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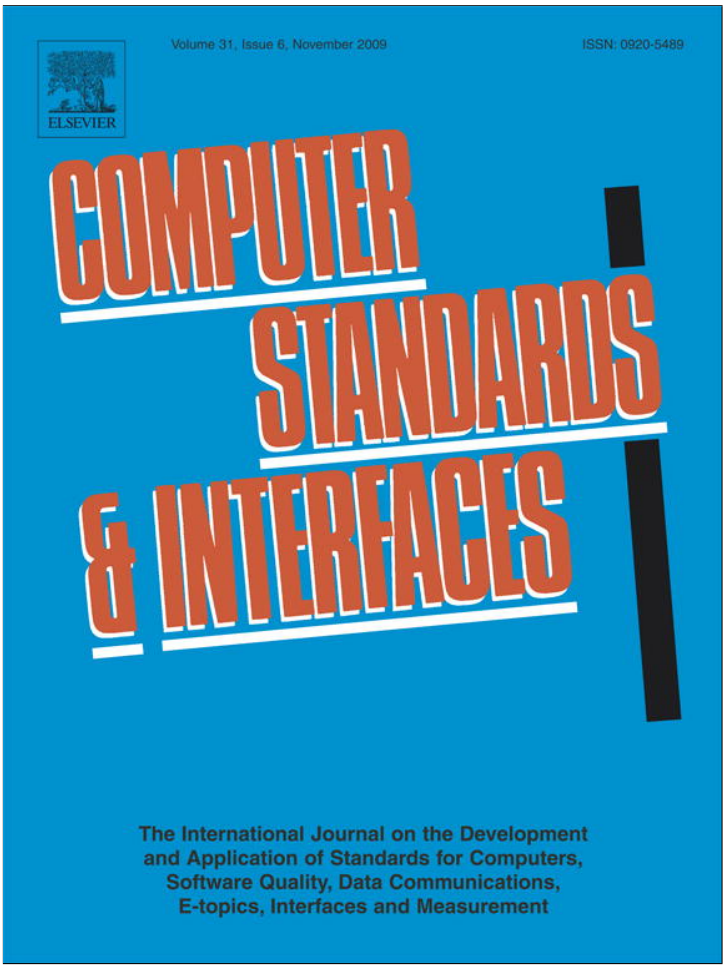

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14. ABSTRACT

Global Interoperability Using Semantics, Standards, Science and Technology is a concept that is predicated on the assumption that the semantic integration, frameworks and standards that support information exchange, and advances in science and technology can enable information-systems interoperability for many diverse users. This paper recommends technologies and approaches for enabling interoperability across a wide spectrum of political, geographical, and organizational levels, e.g. coalition, federal, state, tribal, regional, non government, and private. These recommendations represent steps toward the goal of the Semantic Web, where computers understand information on web sites through knowledge representations, agents, and ontologies. Published by Elsevier B.V., Computer Standards & Interfaces 31 (2009) 11581166

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Global Interoperability Using Semantics, Standards, Science and Technology (GIS^{3}T)

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ABSTRACT

"Global Interoperability Using Semantics, Standards, Science and Technology" is a concept that is predicated on the assumption that the semantic integration, frameworks and standards that support information exchange, and advances in science and technology can enable information-systems interoperability for many diverse users. This paper recommends technologies and approaches for enabling interoperability across a wide spectrum of political, geographical, and organizational levels, e.g. coalition, federal, state, tribal, regional, non government, and private. These recommendations represent steps toward the goal of the Semantic Web, where computers understand information on web sites through knowledge representations, agents, and ontologies.

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1. Introduction

"Global Interoperability Using Semantics, Standards, Science and Technology" is a concept that is predicated on the assumption that the Semantic Web, standards that support information exchange, and advances in science and technology can enable information-systems interoperability for many diverse users. This paper explains and recommends technologies and approaches for enabling interoperability across net-centric software systems that span a wide spectrum of political, geographical, and organizational levels and sector, e.g. coalition, federal, state, tribal, regional, non government, and private. The purpose is to share information in a common operating picture across computer systems to predict, detect, and counter terrorist threats globally. The recommendations in this paper represent steps toward the goal of the Semantic Web, where computers understand information on web sites through knowledge representations, agents, and ontologies.

Current attempts at knowledge sharing to prevent terrorist incidents are often ineffective, overly complex and too reliant on inefficient human-to-human forms of interaction that don't scale. Despite the clarion call of 9/11 and the clear analysis, recommendations, and presidential directive for information sharing, the reality is that most organizations have difficulty obtaining useful information from others. Although the leadership could do more, there are many challenges to information sharing that are hard to overcome.

A proactive approach is needed across multiple organizations, national and multi national, based on a set of simple and clear founding principles for enabling all levels of information sharing, such as the sharing of data, knowledge, and models. (See, for example, [16].) Although no single, easy solution is likely to be identified, this paper outlines a set of existing technologies and standards that could be used as an initial approach. The call for a working group and annual conference is an attempt to move the approach from words into action. Many of the technologies and standards mentioned in this paper are well known with significant communities of interest, yet most in those communities might agree that their ideas and concepts have not been as widely accepted and implemented as they would prefer.

