OVERVIEW OF SITUATION MANAGEMENT AT SIMA 2005

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ABSTRACT

This paper is an introduction to the Workshop on Situation Management, SIMA 2005. We discuss the scope of the workshop, the big picture of situation management, and a summarization of the papers selected for inclusion in the workshop. Topics include Situation Knowledge Acquisition, Learning & Situation Recognition, Structural & Behavioral Models of Sensor Networks, Robotic Sensors & Mobile Sensor Grids, Advanced Architectures for Situation Awareness, and Human-Centric Situation Management. We conclude with a discussion of hard, outstanding challenges in Situation Management and future R&D areas.

1. INTRODUCTION

According to modern US defense doctrine, future wars will be characterized by heightened mobility, increased operational tempo and more complex and dynamic situations. As a result, military commanders will require effective methods of situation monitoring, awareness and control -- operations collectively identifiable as **Situation Management**. Critical aspects of situation management include managing and controlling sources of information, processing real-time or near real-time streams of events, representing and integrating low-level events and higher-level concepts, multi-source information fusion, information presentation that maximizes human comprehension, reasoning about what is happening and what is important. Furthermore, commanders will require management support systems that include control over their current command options, prediction of probable situation evolutions, and analysis of potential threats and vulnerabilities. Similar situation management tasks exist in several other domains including network management, homeland security, emergency/crisis management and real-time management of situations in financial, medical, and other service-related domains.

As a rule, situations often involve a large number of dynamic objects that change states in time and space, and engage each other into fairly complex spatio-temporal relations. From a management viewpoint it is important to understand the situations in which these objects participate, to recognize emerging trends and potential threats, and to undertake required actions. Understanding dynamic situations requires complex cognitive modeling, the building of ontologies, and continuous collection, filtering, and fusion of sensor, intelligence, database, Internet-based and related information sources.

The objective of this workshop is to provide a forum for scientists, engineers and decision makers from government, industry and academia to (i) present the state of their research, including development and systems needs in situation management, (ii) discuss fundamental issues and problems, and (iii) identify future R&D directions.

The workshop call-for-papers (CFP) encouraged contributions from multiple domains and disciplines. Technical papers were sought on topics describing specific information systems, techniques and algorithms that facilitate the process of situation management, for example:

- Situation Monitoring and Awareness
- Logical Foundations of Situation Calculus
- Situation Specification Languages
- Situation Ontologies and Semantics
- Reasoning about Situations
- Learning and Situation Discovery
- Predictive Situation Models
- Level 2+ Fusion Systems
- Threat Identification and Analysis
- Cognitive Models of Information Fusion
- Real-Time Event Management
- Operational Situations
- Battlespace Management
- Homeland Security Monitoring & Awareness

- Emergency Situations & Crisis Management
- Sensor and Ad Hoc Network Management

The SIMA technical committee and our reviewers studied some twenty-five papers for the workshop and ultimately selected about half of them for inclusion. Each paper received at least three independent reviews.

In the next section, An Overview of Situation Management, we set the stage for the SIMA Workshop by drawing up a big picture for Situation Management, sufficiently broad to encompass all of the SIMA papers. In the following sections we provide brief summaries of each paper selected for inclusion in the workshop. Based on our paper selections, the workshop is divided into six paper subsections, plus a final wrap-up session:

- Situation Knowledge Acquisition
- Learning and Situation Recognition
- Structural and Behavioral Modeling of Sensor Networks
- Robotic Sensor Networks and Mobile Sensor Grids
- Advanced Architectures for Situation Awareness
- Human-Centric Situation Management
- Wrap-up Panel Discussion on Situation Management

In the final section we discuss outstanding, hard problems in situation management and future R&D directions.

We regret that we have to write this summary paper before the workshop rather than after. We look forward to crystallizing the day's activities and results, and hopefully a final SIMA report will show up elsewhere.

2. AN OVERVIEW OF SITUATION MANAGEMENT

One way to look at the big picture of situation management is by way of Figure 1. The primary components of Figure 1 are sensing (*S*), reasoning (*R*), and controlling (*C*). This kind of picture is not new; it has appeared in various forms in the literature. In the military domain it is known as the OODA (observation-orientation-decision-action loop) or Boyd loop[1]. In intelligent control, it is called the "perception-reasoning-action triad"[2].

