Ontologies for Rapid Integration of Heterogeneous Data for Command, Control, & Intelligence

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1 Introduction

Increasingly Command and Control (C2) systems require the ability to respond to rapidly changing environments and intelligence. C2 systems must be agile, able to integrate new sources of information rapidly for enhanced situational awareness and response to real-time events. Data from varied sources across the world must be integrated and transformed into knowledge that can be leveraged. Machine-to-machine capabilities are also increasingly necessary to accomplish mission goals. To this end, we developed ontologies and rules to address emerging mission needs. We have found that ontologies and rules offer a powerful tool for rapid enterprise integration. With these, we were able to integrate new sources of data within hours, instead of weeks or months as with traditional software development methods. Our work is being showcased at the Joint Expeditionary Force Experiment (JEFX) 2008 for its quick integration of data into usable intelligence-fed C2. This paper describes the use case, the ontologies used to model the use case, and how they support rapid, enterprise integration of C2 and intelligence information, and our prototype Semantic Environment for Enterprise Reasoning (SEER).

2 Use Case

Initially our research focused on a military C2 domain with a supply convoy moving through an unsecured area. Figure 1 depicts a convoy moving north along a primary route, approaching the location

Figure 1. Convoy movement using theater, routes, regions of interest (shown as green circle), etc.

where intelligence has reported an enemy sniper is stationed. New information can become available at any time, such as the discovery of a new enemy object in theater, change in weather, etc., either via immediate convoy recognition or through various intelligence information communicated to the convoy by way of intelligence summaries (INTSUM) and visual and ground moving target indications (VMTI and GMTI).

Both sources of military intelligence, INTSUM provides a summary of the most current enemy situation covering a period of time designated by the commander whereas GMTI/VMTI provides real time information on ground movers. Both are the result of human reported and sensor based intelligence. Through the ontologies and associated rules, the system provides alerts and recommendations to the convoy commander. The alerts and recommendations enhance situational awareness by fusing events; that is, multiple events from different intelligence sources are combined to form battlefield conditions, which trigger alerts and recommendations. In Figure 1, a convoy has moved so that now its region of interest (the circle surrounding the convoy) has encompassed an enemy unit. In this situation, the system might generate an alert based on an intelligence report of enemy sniper in the vicinity and recommend that the convoy take an alternate route [1].

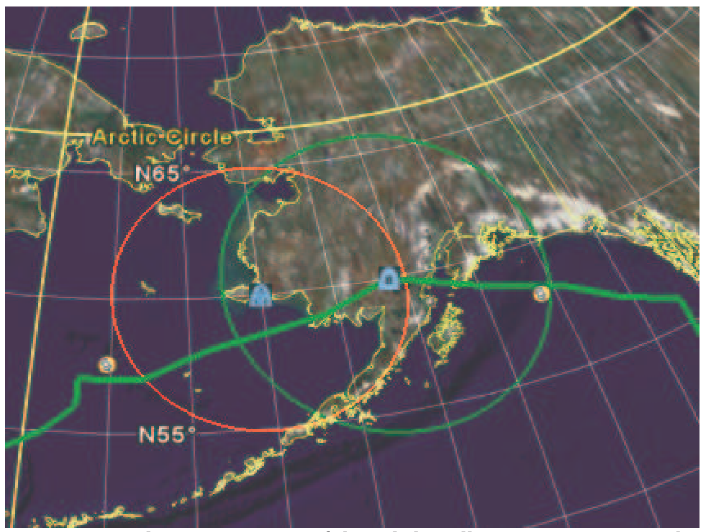

Figure 2. A pilot enters an area of degraded satellite communication. The ROI in red shows the projection of the satellite coverage area onto the Earth.

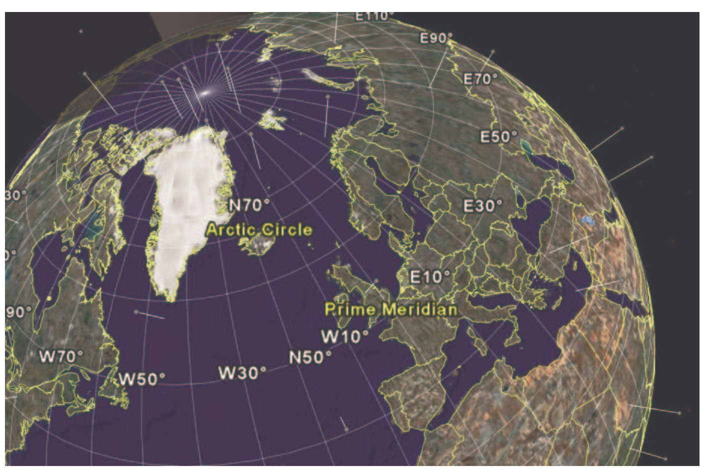

Figure 3. Google Earth view showing constellation of satellites in real time (satellite positions obtained from WWW).

