THEORIES OF HUMAN COGNITION: TO BETTER UNDERSTAND THE CO-ADAPTATION OF PEOPLE AND TECHNOLOGY

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Keywords: artificial intelligence, co-adaptation, cognition, cognitive models, human-centered design, human-computer interaction, knowledge management, learning, organizational memory systems, socio-technical systems

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Summary

Socio-technical systems of our post-industrial era embed their own internal cognitive mechanisms and behavior. New information technology has induced new practices and human roles. The resulting co-adaptation of people and technology will be analyzed in the light of various theories of human cognition. We will analyze various aspects of human cognition embedded into artifacts. Even if they do not use the same kinds of tools and practices, all civilizations need to manage the knowledge that they produce and use. These tools can be physical or conceptual. For a very long period of time, the Art of Memory was used to manage knowledge. Knowledge transfer was essentially based on oral transmission within small groups. Printing started to extend knowledge transfer to larger groups. Descartes created a method that revolutionized knowledge management reducing most problems to mathematical equations that are possible to solve by definition. The fact that Descartes' method worked successfully in the material world tremendously influenced the twentieth century because it was almost totally technology-oriented. It is amazing to observe that the computer, the ultimate production of Descartes' method, suddenly rehabilitates the Art of Memory because the materialistic approach to the world is no longer sufficient. The Web recreates artificial villages (communities) where people can communicate almost exactly as their ancestors communicated in their small villages. We discuss a dual problem in cognitive science that opposes a classical scientific approach to an experiential one, and some of its potential impacts on life support systems such as human/organizational learning and human-centered design.

1. Introduction

"Celestial navigation capitalized on the European virtues of mathematical theory and on instruments of high technological sophistication. In contrast, navigation in Oceania emphasized the deliberate refinement of people's intuitive sense of direction and the learning of direct perceptual cues from the natural environment. For a seaman of Oceania, making a voyage is conceptualized as being within a pattern of islands, the positions of which are represented in his cognitive map." K.G. Oatley.

Automation has been developed to relieve the operator of tedious work and make the system both more efficient and more reliable. Lots of automated tools have fulfilled the hopes of their creators. Unfortunately, however, many of them have introduced new issues. In both cases, i.e., positive and negative use of automation, theories of human cognition have evolved to the increasing need better to understand and predict human adaptation. In this chapter, we target life support systems such as human/organizational learning and human-centered design.

Computers are everywhere, and will probably be even more present during the third millennium. People are faced with the tremendous challenge of adapting to these new artifacts that are becoming more and more invisible. Computers are more invisible because they are becoming integrated and usable. Obtaining money from a cash machine in the street is no longer a complex cognitive process. We have learned to rely on this kind of machine. Sometimes, we wonder if our credit card will come out after a transaction. New automatisms have arisen. New types of issues occur when you either make an error or perform an action that is not allowed by the computer program. We are becoming more and more aware of these types of problems. Credit cards certainly help support our lives when they work well, but they happen to be nightmares when they fail to provide what we expect. We need to manage our nerves. Sometimes, we expect things that are not in the contract. This may be due to our background or the non-explicit phrasing of the contract. In other cases, we make a manipulation error and we do not understand the consequences. Finally, the machine itself may be broken or deliver messages that we don't understand. All these examples are related to human cognition.

Since information technology, and automation in particular, evolves very quickly, emerging practices, and information management in particular, do too. A major issue is that many people do not have time to adapt and mature emerging practices rapidly enough with respect to the increasing speed of technology evolution.

The management of knowledge and action supported by the use of new information technology leads to the creation of new cognitive functions that will be extensively described in this chapter. Humans are often the victims of new information technology because they do not assimilate and accommodate such cognitive functions in the right way, and/or at the right time. A major issue is the integration of computer technology with the current external memories as extensions of the human memory. Information technology enables knowledge management and storage. Will information technology give birth to better life support systems? What will be the role of human beings in these life support systems? What will be the repercussions of this artifactual evolution on the way humans live? Information-based life support systems are taken within a broad scope including their integration and use at school, home, work and public places.

