COMMAND AND CONTROL ONTOLOGY

Guest Editors

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Editorial

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Biographical notes: Andreas Tolk is a Professor of Engineering Management and Systems Engineering at Old Dominion University, Norfolk, Virginia. He holds a PhD in Computer Science from the University of the Federal Armed Forces in Munich, Germany. His research focuses on interoperability and composability challenges in system of systems and modelling and simulation-based systems engineering. He contributed to the NATO Code of Best Practice for Command and Control Assessment and supports the technical activities of NATO's Research and Technology Organization, in particular the panel for Systems, Analyses, and Studies and Information System Technology, as well as the Modelling and Simulation Group. He has edited books on complex systems in knowledge-based environments and intelligence-based systems engineering.

Barry Smith is a Professor at the Departments of Philosophy, Neurology and Computer Science and the Director of the National Center for Ontological Research and of the Center for Brain and Behavior Informatics at the University at Buffalo. His pioneering work on the science of ontology led to the formation of the Open Biomedical Ontologies (OBO) Foundry, a set of resources designed to support information-driven research in biology and biomedicine. He is the Principal Scientist of the NIH National Center for Biomedical Ontology and a Scientific Advisor to the Gene Ontology Consortium and to a number of other ontology development initiatives in the areas of biomedical research and intelligence, defence and security.

Intelligent defence support systems are confronted with the need to manage ever-increasing floods of data in a way that raises significant challenges because the data are described and presented using different terminologies and formats. How, on this basis, is it possible to reach a common understanding of the information content of these data among people and software agents? How is it possible to ensure that domain knowledge is reused in consistent fashion in a way that makes this information available for integration and analysis? How can we support the identification, selection, composition, and orchestration of services based on such diverse data providing homogeneous support by a service-oriented architecture?

One answer to these and a series of related questions consists in the creation of ontologies – most often in the form of controlled, structured vocabularies – which are designed to provide a well-managed set of terminological resources to allow consistent description and analysis of heterogeneous bodies of data even where these data derive from independent sources.

Briefly, the information technology strategy to enable homogeneous data interpretation despite a variety of heterogeneous data descriptions and formats is one according to which terms from common ontologies – or corresponding internet addresses of the logical resource – are used to describe (or 'annotate', or 'tag') data in databases. The underlying assumption is that because common terms are used to serve as tags the data described become more 'easily accessible' and more 'easily retrievable', as homonyms and synonyms are significantly reduced.

Ideally, ontologies are structured in two ways. First, their constituent terms are defined, using a logical language such as the W3C standard Web Ontology Language (OWL). Second, the terms are linked together by means of asserted relations such as is_a and part_of (as in tank is_a vehicle, tank has_part caterpillar tracks) which are also logically defined. Definitions of terms and relations support consistency in use of the ontology by the human beings who apply them to the description of the data. But they also allow computers to exploit the resultant logical structure of the ontology.

The logical resources of the ontology can then be used to link data algorithmically, to reason with the data, and also to search for and visualise the data, using an expanding range of ontology-based software tools.

Benefits of such an ontology approach include:

1. The possibility of incremental adoption – integration and analysis becomes possible even if only subsets of the data have been subject to annotation.
2. Distributed realisation – the strategy can be implemented by multiple different groups working on different portions of the data, provided only that the same ontologies are used for annotation, thus enabling a plug and play approach to integration of data modules that are being worked on independently.
3. Net-centricity – ontologies provide the foundation for improved visibility, accessibility, and understandability of data and services within the framework of the net-centric data strategy.
4. Maintaining authenticity and provenance of the data – the strategy is one of data enhancement through ontology-based annotations; the data themselves are not changed by the process of annotation.
5. Integratability, interoperability and composability – the ability to integrate data from disparate sources (integratability), make data available for use across the system borders (interoperability) into an internally consistent and properly formatted package with consistent interpretation (composability).
6. Effective coordination across a large population of COIs – as more and more groups use the same ontologies to describe their data, this data itself becomes more highly valuable, creating positive network effects leading to larger numbers of users of the ontologies, and thereby still higher value of data.

7 Flexibility – ontologies can be easily modified to incorporate new data sources, data types, or data formats.

8 Communities of interest – get people to own these things, incentivisation – will identify terms to go into the ontology, identify authoritative data sources, and contribute to governance.

The resulting service-oriented architecture is a lightweight, scalable, secure, and deterministic solution. It should be pointed out that deterministic does not imply that uncertainty cannot be captured; it just ensures that ambiguities are expressed using unambiguous terms, i.e., uncertainty and vagueness are still expressed, but that is done in well defined and common terms. The vision is that completely standards-based, the architecture requires minimal development and configuration resources. This solution leverages existing components, allowing both a services oriented architecture and semantic processor available on day one without software development.

Service-oriented architectures are inherent in a number of products and specifications and need support by ontological means, as shown earlier in this editorial. Using a best-of-breed approach, the chosen architecture can reach the point where it has large acceptance within both the defense authorities, such as departments or ministries of defense – and the international commercial installed base. Moving in the same direction as the rest of industry allows the leverage of parallel developments in other areas. It can also bring advantages in resource acquisition by allowing reuse of tested solutions.

To serve data integration these ontologies must satisfy common principles of ontology design in such a way that they form part of a single, consistent network. But what should these principles be, and how should scientists and institutions with ontology needs be incentivised to adopt them? And, of particular interest for readers of this journal, how can these approaches enable better intelligent defence support systems?

Resulting questions requiring research in this domain are: How can we use the recent developments in information technology to effectively and efficiently support command and control (C2)? Why did we decide to collaborate on a special issue on command and control (C2) ontology? Why is it time to professionally address these challenges?

