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Cognitive systems and communication

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A R T I C L E I N F O

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A B S T R A C T

A cognitive system is a thinking (or intelligent) information system. However, the enhanced intelligence is not generated by the activity of intelligent technological functions but emerges from the coordinated collaboration of distributed human agents via their interactions with each other and with functionally heterogeneous technological artifacts. The robustness of a cognitive system is due to the manner in which the human participants in the system integrate their activities.

1. Introduction

Traditionally, cognitive systems have been associated with individual human minds. Today however, most links retrieved by a key word search on cognitive systems refer to software developments in the form of computer-based agents. In what follows, I will argue that the conception of a cognitive system as resident in an individual human mind is too restrictive and its application to computer-based agents is misguided. An analysis of a few examples of military communication and miscommunication suggests that the robustness of socio-technical cognitive systems is due at least as much to the manner in which human actors use and coordinate their actions as to the design of the system itself.

2. What is a cognitive system?

The defining characteristic of a system versus an assemblage is that the constituent parts or subsystems work together. In physical systems, that is accomplished by exchanges of physical energy as constrained by force fields. In cognitive systems, it is accomplished by exchanges of information as constrained by information fields, that is to say, through communication.

We normally think of cognition as something that happens in the head of a single individual but a cognitive system as defined here is more than that. A whole person, a perceiving, thinking, acting entity, is one kind of cognitive system. While each human in a socio-technical system is, in himself or herself, a cognitive system, the larger entity of humans working in collaboration with each other and with the support of capabilities provided by various technologies, is also a cognitive system. It is so, because it does cognitive work. That is, the output of the system is something that can be achieved only through use of cognitive processes such as perceiving, deciding, planning and acting.

We might expect that collaborations and technological aids will result in more effective cognitive systems, but that is not inevitable. As we often observe, people do not always work well together. Nor do they always use their technological systems effectively and in many cases, those technological systems do not support cognition even if used as their designers intended. We need to be careful and systematic as we develop and deploy our own individual capabilities, as we tune our interactions with others, and as we develop and use technological supports. Finally, we need to coalesce all of those capabilities into a

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coordinated and dynamic entity, one in which human purposes, human values and cognitive capabilities are supported seamlessly and robustly by technological capabilities to form an effective, high-performing cognitive system.

A cognitive system has a large number of elements, which may be both human and technological, and they are distributed. Such a cognitive system can be spatially distributed, with its elements spread over a large geographic area, whereby it functions as a cognitive system only via technologies that support coordinated collaboration and communication at a distance. A cognitive system can also be temporally distributed, with cognitive products developed at one point in time feeding into and shaping the development of cognitive products developed at a later point in time. For example, a sextant is a product of a cognitive design effort and, having been designed and placed into use, it exists as a support for the cognitive work of celestial navigation. As cognitive systems, we human beings also develop our biological, cognitive and social capacities through time.

This view of spatially and temporally distributed cognitive systems is aligned with the theory of distributed cognition as outlined by Hutchins (1995). A foremost claim of this theory is that distributed cognition is not a theory about a special type of cognition but rather a theory about fundamental cognitive structures and processes. All cognition is distributed. Because of that, the use of the modifier *distributed* is not strictly necessary. However, the continued use of this term distinguishes this conception of cognition from other mainstream conceptions that do not emphasize its distributed nature.

3. Benefits and risks

All cognitive tools support cognitive work but also constrain the way that work is done. The sextant offers an illustration; celestial navigation can be performed in different ways but reliance on a sextant precludes some of the possibilities. A cognitive support tool should constrain cognitive work in a way that is cognitively economical and cognitively robust, but that is not always the case.

Within commercial aviation, automated systems now assist pilots in most of their tasks. The term clumsy automation has been coined to refer to that sort of automation that induces errors or, in other words, makes the cognitive system, comprised of the flight crew and the cockpit technology, more fragile. In everyday life, the use of cell phones in automobiles has added much desired functionality to the cognitive system of interacting drivers and their automobile systems but has also added to the accident risk. More generally, any advance in information technology brings with it, potentially useful capabilities but, if inappropriately configured, can actually degrade the cognitive system rather than enhance it.

4. Technological mythology

By 2050 robot “brains” *based on computers that execute 100 trillion instructions per second will start rivaling human intelligence* (*Moravec, 1999*).

