environments, especially those that subtend culturally heterogeneous user communities, or hybrid teams comprising both human and software agents. In this paper we have presented our initial thoughts with respect to a refinement of the TSA concept, specifically we have attempted to identify a number of forms of TSA based on the extent to which individual team members share a common awareness of situation-relevant information. Further work clearly needs to be undertaken here in terms of both defining TSA and identifying the factors that affect TSA. Clearly, a whole range of socio-cultural and social psychological factors are important for coalition situation awareness, especially when it comes to inter-agent information exchange, communication and the inter-personal factors that underpin the formation cooperative alliances in *ad hoc*, mission-oriented teams.

In addition to discussing some of the theoretical issues associated with situation awareness in military coalition contexts we have also sought to identify some of the problem/opportunity areas for knowledge-based enhancements to situation awareness. Semantic technologies, in particular, would seem appropriate in this effort because they were developed to enhance information exploitation and knowledge processing in large-scale, distributed information environments similar to those seen in military communication contexts. One difference, however, between the conventional internet and emerging military networks concerns the increasing emphasis on wireless, *ad hoc*, and mobile capabilities. This transition is not, of course, restricted to military contexts - mobile and wireless devices are pretty much ubiquitous nowadays - the problem is that it is not entirely clear at present whether a set of technologies that were developed in the context of the conventional internet are still suited to network architectures that violate some of the assumptions on which the internet is based. In general we suspect semantic technologies can support coalition situation awareness, although such technologies will often need to be combined with other analytic frameworks and technical approaches, e.g. cultural analysis and data charging mechanisms.

As a means of demonstrating the role of semantic technologies in enhancing situation awareness we have focused on one particular framework which was developed in the context of the ITA programme. This is the InfoGlue framework, which provides an approach to information retrieval that is grounded in the use of semantic technologies, particularly domain ontologies, semantic queries and semantic integration/aggregation mechanisms. The further development of this framework will, we suggest, support coalition situation awareness by providing a mechanism for context-aware information retrieval that can be used to aggregate subsets of task-relevant information for the purposes of goal-relevant processing. Such objectives are at the heart of contemporary approaches to user-centred design [7] and they provide a means to align information retrieval/display functions with the task-variant (and perhaps culture-variant) information requirements of military decision-makers in coalition contexts.

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