Tomorrow's Human Computer Interaction from Vision to Reality: Building Cognitively Aware Computational Systems

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ABSTRACT

*The **Augmented Cognition (AugCog)** program will extend, by an order-of-magnitude or more, the information management capacity of the "human-computer" interaction by developing and demonstrating enhancements to human cognitive ability in diverse and stressful operational environments. Specifically, in FY 02 the program is focused on development of the technologies needed to measure and track a subject's cognitive state in real-time - these include functional near infrared imaging (fNIR) devices, as well as single site electroencephalographic (EEG) recordings. Through measurement and understanding of cognitive state in real-time, the ultimate goal of cognitively aware computational systems is within reach. Military operators are often placed in complex human-machine interactive environments that have been shown to fail when a stressful situation is encountered. The technologies under development in AugCog have the potential to enhance operational capability, support reduction in the numbers of persons required to perform current functions, and improve human performance in cognitively challenging environments.*

1.0 Introduction

Military psychologists are faced with many challenges when it comes to the assessment of personnel in operational environments. Behavioral measurements and computer aided testing can take a considerable amount of time and still have varying degrees of success often with poor response rates. With most national militaries focused on reduced manning - selection and retention are most important issues than ever. Reduction in military manning can only be accomplished through the same personnel taking on more tasks and responsibilities. It is critical to ensure that these personnel are equipped to handle this challenge and succeed. To date, measurements of a warfighter's readiness and fitness for duty have been limited to quantification of overt behaviors or post hoc subjective questionnaires. This is becoming insufficient for the fast deployments and missions facing warfighters today. There is a distinct need for assessment tools that can be utilized in operational environments for real-time analysis of the warfighter's state.

Fortunately, significant advances in the cognitive, behavioral, and brain sciences have been made over the past 10 years because of billions of dollars invested by the National Institute of Health (NIH), the Office of Naval Research (ONR), and other federal agencies during a period of time that is referred to as the "Decade of the Brain." This investment in the 1990s focused on increasing our understanding of the basic scientific aspects of the human brain: human cognition and human behavior.

Much of the ongoing work at these agencies is focused on follow-up work that will impact science and society in terms of clinical research. However, this research also provides investigators funded by the Defense Advanced Research Projects Agency (DARPA) an opportunity to apply these findings towards defense related problems. DARPA is now intensifying its focus on the brain, behavior, and cognition. The agency is pursuing research and technology in the aforementioned areas where both risk and payoff are very high and success might

provide dramatic advances for traditional military roles and missions.

The DARPA Augmented Cognition (AugCog) program, in particular, is positioned at the intersection of two of DARPA's principal thrusts. The first focuses on the creation of new computers, sensors, and communications devices. The second thrust focuses on research relating to new biological and medical technologies. The synergy found where these thrusts converge will extend the use of elaborate new tools to the complex operational environments facing today's and tomorrow's warfighters. The Augmented Cognition program will help lay the groundwork for implementing these tools in daily life and, thereby, change the way technology and people interact.

2.0 Program Vision

The goal of the Augmented Cognition program is to enhance the warfighter's cognitive capacity and capability under complex operational and stressful conditions, by enabling dynamic adaptation of computer systems to meet the current needs of the individual. In essence, AugCog will enable computational systems to adapt to the user, rather than forcing the user to adapt to them. In this way the AugCog program moves beyond the traditional approach to redesigning human-computer interfaces – which often fail to take the state of the user into account. AugCog will enable the development of closed loop human-computer interactions, where the state of the user is measured, analyzed and adapted to automatically by the computational system.

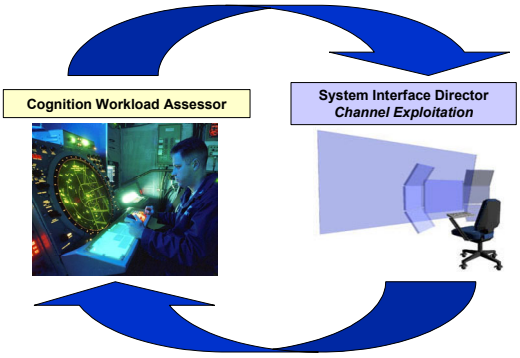

Figure 1. **Graphical representation of closed-loop human-computer interaction.**

The program vision will be carried out by executing the research in four phases:

- Phase 1: Real-time Cognitive State Detection
- Phase 2: Real-time Cognitive State Manipulation
- Phase 3: Autonomous Cognitive State Manipulation
- Phase 4: Operational Demonstration and Transition

Each phase represents a milestone in the ultimate development of the closed-loop human computer system, and relies upon the research and results from the previous phase. In more concrete terms, the program will develop the means to:

- Measure cognitive state
- Manipulate cognitive state
- Exploit human sensory channels
- Optimize information allocation

