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Cognitive Ergonomics in Interface Development Evaluation

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Abstract: Cognitive Ergonomics is a discipline that contributes with its knowledge to construct better machines in the sense of being easier to use by human beings. Cognitive Ergonomists perform a cognitive analysis of interaction to: (1) shorten the time to accomplish interaction tasks; (2) reduce the number of mistakes made by humans; (3) reduce learning time; and (4) improve people's satisfaction with a system. An appropriate methodology for performing this cognitive analysis of interaction could be based on what I call the "Principle of Mutual Dependency" [Cañas et al 2004]. This principle determines that: (1) The optimal interface functions will be those that fit the human cognitive functions involved in the task; (2) The human cognitive functions that are involved in the task depend on the interface functions; (3) The modification, replacement, or introduction of a new interface function implies the adaptation of the human cognitive functions; (4) The development (e.g., learning) or limitation (e.g., Elderly users) of the human cognitive functions will imply limitations on the possible interface functions. I will describe this principle with examples from research projects in which our research group participates.

Keywords: Cognitive Ergonomics, interface evaluation
Categories: H.1.2

1 Cognitive Ergonomics: The Cognitive Analysis of Interaction

Cognitive Ergonomics (also called Cognitive Engineering or Psychological Engineering; [Wickens and Hollands 2000] is the scientific discipline that studies the cognitive processes in the design of technology and the environment in which this technology is used by people. Cognitive ergonomists analyze human work in terms of representations and cognitive processes. When we combine the terms Cognition and Ergonomics we do so in order to indicate that our objective is to study the cognitive aspects of the interaction between the people, the work system and the artefact that we find in it, with the intention of designing them so that the interaction is effective. The cognitive processes like perception, learning or problem solving play an important role in the interaction with artefacts and they must be considered to explain the cognitive tasks that people perform.

We could say that the objectives of cognitive ergonomists are the same as those of any other discipline related to Human-Computer Interaction. The aim is to: (1) shorten the time to accomplish tasks; (2) reduce the number of mistakes made; (3) reduce learning time; and (4) improve people's satisfaction with a system. However, the difference in Cognitive Ergonomics is the methods they use to reach those objectives. Cognitive Ergonomics perform what we might call a "cognitive analysis of interaction".

Traditionally, cognitive analysis of interaction has been implemented by applying theoretical models of human cognitive processes proposed by cognitive psychologists. However, this approach is now facing an serious dilemma, predictions made from these models developed in laboratory settings with particular materials, tasks and people are not confirmed when we have to predict how a person interacts with an artefact. This failure could be explained by acknowledging that these theoretical models incorrectly assume that the human cognitive processes work independently of context. Furthermore, traditional analysis of interaction has also incorrectly assumed that the human being is the only cognitive agent in the interaction. We propose to replace this analysis by another in which interaction design should be based on the idea that human cognitive processes adapt their operations to contextual changes to interact with other cognitive agents and devices, to jointly perform the task at hand.

According to the current thought in the Cognitive Ergonomics school of thought it is considered that in order to find a complete explanation of the human behaviour it is necessary to consider the interaction between the human being and its environment. We have started to call the environment within a determined partner-technical context a "Joint Cognitive System". This proposal is being supported by a group of authors who base themselves on a theory they call the "Engineering of Cognitive Systems" [Hollnagel and Wood 1983] [Woods, Johannesen, Cook, and Sater 1994],[Wood and Roth 1988], [Rasmussen, Pejtersen and Goodstein 1994].

2 What is "cognitive analysis of interaction"?

Cognition is the processing of environmental information acting on the environment. Therefore, we could say that any available system that processes information in its environment to act upon it could be called "Cognitive System" and performs "cognitive work". Also, we can consider artefacts as cognitive agents. Technological development, mainly in the domain of Computer Science, has resulted in the devices being designed currently having a level of automatism that enables them to be considered as cognitive systems within their own right. These are almost at the same level as human beings, in the sense that they have their own dynamics which many occasions are independent of human performance. The fundamental difference between the human being and the device, considered both as cognitive systems, is that the artefact is designed by the human being, while the human being is not designed but modified by a process that we call learning. Cognitive artefacts provide us with representations of the work domain, with processes to transform these representations and with means to express these transformations [Simon, 1969], [Dowell and Long

1998], [Dowell and Long 1989]. For example, a radar in the domain of air traffic control provides representations that allow the controller to reason on the state of the domain (for example, height and distances among airplanes), and to transform these representations into transmitting orders to pilots. Therefore, today in Cognitive Ergonomics we talk about "Joint Cognitive System" [Dowell and Long 1998] [Hollnagel and Wood 1983] to refer to a cognitive system formed by the artefact and the human being. The cognitive functions performed by the Joint Cognitive Systems are distributed between the human being(s) and the artefact(s) (see Figure 1).

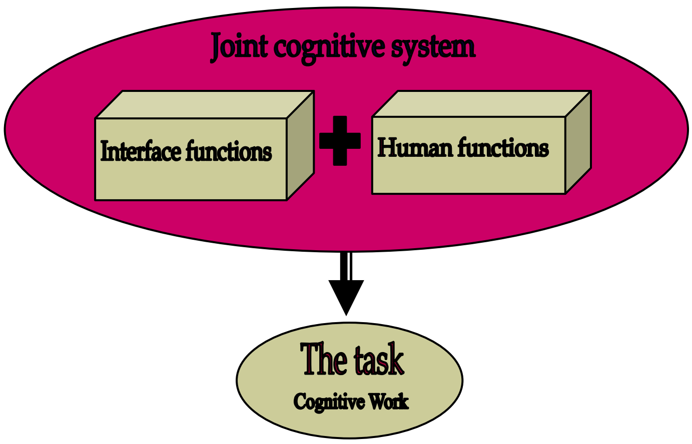

Figure 1: The Joint Cognitive System

There are many definitions of Interaction. For Cognitive Ergonomics, interaction means "Collaboration to perform a task, to do Cognitive Work". Interaction is not the goal. The goal is to perform a task. For example, when describing the task of driving a car we would say that: "My goal is not to sit in my car and play with the equipment. My goal is to sit in my car, so that together we get from one point to another in space, as safely and quickly as possible". This collaboration is impplemented through the interface. To analyze the interaction that occurs between a person and a device, or between a person and other people through devices within the Joint Cognitive System one can follow Hutchins' proposal. This involves basically broadening cognitive analysis used by cognitive psychologists to study human information processing, to describe how the information is processed by the whole system formed by human beings and the devices within a certain socio-technical environment [Hutchins 1996].

