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Complexity in Technical Systems A New HCI Education Issue?

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ABSTRACT

In this paper it is proposed that the future teaching of Human-Computer Interaction will have to consider complexity in a more proactive way than has been the traditional view. The emergence of more and more complex systems that are not specifically co-designed, but where the components are still meant to operate in the same context or under similar conditions puts a new aspect on interface design. The inability to use technology emerges as a new type of accessibility problem in the modern world. In the paper concrete examples of this problem are presented, as well as a discussion on the effects, both on the individual level and on society as a whole.

The central statement in this paper is that Education in Human-Computer Interaction needs to start adding these more general complexity issues as part of the curriculum. The mind set of Computer Science and Human-Computer Interaction students needs to change in order to incorporate also technically connected complex systems, that are conceptually disparate or loosely coupled.

Categories and Subject Descriptors

H.1.2 [User/Machine Systems]: Training, Help and Documentation, User Centered Design, Theory and Methods.

General Terms

Design, Human Factors, Theory.

Keywords

Complex systems, Usability, Education, Complexity, Conceptual Model

1. INTRODUCTION

Teaching Human-Computer Interaction (HCI) is a challenge in many ways. Not only is it a very wide area of research within a rapidly evolving field, it is also very close to a number of other areas within computer science, and the discussions on the role of HCI has a long history, and it is still not resolved whether it should take the role of a supportive area within other disciplines, or whether it can be a self-contained area. The issue is revived as information technology spreads in the society and into many ubiquitous applications. In this respect Human-Computer Interaction necessarily needs to follow the information technology into these realms. The term Human-Computer Interaction will be used throughout this paper. However, as computers are entering more and more areas in the society, it might be just as appropriate to extend the term to incorporate more physical machines, such as the examples used in this paper, where the computer is less clearly visible.

One such example area of interest is home electronics. There is currently a virtual boom of electronic equipment in the homes of many countries today. Home computers are no more the most complex systems in the homes, but other equipment has risen to take the role. Intelligent homes, home video systems, even semi-intelligent robotic companions [1] are mentioned as taking up physical space in homes. However, it is less recognized that this equipment also takes up "cognitive space" in the homes (and of course, just as well in work spaces) of people.

By the term "cognitive space" I want to relate to the older term cognitive ergonomics [2], that was coined in the 80's, where it was thought that work places not only needed to be adapted to the limitations of the human workers in terms of physical ergonomics, but that with the advent of the computer, also the psychological work space needed to be adapted to the cognitive limitations of the human. Cognitive Ergonomics was a way of dealing with these questions in traditional HCI.

Now in terms of home environments, there is often a discussion of a narrowing physical space in apartments and houses. In discussions with people with special needs, the argument is often that any new piece of supportive equipment needs to defend its place in the home, since there is no room for too much equipment around. But with the increasing number of electronic equipment in the home, electronic equipment that is also often difficult to handle, there is also a growing shortage of cognitive resources in the humans at home. Also the cognitive space is becoming more and more crowded, in that more and more time needs to be spent on learning the new equipment. It is also my informal experience that people tend to postpone adopting new replacements for old technology, such as mobile phones, with referral to the implicit requirement of learning new ways of achieving old goals with the new versions of the technology.

One approach to solving this problem is by introducing advice giving agents such as the Paper Clip in Microsoft Office Applications, or as physical agents in terms of moving robots [3][4] or as stationary physical task supporters/advisors [5]. Neither of these applications seem to prove completely successful, not least because they introduce a new interaction level to the task. We need to communicate with these agents in their language to be able to use them. Thus there is another "…just another piece of knowledge to remember…" introduced in the situation. Apart from that there are also other considerations that influence the success of these solutions, such as how people in general regard and approach seemingly intelligent agents as helpers. The Paper Clip, e.g., is not regarded as being helpful at all by many users, mostly because it quickly becomes clear that it is not a ral agent, but only yet another simple help system, based on looking up keywords, in disguise, although there are probably many other contributing factors involved (see [6] for a small treatment of the issue).

