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**Improved Decision Making in an Environment of Extreme Uncertainty through the
Application of Augmented Cognition**

Topics

C2 Concepts, Theory, and Policy: Cognitive and Social Issues

Authors: Jack Lenahan, Mike Nash, and Phil Charles

POC: Jack Lenahan

**Organization: Office of the Chief Engineer
Space and Naval Warfare Systems Command
Charleston, S.C.**

Address: P.O. Box 190022

N. Charleston, South Carolina: 29419

Phone: 843-218-6080

Email: John.Lenahan@Navy.mil

Improved Decision Making in an Environment of Extreme Uncertainty through the Application of Augmented Cognition

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Abstract

The hypothesis of this paper is as follows: Uncertainty and inconsistency during complex endeavors can be reduced through the application of augmented cognition. An analysis of the genealogy of modern decision aides leads one to conclude that we should only be discussing the capability spectrum of intelligent software agents. We believe that this represents a limited view of the field of automated decision aides and assisted cognition. Instead of asking how smart the software agents can become, we would like to propose the following question: Can we make the human being smarter? Is it possible to improve cognitive functions inside the mind resulting in better selections of decision alternatives and interpretations of events? Is it possible to radically alter human training, development, and education to optimize the potential of every individual? The authors believe that the processes and tools being developed in the emerging field of *augmented cognition*¹ can be exploited to provide a novel fusion of more capable human beings and exotic software agents. This fusion should result in breakthrough levels of situational awareness and superior decision making in environments of extreme uncertainty.

Introduction

In this paper we describe augmented cognition research that we believe could be exploited to reduce uncertainty and inconsistency in military planning and decision making. Augmented cognition speaks of directly connecting parts of the brain to external interfaces where agents can monitor internal cognitive states, create ‘external mental models’, evaluate those models and states and request a re-prioritization of certain cognitive and mental activities back to the brain of the human user. We consider agents capable of modifying internal human cognitive processes to be exotic by definition. Uncertainty in decision making has been analyzed in some detail. The two types of uncertainty which we are interested in reducing are aleatoric and epistemic. While only multiple, diverse, and rich courses of action can manage aleatoric uncertainty, epistemic uncertainty arises from the quality of a model; that is, the extent to which a model, because of its necessary assumptions and approximations, does not truly represent that which is being modeled². Situational awareness, a key aspect of decision making, is based upon many models, for example, a common operational picture, a common tactical picture, etc. all of which are based upon the assumption of timeliness, validity, and understandability of track data and its sources. But above all, the common operational picture must be understood by a human mind. The introduction of even more complex COP models such as the single integrated air picture (SIAP) imposes an even greater risk of a ‘complete understanding by the human’ of possibly hundreds of tracks. Why do we say this? Unfortunately there are still blue on blue casualties, mistakes such as the bombing of the Chinese embassy in Belgrade, the shooting of the Iranian Airbus, and civilian casualties due to either poor combat identification or unreliable data sources which create unverifiable models. Risk reduction, in the sense of reducing if not eliminating surprise, again can be split into two distinct approaches. The first is to try systematically to think of all the things that could possibly go wrong, and the second is to put in place strategies to minimize the likelihood of error³. Augmented cognition architectures contain built in mitigation mechanisms which alter the mental model inside the human mind. This feature, described in the architecture section below, offers tremendous promise in reducing the mental errors due to misunderstanding the mental model which may have formed inside the mind but may not actually align with reality.

The hypothesis of this paper is as follows: Uncertainty and inconsistency during complex endeavors can be reduced through the application of augmented cognition. An analysis of the genealogy of modern decision aides leads one to conclude that we should only be discussing the capability spectrum of intelligent software agents. We believe that this represents a limited view of the field of automated decision aides and assisted cognition. Instead of asking how smart the software agents can become, we would like to propose the following question: Can we make the human being smarter? Is it possible to improve cognitive functions inside the mind resulting in better selections of decision alternatives and interpretations of events particularly in the face of growing amounts of data and ever decreasing time to understand that data? Is it possible to improve education, training and warfighter development? The authors believe that the processes and tools being developed in the emerging field of augmented cognition can be exploited to provide a novel fusion of more capable human beings and exotic software agents. This fusion should result in breakthrough levels of superior decision making in environments of extreme uncertainty. A fundamental goal of this research was best stated by Teilhard de Chardin: “The fundamental evil that besets us...is our incapacity to see the whole”⁴. We believe that augmented

cognition can artificially enhance human evolution to a point where very complex mental models are understood in all aspects, thus enabling superior decisions since we will be able to ‘see the whole’.