Therefore, for cognitive ergonomists cognitive analysis of interaction is:

1. The allocation of functions to both humans and artefacts
2. The design of the interface through which humans and artefacts communicate while collaborating in performing the task.

By "Functions" we mean an information processing procedure. Therefore, when we talk about functions we mean: Perceiving, attending, memorizing, decision making, cooperating, etc. Both humans and artefacts have "cognitive" functions. Human and artefacts interact to perform a task by performing cognitive functions. Therefore, the design of interaction is to describe how these cognitive functions are allocated to humans and artefacts. However, we mean something more than traditional "function allocation". Today Cognitive Ergonomists talk about **"***Adaptive function allocation***"** to mean that functions could be re-allocated through the interaction.

When we speak of an interface we must include the means by which the artefact displays information to the person and the means by which the person introduces information in the artefact. We could say that the design of the interface depends on the particular functions carries out not only by the artefact, but also by the human being.

3 How function allocation works and how it affects the design of the interface

First, we need a principle to investigate on the relationship between interface functions and human cognitive functions. This principle, that we could call "The Principle of Mutual Dependency" would serve to define functions that are adaptively allocated to the artefact and the human being. Then we need to identify which "cognitive" functions should be allocated. With this aim, we can propose a framework for identifying the level of functional analysis.

3.1 The Mutual Dependency Principle

This principle means that (see Figure 2):

1. The optimal interface functions will be those that fit the human cognitive functions involved in the task.
2. The human cognitive functions that are involved in the task depend on the interface functions.
3. The modification, replacement, or introduction of a new interface function implies the adaptation of the human cognitive functions.
4. The development (e.g., learning) or limitation (e.g., Elderly users) of the human cognitive functions will imply limitations on the possible interface functions.

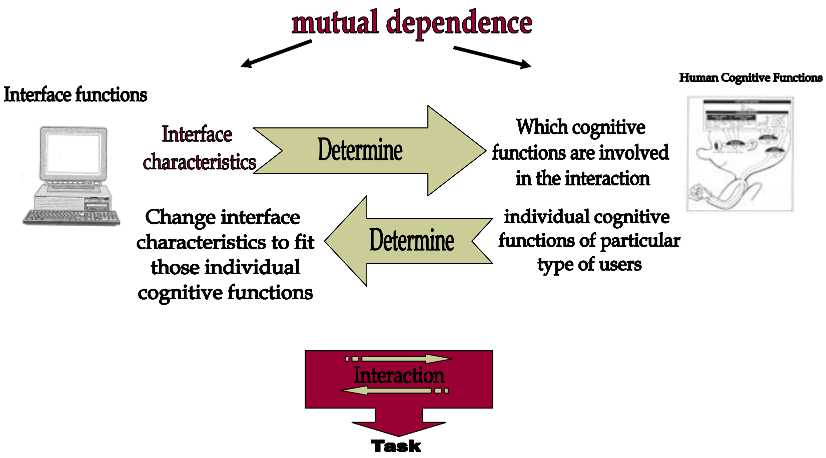

Figure 2: The Mutual Dependency Principle

3.2 Levels of functional analysis

The interaction considered as a cognitive unit of analysis would be a complex activity. Therefore, it would be of great help to have a way of describing it to facilitate its analysis. With this goal in mind, [Cañas and Waern 2001] have proposed a framework of reference that allows us to describe the interaction at several levels accentuating the relationship between particular cognitive processes and types of artefacts that when introduced would affect the human cognitive agent. An adaptation of this framework can be seen in Table 1. In the left column of the table there are examples of cognitive artefacts. Each cognitive level represents a level of analysis. In the right column of the table we have the aspects of human cognition and behaviour affected by the introduction of one artefact.

Starting from the bottom of the table, the first cognitive level that we find is the sensory-motor. In this level interaction is described from the point of view of the characteristics of the human sensorial and motor systems. Interaction occurs when the output of the device, be this visual, auditory, or of any other physical type, is captured by human sensorial receivers. In the same way, human behaviour would be processed through the motor system, and it is essential that the device has the necessary input systems to receive it in the appropriate way. For example, we can be interested here in how people learn to adapt and use neuronal implants cognitively. When a person receives an implant of an artificial motor organ, a hand for example, his actions are not the same as they were before, fundamentally because he does not have direct sensorial feedback. Since many motor functions are dependent on sensitive feedback, any device that compensates for the loss of a motor organ would have to be designed with this in mind. Therefore, it is a challenge for Cognitive Ergonomics to consider how a compensatory type of feedback could be designed, how a person could learn to manage the device as well as his compensatory feedback, and the possible secondary effects of such feedback. Another possible example that is of enormous interest today in this level is “Virtual Reality", where people are provided with a three-dimensional experience of the world and where at least some motor actions are allowed to change the experience of the world. Topics of interest for Cognitive Ergonomics are, for example, the real sensations in the virtual world, and the interactions between virtual reality and natural reality.

Going up a step in the table we find the individual information processing level. In this level we can begin to speak about symbolic information processing. The aspects of devices that are important in this level are related with their performance. The cognitive aspects refer to how the objects are presented by the device (on the screen for example) and how they are perceived by the user. It is important to know, for example, if the objects indicate the pertinent action in a unique way, and the interpretations that the objects confront. The "affordance" concept taken from [Gibson 1979] is useful to analyze the difficulty that the user has to understand what will happen when certain actions affect certain objects (also see [Norman 1986]).

