In Proceedings of the 7th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2003), Orlando, USA, July 27-30, 2003.

Using Agents with Shared Mental Model to Support Network-Centric Warfare

Timothy Hanratty and John Dumer
US Army Research Laboratory
Aberdeen Proving Ground, Maryland

and

John Yen and Xiaocong Fan
School of Information Sciences and Technology
Pennsylvania State University
University Park, Pennsylvania

ABSTRACT

The information age has given way to what many military experts are describing as the next major military advancement – Network Centric Warfare (NCW). At its core, NCW has as its objective the translation of information superiority to supreme combat power; providing unprecedented lethality, survivability, and situational awareness to battle commanders and battle staff. One of the challenges associated with effective NCW is the development of environments that provide accurate, relevant and timely information exchange to the right entities at the right time. Studies have shown that one of the keys to effective information exchange is the ability of teammates to anticipate the needs of other teammates and proactively take appropriate action. Outlined in this paper is an on-going research program between the US Army Research Laboratory (ARL) and Pennsylvania State University aimed at combating the battle command information exchange problem by combining the use of shared mental models with software agent technology.

Keywords: software agent, shared mental model, decision support, battle command.

INTRODUCTION

The information age has brought dramatic and challenging changes in the way the US military will organize and operate in the future. The term associated with this change is Network-Centric Warfare (NCW). From an information technology perspective, NCW is defined as an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision-makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self synchronization. In essence, NCW translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace [1].

For the US Army, NCW is occurring under the auspices of the Army's transformation to the Objective Force (OF). Under this transformation, the US Army has euphemistically traded 70 tons of rolled homogeneous steel for 70 tons of information. Consequently, tomorrow's digitized battlefield will not only provide unprecedented access to data, information, and knowledge, but if not carefully orchestrated threatens to overload commanders and staff with this new technology – *information overload*. Needed are improved methods in retrieving and disseminating data, information and knowledge across the battle functional areas (BFAs) that do not require direct user intervention. Structured and semi-structured data sources from across disparate sources will need to be monitored, filtered, fused against information requirements with appropriate alerts given to commanders and staff.

For this program, the general goal is the development of an environment that promotes the effective exchange and collaboration of information among BFAs that maximizes the translation of information superiority to combat power. To accomplish this goal two research ideas are being combined: software agents and shared mental models.

Software agents are one area growing in popularity as an effective means to manage complex areas of decision support and knowledge management. Software agents are generally defined as processes that are long-lived, semi-autonomous, proactive and adaptive with the goal of assisting users with computer-based tasks [2]. The degree of autonomy and proactive behavior associated with an agent is highly dependent on user preference and the agent's goal and inferential capacity. The popularity of software agents has given raise to an explosion of agent types and architectures, to include interface agents, mobile agents, etc.

A key vision about this research effort is to empower agents in a team (which may include software and human agents) with the notion of "shared mental model" such that agents can anticipate dynamic information needs of teammates and proactively deliver relevant information to them. This vision is motivated by psychological studies about effective human teamwork as well as by needs for addressing the challenges of information overload in network-centric warfare.

BACKGROUND SCENARIO

To help frame the explanation of our approach a simple scenario between a blue (friendly) force and a red (enemy) force is presented in Figure 1. In our exemplar, the blue force has set up a simple frontal assault on the red (enemy) force. Collaborating for the blue side are three battle functional areas (BFAs): the intelligence cell (S2), the operations cell (S3), and the logistics cell (S4). For the purposes of this scenario the goals and priorities of the BFAs have been simplified and defined as follows:

- S2 has as its objective the assessment of all *enemy* locations, actions and intent.
- S3 has as its objective the defeat of the *enemy* and protection of the *supply* routes.
- S4 has as its objective the identification of supply routes and sustainment of supplies.