This paper provides support for their efforts by "connecting the dots" and recommending the formation of a working group to encourage their simple and easy application. The annual conference is envisioned as a series of tutorials to teach and share practical insights and solutions. Every participant should leave with practical approaches to overlay on their current organizational practices as well as access to knowledge feeds offered by participants. The GIS^{3}T community would be encouraged to maintain a distributed interoperability test bed, a virtual set of distributed resources useful for developing ideas, papers, proposals, prototypes, and patents.

A prime example of a challenge concerning to the GIS^{3}T community is joint information-systems interoperability. For example, advances in artificial intelligence (AI) have paved the way for more comprehensive information systems integration [9], particularly at the semantic level. The branch of artificial intelligence that deals with expert system includes inference engines, knowledge bases, and

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the ontologies that support them. Another related branch of artificial intelligence involves research, design, development, and applications of intelligent agents and their interactions. This paper discusses applications of both areas of AI as part of a group of selected technologies, standards and approaches described as examples of how to accomplish the goal based on a set of founding principles. Applications of the technologies described in this paper support the GIS^{3}T vision.

The paper is organized as follows. Section 2 outlines founding principles of GIS^{3}T. Section 3 covers identifying, representing, and managing GIS^{3}T resources, including standards. Section 4 focuses on the relationship to the applications of ontology to information integration, retrieval, and other applications. Section 5 describes the Semantic Web and its original vision. Section 6 discusses semantically enabled web services. Section 7 describes the relationship of GIS^{3}T to interoperability in the Common Operating Picture (COP) and provides a discussion of coalition COP capabilities, issues and recommendations on how semantic web technologies can provide improvements.

2. Founding principles

The founding principles of GIS^{3}T are as follows:

- The purpose is to foster global interoperability and the sharing of information for detecting and preventing terrorist attacks, and for managing emergency responses to them.
- All participants should be ready to share with other participants, useful knowledge meeting the criteria below.
- Information should be generic, concise, and tiered to be widely useful.
- Information should be represented in a manner that allows computer systems to manage it using AI-related techniques of inferencing and reasoning.
- All participants should launch efforts to represent in an open standard format the knowledge of local experts and those with extensive experience or insight. (See, for example, [36,37].)
- The technologies, approaches, and tools should be decentralized, open standard and open source enabling participants to manage their own affairs yet participate efficiently in sharing useful knowledge.
- Obstacles to participation by any government, organization or individual, regardless of size ought to be eliminated.
- An open-source development model should be followed with consideration for an appropriate governance structure where all participants are equal, independent members.

3. Resources

A useful approach to organizing knowledge is to consider each "entity" a resource and then to find a simple way to represent and share the resource. This is a particularly powerful approach if an organization decomposes its systems into resources. The decomposition can be challenging because it should include not merely the obvious low-level "entities" (e.g. A sensor hit), but also the higher-level conceptual "entities" (e.g. A "threat"). The knowledge gained through expertise or experience can be useful for ensuring the definition of "entities" or resources is limited and useful.

3.1. Identifying a resource

Each resource should have a unique id so that different systems can refer to the same "entity." The World Wide Web Consortium (W3C) [47] has a standard identifier called "UID," which can be used for this purpose. A URL is a form of a UID, which also connects to the resource to a representation, so we will use a URL as a unique identifier.

3.2. Representing a resource

Extensible Markup Language (XML) is a simplified subset of Standard Generalized Markup Language (SGML). In 1998 XML was adopted as a significant WWW technology [5]. Its primary purpose is to facilitate the sharing of data across different information systems, particularly systems connected via the Internet. XML is an open standard for representing resources in a text format that can be easy for computers to understand and use. (See, for example, [34,35]).

Whereas XML facilitates access to information from different sources, it does not provide user understanding [5]. It is not as expressive as higher-level standards that are based on XML, such as the Resource Description Framework (RDF), and Ontology Web Language (OWL). All the resources represented in this proposed architecture, will be represented in at least XML format and converted to RDF or OWL. If the resource is not served in RDF or OWL format, then a Gleaning Resource Descriptions from Dialects of Languages (GRDDL) style sheet should be provided to enable the conversion.

RDF is a knowledge-representation language used in ontology engineering and in general a language used for representing information in the World Wide Web. It is intended for representing metadata about Web resources, such as the title, author, and modification date of a Web page. RDF can be conceptualized as a data model for objects (resources) and relations between them. RDF provides a common framework for expressing this information so it can be exchanged between applications without loss of meaning, and so inference engines can understand them [39].

