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Complemation: An Alternative to Automation

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Abstract

This paper presents the concept of complemation - complementary technology that is designed to enhance human skills and abilities rather than replace them. Complemation differs from automation in that it utilizes human skills and functions in a critical rather than ancillary role. The machine is used primarily for monitoring and precise implementation and the human is the primary decision-maker and outer loop performer. In this way, the human remains engaged in the task and aware of the situation. Traditional automation approaches relegate monitoring duties to humans, which are inherently poor monitors of highly reliable systems, while expecting them to intervene in cases where the automation cannot perform. The paper argues that such traditional automation can set the human up for failure.

Keywords: automation, complemation, function allocation, human factors, human error, interfaces, cognitive science.

Introduction

It is evident that technology has radically changed the way we live. One of the areas that has been greatly affected is transportation. Technology has offered greater precision, greater reliability, greater vigilance, and greater capability than previously available. The current trend in transportation technology is one of autonomous technology or automation (for example, Converticar (Anders, *et. al.* 1994), Moller flying car (Moller, 1999), intelligent highway system (Galijan, *et. al.* 1996.)) The reasoning behind this trend is sound. Automation offers the significant advantages listed above and it is more repeatable and compliant than humans are, and therefore less susceptible to traditional human error. The combination of greater precision and capability with less error seems irresistible. However, this brief treatise will attempt to explain why this trend may be oversold. And it will attempt to describe an alternative that will go further towards the goals of traditional automation, than automation itself. To distinguish this concept from automation, I have coined a new phrase – *complemation*. Complemation can be defined as complementary technology that is designed to enhance human skills and abilities rather than replace them.

Automation

Automation has been defined as: “automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human organs of observation, effort, and decision” (Merriam-Webster, 1999) and as “The control of production processes by machines with human intervention reduced to a minimum.” (Krippendorff, 1999) The attributes that I wish to highlight are those of self-government and the replacement of human functions or duties. I proposed that automation is not self governed in the strictest sense but rather is governed at a distance. The rationale is that humans design and manufacture automation, it is not spontaneously created, and in doing so, humans encode the government of the machine. Humans initiate the operation of the machine by turning it on. The automation operates under the direct intentional influence of the human even though it is operating without any physical contact and without any data transmission in real time. The machine gives the appearance of autonomy but is actually performing exactly as the human has commanded. The importance of this seemingly subtle distinction is that humans are not removed from the loop, they are merely distanced from it. Human errors are just as likely to occur. The problem now becomes the ability to correct for the human error and the scope of the consequences of that error. Because the human is distanced from the machine’s execution of the error, it may be difficult or impossible to correct it in time to avoid the consequences of that error. If the error were in the machine’s design or in manufacturing procedures, the error will be replicated in every machine made. Thus the single human error will become multiple errors. Combining this broad scope with the inability to correct for the error due to the distance involved could lead to wide spread failures. This problem is further exacerbated by the human tendency to reduce vigilance in the presence of high reliability (Parasuraman 1993). In other words, if the machine works well for a while, the humans will be less vigilant in looking for problems or errors until they become unavoidable, and at that point it is often too late. Therefore, in some instances, automation may not actually reduce human error but may exacerbate the negative consequences of human error (for further discussion see Wiener and Curry, 1980).

The common response to this criticism is to catch design errors before they go into production through testing and analysis. This will improve the reliability of the automation (unless an error occurs in the testing and analysis). The problem is that exhaustive testing is difficult. Exhaustive testing on the actual hardware is extremely expensive in terms of time and money. Computer simulation testing is much less expensive yet it depends greatly on the fidelity of the model. The model, which is developed by humans and itself susceptible to human error, may not be faithful to the actual performance of the hardware in all conditions. Testing is likely to allow some errors or bugs to go undetected.

There are certainly many cases where this is the best that we could or should do, such as situations that are in threatening or hostile environments (e.g., battlefields, toxic sites) or extremely long duration missions (some space missions). These are cases where the machine takes the risk. In these cases, automation is appropriate. However in a large majority of other cases, I believe that we can do better.

