Abstract – Data fusion is a key enabler for the situation analysis process. The study and the integration of all data fusion levels require both a suited architecture, and a modeling and simulation environment that allows the technological demonstration of the situation analysis concepts to be investigated, and also the demonstration of their supportive contribution to the situational awareness state. This paper discusses both of these aspects. In particular, it focuses on design issues related to development of a simulation environment for the analysis of the tactical situation. Finally, the paper describes a bootstrapping effort to develop a baseline of this environment. This baseline has been successfully used to support the analysis of threat evaluation algorithms for the command and control system of the IROQUOIS class ships.

Keywords: Data fusion, situation analysis, modeling and simulation, integration, architecture.

1 Introduction

The Situation Analysis Group at Defence Research Establishment Valcartier (DREV) is pursuing the exploration of situation analysis (SA) concepts and the prototyping of computer-based situation analysis support systems. The main objective of the situation analysis process is to provide and maintain the state of situational awareness for the decision-maker.

The context of this work is shipboard command and control that is an instance of the dynamic human decision-making process. Therefore, the analysis, design and development of a computer-based tactical situation analysis support capability must be done taking into consideration both a technological and a human factor perspective. This capability is to be included into a decision support system and used to aid/assist/complement a decision-maker during his command and control activities.

Data fusion is a key enabler for the SA process. The data fusion process implicitly calls for the use of several heterogeneous technologies, all of which requiring their integration into a common framework and their control via a process refinement capability. Based on the Joint Directors of Laboratories (JDL) model and its last revision [1-2], DREV has undertaken [3-11,15-16] the study and the integration of all data fusion levels using blackboard architectures as the integration framework of heterogeneous technologies [3].

The context of this work imposes an additional layer of constraints for the analysis, design and implementation of a situation analysis capability using data fusion. One should not underestimate the importance of integrating the human element at the beginning of the analysis process. Indeed, the use of data fusion in support of dynamic human decision-making requires to ensure a cognitive fit of the fusion system with the decision-maker [4]. The demonstration of this aspect is neither trivial, nor easy to do.

One requires a suited modeling and simulation environment that allows the technological demonstration of the SA concepts to be investigated, and also the demonstration of their supportive contribution to the situational awareness state.

This paper mainly discusses the ongoing development at DREV of a modeling and simulation facility, called Simulation Environment for the Analysis of the Tactical Situation (SEATS), for the stimulation and performance measurement of situation analysis agents running on a blackboard architecture.

The paper is organized as follows. Section 2 provides a brief retrospective of the rational behind the choice of blackboard architectures, along with a brief description of the commercial-off-the-shelf (COTS) product that has been selected and used to design and implement blackboard systems in this project. In section 3, an overview of the capabilities to be provided within SEATS is presented, followed by a description of the development strategy in section 4. Finally, section 5 describes a bootstrapping version of SEATS that has been used to support the analysis of threat evaluation algorithms for the command and control system of the IROQUOIS Class ships.

2 Blackboard Architecture

2.1 Description

The blackboard architecture has been chosen to implement the integrated data fusion framework. As illustrated in Figure 1, it is usually composed of three
components: the knowledge sources, the blackboard data structure and the control mechanism [12-14].

The knowledge sources are the result of the partitioning of the knowledge required to solve the problem at hand. All knowledge sources are independent from each other and can be diverse in representation and inference techniques. The blackboard data structure is a global database where the problem-solving states (input data, partial solutions, contextual information, etc.) are maintained. This central repository records all the changes, made by the knowledge sources, leading to an incremental solution to the problem. The opportunistic response to the changes of the blackboard by the knowledge sources is done through the control mechanism. It is responsible to make run-time decisions about the problem-solving course and expenditure. The control mechanism can be implemented as a meta knowledge source that is separated from the other knowledge sources.