2. A CONCRETE EXAMPLE

As a first example of how this problem can appear in a home environment I will use a scenario with a home movie equipment, that is assembled from discrete components (readily bought in the electronics market). In figure 1[1] I have heaped all the remote controls that are used to (mis-)handle my home video system. These are the controls that I have to manage before I can turn on the TV-combo to see the popular Christmas show (hence the four surrounding candles) if I manage to do this in time. The components are from different manufacturers, and consequently the resulting heap of remote controls is largely heterogeneous (see figure 1) although the overall appearances of the remotes is similar (number keys and some similar controls with different functions).

It should be noted that turning on a single artifact in this cluster, e.g., the TV or the video, is in itself not difficult, but it is the combined system that turns almost impossible to master (for anyone else than the assembler of the structure).

Figure 1. A "remote display". Imagine turning on the home video system on Christmas Eve. All the children are waiting for the children's programme. But how do you turn on the television set? And the cable modem, and the stereo, and the…? (Photo by the author)

The problem with the equipment in this example is that there is no simple means for managing the whole home movie system as a single unit. In the living room, it looks like a single unit in some respect (see figure 2).

As can be seen in figure 1, the combinatorial factor of possibilities for maneuvering the remote controls is fairly large, even with this small home video setup. The quiz is to know which buttons to press, on which remotes. Not only do we need to press the right

Figure 2. The "single" unit that appears in the living room (the TV monitor is not shown in the picture). (Photo by the Author)

buttons on the right remotes (for example, pressing the channel selector on the amplifier remote does not achieve anything). But we also need to know which equipment is involved in the activity we are about to start. This means that any user of this home movie system needs to have a pretty good understanding or mental model of how the system is connected, i.e., how it is physically connected!

The issue of mental (or the user's onceptual) models has been a

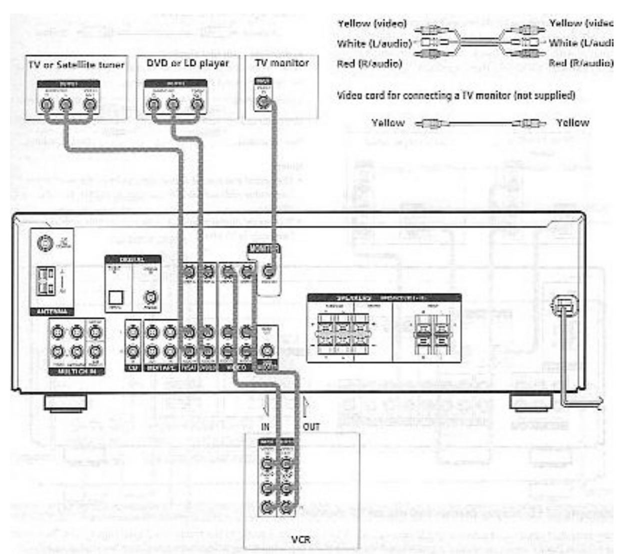

Figure 3. The scheme used to connect the various components to the receiver/amplifier, which is the electronic hub in the net, although not the conceptual centre.

topic within HCI teaching for many years[7][9][10]. However, in most cases mental models have been discussed with single applications as the target area. Even in process industry the mental model concept has mostly been applied to singular, albeit complex

[1] The picture in figure 1 was also used as an example of thought provoking teaching material in [7] However, the issue addressed in this paper was not discussed there)

systems, such as process control. When complex systems are mentioned they are most of the time regarded as singular (although complex) systems. One good teaching example in this manner is the set of two similar controls on the control panel of a nuclear power plant that were referred by Donald Norman [10]. When the controls were confused, the handles were replaced with handles from beer taps of the local pub (page 95).

However, in the example with the home video system we have the opposite situation: simple but connected complexities. Although it

Figure 4. The reality behind a "normal" installation of the system. Additional wiring was required apart from what was shown in figure 3. (Photo and wiring by the author)

is has been criticized, the term *mental model* is still useful, and I will use it to denote the understanding a person has of a complex system, based on optical examination and interaction with the system.

