Cognitive Modeling for Adaptive Use of Knowledge

Muneo Kitajima

Kitajima@nibh.go.jp

http://psych.colorado.edu/~kitajima/

National Institute of Bioscience and Human-Technology

1-1, Higashi, Tsukuba, Ibaraki, 305-8566 Japan

1. Introduction

In daily life, interaction with a variety of tools and devices is of considerable importance. In the modern age, in particular, there is greater opportunity to come into contact with information devices in many aspects of life, and their importance is increasing. In the office can be found such information devices as word-processor, PC, work station, telephone, fax, and VCR. In the home, we see such home appliances as television, audio equipment, microwave, and washing machine, amongst others. All of these contain internal microcomputers, the interfaces of which are no different from information devices. The same also goes for the automobile, public telephone, ticket machine, and ATM (automatic teller machine). Finally, in recent years, the access to massive amounts of information by way of the Internet has become available. Using a browser we access web sites, and the interface offered by the site is an extension of office applications.

Of these above, some devices could be used without difficulty by the large majority of the user population. Others could be mastered after a good deal of trial and error by a fraction of the users. While some could be given up on before competence is achieved. In all cases, despite the fact that the same information is offered by the devices, the manners in which the information processed by the users determine the results — to use comfortably, manage to use, or unable to use. In order to make improvements in safety and comfort in everyday life, there is a need to design an interface through understanding of the cognitive processes that control user s interaction with information devices.

These cognitive processes utilize knowledge stored in long-term memory to deal with information proffered by the devices. This paper will look at this issue in detail. Furthermore, in addition to explaining the qualitatively different two forms of knowledge utilization, that is, *routine* use of knowledge and *adaptive* use of knowledge, this paper will clarify the characteristics of the adaptive use of knowledge, which is particularly important in the everyday use of devices, while comparing it with the routine use of knowledge. In addition, examples of interface designs suited to the various forms of knowledge utilization will be shown, and the importance of interface designs suited to these forms will be discussed.

2. Human-Device Interaction

Until now, the main focus of research concerning the interfaces between man and machine has been such professionals as aircraft pilots and nuclear power plant operators, and has treated aircrafts or power plants as single entity man-machine systems. In line with this, man and machine are thought of as a single unit, and the goal of interface design is to ensure the successful rapid and certain operation of the system.

In contrast with this, the purpose of interface design in daily life is to provide satisfaction in terms of such usability factors as the ease of deducing correct operation, the ease with which operation can be memorized, recalled to memory, and recovered from mistakes, and the unlikelihood of errors. The position of such interface design is expressed in the phrase *User Centered Design* (Norman, 1986), however the importance of R&D to this end has only recently been acknowledged. Device operation in daily life has not become a routine or a procedure. Wanting to perform an operation using a device (purpose) does not necessarily mean that the detailed operation of the device is known. Therefore, each time such a situation arises, the operating procedure must be deduced. User centered design must take into consideration the characteristics of such operation.

However, common to the situation where a professional operator manipulates a system and the one where a user operates a device in an everyday situation is the fact that a variety of knowledge is applied. It includes knowledge pertaining to operation, knowledge relating to the task to be accomplished, and knowledge necessary to comprehend information displayed on the control panel. Figure 1 shows