1.1. Modeling Human Cognition to Rationalize Co-adaptation of People and Technology

In this chapter, theories of human cognition will be used, and sometimes extended, to rationalize the concurrent adaptation of people and technology. We will use alternatively the terms *theory* and *model*, because they are often the same in cognitive science, a field in constant evolution. Theories are often socially-recognized models of data from field and laboratory experiments. The notion of model is important since it influences the way experiments are planned and conducted. Both theories of human cognition that support experiments, and experimenters themselves, are crucial in the genesis and interpretation of experimental data. Anytime we try to measure, assess or understand a life process, we attempt to use one or several models; whether these models are implicit or explicit. We refine our measures, assessments or understandings by refining these models. We might end up either with satisfactory models in the end, or with failures that might suggest drastically different directions of investigation. We are constantly in quest of models that support our lives. Some of these models are already available. They have been tested by many people. They have become part of our life support conceptual tools. Models of human cognition have been debated for a long time, and still are being.

1.2.Outline of the Chapters

In section 2, Rasmussen's model will be used to explain historical facts on automation and the emergence of information-based practices. Section 3 will support the claim that artifacts embed human cognition. The study of affordances is very important for human-centered design because no matter what users are required to perform using an artifact, they will attempt to react to artifact affordances. Cognitive modeling is a primary topic of artificial intelligence that strongly supports cognitivism. Dreyfus' criticism of artificial intelligence had the merit of putting forward situational knowledge developed and used by expert people, and of showing the limits of analytical knowledge that was extensively used by artificial intelligence researchers to develop expert systems. The cognitive function paradigm was developed to take into account situatedness in cognitive modeling. It also fostered the development of function allocation among people and technology. In section 4, we will investigate the current shift from individual intelligent assistance to multi-agent communication in terms of human-machine communication models. Section 5 will present a variety of human memory models to support the analysis, design and evaluation of external memory systems. An example of an organizational memory system of training knowledge will be introduced in section 6. In section 7, we will discuss the co-development of human and artificial cognitive functions by using an evolution of Piaget's action schemes. The search for and satisfaction of the co-reliability of human and artificial agents contribute to the emergence of distributed cognitive activities. Section 8 will present Descartes's heritage and phenomenology (based on human experience) as a background for a new Art of Memory in knowledge management. In the conclusion, these rationalizations will be used to present an epistemology of organizational cognition. The balance of the chapter provides the concurrent approaches of human and organizational learning, and human-centered design.

2. Automation History and Evolution of Practices

Automation has been a major concern for a long time. The clock is certainly one of the best examples of an old automaton that provides time-telling to people with great precision. People rely on clocks to manage their lives. A watch provides precise time information to a user who would not be able to access it otherwise. In addition, a clock may be programmed to alert its user autonomously to wake up, for example. People trust clocks, but they have also learned to know when a clock does not work properly. They have learned to interact with such an automaton. During the twentieth century, more sophisticated automata have been created.

2.1. From Energy-Based to Information-Based Interaction

Several artifacts, such as the telephone, the car, the airplane, television, and the computer, have made the twentieth century a unique period of our era. All these technologies facilitate communication among people. The last born artifact, the World

Wide Web (the Web for short), is certainly the most promising in that regard. Basically, computers are everywhere, and more than ever at the service of communication. The question is not *if* people use and will use newer information technologies to communicate, but rather *how* they use them -- whether to improve their well-being and to become more aware of the needs of others.

This fundamental shift from *energy-based* use of physical artifacts to *information-based* use of cognitive artifacts needs to be further investigated. Cognitive artifacts result from the computerization of our living environments. Because more *cognitive artifacts* have been created to help manage our lives, conventional human-machine interaction models may become rapidly obsolete. We have started to observe this trend in studying the evolution of commercial aircraft cockpits and the emergence of new pilots' practices. In the past, pilots needed to calculate and think at the same time as they needed to act in the short term. Today, they tend to think more than they directly act. In addition, their thinking and (high level) actions are more directed toward long-term action plans that are finally implemented by the machine. Pilots have become flight managers of artificial agents that execute complex tasks that were executed by the pilots' predecessors. The emergence of new practices has forced cognitive scientists to take different human-machine interaction models into account.

Information technology provides new challenging means to do business. Today, in some countries, someone can order food using the Web from his or her house. What he or she needs to do is to connect himself or herself to the appropriate Web address, browse the various product descriptions, check their prices (he or she may run a spreadsheet at the same time to have the total price of what he or she has selected so far), verify the complete order, press the "Order" button, and finally confirm. That is it. The delivery to his or her kitchen will follow in a few hours, or even minutes in some cases.

This short example shows how we are moving from an *energy-based* world to an *information-based* world. People previously would have had to write a shopping list on a piece of paper, go to the supermarket, walk around the various food sections, choose what they need, load their trolley, go to the cashier, load the bags, pay, go back to their house, unload their car, and carry the food to their kitchen. The main difference lies in the energy and time that people used to spend in getting food to their home, and the more cognitive task that is now involved in programming what they need using both their past experience and the information that they have on the Web.