Problem Statement and Discussion

There has been much written in the Network Centric Warfare (NCW) literature concerning situational awareness as it relates to the ability to make better decisions. We would like to borrow the following definition of situational awareness:

Wickens⁵ defines situational awareness as “the continuous extraction of information about a dynamic system or environment, the integration of this information with previously acquired knowledge to form a coherent mental picture, and the use of that picture in directing further perception of, anticipation of, and attention to current events”

Please note that this situational awareness task is currently being performed by humans and computers in tandem, usually consisting of humans absorbing graphical information in a common operational or common tactical picture. We believe that the set of mental activities involved in arriving at the proper level of situational awareness required to perform military planning tasks can be greatly enhanced by augmented cognition techniques. Thus, we are including situational awareness as an integral part of the problem statement which is as follows: Can we directly embellish the human cognitive apparatus involved in acquiring situational awareness, performing complex planning tasks, understanding common operational models, and decision making tasks?

There is a restriction⁶ on the amount of mental tasks a military planner or decision maker can manage when solving planning problems. There is also, at the moment a restriction on just how efficient so called ‘intelligent planning systems’ can become. Creating an intelligent system to aid in this problem-solving task is difficult because of the constant flux of data and knowledge; thus, the military planner or decision maker poses a challenge to intelligent systems design and a new model needs to be created to handle such problem-solving issues. To create a problem-solving system for such an environment, one needs to consider the planners and their environment, in order to determine how humans function in such conditions.

Why we believe that standalone AI (Artificial Intelligence) systems or un-integrated human beings alone are inadequate

The purpose of developing augmented cognition/enhanced human performance technology is to:

1. Create the conditions necessary for an evolutionary leap in the emergence of humans with superior situational awareness capabilities and superior decision making skills.
2. Improve asymmetric thinking, a capability not currently possessed by artificially intelligent systems.
3. Develop intuitive decision making, also a capability not currently possessed by artificially intelligent systems.
4. Recognize non-obvious relationships, a capability possessed by current AI systems but not well demonstrated by human beings

5. Develop dominant speed of pattern recognition, this capability is performed adequately by both AI systems and human beings, but in order to achieve 'dominance' much training is required.
6. Enhance intellectual maneuvering; a capability we believe could be enabled by a marriage of intelligent agents and non-intrusive human-computer direct integration.

Until artificial intelligence reaches a greater level of maturity, and can exhibit intuition, concept integration, or can perform situational awareness per the Wicken's model, we believe that human beings offer a fertile basis for cognitive research. But on the other hand, human beings cannot currently process large amounts of data; we humans have well documented limitations in attention, memory, learning, comprehension, sensory bandwidth, visualization abilities, qualitative judgments, serial processing and decision making. However a successful integration of current intelligent agent (AI based) software and the human cognitive apparatus can possibly create human beings which exhibit superior cognitive abilities with respect to AI or existing human cognition. We believe that the marriage of AI and human beings can alleviate several of the following limitations⁷:

1. Solving complex problems involves both implicit and explicit knowledge. Not all information is known to the expert at the time of solving the problem. The expert needs to search for additional information in order to solve the higher order problems. This is not an easy task based on the massive amount of data that decision maker needs to sift through. Thus the possibility of extreme uncertainty.
2. The amount of data, information, or knowledge required to be analyzed will explode exponentially in the future as pervasive sensor systems are deployed.
3. Solving complex problems involves solving sub-problems, each of these being complex in nature and solution. Many AI systems cannot perform this task.
4. Being able to fuse information at a sub-problem level does not necessarily solve the higher problem – knowledge compression must occur as we progress up the hierarchy of solution space. It is unclear that most AI based systems can accomplish this function without hardwiring an enormous set of rules or providing human users with multiple confusing GUIs to inspect at a cost of declining cognitive performance.

This leads us to conclude that a smart marriage of human cognitive capabilities plus the data processing and the logical consistency of intelligent agents, as part of a well defined synergistic augmented cognition architecture, will produce higher quality of decisions, the ability to process enormous amounts of data, and a substantial and continuously evolving improvement in consistency.

Augmented Cognition Description

What follows below is an extensive set of quotations from the experts in the field of augmented cognition. These quotations describe augmented cognition systems which we believe will facilitate the mental tasks of the planners.

Limitations in human cognition are due to intrinsic restrictions in the number of mental tasks that a person can execute at one time, and this capacity itself may fluctuate from moment to moment depending on a host of factors including mental fatigue, novelty, boredom and stress. As computational interfaces have become more prevalent in society and increasingly complex with

regard to the volume and type of information presented, researchers have investigated novel ways to detect these bottlenecks and have devised and continue to determine strategies to aid users and improve their performance by effectively accommodating capabilities and limitations in human information processing and decision making⁸.