The creation of greater than human intelligence will occur during the next thirty years (*Vinge, 1993*).

Mahnmut and Orphu are intelligent robots who travel great distances in each other’s company. Mahnmut is a Shakespearean scholar (the sonnets, not the plays) and Orphu is a Proust scholar. Mahnmut and Orphu spend much of their time during their travels discussing the work of these two writers. Mahnmut and Orphu are truly intelligent machines. They were created by Dan Simmons (2005), a prolific science fiction author. But what of the quotes by Moravec (1999) and Vinge (1993). Science fiction aside, are we really on the verge of computer-based intelligence?

Both Moravec (1999) and Vinge (1993) assume this to be a capacity problem and that once we have computers that are fast enough and powerful enough, intelligence will emerge via some unexplained process. Moravec goes so far as to claim that we will be able to simulate intelligence once computers can achieve the speed of 100 trillion instructions per second. While Moravec (1999) and Vinge (1993) know how computers work, they do not forward any hypotheses about the processes underlying human intelligence.

Speed, in and of itself, is not the answer. At the very least, construction of an intelligent artifact will demand knowledge of the process algorithms underlying intelligence. Whether such algorithms are knowable, or even whether processes underlying intelligence are algorithmic, is currently undetermined. Notably, Vinge is both a computer scientist and an author of science fiction. He appears to have forgotten that science and science fiction are two distinctive endeavors.

Unfortunately, this sort of mythology is widespread. For example, IEEE Intelligent Systems (2010) sought articles on the theory and applications of systems that perceive, reason, learn, and act intelligently. They invited articles about intelligent software agents but not about intelligent human activity.

5. Technological realism

A cognitive system is a thinking (or intelligent) information system. However, the enhanced intelligence is not generated by the activity of intelligent technological functions but emerges from the coordinated collaboration of distributed human agents via their interactions with each other and with functionally heterogeneous technological artifacts. In the sense that collaborations between humans and their use of technological artifacts are coordinated, effective, robust, and meaningful, the cognitive system is intelligent.

From the perspective I promote here, people reason but technological devices do not. Two people in coordination can possibly reason more effectively than either in isolation, and if they (as a coordinated dyad) avail themselves of the opportunities presented by technological devices that can compute logical relationships, find and organize information, and probably offer a number of as yet unimagined supporting functions, these entities (the two people together with their technological devices) constitute a reasoning system.

Computers do not, for example, exhibit insight, nor do they demonstrate creativity. There are however, ways to use technology in the fabrication of better cognitive systems. I will illustrate with four examples, two of robust cognitive systems in action and two of fragile cognitive systems.

6. Knowledge management

In today's military systems, the flow of information up and down the chain of command and within operational units is critical to success. One particular method of disseminating information that has captured the modern military is the PowerPoint briefing. Despite the central role it is accorded, some recognize the problems that typically accompany this method of information dissemination; a preference for style over substance, a reliance on mind-numbing detail, a failure to engage with the issues, and time-consuming development efforts (Hammes, 2009). There is, however, a better way.

During 2001 and 2002, the US 5th Fleet, while supporting the NATO offensive in Afghanistan, implemented a web-based information system or knowledge web, identified locally as the KWeb (Adkins and Kruse, 2003). The hardware for this system was assembled from commercially available items. The use of the KWeb evolved over several months but its networking and collaboration tools eventually transformed the way information was used and shared in planning and executing missions within the US 5th Fleet during this deployment.

Under the new system, those who had been preparing briefings transferred their effort into development of web pages, which automatically became available to those who would have attended the briefings. Concern that the development of web pages would increase the workload of staff members who were already heavily loaded proved unfounded largely because those staff members developed a more efficient division of labor and because senior staff relieved their subordinates of the requirement to develop traditional briefings once they recognized that there was no need to continue with them.

Furthermore, the new system had a number of unanticipated benefits. It induced high levels of motivation and innovation in its users. Some of those developing web pages became very good at providing summary analyses that others found more informative than the summaries they would have generated on their own. These web pages served as important knowledge archives for planners who had previously found it challenging and onerous to extract the meaningful implications from the raw information available to them. It was not a matter of more complete information but rather one of higher quality information summarized and interpreted in a manner more relevant to operational needs. Concerns about information overload proved unfounded and quickly evaporated.