Complemation

While much can be said of human fallibility, equal (at least) can be said of human ingenuity. The human mind has evolved in to a wonderfully complex and capable thing. One of the capabilities is the ability to cope with new situations. While we have some hints as to how this happens, details about the underlying processes are still not understood. Processes that are not completely understood by humans are rather difficult for them to codify in a machine in a reliable manner. Thus, for the near future, it is unlikely that machines will equal humans in this ability to deal with novelties. The concept of complemation exhorts us not to try. Rather it calls for exploiting the innate human skills and using technology to complement these skills to improve them and to reduce the errors associated with them. The development risk is significantly lower because we already have the black box architecture for creativity and adaptability in the human mind. Our goal is to interface the mind to technology. In doing so we can reduce the distance between human initiation of tasks and the actuation and fulfillment of those intentions. The human would be present to deal with novel situations or to correct design errors. Having a human available at 'the pointy end of the stick' allows for the possibility to troubleshoot at the last minute. Of course, there is the potential that in performing last minute troubleshooting the human will make things worse. But it is precisely these situations where technology can assist the human. Consider some of the more common human frailties, such as poor memory recall, poor vigilance, and lack of precision. These are three areas at which technology excels. Imagine never forgetting a procedure or a piece of information. Imagine never failing to notice a significant change in the environment. Imagine being instantly skilled in a task. Would you be as error prone?

The concept of complemation is not new (See Jordan (1963) for discussion of the complementary use of technology). It is simply that it is being discarded in the light of technological advances such as artificial intelligence and robotics. It is being replaced by the concept of automation – 'autonomous' thinking machines. However, as stated above, this is at present (and the near future) a pipe dream. Instead we should concentrate our efforts on using the capabilities that are available to us in the most productive and efficient manner. A hybrid combination of technology and humans, complemation, should fit the bill.

The Call of Complemation

What does this concept of complemation mean to current research? At first it may seem that this is a Ludditious cry against technology. However, it is the opposite. Significant technological, psychological, philosophical, and biological advances are *required* to fulfill the vision of complemation.

Function allocation - Nowhere is the difference between automation and complemation more apparent than in function allocation. The best example of this is fault management. Perhaps the only unassailable rationale for humans being involved in the real-time operation of a system is to troubleshoot and problem solve. Automation has been used to perform as much of these tasks using technology as possible, making it 'easy' for the human. The problem with this approach is that when humans are finally called upon to deal with a novel event (i.e., something that automation is not designed for), the human is at a significant disadvantage. This is because the human is likely to be low on vigilance (because the automation is so reliable) and therefore low

on situation awareness and low on recent experience in troubleshooting (since human intervention is so rarely necessary). Complemation takes the view that the human should always be performing these tasks at some high level AND that to correctly perform them the human needs to have an awareness of the situation. In order to maintain such awareness, the human needs to be involved (otherwise they will lose interest and reduce vigilance.) Therefore, many of the tasks that could be automated (i.e., performed solely by technology) are deliberately not automated so that the human remains involved in the task. This involvement must be meaningful rather than simply 'doing something' or 'busy work.' Significant preprogrammed technology (where the human programs the technology and then simply monitors its performance) is not the norm in complemation. The reason for this is that humans are poor monitors of highly reliable systems (Parasuraman 1993). They become bored. Technology on the other hand is an excellent monitor. Where automation stresses the human as monitor and the technology as the performer, complemation stresses the technology as the monitor (of both human and machine) and the human as the initiator. Complemation favors the function allocation scheme suggested by Endsley (1999), where technology is used primarily for monitoring and implementation and humans are used primarily for generating alternative actions and selecting among those alternatives.

Cognitive Science, Culture, Personality and Human Error – With the human more involved in a task, there is a greater chance that normal human behavior could lead to negative consequences (i.e., human error). Whereas automation deals with human error by eliminating the human from real-time operation, complemation deals with human error by catching, counteracting, and compensating. Since the technology is given the primary role of monitoring all aspects of the mission (including the health and performance of the humans), technology can be used to catch or detect human error before it significantly propagates to the overall mission. Once the error has been detected, the technology can either counteract (e.g., alerting the human, changing the display configuration, and changing the task distribution) or compensate (e.g., perform extra duties, make error corrections). To this end, designers must have a better understanding of the human mind and thought processes (i.e., Cognitive Science). Since humans are not all alike, the aspects of individual differences due to differences in personality, culture, and physical characteristics must be thoroughly researched and understood. Just as we now provide augmentation for those who used to be labeled as disabled, so we must provide augmentation for those with different personality styles and cultural backgrounds. We can no longer exclude individuals simply because they don't fit a particular personality profile (e.g., 'the right stuff') or come from a different culture. Likewise we should not demand that they change their basic self to fit the designer's perspective. The designer must allow the design to accommodate differences while allowing the human to do what they do best. In complemation, the human is in greater more active control but they are assisted in reducing errors. Of course, there is no way to totally eliminate human errors (either in operation or design) and some will always slip through. The goal of complemation is to block the human errors without blocking the human.