Task	Examples of artefacts involved in the tasks	Levels of functional analysis	Psychological knowledge
Virtual Communities virtual, teleworking,	CMC, e-mail, e-conferences, MUD	Socio-Cultural	Organization, History, Culture
Virtual Communities virtual, teleworking,	CSCW, workflow	Cooperation	Communication y coordination
Ubicous computing	Emotional interfaces	Emotional context	Theories of emotion
Interpretation, search, decision making, problem solving	Knowledge-based systems, decision making support systems	Individual complex information processing	Memory, mental representation, thinking, etc.
Reading, comprehension, writing, etc.	Displays, voice recognizer, voice synthesizers	Perception	Gestalt laws, Attention, Affordance, etc.
Manual and voice control	Input and output component of interfaces, virtual reality systems, etc.	Sensory-Motor functions	Psychophysiology of sensory and motor systems

Table 1: Levels of functional analysis

An important part of the work done in Cognitive Ergonomics has been developed in this level. For example, when we are studying how people understand items on a menu, whether verbal, or represented as icons, or when we are answering questions with regards to how much information can be put on the screen, we are in this level. The necessary attention to perform a task as well as information overload, are also aspects that are considered in this level.

In the following level we find the topics that concern complex individual information processing. The devices that are important in this level are, for example, knowledge management systems, and those that support the decision making and complex problem solving.

New topics that are of interest in this level refer to knowledge awareness, mental models, and situational awareness. For example, it is important to know how the conceptual model of a computer system should be presented so that the user can form a corresponding mental model that allows him to work correctly with it [Cañas, Bajo and Gonzalvo 1994]. To make decisions and to solve problems people develop heuristics, i.e., strategies of information processing that allow them to solve problems efficiently (Newell and Simon, 1972).

Cognitive Ergonomics studies how people can understand the concepts and principles used in support systems, to solve a problem or to elaborate a decision. For example, the heuristic of search used by the computer can be different from that used by the human user. It is possible to wonder then, if it would be necessary for the device to be transparent, i.e. that the human user will be able to understand the heuristic of search that it uses, or that it is enough that it carries out some algorithms correctly without revealing them [Waern and Hägglund 1997].

Next, we meet with higher topics, where people cooperate to perform a task. Many tasks require cooperation for reasons of effectiveness. For example, on some occasions, it would take a person too much time to make all the decisions for the design of a mechanical device. Many tasks require cooperation because the expertise of several people is needed. For example, medical work in a hospital pulls on the knowledge of all fields: laboratory personal, medicine, surgery and psychiatry, which is sometimes applied to one patient alone.

In this level, individual information processing covered in inferior levels should be considered from the point of view of the communication and the coordination that takes place amongst the participants of a task. Of course, individual information processing is still important, but the result of team information processing will be different and will depend on interactions within the team.

Devices that are good for communication and coordination belong to the category called "CSCW" (Computer Supported Cooperative Work). They can vary from the simple support of communication, such as e-mail, to complex systems of support in coordination, such as systems of work flow.

In this level, topics of interest for Cognitive Ergonomics are, for example, studying how CSCW systems affect the habits, strategies or styles of people's communication, how to adapt such systems to the different ways of working that have developed in a work place, and how to allow them to organize tasks flexibly and to distribute the tasks efficiently.

Finally, the level with the most extensive span is the one that covers the socio-cultural aspects of knowledge. In this level it is recognized that actions of people, as well as their expectations are built on historical tradition, where the mutual social influences as well as the devices that are used jointly, play an important role. The devices in this level can help to build a community and keep the historical memory of it. For example, we could discuss at this level how people who use the Internet extensively form a virtual community, with similar effects to a community in real life, from the point of view of traditions and expectations, but where the rules for interaction and action can differ.

This level is so high that it is debatable if it can really affect the design. A community is not designed, but develops over a long period of time. Its members can experience problems and make errors, and they can try to find out for themselves the different ways to overcome them. Solutions are given based on mutual agreements without external advice, and built on general cognitive or social principles in general.

Topics of interest for Cognitive Ergonomics in this level are then, more to do with analysis than with design. Methods and concepts of Cognitive Ergonomics could help participants to meditate its practices, and allow them to choose solutions that favour its goals and own values. For example, some problems can be solved with purely social action, while other problems can be solved technically [O'Day, Bobrow, Shirley 1996].

This reference framework, therefore, offers us three or four levels where Cognitive Ergonomics can offer very pertinent explanations. Although levels overlap, interaction problems can be considered in any single level. An analysis in a higher level does not exclude problems in a different one. It is obvious that solutions at the organizational level are not sufficient to solve perceptual problems and vice versa. In this way, a wider level will also be required to consider other levels.

4 Tools for Supporting the Development Process

This principle of mutual dependency is applied to solving design problems by looking at the relationship between interface functions and human cognitive functions in two directions: (1) From the human cognitive functions to the interface functions; and (2) from the interface functions to the human cognitive functions.

4.1 From Human Cognitive Functions to Interface Functions. Design problems: Deaf users interacting with the Web

The functions of the interface that help to perform a task will be those that are more appropriate to the human cognitive functions that are implied in the task. For example, appropriate interface functions will be those that correspond to the structure and function of the human working memory. We can find good examples of this situation when the human cognitive functions suffer from some kind of limitation that would determine the interface functions that we can design.

