Watson for the Warfighter: Decision Support Software for the Battle Command Staff

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***Abstract*— This paper discusses an application of Associate Technology, presently the Warfighter Associate (WA), to improve the warfighter's abilities in developing situation awareness, collaboration, and decision making, resulting in increased staff performance, as part of the Tactical Human Integration of Networked Knowledge (THINK) initiative. Associates are agent-based decision aids that assist human operators in complex tasks requiring a high cognitive workload. Associates have been shown to be effective in three basic activities: (1) perception, (2) decision making, and (3) assisting in taking courses of action. In perceiving the need to act, an associate can filter through vast amounts of data looking for information of importance to the user. In helping the decision process, it can present to the user the "best" solution to this problem based on currently available information, while supporting the user if a different course of action is chosen. In the action part of the cycle, the associate may be authorized to perform many of the routine tasks that could distract the user from the important events occurring. An associate system is a knowledge-based system that is designed to work in conjunction with a human operator. It observes the same data as the operator about the state of the world, and can monitor other data the human doesn't see or misses, while analyzing that information to reach more abstract and aggregate conclusions about the state of the world. It also observes the actions undertaken by the operator, combining those actions with the state of the world to determine the operator's current goals and plans. Based on the assessment of the state of the world and the activities and objectives of the operator, it can, within the bounds of its authority, carry out activities on behalf of the user, make the user aware of events particularly relevant to his activities, and manage the information content of the user's displays. We describe a knowledge framework that incorporates planning, intent interpretation, and structured situation awareness as implemented for the WA. We explore the benefits of associate systems built on this framework, including dynamic situation assessment, distributed coordination, and information management. Finally, we present a prototype integration effort with an existing Army Battle Command system and demonstrate its benefits in augmenting staff performance.**

Keywords-* Associate Technology; Cognitive Workload; Planning; Intent Interpretation

I. INTRODUCTION

In early 2011, dedicated fans of the game show "Jeopardy", joined by curious onlookers, turned on their television sets in record numbers to see two celebrated undefeated former Jeopardy champions match their knowledge against "Watson", a computer programmed to answer questions posed in natural language with the speed, accuracy, and confidence of the game's best historical players. The result was a resounding and one-sided victory for the computer.

What did this victory mean? Are computers really smart? Do they think? Can they replace humans? Of course not! While Watson won and dealt with a fairly complex problem – picking through human speech, with words with multiple meanings and different words that sound the same – it did suffer from a few gaffes as it encountered situations without corresponding pre-canned expertise. It was outperformed by the human experts on some questions. The computer certainly did not think, nor would it have performed at all on almost any other cognitive task assigned to it. However, what Watson's victory did show was that computers can, with the right programming, handle complicated tasks, as long as those tasks can be expressed or defined with rules. A computer can be programmed to flawlessly execute or automate a series of steps or instructions, even very intricate and complex ones, which have been analyzed and given to it. Watson illustrated how well computers can function in that paradigm, and the previously undefeated Jeopardy champions demonstrated instances where humans process the information better. Could something akin to Watson's "intelligence" be harnessed to work with people in helping them solve practical everyday problems? Could it be used to help military commanders understand situations more completely, and to help them make better decisions more quickly? The answer is "yes!" This paper will explore an exciting Army research program that is doing exactly that.

II. PROBLEM

The humans Watson competed against, even in a fun and largely pressure-free setting, no doubt experienced certain degrees of frustration and anxiety as they raced against the clock to process the information presented to them to come up with the right answer (or the right question, as all good Jeopardy players know). They were extremely intelligent, experienced, and truly world-class at their tasks, yet they struggled at times.

Our Army commanders and staff officers managing combat operations face analogous challenges, albeit the issues they encounter are much more serious, and the stress is much more pronounced. Warfare is chaotic and complex. Warfighters have to quickly analyze overwhelming amounts of incomplete and sometimes contradictory data and make decisions that will have immediate impact on mission success and human life, knowing that the future consequences of those actions aren't always intuitive or even predictable. Often the "right" data are not presented in the right format or the proper context to address the complex situation being faced. Alerting mechanisms that elevate critical decision points with accompanying information are often missing or poorly presented. Additionally, commanders and staff must often do their jobs in challenging environments with lives at stake daily, with minimal trained personnel assigned to complex equipment and systems that sometimes don't work, often can't share data, and operate on a network infrastructure with bandwidth and availability limitations. Seasoned commanders draw on past expertise to help filter data, but even the best commanders have areas where they struggle, and collaboration can be difficult in those intense environments. Neither seasoned nor novice commanders can instantaneously recall the doctrine and policies and procedures that relate to their immediate needs.