The figure includes several levels of a sense/reason/control loop. Typically, the data at the lower levels are close to being "raw," i.e. what is immediately returned by a sensor. Such data might be reasoned about immediately and issue control instructions for effectors, or else simply passed to an operator for further processing. Note that such raw data could include images, text, electronic signals, etc.

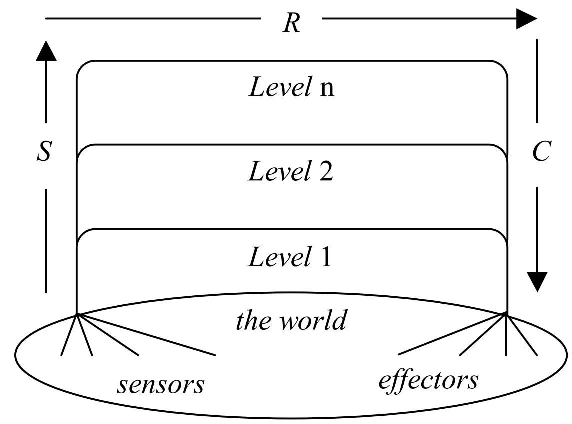

Figure 1. The Big Picture of Situation Management

In other cases, raw data in multiple forms might be abstracted or composed at various levels as we move up the left-most *S* arrow. This in itself is a challenging problem: how do we transform a multiplicity of raw data from disparate sources into meaningful information, and how do we transform information into knowledge and understanding?

The high-level construct that we are interested in is, of course, a situation, which would seem to reside on the higher-most levels of Figure 1 -- i.e. those levels that have to do with reasoning, knowledge, and understanding. In the literature, this is sometimes called level 2+ fusion or cognitive fusion. This notion at once offers several important questions: What is a situation? How do we represent a situation? What inputs are needed to identity a situation? How do we represent the degree of certainty or confidence in an identified situation?

Situation management is not static. If we imagine Figure 1 moving in time from left to right, where sensor data is time-stamped, then we have another set of complex problems. One outstanding problem is this: If the world is sensed at time t1 and a control instruction is issued at time t2, then how can we be sure that the control instruction at t2 is still applicable? Might the world have changed since t1 that would render the instruction inapplicable? Further, how does one update a situation as new data are presented to the system over time?

Some of these problems are addressed in the SIMA Workshop papers. Understandably, no one paper covers the big picture in its entirety. In our organization of the papers we started at the beginning of the loop, as it were, beginning with the papers that address sensors and data composition with an eye towards situation assessment and management, slowly working our way through further areas and complexities in situation management.

3. SITUATION KNOWLEDGE ACQUISITION

Until recently, the prevailing sources for incoming operational events in most situation management applications were either signal intelligence devices or well-formatted and structured time-stamped data streams. Regardless of the variety of physical device (e.g., imagery, audio, RF, ultrasound, infrared, magnetic, etc.), the common issues related to the analysis of information sources have been: (a) large volumes of data, usually coming in at high-speed, (b) high-degree of redundant, incomplete and irrelevant data, (c) very often a high degree of distribution of information sources, e.g. sensor networks, (d) incoming information is either already well-structured or there exist efficient methods of quantification and formalization of raw information, and finally (e) as a rule the raw data contains low semantic content and is weakly associated with the operational context.

Due to changes in the modern battlefield, especially with respect to asymmetric warfare, the importance of human intelligence in the form of textual reports or as pre-structured domain-specific textual messages is gaining significant importance. In many cases such information comes in lower volumes, is focused on fewer information sources rather than distributed across a large number of sources, is usually off-line rather than real-time, the level of redundancy is much lower, and the semantic content of the reports and messages is generally very high. As a consequence of this, a new focus in situation management is on extracting the meaning from textual events and situation reports.

The workshop includes two papers on this topic: "Textually Retrieved Event Analysis Toolset" by John Palmer[3] and "Situation Management in Crisis Scenarios based on Self-Organizing Neural Mapping Technology" by Richard Tango-Lowy and Lundy Lewis[4]. While natural language processing (NLP) of texts has a long history in Artificial Intelligence research, both of these papers look on text processing with objectives that differ from traditional NLP; in particular they tackle different corpuses of texts and they employ less common NLP methods. The first paper by John Paper introduces a pre-defined semantic Actor-Action-Target structure to guide the process of parsing intelligence reports. In addition, semantic closeness metrics measure the statistical occurrences of semantic constituents in the analyzed texts. Together these constitute a promising architecture and toolset for effective processing of textual intelligence reports. In the paper by Richard Tango-Lowy and Lundy Lewis the authors do not impose a predefined structure for their text analysis process, however they maintain effectiveness thanks to the use of an interesting approach of re-enforcement learning using neural networks. While the method employed has been tested with "static" texts with no obvious references to the dynamics of event messages, the authors outline a research agenda to address the dynamics of event messages.