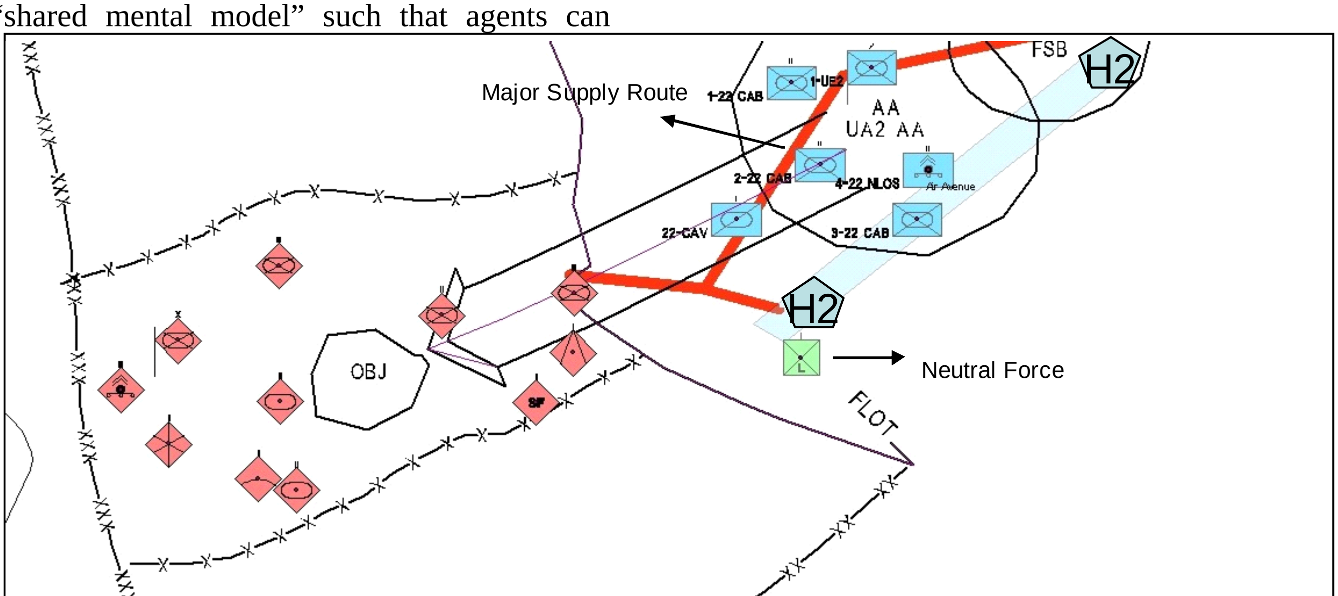

Figure 1: Sample Military Map

The scenario is marked by 5 events.

Event 1: finds the S2 being alerted to message traffic indicating hostile events occurring around H2 airport where it is believed a neutral indigenous force is located. Noteworthy is the fact that H2 airport is not only a critical supply air avenue, but is within 10 kilometers of the major supply route (MSR).

Event 2: has the S4 informing the S2 that some of its forces have come under fire near the H2 airport.

Event 3: has the S2 (prompted by the objective to monitor enemy location and intent) assigning an unmanned aerial vehicles (UAV) to scout the H2 area for clarification.

Event 4: has the UAV confirming through automatic target recognition software the existence of enemy tanks in the vicinity of H2; confirming the belief that the once neutral force is now with the opposition.

Event 5: utilizing teaming agents and the underlaying shared mental model of each of the BFAs objectives, software agents alert each of the areas to the current operational picture and advise on possible courses of actions. Noteworthy are the alerts to the S3. Knowing the objectives and priority associated with the S4, the S3-agents are able to anticipate the importance of the situation and take appropriate action.

APPROACH

As we mentioned earlier, psychologists who study human team performance have noticed that members of high performance team can often anticipate needs of teammates and help them proactively [4]. Team cognition theories suggest that these behaviors are enabled by “overlapping shared mental models” that are developed and maintained by members of the team. The vision of this research is to empower a team of cognitive systems (or agents) not only with a computational representation of the shared mental model but also the desired reflective processing and deliberate processing capabilities such that they can anticipate needs of teammates and assist them proactively, effectively, and timely. To realize this vision, we need to first represent and reason about teamwork knowledge, which provides the basis for the shared mental models (SMM), in the cognitive systems. Second, we need to identify and develop required capabilities for agents to anticipate needs of teammates using the SMM. Third, we need to develop novel algorithms and agent architectures such that detected needs of teammates lead to suitable assist behaviors.

Our technical approach to address these issues is based on a team-based agent architecture called CAST (Collaborative Agents for Simulating Teamworks). The main novelty of the CAST architecture is that it enables agents not only to develop and update their **shared mental model** but also to use such models for **proactive information delivery** to assist teammates with their information needs. Part of this shared mental model is based on teamwork knowledge described in a high-level language (called MALLET); part of the shared mental model is dynamically constructed through agent communications, coordination, and sensing. Based on such a computational representation of “shared mental model”, intelligent agents in CAST uses an algorithm (referred to as DIAG) to anticipate information needs of teammates based on the action they are committed. A more detailed description of CAST, MALLET, and the DIAG algorithm can be found in [5,6]. We have also established a formal foundation for CAST using the SharedPlan theory [7]. More specifically, we have shown that proactive information delivery behavior can be formally derived from the assist axiom in SharedPlan theory with a few extensions [8].

