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A Human-Information Interaction Perspective on Augmented Cognition

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Abstract

Nearly a half-century ago, J.C.R. Licklider expressed a vision for "man-machine symbiosis," coupling human brains and computing machines in a partnership that "will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today." Until relatively recently, this vision was largely left idle by human factors engineering (HFE) research that grew over the decades from an initial focus on design of equipment to accommodate human limitations to cognitive systems engineering research to a more recent perspective focusing on design of human-information interaction. These perspective shifts and insights have brought a degree of success to the field in design efforts aimed at enhancing human-system performance. In recent years, the research area of augmented cognition has begun to shift the focus once more not only to enhancing the interaction environment, but also the cognitive abilities of the human operators and decision makers themselves. Ambitious goals of increasing total cognitive capacity through augmented cognition technologies are still on the horizon of this research program. This paper describes a framework within which augmented cognition research may identify requirements that compensate for human information processing shortcomings and augment human potential.

1 BACKGROUND

Born during World War II, the field of human factors engineering (HFE) gained prominence for its research on the design of controls and displays. With roots in research on human performance and human errors, the field gained prominence through the work of many leaders in the field who came out of the military: Alphonse Chapanis, a psychologist and a Lieutenant in the US Air Force; Alexander Williams, a psychologist and naval aviator; Air Force Colonel Paul Fitts; and J.C.R. Licklider. Beginning with Chapanis, who realized that "pilot errors" were most often cockpit design errors that could be corrected by the application of human factors to display and controls, these early educators were instrumental in launching the discipline of aviation psychology and HFE that led to worldwide standards in the aviation industry. These men were influential in demonstrating that the military and aviation industry could benefit from research and expertise of the human factors academic community; their works (Fitts, 1951a) were inspirational in guiding research and design in engineering psychology for decades. Among the most influential early articles in this academic discipline was George Miller's (1956) "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity to Process Information," which heralded the field of cognitive science and application of more quantitative approaches to the study of cognitive activity and performance.

In 1960 J.C.R. Licklider wrote in his paper *Man-Machine Symbiosis*, "The hope is that in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today."(Licklider, 1960) This statement is breathtaking for its vision—especially considering the state of computer technology at that time, i.e., large mainframes, punch cards, and batch processing. Licklider and Taylor (1968) followed up on this vision by asserting "In a few years, men will be able to communicate more effectively through a machine than face to face." The computer was conceived of as an active participant rather than as a passive communication device. Remember that when this paper was written, computers were large devices used by specialists. The age of personal computing was off in the future.

Licklider's vision of symbiosis was largely left idle by the HFE community as the focus of research evolved from what was largely performance-based to a broader range of cognitive behavior. A strong focus of HFE research was to design systems informed by known human information processing limitations and capabilities—systems that exploit our cognitive strengths and accommodate our weaknesses (inspired by the early ideas represented in the Fitts' List that compared human and machine capabilities, Fitts, 1951b). While the early HFE practice emphasized improvements in the design of equipment to make up for human limitations (reflecting a tradition of *machine centered computing*), a new way of thinking about human factors was characterized by the design of the human-machine system, or more generally, *human-* or *user-centered computing* (Norman & Draper, 1986). The new sub-discipline of interaction design emerged in the 1970's and '80s that emphasizes the need to organize information in ways to help reduce clutter and "information overload" and to help cope with design challenges for next-generation systems that will be increasingly complex while being staffed with fewer people. Emphasis on human cognitive processes and on the need to regard the human-machine system as a joint cognitive system represented a further refinement that has been called *cognitive systems engineering*. (Hollnagel & Woods, 1983)

In the last decade, an emphasis has been placed on design to enhance human-information interaction rather than human-computer interaction. Gershon (1995) coined the term Human-Information Interaction (HII) to focus attention on improving the way people "find, interact with, and understand information." As such, HII includes aspects of many traditional research efforts, including usability evaluation methods and cognitive task analysis; but also design concepts that address the ethnographic and ecological environment in which action takes place. Examples of work in this area include distributed cognition (Zhang & Norman, 1994), naturalistic and recognition-primed decision making (Zsombok, 1997); and information foraging and information scent (Pirolli & Card, 1999).