III. OVERVIEW – ASSOCIATE SYSTEMS

Decades ago, as computers began to progress from room-filling calculators to closet-sized number crunchers, some prognosticators predicted a world of mobile robots to help with everyday tasks, smart computers who could beat humans at cognitive games, and magnificent machines that could translate language. The term "Artificial Intelligence" was coined, and became associated with the idea that the problem-solving or intelligence of a human being could be broken down and described in a way that it could be programmed into and therefore simulated by a computer. Two generations of diverse "Artificial Intelligence" development efforts in many different fields, even with the processing capabilities of computers improving by several orders of magnitude, led to generally underwhelming results. Rule-based systems showed success (e.g., Deep Blue became World chess champion, the Army began to fly pilotless missions from thousands of miles away, financial markets became more and more automated), but attempts to replicate human thought in all its dimensions failed, and AI as a discipline, in the eyes of casual observers, never fulfilled its lofty expectation.

In general, disappointment in the applications of smart computers and AI stems from the separation of the extremely complex and *unpredictable* human cognitive process from the *a priori* rules programmed into the application. Nonetheless, since rule-based systems do work well, it does make sense to take advantage of what they do well, and to use them as an important adjunct to complex human cognitive problems. Additionally, rather than being static, these intelligent systems can be active collectors and processors of information, support multiple methods of problem solving, manage multiple levels of knowledge, adapt to real-world situations, and even learn from experience. Rather than taking the place of humans, systems can be designed so that they work hand-in-glove with a user, assisting them as a friendly and knowledgeable helped would. These aspects of an intelligent system, focused on supporting the user and not replacing him, are what define an Associate System.

An Associate System is software driven by domain knowledge, and is designed to work in conjunction with a human operator. It bridges the gap between autonomous systems (sometimes called "expert systems") that completely remove the human operator from the decision process, and passive data access and presentation systems which merely show the user data when asked to do so.

Associate Systems can be used to help commanders and staff in the warfighting environment described above. That environment alludes to many of the challenges in effective command captured in the late Air Force Colonel John Boyd's concept of the "OODA Loop" [1], where OODA stands for Observe-Orient-Decide-Act. The OODA loop defines a process by which an individual or team responds to a situation and related stimuli, with the need to repeatedly make decisions in light of dynamic events, and is closely related with the concept of Situation Awareness as developed by Mica Endsley [2]. Both concepts illustrate the continuous and dynamic cognitive challenges faced by Battle Command staff. Associate Systems can help humans across the spectrum of tasks associated with the dynamic Situation Assessment, Planning, and Acting act cycle that is central to the OODA loop and the development of Situation Awareness (see figure 1). A properly designed and implemented multi-agent intelligent system must be capable of representing knowledge relevant to all three steps in this process.

Observing and monitoring data and initial data analysis (organization, combination, assessment), which can overwhelm a human, is an obvious application for computer support; the Associate both with and without human input can filter through vast amounts of data looking for information of importance to the user. Making abstract and aggregate conclusions about the state of the world, which normally requires both attention and expertise, can also be made in a more automated fashion. As this information is developed, the computer-based associate can help in the development of this basic situation awareness into identification of patterns, correlation of different data, diagnoses, problem solving, and even goal setting; it can present to the user the "best" solution to this problem based on currently available information, but support the user if a different course of action is chosen. In the action part of the cycle, the associate may be authorized to perform many of the routine tasks that could distract the user from the important events occurring. An associate system also observes the actions undertaken by a human operator, combining those actions with the state of the world to determine the operator's current objectives and activities. Based on the assessment of the state of the world and the activities and objectives of the human operator, the system can, within the bounds of its authority, carry out activities on behalf of the user, make the user aware of events particularly relevant to his activities, and manage the information content of the user's displays.