It is quite impossible to understand the functionality from the appearance of the unit as shown in figure 2 even if it is possible to identify the separate components. It is actually necessary to understand the wiring in the back, which is conceptually very simple, at least if we look at the connection scheme that is provided with the amplifier (see figure 3). To make it easier to understand some of the necessary wiring has been left out from the scheme, and is instead indicated on a different scheme. Still the model of how it works is pretty simple in this case. That is, of course, if we disregard people who have difficulties understanding schemes of this kind. However, there is a problem involved here which is shown in figure 4. It is difficult to match the reality of the wiring in the figure to the theoretical structure shown in figure 3. There is even a difficulty verifying that the connections are the ones depicted in the connection scheme. Not even the person who has installed it can always be completely sure about how the system is connected in the practical sense.

The only way for a person, who has not been involved in the setting up of the home cinema equipment, to understand how the remotes interact with the complete system is, either by testing combinations, or by physically check the connections in the back of the stack of hardware. Even if this is possible, it should not be needed, since a system should be possible to operate also without physical examination of its internal structures. The (internal) complexity should be irrelevant to the user [11] and the external difficulty to use the system should be low.

And of course, in a home environment it might feel strange to have visitors crawling around the floor catching heaps of dust on their clothes, while trying to find out how to turn on the news cast during a visit. Knowledge transfer between this type of units is another non-issue, since there is no guarantee that one system operates in the same way as any other, not even when the same components are used.

3. KNOWLEDGE OF TECHNOLOGY AS A DOMESTIC POWER FACTOR

This simple example could very easily be discarded as a trivial (and technology-oriented) issue of making the correct connections between the units, or the innovation-oriented problem of "just" creating a more potent remote control unit, which is already being

Figure 5. A "Universal" Remote Control. It is designed to alleviate the problem displayed in figure 1. This remote can acquire information about the units in a database (provided they are listed) and be programmed (through a computer) to perform the proper "key press" sequences, emulating the existing remotes on the living room desk. (picture from the web site of the Logitech company [12])

done (see figure 5 [12]). However, there are more things at stake here, namely an issue of domestic (in this case) control. The person who knows the workings of a specific system in the home is effectively possessing a position of domestic power. If you can't turn on the TV without the help of someone you are in a fairly weak position of negotiation. On the reverse side of the coin, is the fact that the person "who-knows-how" is more or less made into a hostage in the home, since the home electronics cannot be operated unless he or she is at home. Thus, technological complexity is an issue containing a sharp sword with two edges, depending on the context.

This "political" situation in the home (or work place) is not new, but has moved from having the knowledge about single artifacts, to having the knowledge about complete systems. There used to be a discussion on the problems with the setting up and programming of video recorders in the 80's and the standard story was that it was possible to see, in a single view, whether the family had a teenager in the house. The trick was to examine the video. If the clock was set correctly, then the house had a teenager living at home (who was presumed to be the only one that could handle the needed programming). This did not imply any power exchange in the family, since the clock was a feature that turned out to be less needed for the function of the video. However, in order to record a program on a certain channel and at a certain time still needed the support of a person that was open to technological complexity.

This situation is more difficult in the example of this paper, since the system is more or less useless, unless all its components work properly. The single components are so closely connected that they need to be correctly set in order for the whole system to work. Thus it remains even more important to not have only one person being in charge of the technical systems, since if this person is not available, the system will be unusable.

The programmable interfaces that are available today, as for example the programmable universal remote (see figure 5), are still do able to consider that the user may have multiple and parallel goals within an activity, nor can they address the fact that he or she has intentions that may not be addressed technically by the combined systems that are involved, although they would be possible to solve by the combined unit as a whole. The design shown in figure 5 is naturally better than the solution shown in figure 1, and at least the usability problem has been recognized through the development of this gadget. Still there remains much to do in the design area. The current solution requires the manufacturer of the component to make sure that it is correctly registered in the data base, and the design still requires the user to use a computer and Internet to program the device according to his or her preferences of action. Even if this is a simple activity, expressed in the wording "…you **only** need to…" it will simply scare many potential users away from the product. Also, the user still needs to have some idea about how the components are connected in the system as is shown in figures 6 and 7.