More recently, research has begun to focus on neuroscience applications. Raja Parasuraman married neuroscience with ergonomics and termed it Neuroergonomics (Parasuraman, 2003). The burgeoning field of augmented cognition (Schmorrow & Kruse, 2004) aims to enhance the cognitive *abilities* of the human operators and decision makers themselves. DARPA's Augmented Cognition program supports research on monitoring and assessment of the user's cognitive state through neurologically-derived measures acquired from the user while interacting with the system and then determining mitigation strategies that adapt or augment the computational interface to improve performance of the user-computer system. Attributing the weak link in the human-computer system to human information processing limitations, Schmorrow and McBride (2005) argue that human and computer capabilities are increasingly reliant on each other to achieve maximal performance. Much of the research within the augmented cognition program seeks to further our understanding of how information processing works in the human mind so that augmentation schemes might be developed and exploited more effectively—in a variety of domains from clinical restoration of function to education to worker productivity to warfighting superiority. Thus, as described by Schmorrow and McBride: "the DARPA Augmented Cognition program at its core is an attempt to create a new frontier, not by optimizing the friendliness of connections between human and computer, but by reconceptualizing a true marriage of silicon- and carbon-based enterprises."

Once more, then, we are on the threshold of resurrecting a vision of symbiosis—but today we have the advantage of far greater computational resources and decades of evolution in the field of human factors/cognitive engineering. Licklider's notion of symbiosis does require updating. Symbiosis implies a *co-equality* between mutually supportive organisms. However, we contend that the human must be in the *superordinate* position. The Dreyfuses (Dreyfus, 1972, 1979, 1992; Dreyfus & Dreyfus, 1986) have made compelling arguments that there are fundamental limitations to what computers can accomplish, limitations that will never be overcome (Dreyfus & Dreyfus, 1986). In this case, it is important that the human remain in the superordinate position so that these computer limitations can be circumvented. On the other hand, Kurzweil has argued for the unlimited potential of computers (Kurzweil, 1999). But should it be proven that computers do, indeed, have this unlimited potential, then some attention needs to be paid to Bill Joy and his nightmarish vision of the future should technology go awry (Joy, 2000). In this case, humans would need to be in the superordinate position for their own survival. Griffith (2005a) has suggested the term neo-symbiosis for this updated vision of symbiosis.

The augmented cognition research community is taking Licklider's vision quite literally in exploring technologies for acquiring, measuring and validating neurological cognitive state sensors to facilitate HII and decision making. Neurobiologically-inspired forms of symbiosis, while consistent with the metaphor that Licklider used, were not a focus of Licklider's vision; but the possibilities for enhanced cognitive performance are enticing. Much work is required to achieve a brain-computer interface that might be called neo-symbiotic—increasing total cognitive capacity, particularly supporting more complex decision making through augmented cognition. This paper describes a framework within which augmented cognition research may identify requirements for such augmentation.

2 AN INFORMATION INTERACTION RESEARCH AGENDA FOR AUGMENTED COGNITION

The principal reason that the beginning of the 21st century is so propitious for the reinvigoration of Licklider's vision is the result of advancements in computer technology and psychological theory. Therefore, one of our major objectives is to increase the human's understanding, accuracy and effectiveness by supporting the development of creative insights. In the context of information analysis tasks, examples of such neo-symbiotic contributions by the computer include considering alternative hypotheses, assessing the accuracy of intelligence sources, and increasing the precision of probability estimates through systematic revision. These types of activity-based support functions, enhanced by cognitive models, are the concepts that we believe will put us more solidly on the path to the original vision of Licklider, a neo-symbiosis where there is a greater focus on cognitive coupling between the human user and the computer. Thus, our interest is in the current potential for enhanced human-computer collaboration that will achieve a level of performance that is superior to either the human or the computer acting alone. For augmented cognition, research aiming at cognitive coupling for HII tasks should be guided by concepts or models of human information processing that identify areas where humans excel and those in which humans suffer from limitations and biases; and by behavioral research to specify and validate appropriate mitigation strategies. The neurological research agenda should then focus on developing and testing cognitive state assessors to recognize and distinguish between these cognitive states, as well as to correlate and validate the impact of mitigations.