To generalize what has been stated so far, *life management is becoming more cognitive*, i.e., it involves more (abstract) thinking than (concrete) doing. The result is that once someone has made a decision, a whole invisible energetic process is started, i.e., some other people will have to collect the food he or she ordered and bring it to his or her house. This person has delegated the physical tasks to people whom he or she doesn't know. He or she doesn't know how many they are, nor what they do either. He or she has learned to trust the system. Since this customer is not close to the energetic process, actions are often irreversible, e.g., any erroneous choice of item that he or she made in the order will be taken as a definitive choice by the delivery person. There will not be any possibility of direct cancellation if the real product that the customer finally sees does not match the representation of the virtual object on the Web.

Human beings have always tried to improve the control of their environment by extending their own capabilities.

However, what do we lose by moving to the information-based interaction world? The Web removes the pleasure of going to the market place, and enjoying the delicate and multiple smells. Walking through the market stands, talking about the latest news with the merchant, weighing the food and smelling it; this is real sensory-motor experience! But where is the pleasure in going to crowded supermarkets, waiting at busy counters, and driving back home during rush hours? Automated shopping is much more pleasant in this case.

It seems that information-based interaction makes a drastic distinction between things that are well formatted and things that require and deserve more human sensitivity and physical presence. Examples of the former things are packs of milk, sugar and mineral water. Examples of the latter are fresh fruit, fish and meat.

2.2. An Interpretation of Automation Evolution

Bernard Ziegler, a former Vice-President of Airbus Industries, recorded the following observations and requirements from his experience as a test pilot and distinguished engineer:

- "the machine that we will be handling will become increasingly automated;
- we must therefore learn to work as a team with automation;
- a robot is not a leader, in the strategic sense of the term, but a remarkable operator;
- humans will never be perfect operators, even if they indisputably have the capabilities to be leaders;
- strategy is in the pilot’s domain, but not necessarily tactics;
- the pilot must understand why the automaton does something, and the necessary details of how;
- it must be possible for the pilot immediately to replace the automaton, but only if he has the capability and can do better;
- whenever humans take control, the robot must be eliminated;
- the pilot must be able to trust automation;
- we must acknowledge that it is not human nature to fly; it follows that a thinking process is required to situate oneself, and in the end, as humiliating as it may be, the only way to insure safety is to use protective barriers."

Ziegler's very high level observations and requirements come from his very rich experience. Cognitive science could benefit from them by proposing appropriate theories of cognition that would rationalize this experience.

Rasmussen’s model has been extensively used over the last decade to explain the behavior of a human operator controlling a complex dynamic system. This model is organized into three levels of behavior: *skill*, *rule* and *knowledge* (Figure 1).