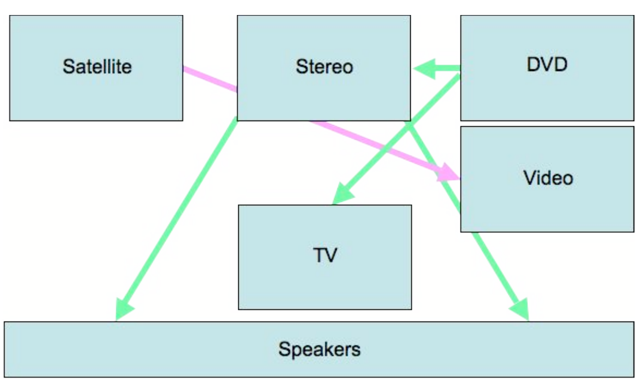

Figure 6. The intention behind an action. Connect the video recorder to the satellite receiver, and connect the audio and TV units to the DVD player.

Figure 6 displays the obvious connections needed to perform the two simultaneous tasks of recording a show from the satellite dish onto a video cassette, while watching a DVD at the same time. This double task would be simple if every component were directly connected with every other component in the system, so that the signals could be sent straight through. In fact the

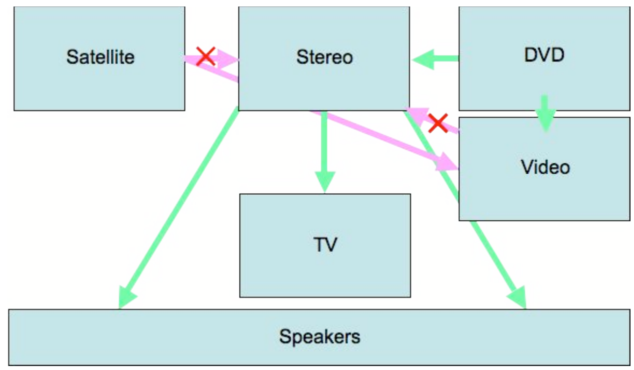

Figure 7. The actual connection status needed, since the stereo receiver does not separate channels the way it might thought.

recommended system configuration (figure 3) is based upon the spider-in-the-net principle, operating by directing all signals through the stereo, and this has the effect that it is necessary to use the signal configuration shown in figure 7.

The situation is in fact so bad that many times this combination of tasks is not possible to perform at all since the stereo amplifier (whose connection scheme is shown in figure 3 above) does not allow for multiple connections through it. The only connection allowed is the one that is going out through the speakers and the TV. Unless we have a good conceptual model of the connected system, it is very difficult to understand shy this double action would not be possible to perform.

Finally, the more or less chaotic situation depicted in figure 4 previously also in some way tells us that in order to predict the behaviour of the complete system it is necessary to know how the components are physically connected in reality (or rather, it is necessary to know that the components *are* properly connected according to the connection scheme) in order to program the universal remote unit correctly. If, for some reason any of the units are connected in an unforeseen fashion, the universal remote will not be able to do its job. Also, hacks, i.e. extra cable connections, that can solve the issue in figure 6 and 7, will make the use of the system more difficult, if we do not know they are there. This is often the case with retrospect (technical) solutions to appearing problems. A good example of this is the original Trash Can concept on the early Macintosh Systems, which has caused some conceptual problems in the past (for a discussion on this, see [11]).

4. NON-TECHNICAL TECHNICAL COMPLEXITY

In a second example from the everyday world it will be shown that technical complexity does not have to be an explicit technical problem. It can just as well be the result of an unlucky combination of factors that make a trivial problem very large. In some cases there are conflicting goals, such as security and usability, which is an issue that is very immanent in the case of use of passwords. Passwords are often required to be as hard to remember as possible, and have to be changed at about the same time as you have started to learn them properly. This means that the technology more or less intentionally creates systems that are difficult to use, in order to protect the users.

Figure 8. The Memory Flower, built from the selection of credit and company cards found in my wallet on a typical day in the life. It illustrates well the memory problems we encounter in regular situations. (Photo by the author)

IT support is handing out forgotten passwords ever so often, and people tend to come back, if they do not have a daily use for the passwords. So what happens when you have forgotten your password a sufficient number of times? The most likely (and human) thing to happen is that you will jot it down on a piece of paper (unless the system allows you to select a very simple one).

Passwords are of course not (yet) intruding into our domestic spheres (outside the realms of Internet banking and shopping). Or are they? In one respect we can see that they really do come into our daily lives, namely in the shape of cash and credit cards. In figure 8 I have displayed the "Memory Flower", which is built from a selection of credit and company cards that I have found in my wallet on a normal day. For each of the cards there is a four-digit code that I need to remember, in order to use the card. It would have been easy if I had had the possibility to choose my own code (preferably the same for all cards). Unfortunately, the number of companies in Sweden that allow for this is small. Even worse, when we lose a card we most of the time receive a new number to memorize, and not the original number.