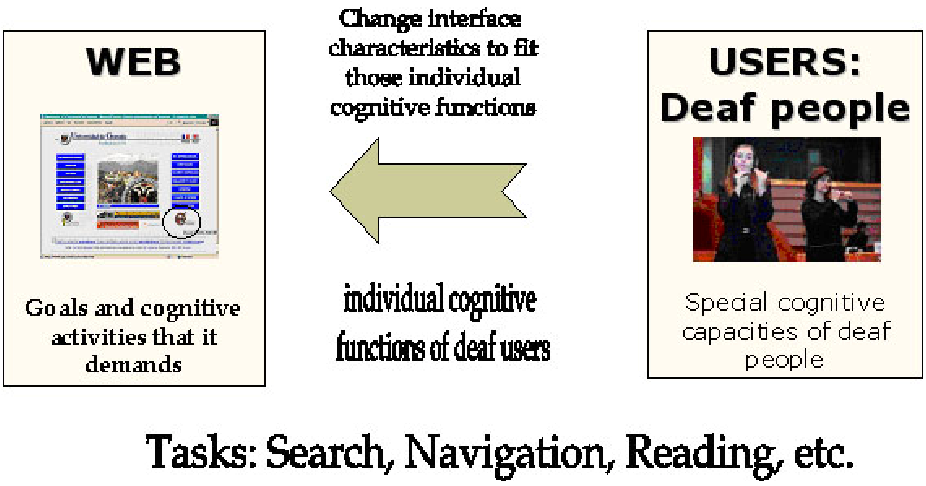

Figure 3: Deaf users interacting with the Web

The Web is becoming the most important media for communicating and accessing information in today's world. However, it is not equally accessible to all its users. There are many people who have problems interacting with the web due to some kind of sensorial or motor disabilities. Therefore, the definition of design guidelines to make Internet accessible to all users is an important area of research for cognitive ergonomists. Deaf people are among those users who have problems interacting with the Web.

Contrary to what we might think intuitively, it is not easy for deaf people to interact with Internet. Since Internet is mainly visual, it should not be a problem for them. However, the auditory deficit of deaf people not only prevents or makes the compression of speech in oral communication difficult for them, but it is also true that there is a remarkable deficit in the processing of any verbal information, whether it be oral or written (see Figure 4). They are at a disadvantage when it comes to interpreting written language that, as we can observe by analyzing any Web page, is strongly implied in the communication via Internet. For that reason it is considered necessary to describe the profile of the cognitive system of the deaf people so that it can be of guidance when designing Web pages for these users.

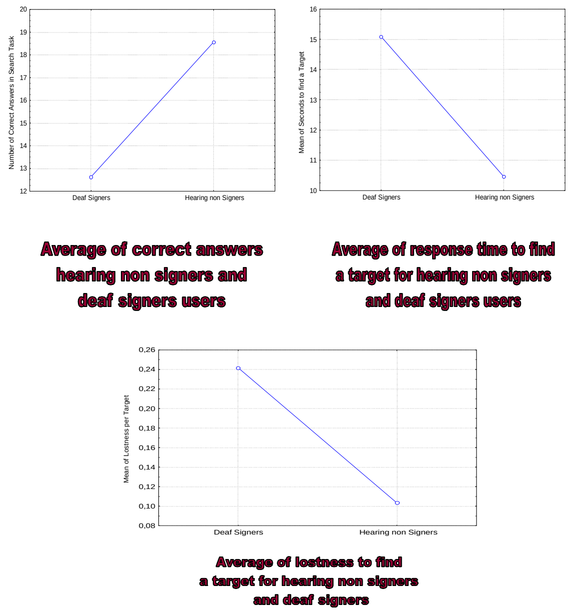

Figure 4: Performance of deaf and hearing non signers users in the search task (data from [Fajardo, Cañas, Salmerón, and Abascal 2006])

When we apply the Mutual Dependency Principle to this design problem, we start by considering a series of aspects: (1) the amount and the type of information that the deaf people process; (2) the strategies of cognitive processing of deaf people; and (3) the cognitive activities that the Web demands. The first two aspects make reference to the characteristics of cognitive processes like attention, memory and language, that is to say, to basic cognitive processes of deaf people that could be different from basic cognitive processes of listeners. The third aspect is related to the levels of functional analysis, and it makes reference to what type of task a person performs when interacting with the Web to reach a certain goal (to purchase something, to obtain data on a certain subject or to send an electronic mail). These tasks would be, for example, tasks that imply attention and perception, like visual searches of elements in a menu, tasks that imply memory like recall, recognition or generation of a mental model, tasks that imply language like reading and text understanding or tasks that imply motor processes like movements of the mouse (tracking) and writing by means of the keyboard. If we know these tasks, we will be able to adapt them to the basic capacities of deaf people and to facilitate navigation and understanding of the Web.

Several recommendations of Web design for deaf people can be done following the logic of this principle. Sometimes, these recommendations are a logical deduction of the cognitive limitations of deaf people already researched empirically; and on other occasions the recommendations result more from empirically demonstrated hypotheses about facts related to deaf people, thus opening possible and interesting lines of investigation.

A priori we might think that a person with auditory deficiency should not have problems remembering information. What does deafness have to do with memory? However, it is the case that the structure and functioning of memory is to a great extent dependent on the type of information that needs to be stored and retrieved. The experimental data seem to indicate that the organization of Working memory can determine the advantages and disadvantages of deaf people with respect to listeners. It is evident that deaf people do not have the possibility of processing phonological information (the sonant forms of the words). Therefore, the phonological loop develops deficiently and the viso-spatial component of Working memory would assume its functions [Wilson and Emmorey 2000]. The fact that this structure is implemented means that the task is becoming more controlled, investing more attentional resources, which means more effort for the person. Furthermore, considering that the viso-spatial tasks demand more attentional resources than the verbal tasks [Miyake, Freidman, Rettinger, Shah and Hegarty 2001] we could assume that it is more difficult to process verbal information for deaf people than for listeners.

Deaf people that use Sign language develop good visuo-spatial abilities. Experimental data has shown that they are better at generating, maintaining and transforming images [Enmorey, Kosslyn and Bellugi, 1993]. Research done by [Arnold and Mills 2001] showed that deaf people seem to be better than listeners at recognizing complex stimuli like faces and shoes.

In addition, Sign language depends more on the spatial aspects of the information than on the temporary aspect, contrary to what happens with oral language. For that reason, deaf people are worse than listeners in tasks of serial memory (to remember the words in the presentation order) [Rollman and Harrison 1996], i.e. deaf people not only process a type of material (visual) better than other (phonological), but also process it in different ways (they base the processing on visual aspects rather than on temporal ones).