After showing how ground position and intelligence data could be integrated using ontologies, we extended our prototype by adding event types, including space events, live satellite positions and ship movement, as reported by additional intelligence sources. We added these events in just hours. As an example, Figure 2 shows a pilot entering into an area in which satellite communication is degraded. Figure 3 shows a constellation of satellite positions.

3 Ontology Design

To model the objects and events described in Section 2, we constructed five ontologies:

- TheaterObject – battlefield objects and reports about them.
- RegionOfInterest – battlefield regions of interest.
- Convoy – the convoy, its mission, components, etc.
- Convoy Routes – routes the convoy might take.
- ConditionsAndAlerts – how the knowledge base aggregates events, resulting in conditions and alerts that affect the convoy.

Figure 4 shows the high level relationships between each original ontology and its major concepts (in blue and red; subsequent modifications are in yellow). TheaterObjects are MilitaryUnit, Sniper, RoadObstacle, and Facility. TheaterObjects have a location, and may have a speed, heading, and combatIntent (hostile, friendly, etc.).

To distinguish the entity in theater from reports about it, we specified the class of ObservationArtifacts, intelligence reports about objects in theater. ObservationArtifacts have properties such as timeOfObservation, locationOfObservation, speedObservation, etc. The distinction between theater object and observation is important, allowing inference over multiple reports about the same object in theater.

The RegionOfInterest (ROI) ontology models the geospatial areas of special interest surrounding TheaterObjects. An ROI is centered on the position of its focal object, and has shape, dimensions and area -- the dimension and area dependent on the type of threat or interest. ROIs are used to define a "safety zone" around a convoy which must not be violated by hostile or suspicious objects. An ROI also models the area around a reported hostile track that defines the potential strike area of the threat.

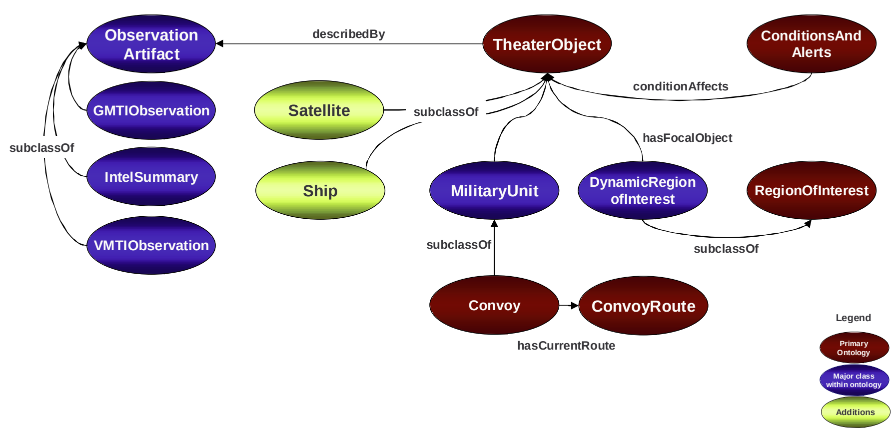

Figure 4. Original ontologies, with modifications (in yellow).

The Convoy ontology, using [2], models the organized blue (US & allied) forces moving on the ground and includes the Convoy's mission, components and personnel.

The ConvoyRoute ontology represents the paths of a convoy, including critical points (CPs) for primary and alternate routes. Recommended routes can change based on application of rules.

The ConditionsAndAlerts ontology models situations on the battlefield based on aggregations of events and actions of theater objects. Conditions based on events result in alerts and recommendations to blue forces.

With SEER we are able to provide new capabilities very quickly. For example, by adding satellite positions and maritime events (displayed in yellow in the figure) to the TheaterObject ontology, instances of those classes are automatically retrieved. We are thus able to integrate new sources of data in hours.

4 SEER Prototype Design

We integrated the ontologies and rules that model C2 scenarios and battlefield intelligence into a loosely coupled service-oriented architecture that uses XML-based messages. The high-level design of the application is shown in Figure 5. The components of the system include the following.