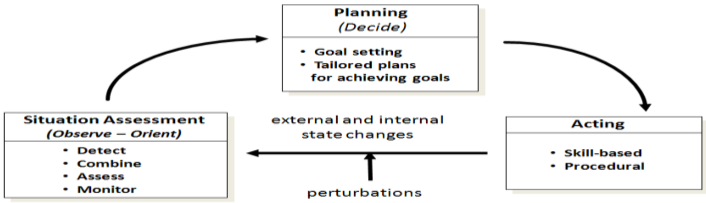

Figure 1: The OODA Loop

Associate Systems provide additional features that are critical to providing cognitive assistance to the Battle Command Staff; these are all central to the Warfighter Associate. These capabilities include:

- Assessing. An associate is capable of assessing the state of the environment and recognizing events of importance as they occur. Importance is not static, but changes based on current plans and goals.
- Planning. An associate is able to generate plans in conjunction with its human users in a mixed initiative manner.
- Intent Model. An associate must remain aware of the intentions of its users so that it can conform its behavior to their needs.
- Execution Aid. When authorized by its users, an associate can take action and autonomously perform tasks in accordance with the accepted plans of the users.
- Information Management. An associate provides value to its users by managing information in a context- and task- sensitive manner.

In a way analogous to a smart and capable assistant, an Associate System can act without explicitly being ordered while remaining within the bounds of its authority, without taking final control away from the human operator. Associate systems are useful in domains with the following characteristics, all of which are central to Battle Command cognitive challenges:

• There is a large volume of data– The associate can provide context sensitive display management, filter out irrelevant data, and transform data into a useful form. The overabundance of data is a key impediment to the rapid development of Situation Awareness by a Commander.
• There is a complex array of actions– The associate can propose or select plans based on the current intentions of the actors and the state of the environment.
• Response time is critical– Adaptive planning (as opposed to optimal planning) allows associates to make context sensitive decisions relatively quickly.
• Limited number of capable experts – The associate can help less experienced personnel perform the tasks of an expert or help an expert focus on tasks requiring expert attention by off-loading tasks of less consequence. A recurring challenge in battle command is high training requirements to develop expertise, compounded by rapid rotation of personnel.

Associates also have the following three behavioral characteristics, which are extremely important to the military command paradigm:

• Mixed initiative. This capability is met when the human user and the associate each individually possess the information and the knowledge to recognize the need to take action, to determine the course of action, and to execute the course of action successfully.

• Bounded discretion. Despite the associate's capabilities to exercise the initiative in responding to the situation, the human user is in charge. The associate may only perform those activities it has been authorized to perform and that are consistent with the human user's intentions.

• Domain competency. An associate is expected to be broadly competent in the operational domain, but may have less expertise than its human counterpart. Its domain skills are less than those of a narrow expert but more those of a well-integrated generalist. Its formal knowledge includes specific knowledge about its human user and about other machine functions that it and the human jointly control.

An associate system is designed to follow the human user's lead, aiding whenever necessary without the need for explicit instructions if within its bounded discretion. The Warfighter Associate is designed to be the smart and seasoned assistant to the human user, designed to follow the human's lead, aiding whenever necessary without the need for explicit instructions if within its bounded discretion. The human user preserves the opportunity to perform all system tasks completely manually or with aiding from the associate. In the extreme, the associate also has the capability to perform all of the system tasks autonomously, although perhaps not as well as the fully rested and alert human user, and only if authorized. An associate system provides as its goal, a completely functionally integrated system. All of the associate systems built to date share a number of important architectural features that are the result of designed function integration with their human users.