Given the differently developed cognitive abilities of deaf people, we can derive hypotheses about how to improve the design of Web pages accessible for them. [Fajardo, Cañas, Salmerón, and Abascal 2006] have conducted an experiment to test some of these hypotheses. In their experiment, two groups of subjects, one with deaf people and another one with hearing non signers, performed a navigation task on the Web designed to manipulate their visuo-spatial characteristics by means of the depth and the width of the menus (see Figure 5). The objective of the investigation was to verify the hypothesis that the effectiveness and efficiency of navigation would be affected by the complexity of the Web more for deaf people than for listeners.

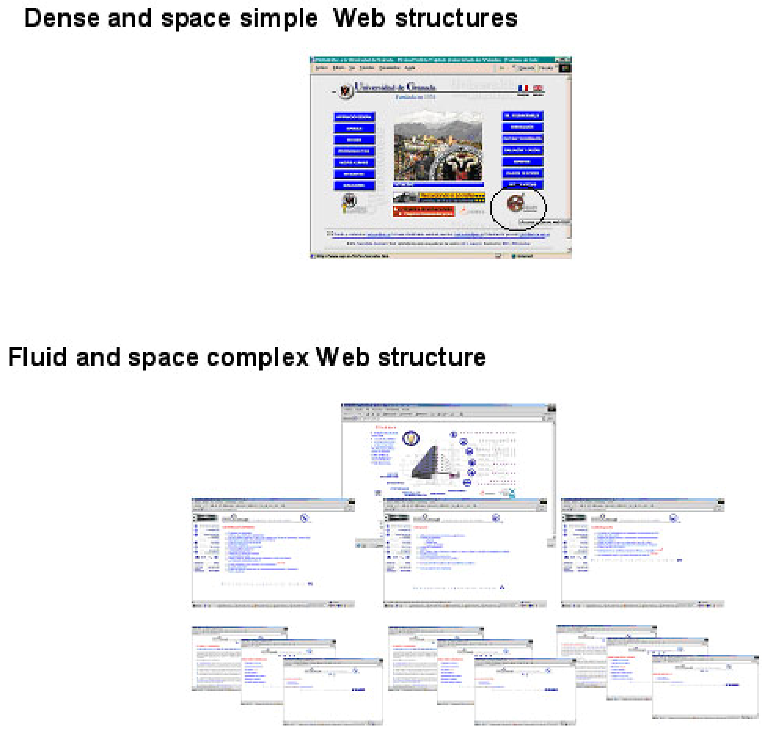

Figure 5: Two Web sites that differ on complexity

The authors designed three versions of a digital newspaper with the same content but with different degrees of depth. The subjects had to look for a series of holders of the news that were indicated to them (See Figure 6). The results showed that the deaf users found more targets, were faster, less disoriented and learnt less than hearing non signers (see Figure 7). However, what was more important was the effects that the different Web structures had on the performance of both groups of subjects. As can be seen on Figure 7, the advantage that the wide structure had on response time and disorientation for hearing people disappeared for deaf people. There was a tendency for deaf people to be faster, less disoriented and learn more on the deep structure.

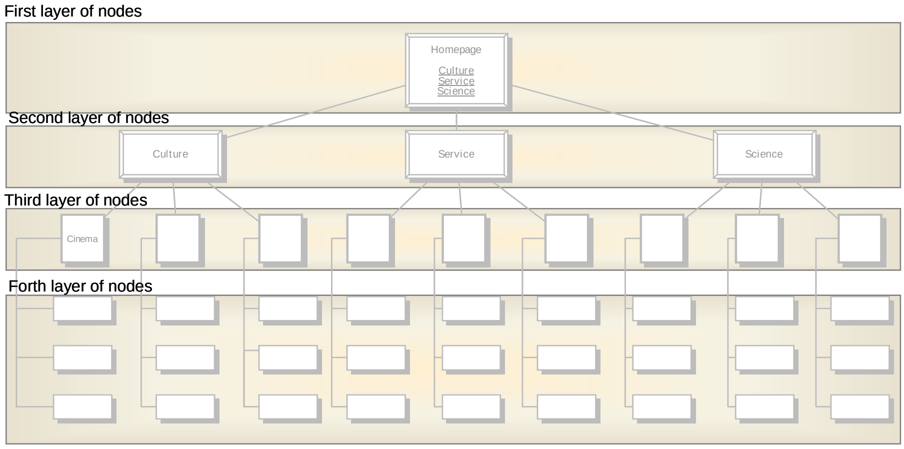

Figure 6: Three different hierarchical structures of the online newspaper containing the 90 sections: Wide, Mid Wide and Deep

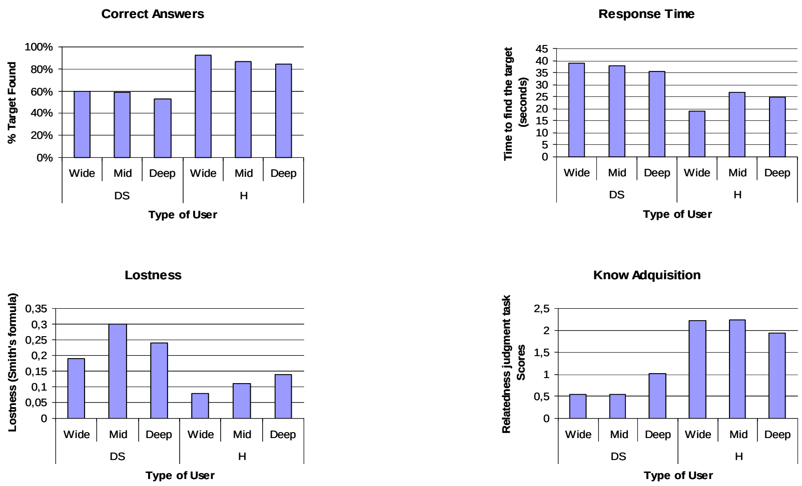

Figure 7: Effect of web structures for deaf and hearing non signers people

In order to interpret these results the authors consider that it is necessary to begin recognizing the role that Working Memory plays in navigation through each type of structure. On the one hand, the verbal component of Working Memory has a more important role in a superficial menu since the users must process a greater number of categories with these menus. Due to the smaller span the verbal store of deaf people, these superficial structures are more difficult to use for them than for hearing people. On the other hand, the visuo-spatial store is more important when navigating through a deep structure since it is a more complex one. For that reason, deaf users improve their performance in these types of structures, whereas hearing people perform worse on them. Therefore, the results show that the greater space ability of the signed deaf users, due to the use of sign language, can facilitate navigation in the Web when the verbal content is distributed in many pages.