3.3. Managing the resource

The Internet is based on a Resource-Oriented Architecture (ROA) where each "page" is a representation of an entity, e.g. A news story or a product. This architecture is called Representation State Transfer (REST). The architecture is simple, robust and scalable. The main features of the architecture are: a) everything is represented as a resource; b) all resources have a unique URL; c) resource state is maintained on the server (but not application state); and d) Hypertext Transfer Protocol (HTTP) methods (POST, GET, PUT, DELETE) are used to create, retrieve, update, and delete (CRUD) a resource.

The advantages of the REST approach are its simplicity, comprehensibility, and scalability. For example, anyone who knows how to type a URL into a browser also knows how to GET information in this proposed architecture.

Still, the Internet is mainly designed to be understood by people, not computer systems. Thus, the Semantic-Web community has made an effort to develop approaches to enable information to be represented in ways that are usable by computers. Really Simple Syndication (RSS) is a simple example of a step in the right direction, where an XML format is used to define the basic components of a news story (e.g. title, description, author). Microformats are an approach to adding extra information to html pages to allow computers to derive meaning for given types of information. The recent W3C GRDDL standard is a way to bridge the gap by offering a way to refer to a style sheet (or other mechanism) for converting XML or XHTML (with microformats) to a form more usable for deriving meaning, such as RDF.

The REST approach is recommended here along with a representation that enables all resources to be converted into RDF or OWL.

4. Applications of ontology

Ontologies enable semantic integration; any meaningful integration must initiate at the ontological level. (See, for example, [11,19,26,30–33,38,40,42].) Ontologies specify how data elements relate to other data and define relationships between data objects regardless of how they are named in disparate databases. Ontologies

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can describe concepts in different domains or world views. The same concept can have different names in different domains. Moreover, the same word can have different definitions in different domains.

Ontologies are based on concepts defined by subject-matter experts. Metadata specifications are based on one or more ontologies, which can act as filters to enhance the efficiency of information retrieval. In an expert system, an inference engine can interpret ontological relationships automatically, through its knowledge bases that instantiate ontological concepts. Referentially integral languages, such as RDF, its schema implementation (RDF-S) and OWL, are among the leading standards to support machine-readable communication of semantic information.

Ontology alignments describe the relationship between two ontologies. (See, for example, [19].) An ontology alignment between synonymous terms and some additional information, such as positional data and type of object, can indicate that the terms refer to the same object. Instance unification determines whether two instances in an ontology refer to the same physical object. From a software-engineering perspective, instance unification in ontologies is important for information-systems integration and interoperability.

A data model is a description of the entities in a system and how they are represented and interconnected. Each data model is based on one or more ontologies, either explicitly or implicitly. For this reason, any integration between data models must proceed first from the ontological level.

Data models can be represented in different formats, and are most useful when instantiated in specific tables and records in a relational database or some other type of database. The proposed architecture in this paper assumes distributed, decentralized resources, which means that a centralized ontology or database design is not appropriate. Distributed ontologies, metadata, and databases will serve among the information storage mechanisms of the resources. However, distributed XML representations that support data models should be independent of the underlying database design.

In addition to information-systems integration, ontologies can support information selection, retrieval, and fusion, including disparate data from text as well as non-textual sources such as, audio, video, and imagery [30]. This is because information retrieval is a de facto ad hoc aggregation between the information retrieved based on the search criteria and the intended use of that information in an application that may already have accumulated some data from other sources. Without using ontologies to compare semantically equivalent terms, information selection and retrieval based only on key words can be an incomplete process that misses terms that are lexically distant but semantically equivalent or closely related.

This problem can be addressed using a meaning-based index structure and domain ontologies [30], which could be important in support of coalition interoperability where terms for the same concept are likely to differ.

Another important function in command and intelligence centers of military coalitions is the Geographic Information System (GIS). The integration of GIS systems can present a significant problem for coalition interoperability, especially when new members join a coalition. This is because unique forms of semantic heterogeneity that occur in a GIS require multiple matching approaches [38]. As is the case for information retrieval, robust integration of GISs and interoperability of coalition GIS tools depend on ontology alignment. For example, common concepts can be identified in GIS ontologies based on similarity calculations involving data types from the analysis of specific instances [38].

Dai et al. describe the importance of an "invalidation certificate" as a decision aid [21]. The semantic match between attributes of different database was tested and when appropriate, an invalidation certificate was issued to the operator [21]. Validity is difficult to demonstrate reliably. Many attributes have similar but not identical definitions. Even when attributes have the same data type, differences between the meanings of attributes are not always obvious from consulting data dictionaries and other metadata. Terms in data dictionaries often are not well defined. Sometimes the data fill does not contain enough instances to validate the correctness of a match. Even in the case of extensive data-fill values for both candidate attributes where the data type is identical, the existence of common data cannot be guaranteed.

However, detecting reliably a false mapping between attributes of different databases is easier than proving that a correct mappings is valid [21]. This amounts to demonstrating a single disqualifying difference (assuming the attributes represent correct data values). In any case, a human operator ultimately can decide to accept or reject the match [21]. This approach has practical applications in schema mapping and database integration.