Within the USA, a current project is targeting to develop a common C2 core ontology (C2CO), which is envisioned to become a common controlled vocabulary to describe the C2 data needed for operational purposes, following the strategy of maximal realism: seeking not another data model, but a reality model that captures the perception of the C2 community. C2CO shall be based on military doctrine, using common terms used by the warfighters themselves in their manuals. In addition, it shall reuse operationally relevant data and data exchange models, such as the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM), and also on related Federal Government and Army initiatives such as the universal core (UCore) and UCore semantic layer (SL). The idea behind these efforts is to maximise reuse and facilitate migration of legacy systems without sacrificing consistency.

How can this be accomplished? The best way is by being precise and unambiguous when the terms of the C2 ontology are defined, which requires formal approaches. Gruber (1993) defined an ontology as the formal specification of a conceptualisation. In our view, an ontology is more than a controlled vocabulary or dictionary: an ontology defines the terms as labelled related structures resulting in machine-interpretable definitions of the different types of entities in the domain and relations among them. This allows the application of automatic reasoners to check consistency, allows for intelligent search, and generally supports the application of intelligent software systems (Musen, 1998), may perhaps even allow intelligent systems engineering (Tolk and Jain, 2011).

But why is this currently of interest to the defence community? How can this improve C2? C2 is defined by the field manuals of the armed forces and generally understood as giving tasks and orders to direct subordinated forces to fulfil a mission assigned by the superior force. Two factors made these endeavours more complicated:

1 As a rule, military operations are no longer conducted by one nation. This results necessarily in the need to orchestrate different understandings. Sharing common understanding and making assumptions explicit becomes pivotal. Furthermore, unity of command is unlikely in multinational operations, so that additional coordination efforts are needed.

2 Furthermore, military operations are conducted increasingly in orchestration with non-military organisations. Alberts and Hayes (2006, p.32) observe that generally C2 is about "focusing the efforts of a number of entities (individuals and organisations) and resources, including information, toward the achievement of some task, objective, or goal." This requires that the mission as well as the metrics to measure success needs to be defined and distributed commonly and unambiguously, which requires the rigor provided by ontological structures.

The need for C2 ontologies can directly be derived from these observations. However, it would be dangerous to see ontologies as silver bullets that automatically provide solutions. Conceptually, each ontology is limited by the domain understanding of its developers. That is why approaches in which the ontology is developed within the community are preferable to solutions where only a small group defines an ontology that is after-the-fact handed over to the community. Technically, ontologies as used here are implemented on computers, and therefore are ruled by the constraints of computability. The developers often have to compromise between expressiveness and computational complexity as well as between versatility and simplicity.

The application of algorithmic means in support of warfare is not without dispute, as in particular the recent discussion on the usefulness of effect-based operations shows [Gregor, (2010), p.102]: the use of mathematical methods for predicting and measuring effects shows a trend toward using metrics to assess the essentially unquantifiable aspects of warfare that reinforces the unrealistic view that warfare is a science rather than an art and a science. As the US Joint Publication 1 (DoD, 2009) states: "War is a complex, human undertaking that does not respond to deterministic rules." However, this cannot be an argument against the use of ontological means but in favour thereof. Carvalho et al. (2010) show how to use probabilistic ontologies in support of situational awareness under uncertainty.

In order to highlight the depth and breadth of the emerging approach to enhancing C2 support by intelligent defence support systems using C2 ontologies, the *International Journal of Intelligent Defence Support Systems* has dedicated this special issue to this topic. The papers published in this special issue are the result of a rigorous selection process and highlight several aspects and challenges when dealing with C2 ontologies.

We start with the operational viewpoint that always should be the focus of academic research: what is the sponsor's need and problem. In the paper 'Creating an extensible command and control ontology', Lieutenant Colonel Bill Mandrick uses his operational knowledge of the domain and his technological knowledge of ontological means to show opportunities and constraints of ontological support to current day defence operations.

Another application example is given in great detail by Chris Partridge, Mike Lambert, Mike Loneragan, Andrew Mitchell and Pawel Garbacz is described in 'A novel ontological approach to semantic interoperability between legacy air defence command and control systems'. The authors describe their approach and generalise the findings for the broader application domain.

A focus on multinational operations and the migration of legacy data standards, in case of this paper the JC3IEDM developed by an international expert consortium, is given in the third paper on 'Defining C2 semantics by a platform-independent JC3IEDM' by Michael Gerz and Olivier Meyer.

Finally, Kevin Gupton, Curtis Blais and Kevin Heffner evaluate the 'Management of C2 data standards with modular OWL ontologies' showing a possible way forward to utilise ontological means to support homogeneous support based on heterogeneous support models.

The ultimate goal of all these efforts described in the selected papers is not to generate 'yet another point solution in time' in form of one solution that every participating partner is enforced to use, but to utilise the ideas of the semantic web to meaningfully integrate solutions with each other based on a common agreement on the meaning of data within each system. When departments or organisations create their ontology, they usually base their work on localised needs and terms. The overarching C2 ontology can therefore not be a local ontology. It uses solution specific views to map between legacy sources and solutions containing similar information using different ontologies. As such, it initially results from bottom-up contributions of relevant part-solutions that are aligned and harmonised by a common government. This endeavour does not only avoid double work, it is also an obvious advantage to minimise the number of ontologies that are being constructed and at the same time maximise their mutual consistency (Smith and Ceusters 2010). All papers focus on different aspects of this underlying vision.

In summary, this special issue summarises not only the current state of the art, it also contributes to establishing a research agenda to address the challenges of professional C2 ontology development by the community. The operational needs and requirements must be communicated and documented and developments must be aligned and federated to provide soldiers with the best support possible to conduct the tasks.

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