4. LEARNING AND SITUATION RECOGNITION

Recognition of dynamic situations, especially those represented as continuously changing visual scenes, is one of the most challenging tasks in situation management. In addition to the traditional task of image processing, which includes static and dynamic feature extraction and recognition of individual objects, the primary research focus here is on identification of topological relations between the objects and analysis of those relations in motion. Since the visual scenes provide a high level of ambiguity and multiplicity of interpretations, the incorporation of machine learning procedures has found a prominent place in recognition of dynamic situations. This topic is covered by two papers: "Automatic Event Recognition for Enhanced Situational Awareness in UAV Video" by Robert P. Higgins[5] and "Maritime Situation Monitoring and Awareness Using Learning Mechanisms" by Bradley J. Rhodes, Neil E. Bomberger, Michael Seibert, and Allen M. Waxman[6].

In the first paper the incoming event source is a surveillance video coming from a camera mounted on an unmanned aerial vehicle (UAV). The proposed event (and essentially, the dynamic situation) recognition method is based on two assumptions: (a) the used video event representation language (VERL) is rich enough to describe the typical fragments as well as complex composite visual scenes, and (b) the event/situation recognition method based on a Bayesian network is able to catch the important events and situations. On the low-level of video analysis the method uses traditional static and dynamic feature extraction methods followed by the use of a Bayesian network to recognize the objects and scenes. While at this moment a relatively small catalog of typical events and situations are recorded, the overall method is interesting and deserving of continued research.

The research focus of the second paper in this section concerns learning abnormal situations. Although the paper describes an application related to analysis of maritime port situations, it is easy to see the extension of the discussed research to other domains. Essentially, the proposed method of abnormality recognition is divided into two phases, a supervised learning phase, where the system is trained to recognize normal port situations, and the phase of recognition of abnormal situations as deviations from the trained set of typical situations. The recognition process is based on an extension of the fuzzy ARTMAP neural network classifier. An interesting and important feature introduced in the paper is the addition of a human expert into the loop.

5. STRUCTURAL AND BEHAVIORAL MODELS OF SENSOR NETWORKS

Four workshop papers are devoted to situation management in sensor networks. In this section we examine the first two of them, which analyze the situation management in sensor networks from the viewpoints of structural and behavioral modeling of sensor networks.

Sensor networks are becoming an essential component of surveillance and situation control applications in military, homeland security, environmental protection, health and many other areas. Distinct from many other signal intelligence devices, sensor nodes are capable of data collection, limited local processing, and transmission of data via inter-node broadcasting to one or more information sinks. The sinks, possibly forming their own communication structure, communicate with the management node via satellite network or Internet. The sensors themselves range from small micro-sensors deployed in the thousands for registering biological, chemical, radioactive and other activities, to complex measurement devices for monitoring oceanic and atmospheric processes. In many applications, especially those related to military domains, sensor networks need to be capable of relatively lengthy autonomous functioning and should be able to self-organize their behaviors in order to perform the defined global objectives. Often distributed in the thousands (e.g. "smart dust"), the sensors need to immediately establish communications with other sensors in order to begin working collaboratively.

There are several critical aspects that make the management of such sensor networks different from traditional telecommunication and data networks, namely:

- The configuration of sensor networks changes frequently.
- Each node or sensor in the sensor network is a relatively simple device with limited computational capabilities, memory, and power.
- Sensor networks have a higher rate of node and link failures.
- Sensor networks use mostly multi-hop broadcasting inter-node communication technology.

The first paper in this section, "Protecting with Sensor Networks: Perimeters and Axes" by Jeffrey Nickerson[7], is devoted to the problem of optimal spatial distribution of sensors. It is quite obvious that limited individual situation recognition capabilities of sensor nodes should be compensated for by large numbers of nodes so that that the final operational situation can be compiled via fusion of the inputs. In association with this, it is critical to distribute the sensors appropriately to ensure coverage and maintain inter-node connectivity. The paper discusses a novel algorithm of placement of sensor networks and demonstrates the feasibility of the proposed algorithm in building aerial and perimeter security protection systems.