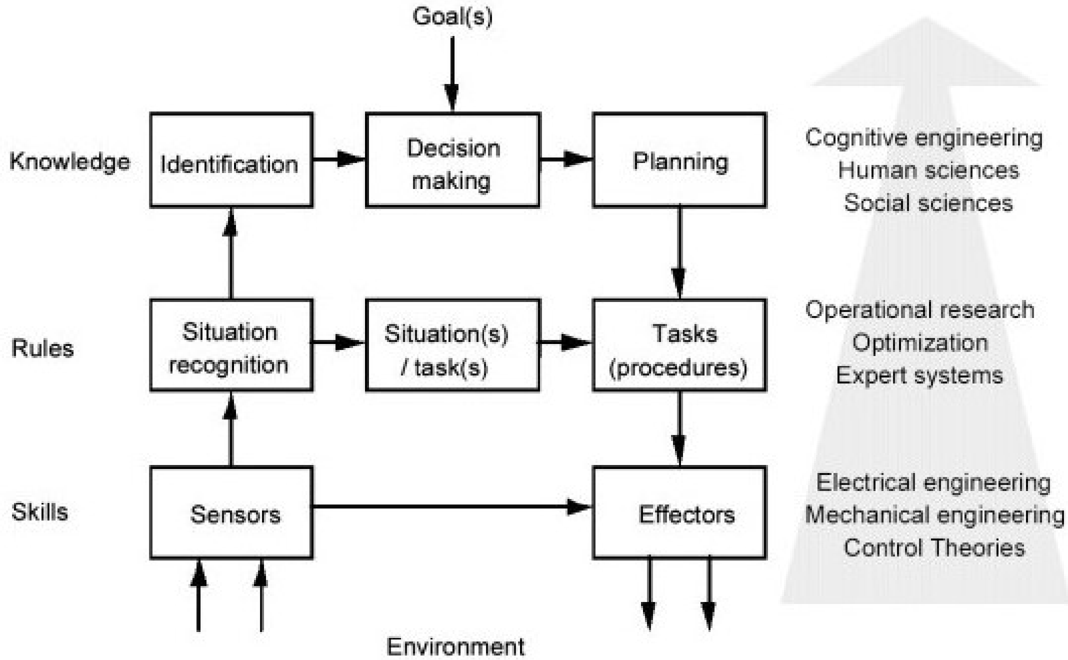

Figure 1: Rasmussen's model, the evolution of automation and the emergence of contributing disciplines.

Historically, automation of complex dynamic systems, aircraft in particular, led to the transfer of human operators' skills (e.g., performing a tracking task) to the machine. Autopilots have been in charge of simple tracking tasks since the 1930s. This kind of automation was made possible using concepts and tools from electrical engineering, mechanical engineering and control theories, such as mechanical regulators, *proportional-integral-derivative* controllers (PID), Laplace functions and stochastic filtering. Autopilots were deeply refined and rationalized during the 1960s and the 1970s. Human skill models were based on quasi-linear models' functions and optimal control models. Human engineering specialists have developed quantitative models to describe and predict human control performance and workload at Rasmussen's skill level. They have been successfully applied to study a wide range of problems in the aviation domain such as handling qualities, display and control system design and analysis, and simulator design and use.

The second automation revolution took place when the rule-based level was transferred to the machine. In aviation, a second layer was put on top of the autopilot to take care of navigation. The *flight management system* (FMS) was designed and implemented to provide set points for the autopilot. A database is now available onboard with a large variety of routes that cover most of the flights in a specific geographical sector. Pilots need to program the FMS by recalling routes from the database and eventually customize them for a specific flight. Once they have programmed the FMS, the aircraft is "capable of flying by itself" under certain conditions, i.e., the FMS is in charge of the navigation task in pre-programmed situations.

Today, human factors, research and practice have evolved towards *cognitive engineering*, and *hermeneutics*, because the control of highly automated systems does not require the same abilities and requirements as traditional tools. Human operators are mostly working at Rasmussen's knowledge-based level. Basic operations are delegated to the machine, and humans progressively become managers of (networked) cognitive systems. Humans need to identify a situation when there is no pattern-matching (situation recognition) at the rule-based level, to decide according to specified (or sometimes unspecified) goals, and to plan a series of tasks. These are typical strategic activities. Some people are good at strategic activities, others prefer to execute what they are told to do. In any case, the control of cognitive systems requires strategic training. In the food shopping example, using the Web has totally transferred the shopping task to Rasmussen's knowledge-based level. The selection of food items is made using virtual objects. The delivery is planned with respect to the customer's schedule and the nature of the food.

Technology has always shaped the way people interact with the world. Conversely, interacting with the world has direct impact on how technology evolves. Rationalization of experience feedback influences the development of theories that make new artifacts emerge. In a technology-driven society, this works the other way around, i.e., the use of artifacts makes new practices and new jobs emerge, as the film technology did, for example. The twentieth century was rich in technology innovation and development. The speed of the evolution of technology and resulting practices is very sensitive to economical impacts. In some cases, when economical benefits were not obvious a priori but the evolution of human kind was at stake, technological advances were decided at the political level. One example was designing and developing a technology that enabled a man to walk on the moon. Today following these grandiose projects, we realize that human-centered automation, and, more generally, human-centered design, are not effectively taken into account at the political level yet. A new paradigm needs to be found to understand the balance better between human and machine cognition.

3. Artifacts Embed Human Cognition

People build and interact with artifacts by satisfying both physical and cognitive constraints. Different people may not see the same kind of physical and cognitive constraints in the same artifact.

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Biographical Sketch

Guy Boy holds a Ph.D in Automation and System Design (1980) from Ecole Nationale Supérieure de 'lAéronautique et de l'Espace (SUPAERO). He is the author of numerous books and articles on subjects ranging from cognitive engineering to human-computer interaction to knowledge acquisition and knowledge-based systems. He has received numerous awards for contributions to his profession. Since 1992 he has served as Director, European Institute of Cognitive Sciences and Engineering (EURISCO).