5. Semantic Web

The Semantic Web was envisioned as "an extension of the current Web in which information is given well defined meaning, better enabling computers and users to work in cooperation" [2,3]. The Semantic Web is based on the idea of having information on the Web defined and linked in a way that machines can use it not just for display purposes, but for automation, integration, and reuse of information across various applications [47].

The Semantic Web is about common formats for interchange of information and, most importantly, about language for defining how the information relates to physical objects. In the Semantic Web, information itself becomes part of the Web and can be processed independently of application, platform, or domain. The design and vision for the development of the Semantic Web is a layered approach depicted in Fig. 1 [3].

Semantic-Web technologies and concepts have been used in a variety of different domains to facilitate information sharing and retrieval. (See, for example, [20,26,32,39,41]).

Semantically enabled Internet-search concepts can be applied to the acquisition of information from sources such as sensors [36], Command and Control (C2) databases, commercial databases and data links from heterogeneous systems.

Many military "stovepipe" systems present a limited COP, the scope of which includes only their respective domains. These systems contain valuable information that is not integrated and that other systems cannot process because they have been integrated only for the most part at the physical-network layer. (See, for example, [13].) Although this is necessary and much effort has been made to connect these systems at the network level, this is simply not enough to provide meaningful information sufficient to support situational awareness. Each limited COP must be combined into a single-integrated picture and kept up to date in a timely manner to stay

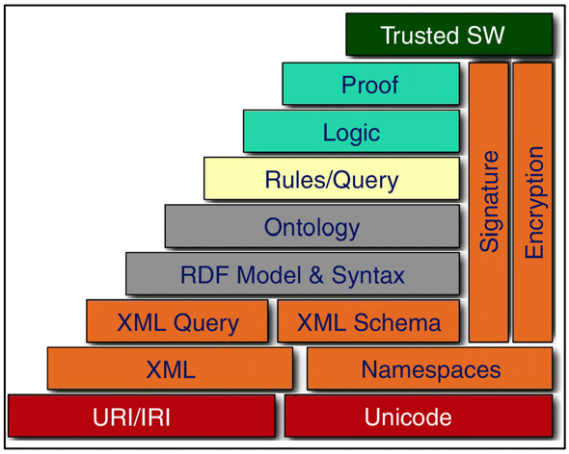

Fig. 1. Semantic web stack.

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abreast of battle-space developments [14]. In the domain of military operations, where dynamic situations require reassessment of the current problem, Semantic-Web technologies can provide the war fighter context-based information, not just vast amounts of uncorrelated and ill-defined data, via a COP of the battle space [39].

6. Semantically enabled web services

The W3C defines "Web Service" as a software system designed to support interoperable machine-to-machine interaction over a network. A Semantic Web Service is described as a web service with an internal and external description in a language that has well defined semantics. Thus, semantics enable web services to describe their capabilities and processes. Semantic markup of web services enables machines and users to understand them.

The application of semantics to web services can also increase interoperability among information systems, so that each system in a net-centric environment can "understand" what's available, negotiate for resources, and execute application logic to obtain the most relevant information for situational awareness. Currently, humans have to understand the information that is required to execute a service and to interpret the information that the service returns, which wastes valuable time [39].

A better solution is that of automatic-Web-service discovery and execution, where intelligent agents would act as brokers to send requests for service to appropriate Web services and dispatch specialized services that provide responses back to the agent according to the requested properties and constraints. With semantic markup of services at the Service Web site, what the service needs as input to execute and what it provides in return, are described in computer executable language. Thus, semantic markup of Web services provides a formal, Application Program Interface (API) for automated service execution [39].

In automatic web-service composition and interoperation, semantic markups can also use agent technology, to support automated composition and governance of Semantic-Web services. Based on user-specified mission requirements, agents can identify and select those services that can interoperate to perform some task, according to a high-level description of the task's objective. Intelligent agents also have been suggested to update the COP to provide efficient situational awareness [8,15,18,39].

7. North Atlantic Treaty Organization (NATO) Network Enabled Capabilities (NNEC) COP

The NATO Network Enabled Capabilities (NNEC) [6] "next-generation" COP, integrates various information sources to facilitate collaborative planning and decision making by providing context and a common relevant understanding of the battle-space situation to all players in the operational network [39]. In this context, the application of Semantic Web technologies can enhance future COP capabilities, by providing greater interoperability at the semantic level.

For example, in the NNEC, situational awareness is paramount and the information on which it depends can be realised only when data can be aggregated into knowledge in a timely manner, thus leading to better decisions. Information on which decisions and actions can be based is critical to successful operations. Decision makers must know what, when, where, and why information is needed [39].

Most importantly, information systems that enable a relevant COP must work not only from shared networks, but also from the information contained in their operational databases. Data obtained via sensors and tactical data links must be integrated at the semantic level to provide a semantic-interoperability layer for information aggregation that can be exploited by end-user web services, and intelligent agents [39].