While the first paper dealt with "static" structural issues of sensor networks, the second paper "Biomimetic Models for Massively-Deployed Sensor Networks in Situation Management" by K. H. Jones, K. N. Lodding, S. Olariu, L. Wilson, and C. Xin[8], examines the behavioral aspect of sensor networks. The authors rightly argue that sensor networks are well suited for distributed systems modeling rather than centralized methods used in traditional communication networks. The authors propose an interesting idea for how to mimic the behavior of biological ecosystems, where self-organization and inter-node cooperation are fundamental concepts of behavior. The paper describes a formal model of distributed cooperative behavior based on the theory of self-organized cellular automata.

6. ROBOTIC SENSORS NETWORKS AND MOBILE SENSOR GRIDS

The third paper in the collection on sensors and sensor networks, "Target Tracking with Distributed Robotic Macrosensors" by Brian Shucker and John K. Bennett[9], is similar to the two previous papers in that it proposes to solve the structural and behavioral issues of sensor networks within one formal framework. The objectives and the ambitions of the presented work are significant: the authors are proposing a method and algorithm for building a scalable, autonomous and efficient "mesh" of distributed robotic macro-sensors capable for a goal-directed behavior, e.g. target tracking.

The fourth paper on sensors, "Combining Multiple Autonomous Mobile Sensor Behaviors Using Local Clustering" by Rustam Stolkin and Jeffrey Nickerson[10], analyzes several algorithms for the optima spatial distribution of mobile robotic sensors. The paper proposes a method for combining and/or selecting multiple distribution algorithms to reach a certain optimum behavior, e.g. the best communication pattern between the robotic sensors.

7. ADVANCED ARCHITECTURES FOR SITUATION AWARENESS

Three papers of the workshop are devoted to advanced architectures for situation management. The first paper, "Cognitive Situation Monitoring and Awareness of Grid Systems" by Todd Carrico and Filip Perich[11], describes a situation management platform called ActiveEdge, which has been developed by Cougaar Software. Although not all components of the platform have been completed (particularly the on-line situation and decision learning component), the platform represents a fairly complete implementation of the overall conceptual framework for situation management depicted in Figure 1. On the lower, system engineering level the ActiveEdge platform exists as a collection of basic inter-operable standard services defined by the Open Grid Service Architecture (OGSA), which follows the principles of object-based service architecture defined, for example, by CORBA or J2EE. The interesting and the innovative part of ActiveEdge is the situation management infrastructure consisting of multiple services build atop of OGSA. The situation management services (the authors present them as cooperating intelligent agents) execute the basic functions of incoming data and event interpretation, situation recognition, action planning, and implementation of the planned actions. The platform uses several advanced technologies to enable those functions, including the OWL language for ontology specifications and the JESS rule engine for implementing the planning and decision-making agents of the platform. The effectiveness of those components working in conjunction with additional components that perform the functions of cognitive fusion, event correlation, and learning remains an open question.

The second paper on architecture, "Achieving Situation Awareness in a Cyber Environment" by John J. Salerno, George Tadda, Douglas Boulware and Michael Hinman[12], looks at the issues of situation management architectures from a different angle. The authors are interested in several fundamental issues of situation awareness and their associated architectural alternatives as they apply to the domain of cyberspace. Starting from two well-known architectures, the situation awareness architecture by Mica Ensley (the Perception, Comprehension and Projection paradigm) and JDL's Fusion Model, the authors propose their own situation awareness architecture, which involves a novel cognitive step for fusing multiple alerts into a situational pattern. The paper also provides an interesting discussion on the pros and cons of different algorithmic solutions to implement this step, presents several experimental results and outlines future research directions.

The third architectural paper, "Real-time Multistage Attack Awareness Through Enhanced Intrusion Alert Clustering" by Sunu Mathew, Daniel Britt, Richard Giomundo, and Shambhu Upadhyaya[13], describes a general framework of multistage intrusion detection system (IDS) based on correlating multiple alerts into an alert pattern. The paper uses a graph-theoretical approach (one of the approaches mentioned in the previous paper) to map from multiple events into an event pattern, which are represented as a typical IDS graph (scenario). The novelty of the proposed approach is the introduction of a taxonomy of alert categories, and the use of this taxonomy in real-time for initial alert clustering followed by IDS graph matching for identification of intrusions. The method could be also used from IDS threat analysis and the prediction of potential attacks.