2.1 Human Information Processing Capabilities and Limitations

Classic work by Fitts (1951b) described human and machine capabilities and limitations to guide the allocation of functions to humans and computers. Cognitive engineering research in the 1970s and 1980s stressed the need to identify computer-based intelligent support functions to address human cognitive limitations. Some thoughtful prescriptions from two decades ago still apply: In this literature proposing intelligent support functions, we find examples such as: knowledge of the user's goals and intentions, contextual knowledge (Croft, 1984); and cognitive coupling (Fitter & Sime, 1980) functions that include (Greitzer, Hershman & Kaiwi, 1985) the ability to inform the user about the status of tasks, remind the user to perform certain tasks, advise the user in selecting alternative actions, monitor progress toward the goal, anticipate requests to display or process information, and test hypotheses.

More recently, Kahneman (2002; 2003; Kahneman & Frederick, 2002) has portrayed strengths and weaknesses in human judgment within a theoretical framework that can provide guidance for augmented cognition research aiming to recognize what to augment and when to augment human performance. In an effort to organize seemingly contradictory results in studies of judgment under uncertainty, Kahneman advanced the notion of two cognitive systems introduced by Sloman (1996, 2002) and others (Stanovich, 1999; Stanovich & West, 2002). System 1, termed *Intuition*, is fast, parallel, automatic, effortless, associative, slow-learning, and emotional. System 2, *Reasoning*, is slow, serial, controlled, effortful, rule-governed, flexible, and neutral. The cognitive illusions, which were part of the work for which he won the Nobel Prize, as well as perceptual illusions, are the results of System 1 processing. Expertise is primarily a resident of System 1, as is most of our skilled performance such as recognition, speaking, driving, and many social interactions. System 2 processing, on the other hand, consists of conscious operations such as what is commonly thought of as thinking. Table 1 summarizes these characteristics and relationships. The upper portion of the table describes human information processing characteristics and strengths, interpreted within Kahneman's (2003) System 1/System 2 conceptualization. The bottom portion of the table (cast within the System 1/System 2 framework) represents an update of traditional characterizations of functional allocation based on human and computer capabilities (Fitts, 1951b) and exhibits examples of how human and computer contributions can be allocated to System 1 and System 2 processing in a neo-symbiotic system.

A goal for augmented cognition should be to identify and respond to opportunities to foster new ways of thinking about a problem—in the System 1 sense as exemplified in Table 1 (e.g., seeing contextual shifts, recognizing new patterns, finding creative insights). The ability to manipulate information and view it in different contexts is key to the achievement of novel insights and the elimination of cognitive biases. Questions to guide research should center on identifying the cognitive states that need to be measured. We suggest that the System 1/System 2 distinction can provide a useful framework. Clearly it would be beneficial to identify neurological correlates for System 1 and System 2 processes. It would be especially beneficial to identify neurological correlates of System 2 while monitoring System 1 processing. Perhaps there is a neurological signature when potential errors are detected in System 1 processing. It is conceivable that some of these errors remain below the threshold of consciousness. If these errors were detectable in the neurological stream, computers could assist in this error monitoring process.