The blackboard model is a powerful opportunistic problem-solving model that provides a conceptual framework for the organization of knowledge and data. In addition, the blackboard model prescribes the appropriate strategy for the processing of knowledge (problem-solving behavior). Indeed, the reasoning mechanism of the blackboard model manages pieces of knowledge, according to a pre-defined strategy, either forward (i.e., data-driven) or backward (i.e., goal-driven), at the most “opportune” time, in order to construct a solution to the problem.

The blackboard model is suitable to deal with problems whose nature are such that [12]:
- many diverse, specialized knowledge representations are needed;
- an integration framework is needed that allows for heterogeneous problem-solving representations and expertise;
- the development of an application involves numerous developers;
- uncertain knowledge or limited data inhibits absolute determination of a solution;
- multilevel reasoning or flexible, dynamic control of problem-solving activities is required in an application.

Moreover, the blackboard system architecture offers a great deal of flexibility and adaptability, supports incremental and structural problem-solving strategies, and is well suited to find solutions in a large search space.

### 2.2 Design framework

There are several possible ways of building blackboard systems, depending on problem-solving strategies.

A blackboard design framework called the Generic Blackboard Builder (GBB) has been chosen in this project to be used for the integration of all levels of data fusion. The GBB framework has been selected for its maturity and for the flexibility and generality of its architecture.

The GBB framework provides the capability to explore and rapidly prototype different configurations of blackboard architectures. This capability ensures that the intended research focus on SA and data fusion issues won’t drift on blackboard architecture implementation issues solely.

GBB is written in the Common Lisp Object System (CLOS) object-oriented language and is therefore using a CLOS compiler. Bearing in mind that LISP is an appropriate language for many Artificial Intelligence (AI) applications, and that AI techniques are put forward to address higher levels of fusion, it makes the GBB framework a suitable environment to investigate the use of AI in data fusion.

All these inherent characteristics of the GBB framework also make it a good candidate for a rapid prototyping framework for international collaborations on data fusion.

### 3 SEATS Description

SEATS is a proof-of-concept facility used to support the SA Group during their exploration and demonstration of SA concepts, algorithms and enabling technologies. SEATS provides a modeling and simulation capability for the stimulation and performance measurements of situation analysis agents running on blackboard architecture. This capability is illustrated in Figure 2.
The SEATS test bed has been designed with the intention to minimize as much as possible the development and maintenance cost of supporting technologies, and to maximize the exploration and demonstration of SA concepts. Therefore, the modeling and simulation capabilities of SEATS are implemented via the use of Commercial-off-the-shelf (COTS) products, and the re-use of legacy systems. The test bed includes a set of capabilities, namely:

- a simulation framework for developing complex synthetic tactical environments,
- a 3D visualization capability of the tactical scenarios,
- a human in the loop interaction capability,
- a graphical interface,
- a Performance Analysis Database (PADB), and,
- a Performance Evaluation (PE) capability.

There was also a requirement to design the test bed on a personal computer (PC), allowing a low cost development, and making the test bed transportable.

Finally, in addition to be DIS/HLA (distributed interactive simulation/high level architecture) compliant, SEATS provides different solutions to ensure the interconnectivity of the capabilities mentioned above and described next.

3.1 Simulation capability

This capability supports the building and the real-time animation of synthetic tactical environments containing dynamic entities (e.g., planes, ships, tanks, missiles, etc.) interacting via tactical means (detection, communication, engagement, etc.).

The capability also provides an extendable script language to allow entities in the simulation to react to the conditions of their environment. This feature is important for temporal and spatial behavior analysis as one can simulate behaviors and therefore stimulate behavior analysis algorithms.

3.2 3D visualization capability

A 3D visualization capability presents, in real-time, different 3D perspectives of the DIS/HLA battlefield provided by the simulation capability.

It allows the user to visualize and virtually move through the DIS/HLA battlefield, view an entity/object or group of entities/objects, or even attach the view point to a specific entity/object. Such a capability can be useful for the understanding and the analysis of tactical scenarios.