8. HUMAN-CENTRIC SITUATION MANAGEMENT

Two of the workshop papers discuss the issues of human-centric situation management, where significant numbers of people are part of the situation management process. The first of these papers, "KSNet-Approach Application to Knowledge-Driven Evacuation Operation Management" by Alexander Smirnov, Michael Pashkin, Tatiana Levashova and Nikolai Chilov[14], examines the issues of managing complex real-time informational assets, networks, transportations systems, and most importantly, human assets, engaged in fast-paced situation assessment and action planning. The authors evaluate their method in an application area related to crisis and human rescue operations. The central idea of the proposed situation management approach is to examine all involved activities as interacting services, some acting as service providers and others as service consumers. A critical component of the approach is logistics knowledge based on multiple ontologies, ontology sharing and the use of ontologies for action planning.

The second paper, "Effects Based Decision Support for Riot Control: Employing Influence Diagrams and Embedded Simulation" by Robert Suzic and Klas Wallenius[15], addresses the tactics of situation management in domains with unpredictable and conflicting situations. As an example domain the authors consider operational control of situations happening during riot control. The solution uses influence diagrams to describe situations and the emerging relations between them. Influence diagrams can be considered as dependency graphs with, however, several important advancements, namely, the distinction of different types of nodes and the use of uncertainty levels between the dependent nodes. The authors demonstrate the benefits of the use of the influence diagrams over some other technologies, e.g. Bayesian networks. The authors also use situation simulation in order to test the effectiveness of the proposed method.

9. CONCLUSIONS

While the workshop papers encompass a wide array of approaches and address many of the critical issues involved in situation management, there still remain many open issues and challenges. Much research has gone into the problems of sensing the world and fusing the resulting data into higher levels of information and knowledge. The problems of situation assessment and threat identification, while far from solved, are well understood and progress towards practical solutions is ongoing. Recently, increased activity has begun to focus on the harder problems of higher-level reasoning, decision-making and planning[16,17]. Less abundant are efforts to close the sense-reason-control loop with mechanisms for communicating with and controlling the sensors, effectors and actors involved in an evolving situation – an area we believe is ready for serious attention.

Within the problem of situation management as a whole there are a number of ongoing challenges that continue to demand more effective solutions. An important distinguishing characteristic of situation management is the issue of time and the evolution of objects over time. A situation is defined by a sequence of events describing characteristics of the situation's objects as reported by sensors at discrete moments of time; seldom if ever does one have the luxury of receiving continuous level 1 information about all the characteristics of all the relevant situation objects. It thus becomes necessary to develop and maintain dynamic models of the situation objects in order to predict their time-dependent features over the intervals between sensor readings. Since the modeling of complex behavior is never perfect, the predictions from dynamic models must incorporate uncertainties, which invariably must increase the further away in time one moves from the latest sensor report. The fact that sensory data itself usually involves some level of imprecision only further complicates the problem of constructing an accurate operational picture from time-sensitive information. Even with a wealth of available modeling methods and uncertainty reasoning approaches, today's situation management applications fall far short of human abilities in these areas, leaving plenty of room for future research and continued incremental improvement.

Increased importance of intelligence reports requires the development of fast and comprehensive methods of analysis and extraction of meaning from natural language texts, and most importantly, fusing them with signal intelligence and other data-oriented information sources. Ultimately, we need more advanced cognitive methods of fusing multi-modal information, be it data, images, video, or audio information.

A growing number of situation management applications are leveraging recent developments in the area of formal ontology languages and ontology-based reasoning systems. This movement represents a positive step on the path towards increased system interoperability and collaboration. It's now becoming possible to develop systems that can exchange descriptions of sensors, data, situations, decisions, etc. and formally reason about the information using a shared "understanding" of their meaning. This capability further opens the door for developing independent services that can be interconnected on demand as needed to perform a wide array of situation management functions across various problem domains. A necessary development in realizing this vision will be the establishment of shared core ontologies[18] that will serve as the basis from which domain specific and problem specific solutions can be developed.

Situation Management faces interesting research challenges in many other areas, including learning of situation recognition, formal algebraic methods of reasoning about the completeness, consistency, and correctness of situations, and understanding the synergy of human and machine intelligence in the situation management loop.

Although the workshop concentrates on situations in military and emergency/crisis management settings, there are many applications in health care, finance, transportation, environment protection, and other areas, where similar situation management problems exist.

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