The design guideline that we recommend from these results is this: To make Web pages more accessible to deaf people you should reduce the information on each page and increase the number of pages (less text on each page and more visual complexity). The reduction of information by page is at the cost of increasing the number of pages, but there are many advantages as there is a smaller degree of disorientation. Figure 8 summarizes this design guideline. We should point out that we have reached this conclusion on design guideline by applying the Mutual Dependency Principle at the appropriate level of cognitive analysis and individual complex information processing

	Web structure	
	Wide (Verbal demand)	Deep (Visual demand)
Signer Deaf people	X	√
Hearing No signer People	√	X

Figure 8: Different Web structures for Deaf and hearing people

4.2 From Interface Functions to Human Cognitive Functions. Design problem: Is hypertext really better than lineal text?

We can express the idea that is behind this proposal by taking what [Dix, Howes and Payne 2003] have said about the relation between human intelligence and the use of artefacts: "Human intelligence is based on the capacity to process, store, and retrieve information that is relevant to social, emotional, and cognitive needs. This capacity has developed and exists through interaction with an information-bearing environment, which itself is created and evolving. Human intelligence both shapes and is shaped by the information processing tools that it has created (p. 1) ".

The human cognitive system is characterized by its capacity to acquire, to store and to retrieve information. Throughout evolution human beings have acquired information from the environment directly or through systems (devices) where that information previously has been stored by other human beings (e.g.books). Nowadays, hypermedia systems have become one of the most important sources from which human beings acquire information. A hypermedia system is that in which the information is contained in a set of pieces of information connected by links that represent the relationship among them. The information can be in any format (text, images, etc). In the special case in which it contains only textual information we call it hypertext system instead of hypermedia system. The most important example of hypermedia system is Internet.

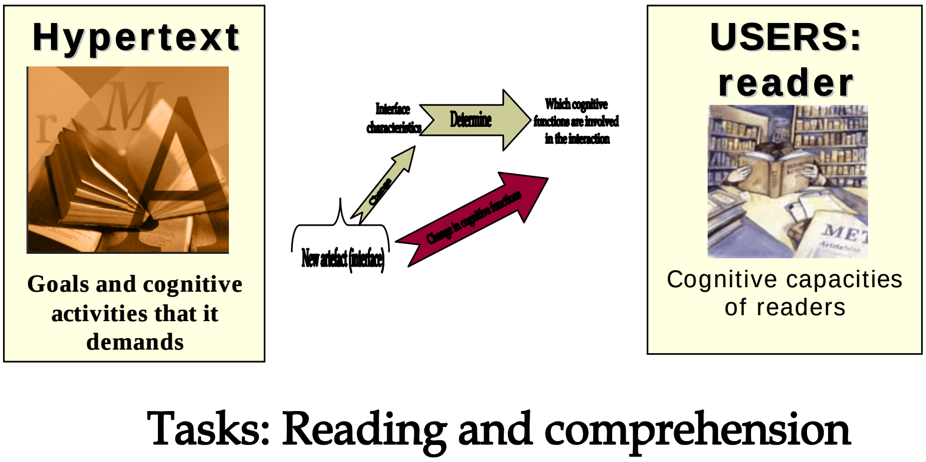

Figure 9: Interacting with hypertext systems

Hypermedia navigation faces two problems that limit their utility and that have interested many researchers: (1) When the goal is to look for information, people undergo a phenomenon which we call disorientation. Disorientation happens when a person does not remember the visited information and loses the sense and the objective of its search; (2) When the goal is to learn and to understand, conclusive experimental evidence of what is learned and of whether people learn more from hypermedia system than from what we call linear systems (the traditional book) does not exist. Conclusive experimental results do not exist to demonstrate that hypermedia systems are superior to the linear systems in any learning criterion that we might consider [Chen and Road 1996], [Dillon and Gabbard 1998]. These two problems are related. For example, there is some empirical evidence of which disorientation entails a worse learning [Ahuja and Webster 2001]. As a result several solutions are being considered that would avoid disorientation as, for example, the use of content maps.

In any case, to avoid the problems associated with navigation and to design the hypermedia systems in such a way that they are really an alternative that improves searching, understanding and learning, it is necessary to conduct research to study how the human cognitive system interacts with these systems to search and to find information. Also we need to propose theoretical models that can allow us to make predictions on the effectiveness of the tasks of searching and learning.

According to the Mutual Dependency Principle, we should start by analysing the activity that a person performs to acquire information contained in hypermedia system such as navigation (see Figure 9). In order to navigate a person begins with a unit of information (page) and continues through the links that lead to other units of information. Navigation can have two objectives. In the first place, a person might want to find a particular unit of information, in which case we speak of searching task. But also, very frequently, a person navigates with the goal of understanding the information found and acquiring knowledge, and in that case we speak of learning or understanding tasks. For example, in the case of hypermedia systems used in the field of education, navigation has the goal of understanding and learning.