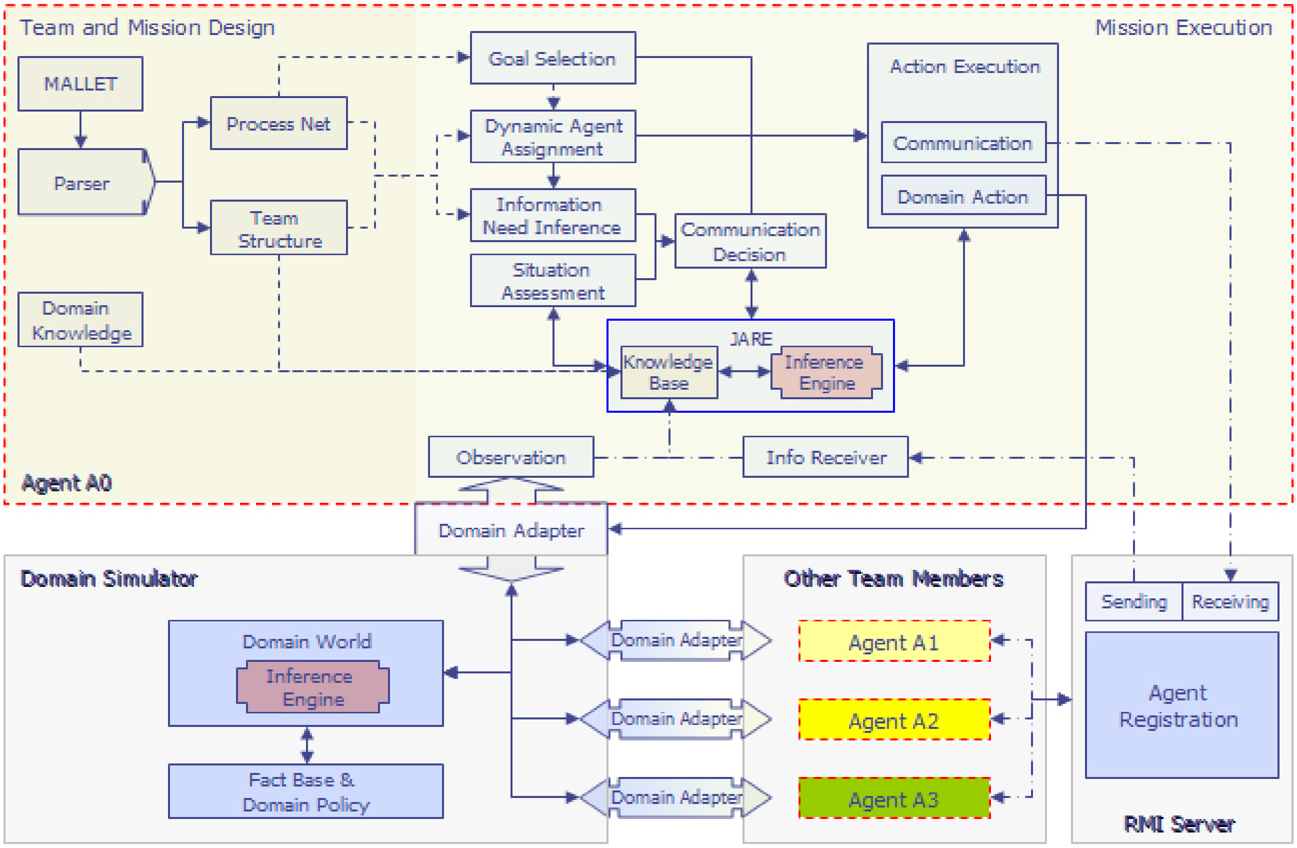

Figure 2: The software architecture of CAST

The SMM of a CAST agent has three components. First, team structure and team process knowledge is described in MALLET. The structure knowledge describes roles in the team, agents in the team, and the role each agent can play. The process knowledge describes what the team is planning to do and a process of how the team is to accomplish its goals. All agents have a copy of these plans, and hence know what is to be done. Second, a MALLET parser compiles the teamwork knowledge into a Predicate Transition (PrT) Net representation, which is an internal representation of the agent's SMM about the status of the team's process. The third component of the agent's SMM is a knowledge base that reasons about the agent's belief regarding the world and the structure of the team. This knowledge base also contains domain knowledge of the agents. The knowledge base of an agent is initialized by facts and domain knowledge known to the agent. However, it is continuously updated by sensor inputs and communication messages received by the agent. Therefore, even if a team of agents starts with the same knowledge base, they will evolve into different (but overlapping) ones as they sense different information from the environment and receive different messages from teammates.