IV. THE COGNITIVE FRAMEWORK

To create a useful Associate, a cognitive model that encapsulates the human decision making process is essential. A cognitive model has the following components:

- Domain-specific knowledge
- The ability to accept situational data as input
- The ability to accept user actions as input
- Algorithms to assess user actions, situational data, and corresponding knowledge and do one or more of the following: provide notifications, provide suggestions, or perform system actions

The capability to model the knowledge used to represent the decision making process and to drive the behavior of the Warfighter Associate is provided by the PreAct Intelligent Software Suite [3]. Figure 2 is a diagram of PreAct. The first of two main distinct knowledge structures in PreAct is the Plan-Goal Graph, which is a hierarchical description / graphical depiction of the task structure in the system being modeled. This structure allows a principled separation between the desired or intended future state or purpose of the environment (goal) from the means or method through which that goal might be attained (plan). It supports plan generation and plan recognition in dynamic, uncertain environments. A collection of goals and possible plans for achieving the goals makes up a course of action for a group. The Plan-Goal Graph is defined to represent the alternative ways that goals can be achieved, so each plan child of a goal is a possible means to achieve the parent goal. Lower level Plan nodes are then decomposed into sub goals, with decomposition in this manner continuing until the level of basic interactions is reached in the form of scripts. The Plan-Goal Graph provides for the intentions of many types of groups within the model. By observing the human's actions, and interpreting them in the context of the task models in the Plan-Goal Graph, the Warfighter Associate can infer the human's intentions by explaining them in terms of implied plans for achieving shared task goals. Implicit intent to switch tasks, strategies, or operational modes can be deduced through task-oriented behavior.

The second knowledge structure is the Concept Node Graph. The Concept Node Graph represents general and situational knowledge about the current world-state ("who," "what," "when," and "how-much"), and links for the relationships among concepts represented. It is a depiction of and a structure for a hierarchical and dynamic description of the factual or perceived state of the world, and can include many types of information (e.g., political, economic, and social data). The Concept Node Graph provides a means for distinguishing between the population's beliefs about the state of the environment and its true state. It also supports the representation of uncertain or evidential relationships between dynamic concepts by building belief nets using Bayesian analysis. Concepts are dynamically updated as a result of observations in the form of incoming data about the perceived state of some aspect of the environment; the updated situation awareness influences the Associate's purposeful interactions with the environment. The links between the concepts contain instructions for computing higher level aggregations and abstractions contained in each "parent" concept from the data contained within each "child" concept. Uncertainty calculations are also contained in the links, allowing different sources of information to receive more or less influence in shaping the belief value of the concepts.

To provide dynamic behavior to the model, both Concepts and Plans-Goals have dynamic life cycle states, which represent the prominence of a concept, and allow concepts that are no longer supported by evidence to become forgotten. The life cycle states allow representation of the commitment status of the goal or plan. For example, a plan instance describing a possible behavior may be under consideration by an individual or group but not yet fully defined or proposed. Once proposed, the plan may become accepted by the group, but may not be ready to start. The allowed life cycle states of a plan continue through execution, completion, and termination. The feasibility and desirability of any particular course of action (path through the Plan-Goal Graphs) will depend on what the group believes about the environment and what stage of development the group is in (Concept Graph). To implement the dynamic connection between the state of the environment and the possible courses of action, the model framework provides a concept monitoring mechanism. For example, a group may consider multiple ways to accomplish a goal. The specific way selected will activate monitors for the most likely real-world data (e.g., locations, time, people involved) in the Concept Node Graph. If a conditional statement in a monitor is found to be true, the detected event may be used to transition a plan or goal to a different life cycle state. In this way, plans and goals that are no longer feasible or desirable can be discarded and replaced with more desirable ones as the state of the beliefs change over time and in different stages of the group development.

The third knowledge structure in PreAct is the Context Situated Script component. Scripts contain the procedural knowledge to execute a plan. They are the mechanism through which the Warfighter Associate takes action, and they help with the interpretation of user intent.

The Warfighter Associate decomposes high-level, abstract plans into lower-level, more concrete plans. Eventually, all decisions are made, and a plan can then be executed by running a script. PreAct scripts contain actions and logic to determine when each action is appropriate.

Actions, which are manipulations of the world state, can be performed by the Associate ("performed action") or executed by the human and observed by the Associate ("observed action"). Since the Associates is mixed-initiative, whether an action is performed or observed can be determined during runtime. Examples of actions include calling a route planner, querying a database, or re-tasking an asset.

As a key part of the OODA loop, actions, by their definition, change the state of the world, which causes the Concept Node Graph to be updated. This may result in re-planning, which may then cause additional actions to be performed.