Planning staff noticed a dramatic difference in the way they did their work. Previously, they had found themselves overloaded, formulating plans reactively with critical deadlines looming. They found it considerably easier under the new system to respond to planning requests because essential information was easier to find and to interpret. No longer were they struggling to meet critical deadlines. Rather, much of their time was now spent on contingency planning; preparing ideas and summaries that they could later co-opt when they needed to develop a plan under a tight time constraint. Staff at all levels found that the new system supported informal discussions because the information for support of those discussions was available at any work station in the fleet. Those involved no longer had to run to a stateroom, ready room or operation center to access information critical to a discussion.

Because the KWeb was available to all, others not directly involved in developing plans also used it to become better informed. Many who studied it out of curiosity developed close working ties across the organization through use of a KWeb chat function. Previously, close working ties developed largely through interactions encouraged by spatial proximity.

Certain staff members became trusted knowledge providers while, much as with Wikipedia, many only peripherally related to the actual development of web pages contributed to the accuracy and completeness of those pages. When information posted to a page conflicted with another source, electronic conversations raised the issue. A more accurate information picture was typically posted after such discussions.

Members of the task force at different levels of command believed that the KWeb helped them develop a better situational appreciation of task force operations. To illustrate, one officer responsible for a command center commented on the requirement to know about all aircraft missions scheduled during his watch. Normally, the watch commander would rely on an Air Tasking Order, a document that lists all aircraft missions. This watch commander observed that the Air Tasking Order had not helped him develop a situational appreciation of daily flight operations but with the advent of the KWeb, he could now build a robust mental picture of all allied flights and their relationship to allied forces in the area.

In final analysis, much of the success of this system can be attributed to enlightened management. In developing the system, senior officers emphasized the use of conventional tools that could be mastered quickly. They promoted use of the system at all levels of the chain of command, they remained ready to dispense with legacy systems and practices that became redundant, they supported a transformation in the practices of information management, and they publicly acknowledged the efforts of those who used the system effectively.

7. Safety management

Commercial aviation pilots in the US can submit incident reports to the Aviation Safety Reporting System administered by NASA. These reports are assessed by experienced aviation professionals (pilots, air traffic controllers and aviation mechanics) to identify system deficiencies. Any deficiencies identified in this manner are implemented by advising persons in a position to correct the problem.

None of this sounds particularly insightful and it is worth remarking largely because it is almost never done. Safety critical organizations do not always perform safety audits. Many that do perform safety audits do not extract insights from their experienced operational staff and many times, even where a safety audit reveals problems, nothing is done to correct them. Notably, Union Carbide's safety management team conducted a safety audit of their Bhopal chemical plant several months prior to the accident in which several thousand people were afflicted by a cloud of Methyl Isocyanate vapor from the plant (Lapierre and Moro, 2002). The safety report anticipated some aspects of the problems that led to the accident but its recommendations were not implemented.

8. Friendly fire

In the aftermath of the first Gulf war, the US defense forces mounted an operation in Northern Iraq, designated Operation Provide Comfort, to protect the Kurdish population from reprisals by the Iraqi government. During this operation, two USAF F-15s shot down two US Army Black Hawk helicopters. All on board the Black Hawk helicopters, which included a number of UN peacekeepers, perished. The accident, analyzed in detail by Snook (2000), occurred despite continuous surveillance by airborne command and control and despite a host of carefully designed systems that should have prevented it.

The F-15s involved in this accident were assigned the task of sanitizing the operational area, i.e., of ensuring there were no enemy aircraft and that it was safe for other allied flights. Although the F-15 flight was to be the first into the area that day, the two Black Hawks were already there. The F-15 pilots asked at two different times whether there were allied flights in the area that were not listed on the Air Tasking Order and both times they were advised that there were not. Although it was widely understood that all flights over the area were listed on the Air Tasking Order, US Army Black Hawk operations had not been listed for some time.