A main goal⁹ of the field of Augmented Cognition (AugCog) is “to research and develop technologies capable of extending, by an order of magnitude or more, the information management capacity of individuals working with 21st Century computing technologies. AugCog science and technology (S&T) research and development (R&D) is therefore focused on accelerating the production of novel concepts in human-system integration and includes the study of methods for addressing cognitive bottlenecks (e.g., limitations in attention, memory, learning, comprehension, visualization abilities, and decision making) via technologies that assess the user's cognitive status in real time. A computational interaction employing such novel system concepts monitors the state of the user, through behavioral, psychophysiological and/or neurophysiological data acquired from the user in real time, and then adapts or augments the computational interface to significantly improve their performance on the task at hand.”

Components of an Augmented Cognition System¹⁰

“At the most general level, the field of Augmented Cognition has the explicit goal of utilizing methods and designs that harness computation and explicit knowledge about human limitations to open bottlenecks and address the biases and deficits in human cognition. It proposes to do this through continual background sensing, learning, and inferences to understand trends, patterns, and situations relevant to a user's context and goals. At its most basic level, an augmented cognition system should contain at least four components - sensors for determining user state, an inference engine or classifier to evaluate incoming sensor information, an adaptive user interface, and an underlying computational architecture to integrate these components. In reality a fully functioning system would have many more components, but these are the most critical for inclusion as an augmented cognition system. Independently, each of these components is fairly straightforward. Much of the ongoing augmented cognition research focuses on integrating these components to “close the loop,” and create computational systems that adapt to their users.”

Example of a Possible Augmented Cognition Architecture

How would we marry the capabilities of intelligent agents and human cognition? In order to solve the awareness improvement issues, data overload issues, and concept integration issues, we need a design that can be implemented without user discomfort. The diagram below depicts the closed loop approach to augmented cognition. Given that the human is interfaced by either an eeg like hat or directly through invasive procedures, the agent sequence is as follows: First the task agent maintains a prioritized list of tasks that must be executed by the human and the other agents, next the cognitive state sensor agents monitor key areas of memory, perception, and awareness and determine if the highest priority task is being executed, if not the state effectors agent manipulates the humans awareness queue to force the attention center to that task, next the cognitive state sensor agent determines if the human is overloaded with data, or too many high priority tasks, and requests a mitigation plan from the mitigation planning agent. The mitigation plan is sent to the cognitive mapping agent to determine the precise plan for adjusting attention and data flow to the human, and finally these “adjustments” are implemented by the effectors

agent. If data is missing, or the task is poorly described, the mitigation agent will request data from external sources to pass to the human in a managed manner.