Interfaces, neuroscience, and biology – Another burden that complemation places on technology is to provide more elegant and natural interfaces (Schutte, 1997). Technology must move from being an awkward crutch to being an extensible tool (Reason, 1987). Technology

must take advantage of the somatic, autonomic, and central nervous systems – indeed the brain itself. Imagine being able to complement human memory with computer random access memory. Instead of having to acquire factual and procedural knowledge through reading and listening, humans could simply 'know' a wide variety of things. Imagine never having to look up a word in the dictionary, but simply knowing all words. Imagine not having to read this paper but knowing it thoroughly as soon I published it. This is complemation at its finest. However, in order to do this we must know more about how the brain stores information and we must have technology that can non-intrusively transmit data to and from the brain. In this way technology can communicate not through natural language but through natural thought.

Speed research (communication and travel) – The laws of Nature (e.g., time and space) prohibit the use of complemation on all missions. For example, complemation (requiring a real-time human presence) on long distance space missions is impractical in the current technology. If the human is on board a spacecraft so as to be in the operational loop, the years required to travel to a neighboring planet could place enormous amounts of stress on the human, making them more prone or susceptible to error. If humans can remain on Earth and maintain a virtual presence on the spacecraft, they face the communications time lag that can make real-time operations and adjustments impossible. However, if we can make the voyage shorter or the communications faster, complemation may be appropriate. Complemation calls on research to enhance speed of transporting humans (to reduce mission duration) and of communications. Of significant concern is the ability to surpass the speed of light in communications. So while such feats may seem the realm of science fiction, Nature has rarely permanently closed a door on us in the past. There may be a way to get around this in the future.

The future of humanity is at stake

This rather dramatic heading is meant to set the stage for the following discussion. Suppose that we are able to create thinking machines that can reason as well as humans, but do not commit the types of errors that humans do – in other words, all the good of humanity and none of the bad. Where does that leave humans? It places humans in a rather delicate position – that of being inferior in every way to our creation. How does such an inferior human fit in? The human is no longer the fittest. Humans will survive only due to their creator status. Such positions are not permanently supported. Eventually, from an evolutionary perspective, humans will have a secondary position in the world. An entire library of science fiction horror can be written (and much has) on this premise – the controlled march into obsolescence. In this grim and admittedly extreme circumstance, humanity has gone faster and faster towards a dead end.

However, complemation offers an unlimited vista of human expansion and expression. Technology can race forward in such a way that may lead to the next step of human evolution. Technology already offers us significant adaptability (e.g., we can breath in space and we can be cool on hot days). Continuing this trend of adaptation (i.e., complementing humanity to survive in more varied environments) will continuously open new avenues for the human adventure and advancement. Instead of approaching obsolescence, humanity will continue to be mission critical.

References:

Anders, S.G., Asbury, S.C., Brentner, K.S., Bushnell, D.M., Glass, C.E., Hodges, W.T., Morris, Jr. S.J., and Scott, M.A., (1994)*The Personal Aircraft–Status and Issues*, NASA Technical Memorandum 109174, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA, December.

Endsley, M.R., and Kaber, D.B., (1999)*Level of automation effects on performance, situation awareness and workload in a dynamic control task,* Ergonomics, Vol. 42, No. 3. P 462-492,.

Galijan, R. C., Sinko, J. W., Bolles, R., and Ruspini, E., (1996)"AHS concept based on precise positioning, image recognition, and intelligent autonomous control," Tech. Rep. 6697-96-FR-66, SRI International, 333 Ravenswood Avenue, Menlo Park, California 94025.

Jordan, N (1963) Allocation of functions betweeen man and machines in automated systems. Journal of Applied Psychology, 47(3), 161-165

Krippendorff, K., (1999) Dictionary of Cybernetics, http://pespmc1.vub.ac.be/ASC/ indexASC.html.

Merriam-Webster Online Dictionary (1999) http://www.m-w.com/

Moller (1999), http://www.moller.com/index.html

Parasuraman, R., Molloy, R., and Singh, I. L. (1993). Performance Consequences of Automation-Induced "Complacency." The International Journal of Aviation Psychology, 3(1), 1-23.

Reason, J., (1987) *Cognitive aids in process environments: prostheses or tools?* International Journal of Man-Machine Studies, Vol. 27, p 463-470.

Schutte P.C., (1997) “Wings: A New Paradigm in Human-Centered Design,” *Proceedings of the 9th International Symposium on Aviation Psychology*, Ohio State University, Columbus, Ohio.

Wiener, E. L. and Curry, R.E., (1980) “Flight Deck Automation: Promises and Problems,” NASA Technical Memorandum 81206, National Aeronautics and Space Administration, Ames Research Center, Moffet Field, CA, June.

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