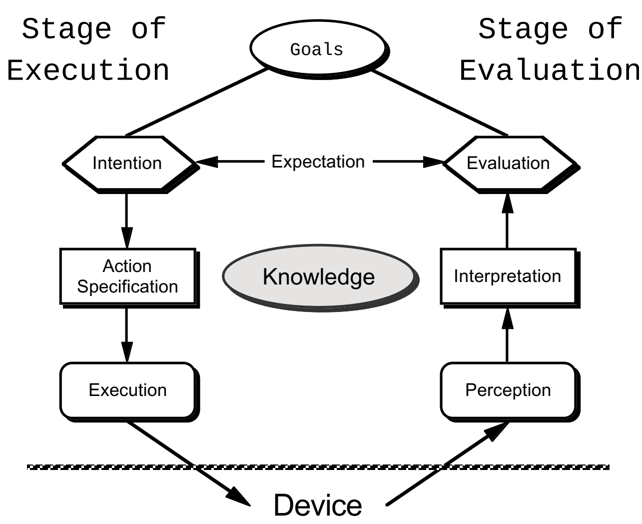

Figure 1. Norman s (1986) Action Cycle Model

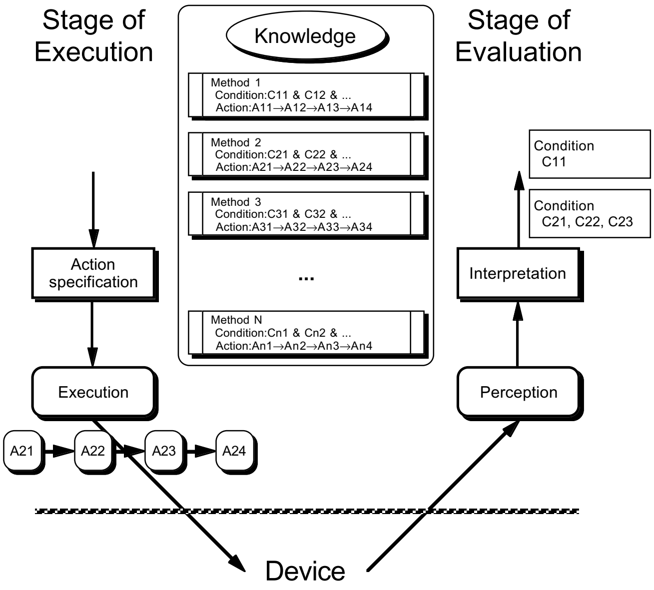

Figure 2. The use of knowledge in routine operations

the Action Cycle Model for user-device interaction (Norman, 1986). A user initiates contact with a device with a purpose (goal) in mind. In the evaluation stage, the user perceives the information displayed on the device, interprets the situation using relevant knowledge, and evaluates the situation from the perspective of accomplishing the goal. In the execution stage, based on this evaluation, the user determines the next operation to be performed, and conducts a series of physical actions on the interface. In all of these stages, the knowledge discussed previously is put into use. However, the manner of its use varies greatly in the case of professional operators and operations performed on a daily basis. This point is discussed in the following section.

2.1. The use of Knowledge in Routine Operations (in the case of a professional operator)

In routine operations, once a goal is set, evaluation of the current state of the device is undertaken (evaluation stage), and the series of typical operations most suited to that situation (method) is extracted from long-term memory (execution stage). A method is piles of several production rules , or regulations which can be phrased in the form once given conditions are met, certain operations can be performed. Figure 2 shows the process in which methods are extracted from long-term memory, and operations are executed based on that. A method is only appropriate for use under specific sets of circumstances, however once operations according to a particular method are begun, each operation is generated automatically. Of a professional operator is demanded the ability to perform quickly and repeatedly without error , this is made possible by means of this type of knowledge and the manner of its use. In other words, a method equals how-to knowledge (procedural knowledge).

A method is not memorized from the outset as knowledge, but rather is routine operation acquired as the result of repetition. To use the execution of a computer program as an analogy, a method can be expressed in terms of something compiled by a production rule. In the early stages of training each production rule is consciously applied, however this gradually gives way to the unconscious application of an entire unit. To use the example of driving a car, this would equate to a student driver in the stages of learning to drive and an experienced driver.