Like GIS^{3}T, the NNEC next-generation COP can be realized in part by the application of semantic-web technologies to enhance capabilities.

7.1. COP capabilities

To meet information needs of operational commanders, data and services available in the network must be composed to create a COP. The traditional COP is defined [28] as "a single identical display of relevant information shared by more than one command." The COP capability can be defined in more detail, as the ability to display on a single screen integrated views of the maritime, air and ground pictures, enhanced by other tactical data, such as theatre plans, assets, intelligence and logistics information [23]. The purpose of the COP capability is to provide a comprehensive view of the battle space across all echelons, thereby enhancing situational awareness and the decision-making process across the military command-and-control spectrum. The COP is a military enterprise-information system supporting operations throughout the command structure [39].

COP also has been defined not as any one information system, but as a tool that integrates various information sources to facilitate collaborative planning and decision making, by providing context and a common relevant understanding of the battle space situation to all players within the operational network [39]. The COP is not just a static display but rather, the essence of the COP is the information dynamic behind it, and the communication and collaboration mechanisms that provide situational awareness. This leads to the discussion of the first of several COP issues [39] described in the next section.

7.2. COP issues

7.2.1. Data fusion and integration of information from heterogeneous systems

7.2.1.1. Discussion. Several COPs provide situational awareness to the operational users in their Community Of Interest (COI). The majority of these COPs obtain and display data from a variety of sources. Integration techniques and products have the difficult mission of reconciling the data differences between various systems whenever those systems need to interact. This is the case with respect to command and control and information systems, which present a common operational picture to provide situational awareness. Efforts are underway to address the issues involved in data integration and fusion. Semantic technologies, such as ontology engineering to create cross-domain understanding can support these efforts.

The heart of the problem is the reconciliation of both the data syntax and information semantics. When applying Web technologies to the integration process, the initial application of XML to the data enables users to understand the syntax. However, annotating the data with XML falls short of providing any association of meaning to the data. Context awareness is necessary to determine if the information is relevant to the current situation. Additionally, users still need to read and interpret it before any useful actions can be based on it. One cannot assume a universal meaning for any kind of information, from data elements to models, unless it is has been standardized and has been defined in the same way for all information consumers.

7.2.1.2. Recommendation. Use RDF to annotate the data and make them available to computers for processing. Use OWL to extend the RDF syntax for ontology development to specify domain knowledge and relationships. Use formal logic in support of drawing inferences, and intelligent-agent technology to discover, interpret, combine, fuse, integrate, and act on information from multiple sources. Agents rely on structured sets of information and inference rules that enable them to "understand" the relationship between different data resources.

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Agents don't understand information the way humans do, but they and the ontology they use can be configured to have enough information to make logical connections, recommendations, and decisions.

7.2.2. Dynamic tailoring capability

7.2.2.1. Discussion. In a highly distributed information environment, a single COP display might remain appropriate if the information remains static for periods of time or the distribution of information moves hierarchically. However, a single identical display will create its own problems when the COP becomes a type of real-time-enterprise information system supported by a continuous-data environment. Single identical displays are less useful than displays created dynamically for specific missions and domain views of the battle space. Collaboration capabilities allow users to tailor COP displays and still maintain common, relevant aspects of the operational picture [29]. A real-time environment significantly increases the COP's value if the user can define and tailor the views dynamically [29]. The successful COP of the future will have a dynamic tailoring capability to support future planning requirements and real-time operating requirements.

7.2.2.2. Recommendation. To tailor the COP view to one that supports the current mission, an ontology must be created for the area of interest and in the domain of interest. Intelligent agents could use this ontology for information discovery via selection of the most appropriate web service to furnish the detailed information. For example, suppose a user wanted a view of a certain area in which a helicopter would perform a rescue mission. One key element in scheduling the mission would be weather forecast. Agents could locate available weather services, search for various relevant results, compare the results, and finally, determine which one was most reliable and/or useful for that region.

7.2.3. Multi-level security domain COP

7.2.3.1. Discussion. The aggregation, fusion, and integration of data across multiple security levels and domains are critical for war fighters who must monitor, assess, plan, and execute mission-critical operations. Issues and solutions must be identified for a multiple-security-domain COP, to which non-NATO coalition partners, non-military bodies and public/open sources can contribute data. Coalition partners, non-military bodies and public/open sources also need to access data appropriate to their operational classification level.

7.2.3.2. Recommendation. Implement Guard-based cross-domain solutions to contribute to the mission need, with rule-based inspection and multi-level security connectivity to facilitate dissemination of a rapid, dynamic, and fused COP. Use OWL to specify security tags in an ontology to ensure that the security level of data is identified properly. Use intelligent agents or automated security-policy constraints to determine access rights. When access rights are determined, agents can extract and release appropriately classified composite data to multiple security domains based on Communities of Interest (COI).