Observed actions drive the intent interpretation capability of the Associate. By observing the warfighter's actions, the Associate can interpret which scripts the warfighter is following, allowing it to refine its set of active plans and goals so that it can support the warfighter based upon his actual intent, even if that intent differs from the associate's recommendations.

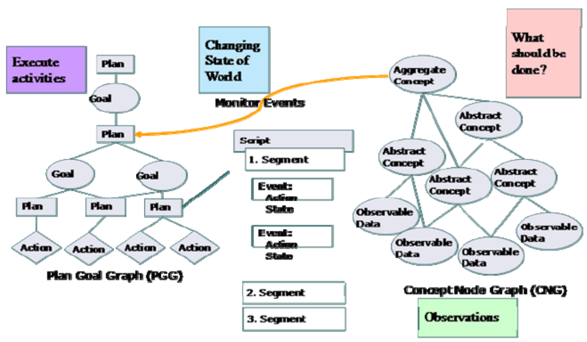

Fig. 2 PreAct® Intelligent Software Suite with Plan-Goal Graph, Concept Node Graph, and scripts

A Knowledge Engineering tool is essential for the development and maintenance of the Plan Goal and Concept Node Graphs and the associated scripts. This tool, integrated with PreAct, enables doctrinal and Subject Matter Expert knowledge to be easily entered and put into a format where it can drive Warfighter Associate behavior.

V. THE WARFIGHTER ASSOCIATE

Associate Systems as tools to help humans with cognitively challenging tasks have a history that dates to the late 1980s. One of the earliest and most successful applications was the Pilot's Associate, sponsored by the Defense Advanced Research Projects Agency (DARPA). The Warfighter Associate has its gestation in that early effort, augmented by years of continuous development and refactoring of the technology. Other successful applications of the technology for government and private industry, including Warfighter Machine Interface System (WMIS) development as part of Future Combat Systems (FCS), are being leveraged as part of the Warfighter Associate.

The Warfighter Associate knowledge base is based upon the Universal Land Warfare Knowledge Base (ULWKB), which is a project independent Plan-Goal Graph and Concept Graph based domain model. Where practical, the ULWKB is based upon the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM), which is an evolving interoperability standard for C2 systems. Basing the Warfighter Associate knowledge base on the ULWKB facilitates the addition of new roles and promotes synchronization between roles by providing a common framework for knowledge development. There is a common Plan-Goal Graph and Concept Node Graph for all roles. Role specific support is provided by selectively activating portions of the graphs.

A rich set of doctrinal and Subject Matter Expert knowledge has been folded into the Plan Goal Graph, the Concept Node Graph, and the Situated Scripts and included in the ULWKB. The following Army publications have been analyzed, broken down, and entered into the Knowledge Base that supports the execution of the Warfighter Associate:

- Brigade Combat Team and Battalion Drills from Operation Iraqi Freedom / OEF
- Field Manual 3.0 Operations Feb 2008
- Field Manual 5.0 The Operations Process Mar 2010
- Field Manual 7-15 The Army Universal Task List Mar 2005
- Joint Publication 3.0 Joint Operations Feb 2008
- Field Manual 6.0 Mission Command Aug 2003
- Field Manual Interim 3.24-2 (FM 90-8, FM 7-98) Tactics in Counterinsurgency Mar 2009

Additionally, Subject Matter Experts have entered knowledge (using their field knowledge as well as sections of several other Field Manuals not listed above) pertaining to the following High Intensity Combat Events into the graphs and scripts:

- Troops in Contact
- Weapons of Mass Destruction
- Attack on a Command Post
- Solider Death / Serious Injury
- Personnel Recovery
- MEDEVAC

Additional knowledge from FCS has also been entered into the knowledge base to support the Warfighter Associate. A total of 118 duty positions were completely modeled, with another 22 warfighter roles partially modeled. A sizeable portion of those graphs and associated scripts has also been entered into the Warfighter Associate knowledge base.

The Knowledge Engineering tools that are part of the Warfighter Associate enable new doctrinal and Subject Matter enable additions to or modifications to the knowledge base.