Table 1. System 1 and System 2 Processes

Human Processes		
	System 1: Intuition	System 2: Reasoning
Processing Characteristics[a]:	o Fast o Parallel o Automatic o Effortless o Associative o Slow-Learning o Emotional	o Slow o Serial o Controlled o Effortful o Rule-governed o Flexible o Neutral
Type of Processing (Examples of Human Information Processing Strengths)	o Expertise o Skilled Performance o Most Perception	o Thinking o Goal-driven Performance o Anomaly and Paradox Detection

Neo-Symbiotic Functions		
	System 1: Intuition	System 2: Reasoning
Examples of Human Contributions	o Providing Context o Detecting Contextual Shifts o Intuition o Pattern Recognition o Creative Insights	o Supervision/Monitoring o Inductive Reasoning o Adaptability to Change o Contextual Evaluations o Anomaly Recognition/Detection o Goal-Driven Processes/Planning o Creative Insights
Examples of Computer Contributions	o Recognize Cognitive State Changes o Adapt Displays/Interaction Characteristics to Human's Cognitive State	o Deductive Reasoning o Search o Situational Awareness o Analysis/Synthesis o Hypothesis Generation/Tracking o Computational Support o Information Storage/Retrieval o Multi-processing o Update Status of Tasks o Advise on Alternatives o Monitor Progress o Monitoring System 1 Processes

[a] This portion of the table based on Kahneman (2003)

More ambitious goals of increasing total cognitive capacity through augmented cognition technologies are still on the horizon of this research program. A new DARPA program on Neurotechnology for Intelligence Analysts (http://www.darpa.mil/dso/thrust/biosci/nia.htm) is a recent off-shoot of augmented cognition R&D that has a current focus on developing information processing triage methods to increase the speed and accuracy of image analysis. This program seeks to correlate robust brain signals with imagery data of potential interest to the analyst. Neuroscience research indicates that the human brain is capable of responding to visually salient objects significantly faster than an individual's visuomotor response—signifying System 1 processes that operate essentially before human awareness. Similarly, augmented cognition research can be applied to other complex decision making tasks (such as those listed in the bottom-right cell of Figure 1) to illuminate System 1 cognitive-state information that may reveal the status of System 2 processes; or that may be used to manage the introduction and control of appropriately-designed mitigation strategies that stimulate System 1 processes.

2.2 Research on Mitigation Strategies

Much of the research in augmented cognition has focused on cognitive activity that tends to be more oriented toward attention, perception, and working memory processes—aiming to enhance perception and decrease load as opposed to support decision making and thinking. For example, of the eight papers published in the *International Journal of*

Human-Computer Interaction 2004 Special Issue on Augmented Cognition, six papers presented results of empirical studies that were based on human performance in laboratory tasks that may be predominantly characterized as involving neurological cognitive state sensors focused on vigilance/arousal or workload correlates in an engaging short-term/high-tempo target monitoring task (the Warship Commander Task, WCT) or other tasks involving working memory [St. John et al (2004); Berka et al. (2004); Duta et al. (2004); Hoover & Muth (2004); Izzetoglu et al. (2004); Balaban et al. (2004)]. The other two papers (Stanney et al., 2004; Young et al., 2004) did not report empirical results. The WCT (St. John *et al*., 2004) could vary workload systematically and incorporate multitasking subtests. Because workload in this task is associated with the number of stimuli as well as its motor demands, the measured neurological effects of workload may also reflect perceptual and motor activity demands. Recognizing a need to investigate augmented cognition in operational contexts, Cornwall and Kollmorgen (2005) studied cognitive state sensors with mixed success in an operational command/control decision making task involving monitoring a radar display. A general focus of augmented cognition research is on identifying and addressing bottlenecks affecting attention/channel capacity or working memory (limiting the near-term/tactical decision processes). To extend the application of augmented cognition research beyond this fast-paced/high-tempo activity with a short time horizon, Greitzer (2005) argued for augmented cognition research to address mitigation challenges for the longer-term more complex reasoning processes of information/intelligence analysis.

At the level of attention, perception, and workload mitigation, augmented-cognition neurological inputs can serve goals of neo-symbiosis by providing information to the computer that can in turn be fed back to the human in the form of adaptive displays and interactions or other to mitigate the effects of stress or information overload. Stanney et al. (2004) provide an extensive set of modality-specific design guidelines for such mitigation in visual, auditory, haptic, and cross-modality interfaces. An important research question regards the locus of control for mitigation through adaptive user interface features. Parush and Auerbach (2005) report experimental findings that suggest users prefer to control such mitigation and that demonstrate performance decrements following the adaptation. This is consistent with the neo-symbiosis view that places the user in a supervisory position. Nevertheless, the capability to monitor the human's cognitive state through neurological correlates will enhance the ability of system to intervene an offer options for support at critical times.