In phase 1, where the focus is on cognitive state detection, the detectors and sensors for assessing brain function are the cornerstone. Currently, over 70% of phase 1 efforts are directed toward the measurement of cognitive state in real-time. This will be accomplished using both established technologies and ones under prototype development. Phase 2 will be focused on real-time cognitive state manipulation. With the detection of cognitive state in real-time established, operational testbeds under development will allow for the user to experience a variety of workload levels, including tasks that specifically target verbal and spatial working memory systems. These testbeds and environments will be used to manipulate the user's cognitive state in real-time. Phase 3 will be focused on autonomous cognitive state manipulation. This phase will rely heavily on computational systems and architectures that will have the ability to automatically sense the cognitive state of the user and adapt/compensate the environment and workload. Technologies from agent based computing and modeling and simulation will be exploited for this phase. Finally, Phase 4 will be the culmination of the prior phases into an end to end system with demonstrated military relevance. This operational system will be able to sense, analyze, and autonomously manipulate the user's cognitive state – through context, workload, sensory channel exploitation, and information allocation.

3.0 Technical Developments

Many of the advances that have made the program possible have, in large part, been due to the extensive use of tools such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). These technologies have allowed for distinct spatial and temporal elements of neuronal activity to be identified. However, these remarkable tools, although robust in the controlled environments of laboratories and hospitals, are not practical to field in operational environments. In order to extend the results provided from experiments using hospital and laboratory tools, Phase 1 of the Augmented Cognition program is focused on developing robust tools for the real-time detection of cognitive state.

Cognitive states of interest include, but are not limited to:

- Arousal
- Attention
- Verbal Working Memory
- Spatial Working Memory
- Error Detection
- Stress
- Cognitive Workload

Since this phase is focused on identifying shifts in cognitive-state in less than a minute - preferably on the order of seconds – significant advances need to occur in both the sensor development and signal processing. The further requirement that the detectors and sensors be deployable in operational settings puts additional pressure on researchers to accelerate the creation of rugged, portable and wireless technologies.

To overcome these restrictions, the AugCog program is employing a variety of novel technical approaches. One of these approaches involves the development of wearable, optically based brain-imaging devices to enable continuous, non-invasive, and portable monitoring of the brain's neuronal (event related optical signal - EROS) and hemodynamic (near infrared spectroscopy - NIRS) responses. Using near-infrared light (NIR), it is possible to image the brain's neurovascular response by detecting changes in light scattering resulting from changes in blood oxygenation and local neuronal firing. Near-infrared light is transmitted through the skull and the reflected light from the cortical level, encoding the neurovascular response, is measured and reconstructed into a map of brain activity.

This technique is particularly promising since it allows for the measurement of hemodynamic and neuronal activity from the same volume of brain tissue in real-time. The current limitation of this groundbreaking technology is its inability to collect signal from deeper brain structures. However, we have only begun to invest in this area – and new NIR light sources and detectors are under development to address this issue. NIR imaging – despite its limitations, holds the additional benefit of compatibility with techniques like EEG and ERP, which can collect signal from deeper brain structures. Thus, the AugCog program is also focusing efforts on the creation of combined wearable sensors that integrate several brain-imaging/recording technologies into one device. We believe this approach holds great promise for a functional, wearable, and comprehensive cognitive state monitor.

These near-infrared devices represent only a portion of the technologies currently utilized by AugCog researchers to analyze and assess cognitive state. A more comprehensive list includes:

- EEG – electroencephalography
- ERP – event related potential
- NIRS – near infrared spectroscopy & EROS – event related optical signals
- Pupillary reflexes & eye tracking
- Physiological – measures of parasympathetic & sympathetic activity, temperature, galvanic skin response, blood pressure, heart rate
- Behavioral Measures – voice stress, pressure mouse, error rates, task performance

Preliminary results from program researchers indicate that we are currently on track for the phase 1 goal of measuring the cognitive state of the individual in real time.

4.0 Conclusions

By accessing the cognitive state of the individual in real-time, we will enable existing automated technologies to leverage brain activity to modify and mediate cognition. On-line processing and analysis of cognitive state will allow computers to provide operational data in a manner specifically targeted to the user – and in a way that will not disrupt the user's current functions. This new interaction will be significantly more potent than just the simple sum of a brain and a computer system - we will achieve an increase the overall system IQ – capitalizing on the synergistic effect of this new human computer symbiosis.

These new computational systems will not only be powerful tools for enhancing warfighter performance in complex and stressful operational environments but will also enable the assessment of personnel before and after their missions. These tools could prove effective for training, selection, assessment of fitness for duty and post mission mental status. This is particularly critical in today's environment of reduced manning and complex selection processes. This program will enable military psychologists to incorporate the latest tools and techniques from the neurosciences into their day to day practices. These tools will enhance the lives of the personnel that they serve and create a more effective and powerful military force.