The relationship between the PrT net and the knowledge base is established by the CAST kernel. The kernel interprets the PrT net using the knowledge base. More specifically, whenever the kernel encounters a decision point in the PrT net (e.g., condition for if-then-else), it posts the decision to the knowledge base as a query. Based on the replies from the knowledge base, the kernel enables each agent to collaborative and proactively assist teammates (whether they are agents or humans) effectively while remaining adaptive to the dynamic environment. The software architecture of CAST is shown in Figure 2.

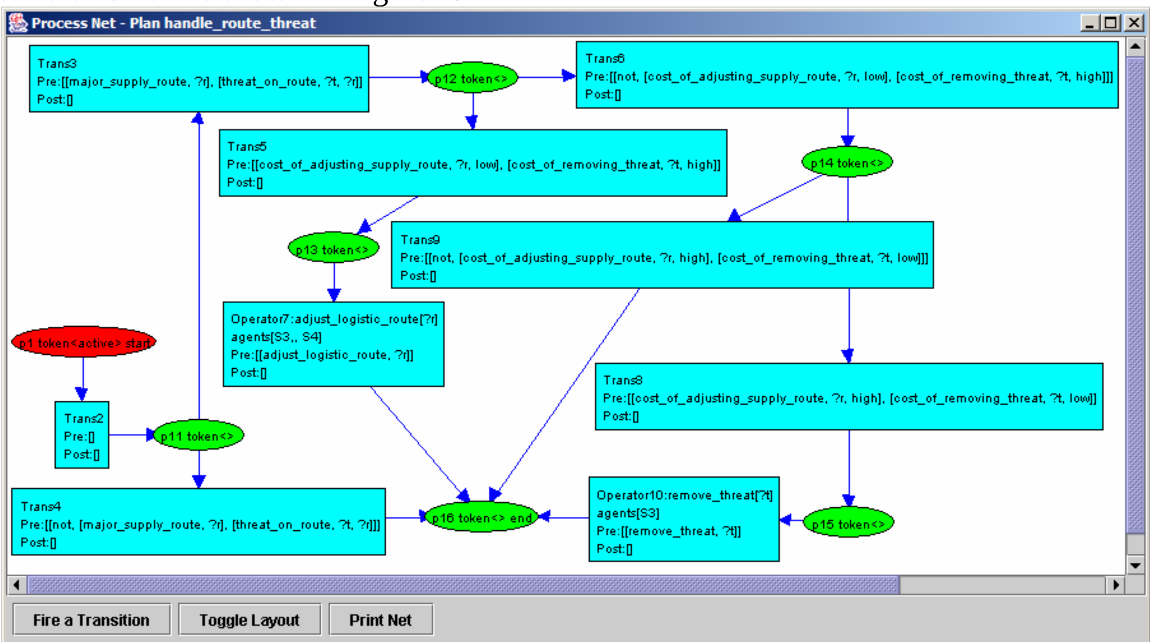

Figure 3: The PrT net generated by the MALLET parser

SCENARIO REVISITED

We will use the scenario described earlier to illustrate the key features of CAST. We will focus on how a CAST agent assisting the intelligence cell (S2) can anticipate information needs of the operation cell (S3) using a mental model shared by S2, S3, and S4 (the logistic cell).

CAST agents can anticipate two types of information needed by teammates: (1) information needed to perform a task, and (2) information needed to protect its goals. We call these two types of information needs *action-performing information needs* and *goal-protection information needs*. Typically, action-performing information needs can be extracted from the precondition of the action. The goal-protection information need allows an agent to protect a goal from potential threats to the goal.

In the scenario, an S2 assistant agent (based on CAST) can alert S4 and S3 cells about the enemy at the airport H2 because it can detect that this information imposes a threat to the goal of S3 and S4, which includes protecting major supply route. Hence, this example illustrates CAST agent's capability to proactively deliver information related to goal-protection information needs. Obviously, this requires the S2 assistant agent to have knowledge required (e.g., the role of H2 airport on the supply route) to infer that enemy at the airport H2 imposes a threat to the major supply route.