3.3 Human in the loop interaction capability

This capability provides means to monitor users actions (voice, keyboard, mouse, etc.) as these persons are being stimulated during training simulations. It also provides means to allow human interactions with the simulation. For instance, a real pilot, via the used of an aircraft simulation model, could control one specific aircraft entity in the environment.

3.4 Graphical Interface Design Capability

This capability provides means for the design of 2D/3D analytical and operator-like interfaces.

Analytical displays are designed to support the evaluation of the SA algorithms by the system designers/developers. They must provide a global view of the situation, and allow a quick assessment of the SA system performance. The main purpose of analytical displays is to represent the data of interest to the end user of SEATS.

Operator-like interfaces are meant to be used for investigations on methodologies for situational awareness measurements with military users. They are designed for the display, on an operational-like interface, of both the tactical picture and the situation analysis support system (SASS) information.

3.5 Performance Analysis Database Capability

The Performance Analysis Database (PADB) capability allows the archiving of all the data manipulated by either the operators or the SA algorithms in the SEATS test bed. The archived data for a given scenario include the white and black box data produced by the applications of interest, the stimulation data, the error reporting data generated by SEATS, and the log data about any user requests that may affect the application output results.

3.6 Performance Evaluation Capability

The main purpose of the Performance Evaluation (PE) module is to provide a capability that allows the end user to assess if the investigated application is working properly, as expected. The PE module thus comprises a set of tools to support the designer/user/operator in his quantitative assessment of the performance of the investigated algorithms and techniques, and their supportive contribution to the situational awareness state.

3.7 Interconnectivity Capability

The SEATS test bed provides different solutions to ensure an interconnectivity of the above capabilities. Local or distributed interconnections of multiple simulation applications using DIS or HLA protocols are provided, thereby granting their participation to DIS/HLA exercises. The use of stream socket communication protocols or shared memory is also possible. Finally, middleware solutions for interconnectivity like Common Object Request Broker Architecture (CORBA) are also provided in SEATS.

4 Design Issues

4.1 Research and Engineering Strategy

In collaboration with the Canadian Forces, the SA group at DREV has defined a strategy to cope with the lack of operational trial opportunities, and to minimize engineering risks and cost during the design of data fusion systems for military applications. Figure 3 illustrates this strategy and also indicates where the SEATS test bed fits.
During the research and engineering process, concepts and ideas must be elaborated and tested through a suite of test beds. The first category of test beds provides a capability to demonstrate the validity of the concepts being investigated. The second category of test beds is used to demonstrate, from an operational point of view and taking into account real-time considerations, the use of the chosen technologies in support of the investigated concepts. The next step is to demonstrate the technological considerations using the engineering test bed (an ashore mock-up of the ship, also known as the training facility). Finally, the last step before the production process is the demonstration within formal experimental trials, at sea.

The design issues raised in the engineering guidelines of the last revision of the JDL data fusion model [1-2] are taken into account throughout the strategy outlined above.

4.2 Evolutionary Approach

The analysis, design and development of a situation analysis capability on a blackboard architecture, and of the supporting modeling and simulation capability for the context of interest, is a difficult task to accomplish. In this respect, an evolutionary approach has been adopted over a revolutionary one.

An effort is made to inject into this approach the results of the data fusion foundation work as they become available. Analysis activities are ongoing with the objective of acquiring a better understanding of the SA process, its information structure, its domain constraints, and cognitive requirements. This understanding is essential and will be used to steer and refine the design of advanced, integrated and cognitively fitted situation analysis functionalities. It will also be used to configure the blackboard architecture and the simulation environment where the SA functionalities will be running.

In terms of legacy assets, DREV has the Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification (CASE_ATTI) test bed (see Figure 4) that has already been developed as a proof-of-concept demonstrator to achieve the continuing exploration of level 1 data fusion (L1DF) [15].

The short-term development plan of SEATS, from an application perspective, is to leverage from this legacy asset and conduct a migration and expansion of the L1DF (tracking and identification) algorithms toward the GBB framework. Higher-level data fusion algorithms recently developed will then progressively be integrated with the L1DF ones while applying the notion of process refinement [3].