From that analysis, we should identify then the critical difference between the hypertext and the lineal text is that readers on hypertext have to navigate in hypertext to find and read the information. The special characteristic of the reading in Hypertext, which is not present in lineal text, is the particular order in which the reader accesses the different contents. Therefore, navigation in hypertext requires many cognitive resources to plan the search, to determine if the information found is the one being looked for, to understand its content and to integrate this content with the knowledge stored in the long term memory (as the results show on the differences among the different people with previous knowledge. see [Salmerón, Kintsch and Cañas 2006]. In an updated study, [DeStefano and LeFevre in press] indicate that due to the characteristics of the hypermedia system, the reading and comprehension tasks require a greater number of Working Memory resources, decision making and understanding processes. In addition this excessive demand of resources cannot easily be palliated by some of the characteristics that have been introduced by the designers to improve navigation. For example, the semantic maps designed in some systems that supposedly must facilitate navigation, increase the demand of spatial cognitive resources and negatively affect understanding. Therefore, the most important factor when deciding the best hypertext design is the selection of an optimal strategy that would allow the effective reading, because a strategy of inadequate reading leads readers to misunderstanding [Salmerón, Cañas, Kinstch and Fajardo 2005], [(Salmerón, Kintsch and Cañas 2006].

In the present state of the investigation in this topic, it is considered that it is necessary now to investigate the factors that determine the strategy that a person adopts for navigation. In this sense, researchers who worked on this topic think that the adoption of a particular strategy depends on several factors that concern both the structure of the system and the characteristics of the human cognitive system. Nevertheless, the complexity and the number of these determining factors of the strategies can complicate the investigation and lead to confusing results and to erroneous conclusions. Therefore, [Madrid and Cañas 2007] have proposed a scheme that can allow us to identify those factors and their interactions. In this theoretical scheme, the adoption of a particular strategy of navigation must be explained based on the characteristics of the human cognitive system and the characteristics of the hypermedia system (see Figure 10). This scheme derives directly from the Mutual Dependency Principle.

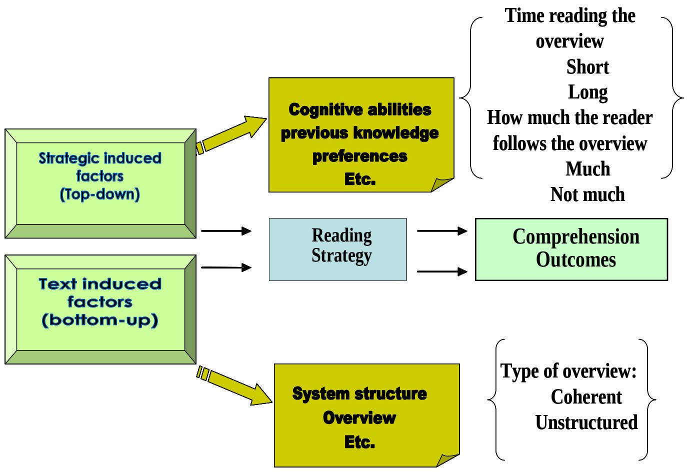

Figure 10: Scheme to explain the factors that determine the selection of a particular reading strategy

Currently we are investigating the factors that depend on the structure of the system. For example, [Salmerón, Baccino, Cañas, Madrid under review] have found results that demonstrate that when the readers have a semantic map (overview) of the structure of the hypertext, an interaction takes place between the reading strategy, previous knowledge and coherence of the text at the time of determining the time dedicated to the processing of the map and text itself which affects the result of the understanding. The time of processing is greater for the map and the text when this one is unfamiliar or no coherent.

In relation to the characteristics of the human cognitive system, [Juvina and va Oostendorp 2004] have conducted an experiment to determine the cognitive predictors of navigation behavior in hypertext systems. The results showed that the space abilities, the capacity of Working Memory and Episodic Memory are related to navigation behavior. To sum up, a low Working Memory capacity is a good predicting factor of disorientation problems, whereas the space abilities are predictors of the performance on the task. In the same line, [Madrid, Salmerón, Cañas and Fajardo 2005] have examined the role of nine cognitive factors in the determination of the navigation strategy. The results showed that the space abilities are related to the amount of information read and that the level in which the reader follows the structure shown in a map was affected by the capacity of Working Memory. The authors interpreted these results from the concept of cognitive load. Navigation is a task that exceeds our cognitive resources, fundamentally because the reader must perform two simultaneous tasks, deciding what to read next and understanding what is being read.

5 Conclusions

We could conclude by saying what is unique to Cognitive Ergonomists is the stress that we make on the cognitive analysis of the interaction between human being and the artefacts that are designed for performing tasks. The idea that us to analyze the interface is based on the mutual dependency between interface functions and user functions and the cognitive level of interaction. As a result we recommend that designers should consider that any modification, substitution or introduction of a new function in the interface will imply a change in the human cognitive functioning that intervenes in the task. Furthermore, anything that is particular or constraining in the characteristics of the human cognitive functions that are present in some or in all users will imply a limitation in the possible functions that are included in the interface.

References

[Ahuja and Webster 2001] Ahuja, J.S. and Webster, J.. Perceived disorientation: an examination of a new measure to assess web design effectiveness, *Interacting with Computers*, 14(1), (2001), pages 15-29.

[Arnold and Mills 2001] Arnolds, P., and Mills, M. Memory for faces, shoes and objects by Deaf and Hearing Signers and Hearing Nonsigners. *Journal of Psycholinguistic research*, *30*, (2001), 185-195.

[Cañas, Bajo and Gonzalvo 1994] Cañas, J.J., Bajo, M.T. and Gonzalvo, P.. Mental Models and computer programming. *International Journal of Human-Computer Studies*, 40, (1994), 795-811.

[Cañas and Waern 2004] Cañas, J.J. and Waern, Y.. *Ergonomía Cognitiva. Madrid: Editorial Médica Panamericana.* (2001)

[Cañas et al 2004] Towards the analysis of the interaction in the joint cognitive system. In A. Pirhonen, H. Isomäki, C. Roast, and P. Saariluoma ((Eds.). *Future interaction design. London: Springer-Verglag (2004).*

[Chen and Road 1996] Chen, C. and Rada, R.. Interacting with hypertext: A meta-analysis of experimental studies. Human- Computer interaction, 11, (1996), 125-156.

[DeStefano and LeFevre in press] DeStefano, D. and LeFevre, JA. (in press). Cognitive load in hypertext reading: A review. *Computers in Human Behavior*.