One of the requests from the F-15 pilots regarding unlisted flights went to the airborne command and control crew who knew of the Black Hawk operation. Some members of the airborne command and control crew followed the engagement of the F-15s with the Black Hawks without raising the possibility that these two helicopters, read by the F-15 pilots as hostile, were in fact US aircraft. This particular airborne command and control crew was on their second mission in Iraq, having recently assembled as a crew in the US. Airborne command and control crews are required to participate (as a team) in two simulator-training sessions prior to deployment from the US. This crew participated in only one session. Furthermore, three of the crew's senior members did not attend even that session because, they argued, due to their seniority and experience they did not have to. They had apparently forgotten that this training was about teamwork rather than about individual skills.

9. On developing better cognitive systems

Breakdowns in communication and information sharing are pervasive within the socio-technical systems accident literature. The Bhopal and Friendly Fire accidents I discuss above are a miniscule fraction of the illustrations I could have presented. However, there is little to be learned from a seemingly endless parade of the frailties of poorly-managed socio-technical systems except possibly to reinforce what we already know; that humans do not function well in systems that are poorly designed. In contrast, the positive illustrations of the US 5th Fleet KWeb and the Aviation Safety Reporting System suggest lessons that are not widely appreciated in any scientific or technological area.

In the terms I have defined early in this paper, both US 5th Fleet KWeb and the Aviation Safety Reporting System are robust cognitive systems and their robustness is partially due to the manner in which the human participants in these systems work on making sure that information is organized and formatted so that it is readily accessible and its operational relevance is immediately apparent. It is also partially due to the manner in which the human participants in the system interact with each other. Those in authority support and promote the practices, processes and interactions that contribute to the cognitive potency of these work systems while peers shape, share and use information in an operationally meaningful manner.

One distressing aspect of all of this is that nothing I have said here is profound. I imagine that all of my readers will, by looking into their own circumstances, recognize it as self evident. One does not have to look far to find unfortunate examples; systems in which information is not organized in any manner that makes it operationally meaningful, systems in which the human participants do not engage significantly with each other on matters of planning and information sharing, and systems in which management mandates practices, processes and interactions that disrupt the cognitive potency of work systems. Furthermore, as self evident as all of this may seem, it appears to have escaped the notice of technologists who would develop intelligent systems.

10. Conclusion

The illustrations I offer do not tell the whole story. There is something more fundamental that starts before we get to the development of the US 5th Fleet KWeb or the Aviation Safety Reporting System. These two systems are striking only because their style of information management is the exception rather than the rule. They are, of course, not the only effective cognitive systems in our modern society but effective cognitive systems are far outnumbered by ineffective ones. What can we do about this? What is the general strategy for developing better cognitive systems?

For those who imagine that the development of cognitive systems is a new endeavor, I wish to point out that it is not. Going back millennia, anyone who has been a parent has been at least partially responsible for the creation of a cognitive system. If we are to build better cognitive systems, we need to start with the cognitive capabilities of our children, perhaps most of all their communication skills.

One of the things that might be obvious from the positive illustrations I discuss above is that these are information or knowledge systems in which intermediaries massage the information and encourage others into intellectual engagement with it. Teachers and librarians might justifiably imagine that they do this. And that is the point. They do. And so one of the ways we might attack this problem of developing better cognitive systems more comprehensively is to develop better schools and better libraries.

I should clarify that this is not a call for better teachers and better librarians. Particularly in the field of education, it is currently popular to focus on the failings of our teachers and to extoll the educational benefits of computers. It would seem that one sure way to improve education is to give students access to computers, but there is little in this public dialog about how computers can be used to advance education; just having them will be sufficient. The outstanding work of Papert (1993), Liu (2003) and many other educational researchers is typically ignored.

Rather, the public dialog is driven by the imperatives of our technological myths. Embedded in that mythology is the belief that even if technology is not yet good enough, it soon will be. This sort of attitude is doomed to disappoint. If we are to develop better cognitive systems, we need to relegate technology to its proper role. We need to make explicit the human purposes and values that motivate and shape any endeavor and we need to develop a human-centric plan to achieve our purposes in a manner consistent with our values. Technology cannot provide cognitive systems to execute that plan but it can provide an infrastructure that will help us execute it. If that strategy is to work, we, the cognitive systems now in operation, need to identify what it is that will help us be better cognitive systems and demand that technologists provide that for us rather than that they pursue the fantasy that they can replace us. For the human being is, after all, not only or merely a cognitive system.

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