Receiving the alert from the S2 agent, a CAST agent assisting the logistic cell (S4) can anticipate information that the operation cell (S3) needs to make decisions about (1) the impact of the threat, and (2) how to respond to the threat. Realizing such information needs, the S4 agent can proactively deliver information about the impacts of the detected enemy (i.e., imposes a major threat to the major supply route) to the operation cell (S3). Furthermore, the S4 assistant agent can anticipate that S3 needs to know the cost for adjusting major supply route and compare it with the cost of adjusting battle plan. Hence, it will proactively deliver the cost for adjusting major supply route to avoid the enemy at H2. If the cost for changing supply route is high and it is not costly to allocate some units to attack the enemy at H2 airport, then S3 cell chooses to adjust the battle plan to remove the threat. If the cost for changing the supply route is low and the cost for changing the battle plan is high, then S3 cell will request the S4 cell to adjust the major supply route. The S4 assistant agent's proactive delivery of impacts of threats and cost for adjusting supply routes are examples of CAST agent's help behaviors regarding teammate's action-performing information needs.

The following shows a slice of the teamwork knowledge (described in MALLET) relevant to this example[1], and Fig. 3 shows the PrT net representation of plan *handle_route_threat()* generated by the MALLET parser.

```
(team BlueTeam (S2 S3 S4))
(agent S2)
(agent S3)
(agent S4)
(plays-role S2      (intelligence))
(plays-role S3      (operations))
(plays-role S4      (logistics))
…
(plan handle_route_threat (?t)
(process
   (if (cond
              (major_supply_route ?r)
              (threat_on_route ?t ?r))
     (if (cond
                (cost_of_adjusting_supply_route ?r  low)
                (cost_of_removing_threat ?t high) )
         (DO (S3, S4) (adjust_logistic_route ?r))
         (if (cond
                  (cost_of_adjusting_supply_route ?r high)
                  (cost_of_removing_threat ?t low) )
             (DO S3 (remove_threat ?t)) )
))))
```

SUMMARY

In this paper, we showed how CAST architecture supports several key components of shared mental models (SMM) for enabling software agents to support the information exchange between battle commanders and battle staff. Empowered with such SMM, CAST agents can anticipate the information needs of battle staff and proactively deliver relevant information to them. Such intelligent teamwork behaviors are highly needed in developing effective NCW environments that can provide accurate, relevant and timely information exchange to the right entities at the right time.

REFERENCES

[1] David Alberts, John Garstka, Frederick Stein, Network Centric Warfare, CCRP, July 2002.

[2] Maes, P., Software Agents Group of the MIT Media Laboratory, http://agents.www.media.mit.edu/groups/agents/.

[3] Hanratty, T., Helfman, R., Dumer, J., Baur, E., and Ingham, H., "Soldier-centric Knowledge Engineering", *IEEE Intelligent System Journal*, January/February 1999.

[4] Cannon-Bowers J.A., Salas E., and Converse S.A. (1993). Shared mental models in expert team decision making. In N.J. Castellan (Ed.), *Individual and group decision making*, (pp.221-246). Hillsdale, NJ: Lawrence Erlbaum Associates.

[5] Grosz, B. and S. Kraus, (1996). Collaborative plans for complex group actions. Artificial Intelligence, 86, 269-358.

[6] Yin, J. M. S. Miller, T. R. Ioerger, J. Yen, R. A. Volz, (2000). A knowledge-based approach for designing intelligent team training systems. In Proceedings of the Fourth International Conference on Autonomous Agents (Agents 2000), Barcelona, Spain, pp. 427-434.

[7] Yen, J., Yin, J., Ioerger, T. R., Miller, M. S., Xu, D., & Volz, R. A. (2001). CAST: Collaborative Agents for Simulating Teamwork. Paper presented at the Proceedings of the 17th International Joint Conference on Artificial Intelligence (IJCAI'2001), Seattle, WA.

[1] The plan is only for illustration purpose. A complete plan for handling route threat also involves other alternatives.

In Proceedings of the 7th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2003), Orlando, USA, July 27-30, 2003.

[8] Yen, J., X. Fan, and R.A. Volz, (2002). On Proactive Delivery of Needed Information to Teammates, Working Notes of AAMAS (International Joint Conference on Autonomous Agents and Multi Agent Systems) 2002 Workshop on Agent-based Teamwork and Coalition Forming, Italy, August 2002.