7.2.4. Information assurance and data pedigree

7.2.4.1. Discussion. To make good decisions war fighters must have confidence in the reliability of their information. Data pedigree is important to users who need to assess the reliability of data [9]. Although the pedigree of the data is of utmost importance to commanders who need to make decisions on the basis of these data, the pedigree information often is not available when messages with important data are received. Several issues associated with pedigree metadata have emerged, such as automation, confidence levels, trust, completeness, and what to include in the pedigree content [12]. Today, maintaining extensive pedigree metadata is too time consuming to do manually, so it is not done. Automation is needed to capture, process, and validate pedigree information [12]. Trust of pedigree information is important to commanders who must use these data in the decision process. Commanders demand pedigree information to assign a trust level to each data-fusion product involved in situation and threat assessment. Metadata describing pedigree need to be available in command and intelligence centres together with the data they support. For example, intelligence information is important with respect to the degree of trust that is assigned to the pedigree metadata.

7.2.4.2. Recommendation. The certification of pedigree metadata itself must be automated to be useful [12]. For example, software agents are needed that automatically modify derived or processed data and their pedigree descriptions when information about the source changes. This automation is necessary to achieve referential integrity among data and metadata. OWL could be used for annotating the pedigree of metadata information during ontology development, such as the reliability of past performance of the Maritime commercial shipping sources. Agents then could use this information to select the best source of information for the given situation based on the pedigree metadata.

7.2.5. Knowledge management

7.2.5.1. Discussion. A definition of the word, knowledge, on which everyone can agree may not be available [24]. For example, Davenport and Prusak define knowledge as “an evolving mix of framed experience, values, contextual information and expert insight that provides a framework for evaluating and incorporating new ideas and information.” Webster's dictionary [46] lists many definitions of the word, knowledge, some of which pertain to information systems. For example knowledge can be defined as “the sum of what is known: the body of truth, information, and principles…” From these and other definitions [7,16], knowledge clearly results from carefully selected data and their relationships aggregated at a higher level of complexity than simply a collection of data elements. Knowledge is the result of insights and a body of truth requires facts, assertions, and structures consisting of multiple data elements, for example, declarative statements. Knowledge goes beyond the data level to include a mixture of concepts and the relationships between data elements, or even data sets. Thus, the notion of complexity is a key distinction between data and knowledge [7].

Knowledge management is directly related to providing a meaningful COP, because it is essential to timely access of information in the context of the current situation. One type of a knowledge base is a state of information that consists of a collection of rules, axioms or assertions structured according to an ontology and a knowledge representation that allows knowledge to be stored explicitly, and from which conclusions can be drawn using an inference [7], [16]. A knowledge base is based on one or more ontologies that define data concepts and the relationships between them [16].

7.2.5.2. Recommendation. Develop ontologies to cross reference and organize the concepts contained in information across multiple information systems and domains. This will pave the way for intelligent agents to locate information and reason on it to determine information that is required to meet mission-planning requirement.

For example, large knowledge bases often have axioms that pertain to many different contexts and subject areas. For information comprehension, organization, integration, and maintenance, the knowledge base can be divided into sections that sometimes are

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called microtheories, partitions, or domains. In fact, a microtheories in a knowledge base may be detailed enough to constitute models, in which case the knowledge base may serve as a precursor to a model base [16].

Axioms that are true in one domain may not be true in another [16]. For example, in the domain of Navy ships, nm is a unit that is used in the measurement of long distances that ships travel. Here nm means "nautical mile" whereas in the domain of molecular spectroscopy, nm means nanometre, a measurement of wavelength [18]. To cite another example, in a microtheory about zoos, elephants do not fly, but in a micro theory about children's stories and fantasies, they do [18]. The apparent contradictions are resolved by the use namespaces. The axioms of one domain are not used together in the same line of reasoning with axioms from a totally disjoint domain. For example, it is very unlikely that both uses of nm would appear in the same application. Even more unlikely is the idea that zoo keepers should ever need to concern themselves with elephants that fly [18]. Clustering of similar information in both databases and knowledge bases lends itself to better error detection and the resolution of semantic inconsistencies [18].

7.2.6. Data integration and interoperability across joint and NATO coalition military domains

7.2.6.1. Discussion. The aim of data integration is interoperability [7], and the aim of interoperability is interoperation. A keyword search on the internet yielded over four million pages of definitions of the term "interoperability," including but not limited to definitions that pertain to military information systems. Several of the most germane definitions are discussed here [4,25,27,39].

For example, interoperability can be defined as the "ability of two or more systems or components to exchange information and to use the information that has been exchanged" [27]. In communications systems, interoperability can be defined as the "capability to provide successful communication between end users across a mixed environment of different domains, networks, facilities, equipment, etc. from different manufacturers and/or providers" [25]. This definition refers to communication between end users or between an end user and a service provider [29]. More specifically, data interoperability can be defined as the ability to reuse data from another information system without any intermediate transformation and human intervention [39]. This ties in with the definition of interoperability in [4], which is "the ability of a system or a product to work with other systems or products without special effort on the part of the customer." In both [25] and [4] the emphasis is on back-end automation that obviates the need for the user to perform explicit integration of disparate systems.