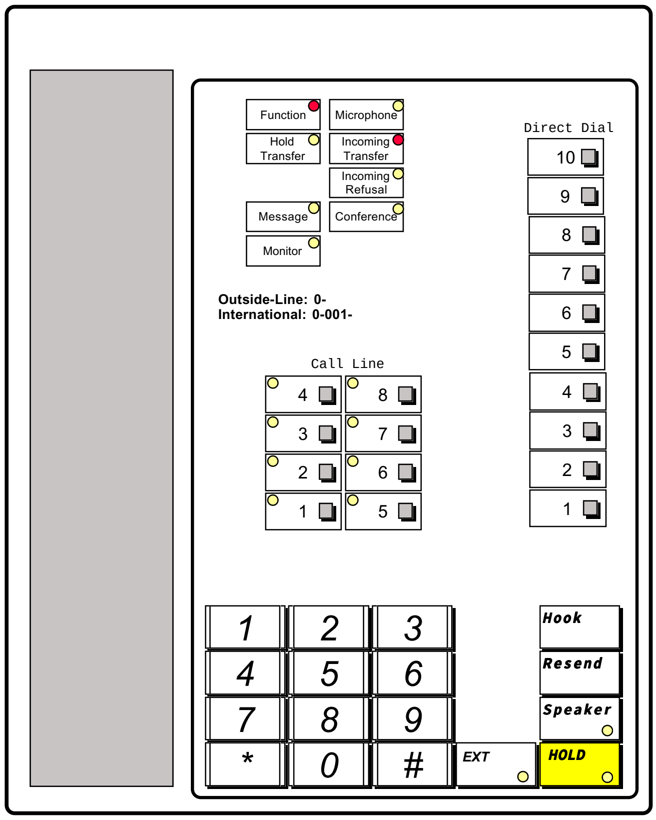

Figure 3. The use of adaptive knowledge is required in the operation of a telephone

A method permits the smooth execution of a series of operations. As a result, once a production series is compiled as a method, it can be difficult to express its contents in words. The difficulty of putting into words the procedure by which a car with a manual transmission is put into motion is an example of this. On the other hand, for some reason if a method is interrupted during the chain of operations, resumption would be difficult. This can also be the source of error. An example of this is, when getting out of a car, the driver turns off the engine, but before removing the key, he is suddenly distracted by the need to check the items in his bag and locks the door without removing the key. In addition, as a result of the fact that a method is only applicable to a certain set of circumstances, certainty and speed can be accomplished. On the down side, if the circumstances change even slightly, it would no longer be applicable. In other words, certainty and speed are guaranteed at the sacrifice of flexibility and adaptability.

2.2. The Use of Knowledge in Adaptive Operations

In everyday situations, it is not the ability to use the previously discussed method-type knowledge, but *the ability of humans to appropriately judge any situation and act accordingly* is important. For example, a person borrows the telephone at a friend s office to call her own office. On the telephone, series of panels are displayed as shown in Figure