- Enterprise Service Bus (ESB)
- Google Earth[1] Client
- SWORIER (Semantic Web Ontologies and Rules for Interoperability with Efficient Reasoning) [3]:
    - Reasoner, implemented in AMZI! Prolog Logic Server[2]
    - Knowledge Base (KB), composed of ontologies in OWL with instances, rules in SWRL
- Situational Awareness Service (SAS)
- Event Mediation Services (EMS)
- Adaptors
- Message Simulator (MS)

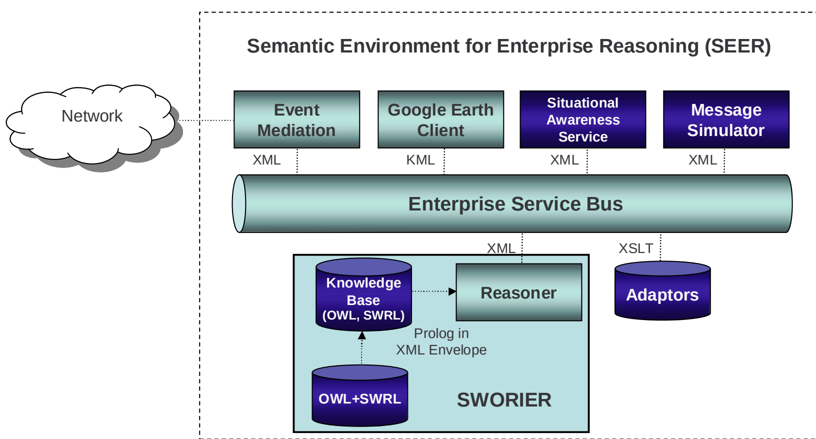

Figure 5. SEER architecture with SWORIER.

We use Mule[3] as the ESB abstraction layer over disparate messaging technologies, allowing interaction between components with minimal code development. Mule supports

[1] http://earth.google.com/
[2] http://www.amzi.com/
[3] http://mule.codehaus.org/

transport and transformation of publisher/subscriber pairs, applying the XSLTs of the Adaptors when appropriate. Mule also detects events, including trigger events that cause the swapping of knowledge bases, enabling us to integrate sources for satellite information and other events.

We use Google Earth since it offers seamless integration of multiple data sources via its Keyhole Markup Language (KML), and also provides excellent maps and zoom capabilities.

AMZI! is the platform on which we host the integrated ontologies and rule base to perform efficient runtime reasoning.

The KB consists of integrated ontologies, rules and instances. OWL ontologies and SWRL rules were translated to Prolog, then optimized [3]. Together with the reasoner, these constitute SWORIER.

SAS detects events (message exchanges over the ESB), consults the knowledge base, and delivers appropriate alerts and recommendations to the convoy commander via Google Earth clients. Events can be object movement, changes in weather, changes in alert conditions, etc. These events constitute reception of simulated INTSUM, GMTI, VMTI, and other intelligence reports. The service can dynamically query the KB.

EMS handles different types of service communication including SOAP synchronous request/response, SOAP pub/sub, polling and REST. SEER uses EMS to interact with outside message sources.

The Adaptors are a set of XSLTs that are invoked by the ESB to translate messages to the appropriate format as they move between components. Events are in an XML format that contains the AMZI! command format, and are asserted to the KBs and translated to KML for display on Google Earth. The active KB generates alarms and recommendations (when queried by the MS) and these messages are translated to KML for display.

The MS sends messages over the ESB to simulate events on the battlefield.

The SEER application works as follows. First, messages are received on the ESB, either from network sources or by the MS. The ESB applies the appropriate XLSTs of the Adaptor and commits the new information to the KB and sends KML to Google Earth.

5 Conclusion

Ontologies can be applied for rapid enterprise integration, allowing delivery of new capabilities for example in C2-Intelligence applications in hours, as long as a clear distinction is made between intelligence information reception and actual theater object representation and behavior.

References

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3. Samuel, Ken; Leo Obrst; Suzette Stoutenberg; Karen Fox; Adrian Johnson; Ken Laskey; Deborah Nichols; and Jason Peterson. 2007. Applying Prolog to Semantic Web Ontologies & Rules: Moving Toward Description Logic Programs. The Journal of the Theory and Practice of Logic Programming, Massimo Marchiori, ed., forthcoming.