[Dillon and Gabbard 1998] Dillon, A. and Gabbard, R.. Hypermedia as an educational technology: A review of the quantitative research literature on learner comprehension, control, and style. Review of Educational Research, 68, (1998), 322-349.

[Dix, Howes and Payne 2003] Dix, A., Howes, A., and Payne, S. Post-web cognition: evolving information environments. *International Journal of Web Engineering Technology*, 1, (2003), 1-12.

[Dowell and Long 1989] Dowell, J., and Long, J.B. (1989). Towards a conception for an engineering discipline of human factors. *Ergonomics*, *32*, 1513-1535.

[Dowell and Long 1998] Dowell, J., and Long, J.B.. Conception of the cognitive engineering design problem. *Ergonomics*, *41*, (1998), 126-139.

[Enmorey, Kosslyn and Bellugi, 1993] Emmorey, K., Kosslyn, S., and Bellugi, U. Visual imagery and visual-spatial language: Enhanced imagery abilities in deaf and hearing ASL signers. *Cognition*, *46*, (1993), 139-181.

[Fajardo, Cañas, Salmerón, and Abascal *2006]* Fajardo, I, Cañas, JJ, Salmerón, L. and Abascal, J.. Improving deaf users' accessibility in hypertext information retrieval: Are graphical interfaces useful for them? *Behaviour and Information Technology, 25,* (2006)*, 455-467.*

[Gibson 1979] Gibson, J.J.. *The ecological approach to visual perception*. Houghton Mifflin. (1979)

[Hollnagel and Wood 1983] Hollnagel, E. and Woods, D.D.. Cognitive systems engineering: New wine in new bottles. *International Journal of Man-Machine Studies*, *18*, (1983) 583-600.

[Hutchins 1996] Hutchins, E.. How a cockpit remembers its speeds. *Cognitive Science*, *19*, (1996), 265-288.

[Juvina and va Oostendorp 2004] Juvina, I. and van Oostendorp, H.. Individual differences and behavioral aspects involved in modeling web navigation. In *Proceedings of The UI4ALL Conference*. (2004)

[Madrid and Cañas 2007] Madrid, R.I., and Cañas, J.J.. How reading strategies affect the comprehension of texts in hypertext systems. In D. Alamargot, P. Terrier, and J.M. Cellier (Eds) Improving the production and understanding of written documents in the workplace. Elsevier (2007)

[Madrid, Salmerón, Cañas and Fajardo 2005] Madrid, R.I., Salmeron, L., Cañas, J.J. & Fajardo, I.. Cognitive factors related to text comprehension with hypertext overviews. In G. Chiazzese, M. Allegra, A. Chifari & S. Ottaviano (Eds.). Methods and technologies for learning. Southampton: WIT Press. (pp. 597-598)] (2005)

[Miyake, Freidman, Rettinger, Shah and Hegarty 2001] Miyake, A, Freidman, N, Rettinger, D, Shah, P., and Hegarty, M.. How are Visuospatial Working Memory, Executive Functioning and Spatial Abilities Related? A Latent Variable Analysis. *Journal of Experimental psychology: General*. *130,* (2001), 621-640

[Norman 1986] Norman, D.A.. Cognitive engineering. In D.A. Norman and S.W. Draper (Eds.), *User Centred System Design*. Hillsdale, NJ: Erlbaum. (1986)

[O'Day, Bobrow, Shirley 1996] O'Day, V.L., Bobrow, D.G., and Shirley, M.. The socio-technical design cycle. In *Proceedings from CSCW 1996*, pp. 160-169. (1996)

[Rasmussen, Pejtersen and Goodstein 1994] Rasmussen, W.B., Pejtersen, A., and Goodstein, L. *Cognitive Systems Engineering*. New York: Wiley. (1994)

[Rollman and Harrison 1996] Rollman, S., and Harrison, R.. A comparison of deaf and Hearing subjects in Visual Nonverbal sensitivity and Information 21. Processing. *American Annals of the Deaf*, *141*, (1996), 37-41.

[Salmerón, Kintsch and Cañas 2006] Salmerón, L., Cañas, J.J., Kinstch, W..Reading strategies and hypertext comprehension. *Memory and Cognition, 34, 5 (2006), 1157-1171.*

[Salmerón, Cañas, Kinstch and Fajardo 2005] Salmerón, L., Cañas, J.J., Kinstch, W. and Fajardo, I. Reading strategies and hypertext comprehension. Discourse processes, 40, (2005) 171-191.

[Salmerón, Baccino, Cañas, Madrid under review] Salmerón, L., Baccino, T., and Cañas, J.J. (under review). How overview processing strategies affect comprehension in hypertext: an eye-tracking study

[Simon 1969] Simon, H.. *The Science of the Artificial*. Cambridge, MA: MIT Press. (1969)

[Waern and Hägglund 1997] Waern, and y Hägglund, S.). User aspects of knowledge systems. In I. Helander, M.G. Landauer, and T.K. Prabhu (Eds) *Handbook of Human-Computer Interaction*, 2ª edition*. Amsterdam, The Netherlands: Elsevier Science.* (1997

[Wickens and Hollands 2000] Wickens, C.D., and Hollands, J..D..*Engineering psychology and human performance*. Upper Saddle River, NJ : Prentice Hall, 2000.

[Wilson and Emmorey 2000]Wilson, M., and Emmorey, K.. When Does Modality Matter? Evidence from ASL on the nature of Working Memory. In K. Emmorey and H. Lane (Eds.), *The signs of language revisited*. London: LEA. (2000)

[Woods, Johannesen, Cook, and Sater 1994] Woods, D.D., Johannesen, L.J., Cook, R.I., and Sater, N.B.. *Behind human error: Cognitive systems, computers and hindsight*. Columbus, Ohio: CSERIAC. (1994)

[Wood and Roth 1988] Woods, D.D., and Roth, E.M.. Cognitive systems engineering. In M.Helander (Ed.) *Handbook of Human Computer Interaction*. Amsterdam: Elsevier North- Holland. (1988)