Augmented Cognition Flow Chart

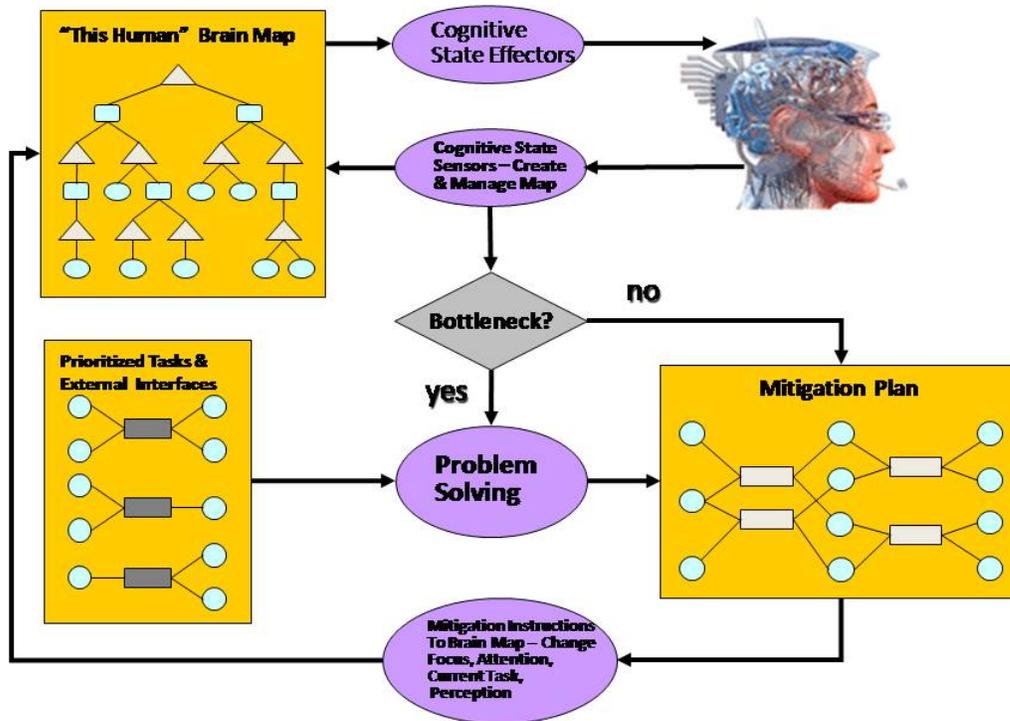


Figure 1 – Augmented Cognition Architecture¹¹

Thus, the challenge with these systems is not the sensing component (although researchers are using increasingly complex sensors). The primary challenge with these systems is accurately predicting/assessing, from the incoming sensor information, the correct state of the user and having the computer select an appropriate strategy to assist the user at that time. As discussed in the first section, humans have well documented limitations in attention, memory, learning, comprehension, sensory bandwidth, visualization abilities, qualitative judgments, serial processing and decision making. For an augmented cognition system to be successful it must identify at least one of these bottlenecks in real time and alleviate it through a performance enhancing mitigation strategy. These mitigation strategies are conveyed to the user through the adaptive interface and might involve: modality switching (between visual, auditory, & haptic), intelligent interruption, task negotiation and scheduling, and assisted context retrieval via book marking. When a user state is correctly sensed and an appropriate strategy chosen to alleviate the bottleneck, the interface adapted to carry out the strategy and the resulting sensor information indicates that the aiding has worked – only then has a system “closed the loop” and successfully augmented the user’s cognition. Also, when designing such a system, individual medical and learning parameters must be assessed. Each system will need to be tailored to the target individual for comfort and facilitation of use in combat and non-combat environments.

Applications of Augmented Cognition¹²

The applications of Augmented Cognition research are numerous, and although initial investments in systems that explicitly monitor cognitive state have been sponsored by military and defense agencies, there is an interest from the commercial sector to develop augmented cognition systems for non-military applications. As mentioned earlier, closely related work on methods and architectures for detecting and reasoning about a user's workload based on such information as activity with computing systems and gaze have been studied for non-military applications such as commercial notification systems and communication. There has also been interest from civilian agencies such as NASA on the use of methods for limiting workload and managing information overload. Hardware and software manufacturers are always eager to include technologies that make their systems easier to use, and augmented cognition systems would likely result in an increase in worker productivity with a savings of both time and money to companies that purchased these systems. In more specific cases, stressful jobs that involve constant information overload from computational sources, like air traffic control would also benefit from technology. Finally, the fields of education and training are the next likely targets for this technology once it reaches commercial viability. Education and training are moving towards an increasingly computational medium. With distance learning in high demand, educational systems will need to adapt to this new non-human teaching interaction while ensuring quality of education. Augmented Cognition technologies could be applied to educational settings and guarantee students a teaching strategy that is adapted to their style of learning. Above all other domains, this application of Augmented Cognition could have the biggest impact on society at large. The positive impacts of a non-intrusive augmented cognition system would be to raise the educational level of society as a whole, creating human populations with higher average IQ scores, increased situational awareness during combat scenarios reducing casualties, identify mental disorders more rapidly so that early diagnosis and treatment can be offered to the afflicted individual, and provide a novel suite of medical tools to address problems such as attention deficit disorder. The negative impacts of course would be the development of intrusive brain interfaces with connections which could possibly override individual judgments or free will. A detailed discussion of these however is outside the scope of this short paper.

Military examples of augmented cognition¹³

To alleviate information and cognitive bottlenecks, the Marine Corps is demonstrating an interest in augmented cognition. Virtual reality-based training systems now under development use computer-generated visuals that enable Marines to practice their skills in a variety of realistic situations. Augmented cognition techniques allow researchers to observe trainees and fit the level of training to the individual. By directly observing a trainee's brain activity, test observers can take the training to a more advanced level or scale it back if the trainee shows signs of overload.

The purpose of developing instrumentation and situational awareness technology is to demonstrate affordable capability to enhance close quarters battle (CQB) and military operations on urbanized terrain (MOUT) training. This capability will focus on a portable solution that can

provide dismounted situational awareness and tracking instrumentation for small unit training. The benefits include:

1. Enhanced situational awareness capability for small units. Thus addressing data and cognitive overload during periods of high stress.
2. Portable, non-virtual MOUT and CQB training capability for supporting improved mission planning and rehearsal. Reducing the time for data and concept integration.