The US DOD [22] and NATO define interoperability as: 1. 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. 2. (DOD only) The condition achieved among communications-electronics systems or items of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users. The degree of interoperability should be defined when referring to specific cases.

Semantic interoperability has been defined as agreement among separately developed systems about the meaning of their exchanged data [43]. Semantic Interoperability also has been defined as the ability of two or more computer systems to exchange information and have the meaning of that information accurately and automatically interpreted by the receiving system [1].

Semantic heterogeneity cannot be resolved fully in any information of arbitrary size because a total solution to the problem of semantic integration is computationally intractable [13]. This is why today's networks do not address semantic interoperability; they simply provide the connectivity that enables other software to be used to improve semantic interoperability. Even if semantic interoperability could be achieved technically, in many cases it is not even attempted [9] because of political and economic obstacles. That not withstanding, interoperability can been achieved at the coarser levels of granularity, such as the platform and even the syntactic level in some cases [10]. However, if a common, integrated land, air and maritime ontology were available to the joint and coalition community, it could support the resolution of semantic heterogeneity in the COP so that a partial solution could be achieved consistent with the application of available resources. (See, for example, [17].)

To cite a hypothetical example of the need for a common ontology and semantic interoperability in a joint environment, an intelligent agent could send an alert to the COP regarding a damaged "bridge." Upon receiving the alert, an army commander might want information about the materials (e.g. wood, concrete, steel), design (e.g. suspension type), and structural integrity of the "bridge" to determine whether or not the bridge could support the weight of tanks and other vehicles in convoy.

In contrast, a naval commander would want to know whether the damage was to the "bridge" of a ship (either own ship or another in the battle group). If the "bridge" were a fixed, land structure designed to support vehicular traffic, the naval commander concept of and interest in the "bridge" still would differ from those of the army commander. The structural integrity of a land bridge spanning, say, a river would still concern a naval commander who may be tasked to navigate the river during the course of a mission. In this case, the naval commander would want to know whether any part of the damaged structure would constitute a hazard to navigation and whether *any* vehicle (not just tanks) could pass over the bridge without causing it to collapse.

With the development of cross-domain ontologies, agents can provide force protection and support to detect, monitor, assess, characterize, correlate, and analyze events in particular situations of interest and to and issue warnings about threats. Thus, intelligent agents that monitor situations in the battle space to issue alerts can use an integrated joint and coalition ontology to clarify who should receive these notifications.

7.2.6.2. Recommendation. Use ontology and knowledge engineering to develop cross-domain ontologies to support the use of intelligent agents in tasks designed to discover and fuse information in a timelier manner.

Thus, ontologies are very important to information-systems integration. Therefore, information bases, including databases, knowledge bases and model bases, and the metadata that describe them, should be designed to express clearly the ontology or group of ontologies from which the information base was derived.

7.2.7. Support for adaptive planning and execution

7.2.7.1. Discussion. The COP must enable adaptive planning across planning horizons to achieve coherent, systemic effects. In the future complex information systems will assist military planners, by anticipating future enemy Courses of Action (COA). A transparent, tailored, integrated COP supports this anticipatory function. By identifying and generating options, anticipatory planning can streamline the decision cycle.

7.2.7.2. Recommendation. The emergence of intelligent, agent-based, adaptive software greatly improves military capabilities at the operational level by providing decision support for both planning and execution. Agents that continuously monitor the events in the operational environment can provide information for staff planners to conduct threat analysis, terrain analysis, asset scheduling and tracking, route planning, logistical planning, fires coordination,

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communications planning, force protection planning, and coordination with multi-national allied forces [15].

Continuous sensing of the battle space; a fundamental reordering of information distribution; and, integrated reasoning are needed to support operational users in the planning processes. Use of adaptive intelligent agents could be employed to monitor the battle space to support logistics operations. For example, just as the United States Forest Service makes use of real-time weather data in forest fire simulation models to anticipate and plan by adjusting assets, an agent could monitor real-time weather data in the area of operations and provide recommendations on the best time for airlift operations or supply deliveries.

8. GIS^{3}T use cases

A Purpose-Centered Design (PCD) approach is recommended. This begins with User-Centered Design (UCD) where the users' activities are analyzed to determine roles and tasks with an eye toward possible improvements and efficiencies. This is similar to knowledge engineering. Some improvements may be incremental and some may be transformational, although initially which is which is not always apparent. From this analysis, prototype systems are designed beginning with low-fidelity (e.g. paper) to high-fidelity (e.g. software) prototypes to help plan required and desired upgrades.