To address complex cognitive processing limitations that we have described within a neo-symbiosis framework, mitigation strategies must embrace intelligent support functions. Kahneman's conceptual model of System 1/System 2 processing provides motivation for these mitigation strategies. Most of the time, System 1 processing is quite effective, but because it uses nonconscious heuristics to achieve these efficiencies, it can occasionally err and misfire. Such misfires are responsible for perceptual and cognitive errors. One of the roles of System 2 is to monitor the outputs of System 1 processes. It is the System 2 processes that require computer support, not only with respect to the pure drudgery and slowness of human System 2 processes, but also with respect to the monitoring of System 1 processes. In most cases, however, it is a mistake to assign System 1 processes to the computer. This was the fundamental error in many automatic target recognition and image interpretation algorithms that attempted to automate the human out of the loop. Even to this day, computer technology has been unsuccessful in modeling human expertise in System 1 domains; as Anderson (2005) has observed, human expertise in System 1 domains has been very difficult to model in computers, and many researchers (connectionists, behavior-based roboticists) have used this to argue that digital computer metaphor is flawed.

Intelligent support should focus on augmenting System 2 processes, providing support to areas of human information processing such as search (there is a tendency to overlook targets); interpretation keys to provide a check and support for the recognition process; analysis and synthesis (e.g., to augment reasoning processes); support to facilitate adjusting to changes in context (e.g., to maintain situational awareness); and computational support (e.g., to make predictions). Research is needed to develop and calibrate cognitive state assessors that reveal diminished capacity (and need for mitigation) of complex reasoning processes due to information overload (behavioral correlates of information overload in intelligence analysis have been reported by Patterson et al. (2001) and others. Intelligent support and augmented cognition mitigation strategies also have great potential to enhance the effectiveness of training. This is a research topic that has been largely untapped. Cognitive state assessors should be examined to determine if correlates may be found to signal when the learner is confused and when insight has occurred, or perhaps exploited to increase speed, accuracy, or eliminate bias. Finally, it is obvious that augmented cognition and neo-symbiosis have important contributions to make in areas of increasing human abilities and potential in physical domains. There is a growing body of research in augmented cognition that addresses the need to help people overcome physical deficits, e.g., through augmentative/assistive technology, or to help people enhance or extend their physical attributes. This neurologically-based symbiotic research uses implant technology in which a connection is made between technology and the human brain or nervous system. Medical applications include restoring lost functionality in individuals due to neurological trauma or a debilitating disease; or for ameliorating symptoms of physical impairment such as blindness or deafness. Applications that aim to enhance or augment mental or physical attributes provide a rich area of research in the growing area of augmented cognition. Warwick and Gasson (2005) review this field of research.

3 CONCLUSIONS

The convergence of developments in different fields provides the foundation for a quantum leap in HII. Advancements in computer technology, cognitive theory, and neuroscience provide the potential for significant advances. Moreover, there is a movement for a more encompassing view of the scope of the field of human factors and ergonomics. The objective has been raised from making technology usable to using technology to enhance human potential, which was the original goal set by Licklider in 1960. The fulfillment of this objective will require collaboration and interaction among the fields of cognitive science, neuroscience, and computer technology. We have argued that the field of HII is on the threshold of realizing a new vision of symbiosis—one that embraces the concept of mutually supportive systems, but with the human in a leadership position, and that exploits the advances in computational technology and the field of human factors/cognitive engineering to yield a level of human-machine collaboration and communication that was envisioned by Licklider, not yet attained. As we have described, the field of human factors/HII is not static, but rather must inexorably advance. With advances in computer technology, cognitive science, and neuroscience, human potential and fulfillment can be leveraged more, yielding a spiral of progress: As human potential is raised, then that new potential can be leveraged even further.

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