Navy designers made use of augmented cognition methods as they developed the control interface for the Tomahawk cruise missile. "We had our guys wear 'brain caps' as they tested the control interface," said Schmorrow¹⁴. "Instead of relying on the users' subjective evaluation of how easy it was to learn the control system, researchers could observe their brain activity directly and identify the situations in which the users became overwhelmed with information"¹⁵.

Certification and validation of augmented cognition as a serious endeavor¹⁶

In June 2007 the Human Factors and Ergonomics Society (HFES) Executive Council officially approved the new Augmented Cognition Technical Group (AC-TG).

The AC-TG is concerned with fostering the development and application of:

- real-time physiological and neurophysiological sensing technologies that can ascertain a human's cognitive state while interacting with computing-based systems;
- data classification and integration architectures that enable closed-loop system applications;
- mitigation (adaptive) strategies that enable efficient and effective system adaptation based on a user's dynamically changing cognitive state;
- individually- tailored training systems; and
- roadmaps for future directions concerning Augmented Cognition (AugCog) science and technology (S&T) and guidelines of use for the technology and user information that may be garnered from it.

This HFES certification should enhance the transfer of this technology to the general public and facilitate a broader acceptance of augmented cognition by the scientific community as a whole.

Conclusion

It may be a wiser approach to process the deluge of new information with better human cognition than waiting for AI to mimic the human brain completely. It took approximately 30 years from serious chess program inception to the defeat of Kramnik last year by Deep Fritz¹⁷. Deep Fritz still only performs one function: playing chess. Why not use the inherent adaptability of humans as an integral part of our next generation smart machines. Given the ever expanding flood of new knowledge, the military is on the verge of requiring smarter, more aware, and more focused human beings in order to be able to understand and integrate all this information. The push to have intelligent planning agents through the use of AI has been an ongoing effort for many years. But this paper is advocating that the human should not become disengaged from the loop but rather be made smarter. The field of augmented

cognition is opening many new vistas into the mind and also creating creative new concepts for modern command and control. The implications for the military are enormous in that each human being can be treated as a Network Centric node. Nodal capabilities can then be catalogued and accessed on demand possibly reducing the number of physical planning assets required, increasing situational awareness by being able to access nodal awareness at the human mental picture level, data fusion at the nodal level, reduced blue on blue casualties, reduced civilian casualties, improved prediction of combat fatigue and prediction of the likelihood of a particular soldier to develop mental issues such as post traumatic stress syndrome. By using the cognitively augmented war fighters as 'live nodes' on the GIG, this would permit general access to improved skills and globally fused local situational awareness models.

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Biographies

Mr. Phil Charles is the command chief engineer for the Navy’s Space and Naval Warfare Systems Center, located in Charleston, South Carolina. His primary research interests include the operationalization of Network Centric Warfare, Command and Control Research, the use of automated battle management aids in the construction of engagement packages, and the optimization of complex end to end mission threads. Mr. Charles recent CCRP publications, co-authored with Jack Lenahan include “The Grand Challenges of Network Centric Policy”, “Measuring the Effects of Cumulative Influence: Using NCW to Prevent or Minimize Civilian Casualties “, and “Assessing Self Organization and Emergence in C2 Processes”.

Mr. Jack Lenahan is staff scientist to the Command Chief Engineer at SPAWAR Charleston and is currently employed by Imagine-One Corporation. His research interests include the application of advanced technology and software in the field on command and control, the use of evolutionary computation in the creation of engagement packages by automated battle management aids, and an analysis of Grover’s and Shor’s algorithms in quantum computing. Mr. Lenahan’s most recent ACM publication is “The Synthesis of Evolutionary and Quantum Computing” published in the journal SIGEVOLUTION, ACM, 2006. His recent CCRP publications include “The Data Warehouse in Service Oriented Architectures and Network Centric Warfare”, “Agile Assessment Techniques for Evaluating Mission Portfolio Ensembles in Complex Adaptive Architectures”, and the “Is the SOA the only Valid Architectural Approach for the Transformation to NCW?”

Mr. Mike Nash is an industrial engineer in the chief engineer's office at SPAWAR Systems Center Charleston. His projects include research in genetic algorithms, human decision modeling, satellite and sensor simulation, and efficient design of optimization algorithms. He received a Master of Science degree from Georgia Tech in 2005 in the field of operations research. He studied industrial engineering and operations research at Cornell University, where he received a Bachelor of Science degree in 2003. While at Cornell, he received numerous awards and achievements, including the Roger Berman prize for excellence in oral presentation.