VI. NOTIONAL THREAD – THE WARFIGHTER ASSOCIATE IN ACTION

A brief notional thread to illustrate the workings of the knowledge base and the Warfighter Associate's interaction with the warfighter is presented in this section. In this vignette, an Improvised Explosive Device (IED) is detonated. The Warfighter Associate learns about the incident either from a SPOT report or from a chat message (the Warfighter Associate monitors all available chat rooms, and discovers incidents several minutes before the chat message is physically entered into an Army Battle Command System). The data concerning the IED event will be sent to the Concept Node Graph, which will assess it for relevancy based on its location and status. If it is considered relevant, the Associate generates a monitor event that will trigger the creation of nodes in the Plan-Goal Graph and cause the following updates to Command Post of the Future (CPOF) displays for the Brigade Operations Officer, the Brigade Intel Officer, and the Fire Support Officer: a message in the current situation box ("CPOF stickie"), a hyperlink to the IED battle drill, an IED icon added to the map, and a C2 pointer added to the map to draw attention to the IED.

For the Operations Officer (S3), plans and goals will be instantiated in accordance with IED battle drills. One of the S3's goals is to have adequate surveillance at the site of the explosion. If there are no surveillance assets within range, the Warfighter Associate will send a message to the S3's recommendation box (stickie) in CPOF to coordinate surveillance. Another goal of the Operations Officer may be to provide security for the site. This goal will only be instantiated if friendly forces remain in vicinity of the explosion. The Associate will choose between alternate means of providing site security (e.g., having the unit cordon the area), and make appropriate recommendations to the officer via CPOF.

Simultaneously, the Concept Node Graph will assess whether the IED event is related to a Priority Intelligence Requirement (PIR). If so, a monitor event will be generated and all roles will be notified in the PIR/Commander Critical Information Requirement (CCIR) box (stickie) on CPOF. The Concept Node Graph of the Intel Officer (S2) will identify Intelligence Surveillance Reconnaissance (ISR) assets that may have inadvertently captured the event as well as assets which may be able to provide continuing coverage. Plans and goals to perform mission tailored surveillance will be instantiated and recommendations will be written to CPOF.

When the IED is resolved, the icon and C2 pointer will be removed from CPOF. The notifications will be grayed out.

This thread, as described, is an over-simplification. In actuality, an associate system would consider the IED in context of the broader tactical and strategic situation and provide support accordingly. The user interface manipulations described are prototypes, but they were successfully demonstrated at a recent Army exercise (Joint Forcible Entry Warfighting Experiment – JFEWE).

VII. CONCLUSIONS

As mentioned above, the Warfighter Associate has been integrated with CPOF, a battle command system that is in widespread use, and demonstrated at a recent Army exercise. The Warfighter Associate interacts with CPOF through the CPOF Third Party Development Kit (CPOF 3PDK), which exposes a web services interface. The CPOF 3PDK allows the Associate to read and modify a limited set of structures, including stickies, efforts, icons, and graphics. In this exercise, CPOF displays were altered at cognitively challenging points, based on the Warfighter Associate, for three warfighter roles (the battalion operations officer, intelligence officer, and fires support officer). Notional user interface modifications to overcome the problems of data overabundance and to alert the officers to critical incidents were shown.

The Warfighter Associate could be integrated with any Army Battle Command System through similar mechanisms.

A significant feature of the Warfighter Associate is that the knowledge base that drives the Associate is maintained separately from the executable. This means the new or modified doctrinal or Subject Matter Expert knowledge can be entered into the knowledge base without recompiling and relinking the target program (in this case, CPOF). This characteristic enables current insights into handling new situations to be rapidly distributed across the warfighting unit.

Plans for continued work on the Warfighter Associate include:

Integration of additional doctrinal and Subject Matter Expert knowledge

Development/refinement of triggering mechanisms

Development of an Experiment Data Repository component and associated Data Analysis tools to assess the Warfighter Associate's usefulness in reducing cognitive workload for the operator (C2 message and user discourse recording, logging Plan-Goal Graph and Concept Node Graph states during execution, and application of socio-cognitive metrics being developed as part of the THINK Army Technology Objective – Research project).

Driving adaptive displays via the Intelligent Presentation Services that is part of the Warfighter Associate (developed under a previous Army Program of Record)

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