The user solution to this problem is simple, but of course undermining the security, namely to write down the numbers for each card (or the most infrequently used cards). This is the same situation as with passwords, where it is frequently reported that people attach Post-It notes with the passwords to doors, study cabinets or, even, to the screen of the computer.

This problem is not dealing with the technology itself, neither is it with a single system, such as the use of an ATM machine, e.g., but it is inherent in our building more and more connected but conceptually disconnected systems within the society. This is increasing our needs as individuals for managing complex systems, regardless of whether we want to use them or not.

In many cases every new system adds "just a few more things to know, or remember". However, this is like adding water by the drop to a full glass. Eventually there will be a flooding, and the system capsizes. In the credit card context the capsizing means that the user will have to resort to the only solution available to them as mentioned above, that is writing down the credit card numbers that we use less regularly, thus compromising the security restrictions.

It is in my perspective clear that the problem with the memory flower is a basic problem of overall design. This means that it not necessarily a problem with the individual design of each ATM or cash-machine, but a problem that arises from the parallel systems with similar solutions that are built to co-exist in the same general environment. In this respect this issue of system complexity becomes an important issue within Human-Computer Interaction, even if we look at such seemingly simple technical applications as the use of ATM machines or cash registers.

5. COMPLEXITY – A NEW ACCESSIBILITY PROBLEM?

Even without taking the "political" issue of domestic power in section 3 into account, the problem of managing technology in domestic contexts is becoming a growing problem for the individuals. People are not capable of handling the technology that is around them. This means that this technology is not available to them unless they are aided in some way. This essentially means that technology gives rise to a new type of accessibility hindrance .

This new accessibility problem is growing, and the accessibility is not guided by physical disabilities, but more from an induced cognitive inability to use certain devices (physical as well as virtual). Furthermore, the technological growth rate is rising rapidly, and the updating of existing technology continues at a frenetic speed.

This would not be a problem unless each new generation of technology did not require a relearning of old habits. When we replace single units, they are in themselves easy to relearn (sometimes). However, the behaviour of the complex system may even change significantly with the exchange of one unit, depending. This is regardless whether we talk about a combined artifact, such as a mobile phone, a complex, connected artifact such as the home movie system, or a distributed system with many simple access points, such as the ATM-cash register type of systems. The problem is the same at large.

With the increasing dependency on technical solutions we even run the risk of creating a disconnected class of people, as has almost been the case with people who have problems with reading and writing, and with people who have problems understanding mathematics until these problems were officially recognized as disabling factors for a person. These two conditions have now been classified as clinical disorders, but in essence they are induced by the advancing society, where these skills become more and more necessary for the survival of the individual in the society. We are approaching the same type of problem when we come to technological awareness, where the new skill urgently needed in society is not only knowledge about computer science but a general technological understanding of artifacts.

This need for understanding technology is quite likely a result of the rapid development in the area of pervasive information technology. A major Swedish paper with focus on IT-issues refers to a report made by Telia (the Swedish telecom company), which states that 25 % of the Swedes are not connected to the Internet and 25% admit to not using SMS on the mobile phones [14], which means that a large number of the people in Sweden are **not** using information technology, and thus do not have access to this information infrastructure. This should be contrasted to the way that most media companies (news papers, TV broadcasters and radio stations) refer to their home pages as sources for extra information. It is also quite probable that these media companies have work spaces that are sufficiently computerized to make the employees forgetting that there are people outside of the information society who cannot access the information sources that are provided.

One very clear example of how this appears in Sweden today is the issue of a local news paper (Sundsvalls Tidning) that was published on December 30 2007. The complete paper paper was replaced by a 60 page special issue about domestic and street violence (see http://www.st.nu/antivald/). On the paper version, the readers were referred to the web page of the newspaper for the normal news articles. Apart from the mail supporting the general initiative, there were numerous letters from people who felt left out, meaning that they had no chance of reading the news that day since they could not access the web site (or because the web site was not as accessible as a paper newspaper). This clearly shows that the management of the paper had made a clear underestimation of the number of people who do not connect to Internet.