Each prototype is reviewed with users in usability studies to gather feedback and determine the emerging or changing requirements. Each rapid spiral includes knowledge engineering, followed by prototype development, followed by usability testing, all in a few weeks time. The advantage of the approach is that the system develops to the users' requirements. Often systems that are designed and developed in this manner become unique and unexpected when compared to the original stated requirements. The truly useful "purpose" of the system is discovered in this process. When this purpose is understood, the system can be reused wherever that same purpose is a valued goal. From this perspective, "UCD" may be a poor choice of words. The system is not designed for only a specific group of users. Instead, the system is designed for a purpose that is elucidated by the process. The system can be applied to any group of users who share that same purpose.

PCD is appropriate for achieving interoperability because: a) information is gathered to be represented and shared; b) an important and unmet "purpose" is uncovered which helps elucidate the problem and its solution; and c) a prototype system is developed, which can be a resource for others.

9. Assessments

Most decision makers rely on the assessments of others, rather than on raw data that pertain to their specific situation. In fact, what often appear to a decision maker as "raw" data are actually someone else's assessment. An assessment is a person's opinion of something, often based on previous fusion or analysis of that entity or related entities, incorporating the person's experience, expertise, confidence, and current knowledge. Perhaps an assessment could also be an expert system's "opinion" of something, if that system were based on human knowledge.

In certain contexts everyone is a decision maker in that everyone must make certain decisions in completing work assignments. Everyone relies to one degree or another on the assessments of others and passes these assessments them along to colleagues, supervisors, and other decision makers. Most management philosophies note that people are the "resources" most valuable to an organization. If this is true and if everyone is a decision maker on some level, the method to represent and share assessments is crucial to success. That not withstanding, often assessments are represented and shared in inefficient, time-consuming, and unproductive ways. For example, assessments may appear in e-mails, briefs, white papers, blogs, phone calls, video teleconferences and many other forms. Perhaps the primary dreaded form of sharing assessments is "meetings." The literature is replete with complaints about the inefficiencies of these human-to-human forms of communication [44].

Scaling our sharing of assessments to the entire enterprise is problematic. Most traditional forms of communication (meetings, phone calls, email) don't scale well. Scaling is really about visibility. We must be "visible" to each other before we can share our assessments.

Time is a valuable resource that is squandered indiscriminately, ineffectively, and frequently by using most traditional forms of sharing assessments (briefs, meetings). Even Web Logs (BLOGs), which scale well in terms of visibility, do not scale with respect to time. The goal in sharing assessments should be to share as widely as possible, but as quickly and efficiently as possible. Emphasis should be placed on quickly getting to the point. Most decision makers do not have time for anything more than that. For assessments to be widely usable, they must be as generic as possible. No one can be an expert in every domain. However, the potential to share information should be available to all.

Similarly, the assessments should be tiered to be useful. In general, the level of the assessment should match the level of the decision maker. For example, high-level decision makers need high-level assessments. However, even a high-level decision maker may want to "drill down" and may require the knowledge at the lower level to be visible in similarly tiered assessments for all the reasons discussed above (efficient, generic, valuable resource, etc.).

GIS^{3}T will look closely at how to represent and manage assessments. Useful global interoperability may be enhanced most effectively at the various levels of assessments, since managing and sharing assessments today is done inefficiently, not withstanding the fact that everyone uses them to make decision.

10. Tools to improve coalition interoperability

GIS^{3}T is focused on open-standard, open-source tools that can be shared freely. No particular set of tools is required; however, some examples of good tools are summarized below.

A set of semantic tools that includes Protégé, JENA, Pellet, and JESS, is needed for representing and using knowledge in open-standard formats (XML, RDF, OWL). Protege is a tool for developing ontologies. JENA is a software architecture for managing knowledge. Pellet is an inference engine and JESS is a rule engine. Each of these tools represents a class of tools. The tools represent a current capability that is largely open and that can be used as a foundation for successful GIS^{3}T development.

A tool called NESI, which is used for net-centric compliance in the DoD, contains an important governance model and guidance structure similar to assessments. Engineers should consider this tool's structure in developing the capability for GIS^{3}T. An example tool used for managing assessments in a tiered, efficient way is the Knowledge Web (Kweb) [45], which is good candidate tool for assessment sharing in GIS^{3}T.

A tool for generalizing queries based on an ontological model could provide more accurate and complete search results, as well as better interoperability for international coalitions, such as NATO. (See, for example, [30].)

A tool for GIS integration based on the algorithms described in [38] could be particularly useful to NATO for merging GISs across a wide variety of countries and jurisdictions.

11. Conclusions

GIS^{3}T is a nascent effort to address global interoperability of systems for detecting, preventing and managing terror threats.

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The focus is primarily on representing and sharing knowledge across joint and coalition communities, including assessments, using semantic knowledge. The recommended approach is an open-source style working group, tutorial conference, and ongoing interoperability test bed. The benefits to participants are shared knowledge, practical approaches to knowledge sharing, and shared development.

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