From a modeling and simulation perspective, the intention is to re-use useful components from legacy systems to fulfill the capabilities described above. For instance, CASE_ATTI has a high-fidelity stimulation capability that emulates the behavior of real targets, sensor systems and the meteorological environment, and also a performance evaluation capability that provides tools to assist the quantitative assessment of L1DF systems performance. Also available in CASE_ATTI is the analytical 2D/3D display (see figures 5 and 6). All of these capabilities will be migrated into the SEATS test bed.
5 Bootstrapping version of SEATS

DREV has been mandated to support the naval Operational Requirements and Analysis Cell (ORAC) in the analysis of potential threat evaluation algorithms for updating the threat evaluation function currently used in the Command and Control (C2) system of the Canadian IROQUOIS class destroyers.

This project has been an opportunity to experience the design and implementation of threat algorithms on a blackboard architecture, using the generic blackboard builder framework, and to launch the initial effort to interconnect and demonstrate some of the SEATS capabilities. A baseline version of SEATS has thus been developed and used to support conduct this study.

Figure 7 illustrates this baseline version of SEATS. It has been implemented using two PCs. The simulation capability and the blackboard architecture have been installed on the first PC. The visualization capability and analytical display have been installed on the second PC.

The simulation capability has been used to build and animate synthetic tactical scenarios with scripted entities. For instance, one specific scenario (illustrated in Figure 8) has been designed to stress the threat evaluation algorithms under each defense role of the ownship, accounting for the high value unit (HVU). The scenario simulates a tactical situation where all entities are maneuvering with a particular trajectory (orbiting, variation of heading, variation of speed). This produces an interesting threat situation that dynamically evolves in time.

The simulation of the target detection process using the ownship’s radar sensors has also been done in the simulation module (see Figure 9). A detection probability function has been used to model the detection range of the IROQUOIS class radars. Only the detected entities are used to stimulate the threat algorithms under investigation.
The 3D visualization capability allows the viewing of the DIS/HLA battlefield as the scenario is being played by the simulation capability (see Figure 10).

**Figure 10. Battlefield 3D visualization**

The tactical information required to stimulate the threat algorithms is made available to the blackboard architecture via shared memory. A first agent (A1), written in C++ and encapsulated in LISP in the GBB framework, is triggered to read the shared memory and write its contents onto the blackboard database. This event triggers another agent (A2) to read geodetic data from the blackboard database, and convert them into Cartesian data before writing them back to the blackboard database. The next agent (A3) that is triggered reads from the blackboard database the kinematics required to stimulate the threat algorithms, and writes back to the blackboard database the corresponding threat lists. The latter “write” (or data storing) event activates another agent (A4) that is responsible to interface, via stream socket communication, an analytical interface application displaying the threat evaluation algorithm’s results, for each defense role, along with relevant simulation information. Finally, a standby agent (A5) written in LISP is waiting for a SEATS user request event to modify at runtime the default simulation parameters.

The baseline version of SEATS has been found to be very useful for the analysis activity, as the operational users have been able to tailor the tactical scenarios at runtime, while appreciating the relative ranking of the threat list of each threat evaluation algorithm, for each defense role.

6 Conclusions

This paper mainly discussed design issues related to the ongoing development of a modeling and simulation facility, called SEATS, for the stimulation and performance measurement of situation analysis systems that use data fusion agents running on a blackboard architecture. Developing such systems using data fusion in support of dynamic human decision-making requires a suited modeling and simulation environment that supports the technological demonstration of the SA concepts to be investigated, and also the demonstration of their supportive contribution to the situational awareness state.

A bootstrapping effort to develop a baseline of this modeling and simulation facility has been done and the resulting system successfully used in an analysis study of threat evaluation algorithms for Canadian warships.

**Figure 11. Analytical threat evaluation display**
7 References