In all, accessibility to information and services is severely delimited for a large number of people, due to the appearance of more and more complex interaction patterns in the contact with technology and IT. If this problem is neglected, the society will be likely to create a new type of outsiders, namely people who are not coping with the increasingly complex technology (rather than with increasingly complex software or interfaces).

6. TEACHING IMPLICATIONS

This paper is not on how to teach the students in the two example cases presented, but on the much larger issue on how it is necessary to incorporate the awareness of increasingly complex systems, that are increasingly connected, even in situations that are originally not intentional.

Within the area of Human-Computer Interaction research the focus has shifted from interface design to the design of complex artifacts in terms of interaction design [16], where it is not the artifact per se but rather the resulting interaction between human and machine that is the focus of the design process. The technical progress makes it necessary to reconsider this development. Education in Human-Computer Interaction needs not only to include complex systems with co-engineered functions, where the interface is not an issue in itself. It needs addressing the general issue of the complexity of technology, and its increasing connectivity. In interaction terms, this means that the physical design of the interface is often not critical for each product, but the combinatorial effect on the complexity of the domestic systems makes the functional design of the interface once again a critical component.

Complex systems, or rather, complex interfaces are mentioned in the standard text books, but in the major cases only in terms of systems that have been designed as complex systems, such as control panels for process industry, or flight attendant support systems. When simple systems are connected, especially in the cases where they are not physically, but only conceptually connected, the design of these systems are still taught as design of multiple simpler systems. It is then left up to the user to acquire the proper understanding of the inner workings and connections of the system. Thus the user has to understand the technical structure of the system in order to use it.

This observation might seem to contradict the standpoint from some HCI actors, such as Norman [11] who makes a point of separating internal *complexity* from the external *difficulty* of use. As shown here the external difficulty does in some cases depend on the internal complexity, especially as in the two examples presented in this paper, where the complexity comes in a system with parts that have not been designed as integrated units or in a system with many similar units operating under the same principle but with separated solutions.

However, creating a useful conceptual model of the combined system is a difficult issue, but more importantly, it is also a retrospective solution and as such not likely to be very satisfactory. It is the standpoint in this paper that education in Human-Computer Interaction needs to induce a thinking in the students so that they are more inclined to recognize that their product will be used in a more complex context than might ordinarily be considered. In the example in chapter 2, the central point is the receiver-amplifier unit, which is responsible for the connecting of units. The issue is not to explain how it should be used under its current construction restrictions, but how the components should be designed to work seamlessly together with other components to fulfill the users' needs. In the example in chapter 4, the problem lies in having several systems, using the same general solution but with separated implementations, leaving the task of handling the systemscorrectly to the user.

It is also important to recognize that the problem of technical complexity in this type of system is not solved by merely adding a new interface, such as the one in figure 5, although it might be a conceptual first aid kit. The solution needs to address the users' intentions with systems that have vague or fuzzy borders rather than the technically oriented functionality of its components already from the design phase. Essentially this means that when the system designers need to learn to take the overall functionality in the connected system into account also when making components, and create a system that is not difficult to use, even when the complete system becomes complex.

This is difficult even in completely integrated designs, such as mobile phones, where the cameras take pictures, which then are too big to send as messages to another phone. The phone then (not so) gently tells the user that the picture is too big, asking whether he or she wants to change the picture in order to send it. The question for the user is whether it is the original that is transformed (and destroyed) or just a copy. Most people tend to not send the picture, just in case it would be altered.

7. CONCLUSIONS

This paper proposes that in the future teaching of Human-Computer Interaction, it has to be recognized that the future solutions to interaction problems will be more complex than in the traditional education. But also the problem area involving multiple non-integrated artifacts in the same context of usage is a problem that will need to receive a greater attention in teaching in the future. We have an outstanding opportunity from the Human-Computer Interaction field to start architecting a more usable future, even with complex systems, if we only start educating professionals with these issues firmly rooted in the back of their minds when they start designing the technology for tomorrow.

If this is not done, we run the risk of creating a new group of excluded people in the society, namely those who cannot (or do not want to spend time on learning how to) use complex technology.

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