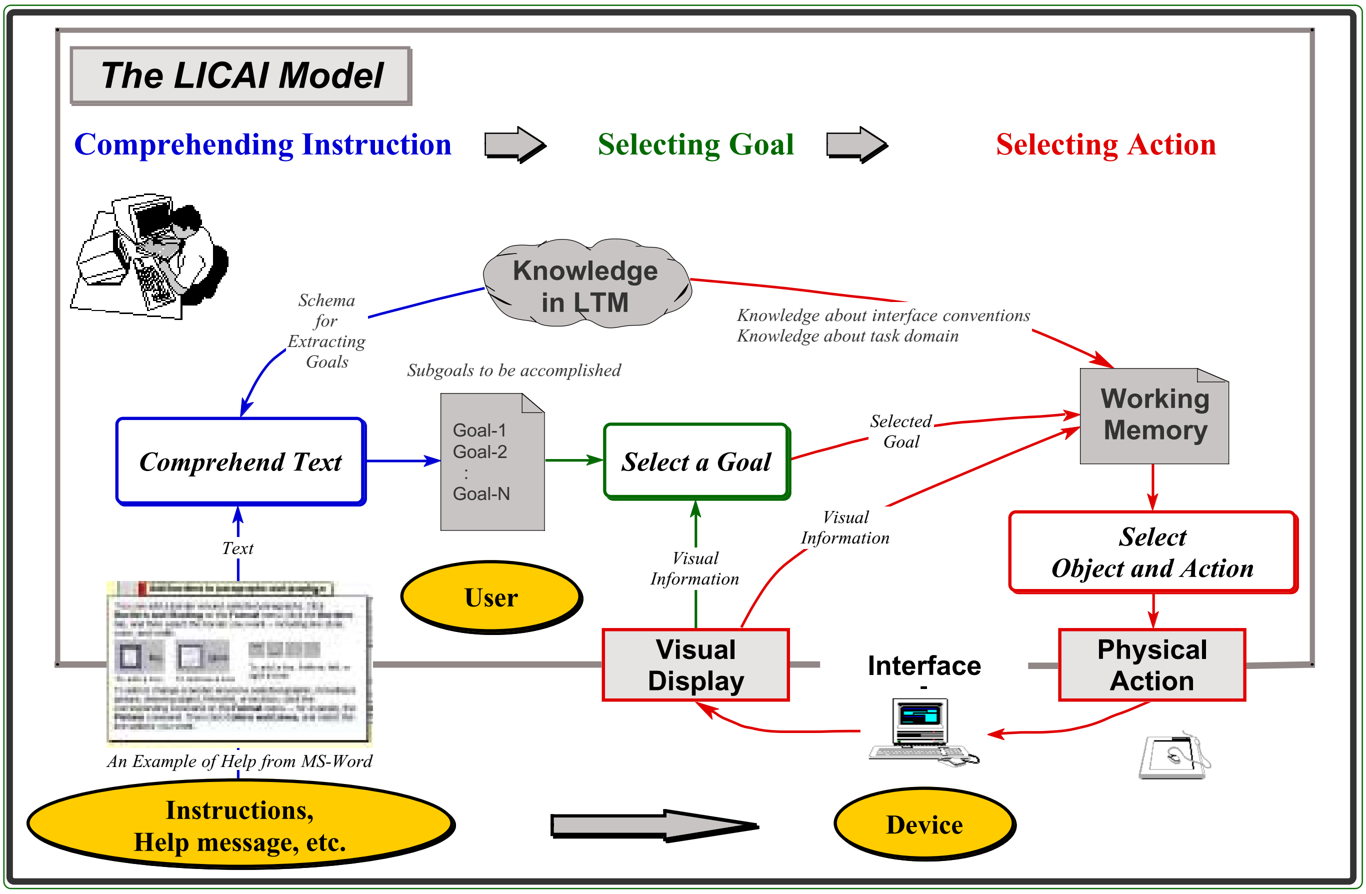

Figure 4. The process of selecting operations by means of the utilization of adaptive knowledge

3. How should the objective of sending a message via an outside line be accomplished? In order to select the appropriate operation, a variety of knowledge and information must be integrated and an overall evaluation must be made. For example, despite it being the first time to use this telephone by the person in question, as when a similar phone was used, the following information was amongst that integrated to carry out the task.

- the goal of making an outside-line call
- perception of the current state of the telephone
- general knowledge relating to telephoning
- general knowledge relating to telephones
- general knowledge relating to the buttons and indicators on the telephone
- knowledge associated with interpreting the displayed character and code.

In contrast to routine operations in which how-to knowledge is applied, the knowledge utilized in this case is meaningful knowledge such as the indicator specifies a situation in which a particular function has been selected , or the knowledge linking a task with an action such as in preparation for making an external-line call, press 0 . Task-action mapping knowledge such as this is fragmentary and knowledge regarding the order of its application is not necessarily committed to memory in advance. The selection of operations is undertaken adaptively while surveying the situation of the device. This point differs significantly from routine operations.

Following, using an example as a basis, is an explanation of how this fragmentary operations knowledge is selected and applied. Let s say that the call line label on the panel shown in Figure 3 is found. For the purpose of making an outside-line call, this label is particularly attractive. Likewise the explanatory label on which is written outside-line call: 0 — . In this manner, to attain the goal, a number of promising operation targets can be selected from the panel. Next, accompanying knowledge relating to the targets for the potential actions is evoked. That is, awareness relating to the condition of the telephone and the fact that beneath the call line label there are buttons, and that the indicators are not lit, in addition to related knowledge such as the button can be pushed (affordance) , the indicator not being lit means that the function has not been selected , and by pushing the button the function can be selected , and by utilizing general knowledge relating to interfaces, the operation of pushing the particular button is selected as the most appropriate action to attain the goal.

3. Cognitive Modeling for the Use of Adaptive Knowledge (Kitajima and Polson, 1997)

The process of evaluating the condition of a device to attain the goal, and selecting appropriate operation targets and the execution is similar to the process of sentence comprehension, that is deciding on the meaning of words in a sentence and deducing the meaning of the sentence. In comprehending a sentence, the aim of getting something out of a sentence greatly influences the manner in which it is read. The personal reasons for reading a mystery novel as compared with technical data is different, and thus is the appropriate manner of reading each. For that reason, the process of sentence comprehension is strategic. According to Kintsch (1997), those strategies are expressed in the form of knowledge called schema. Through schema, the meanings of the words contained in the sentences you are currently reading are elaborated, and an associated network is temporarily constructed (construction process). This process of elaboration is a bottom-up process triggered by the words contained in the sentences, and the possibility exists that contradictory items are included in the knowledge activated. The selection of a meaning appropriate to the context occurs by means of the integration of this network (integration process). This process of construction and integration occurs for each sentence of a paragraph, and the network pattern remaining when the final sentence has been read is the result of sentence comprehension.

Kitajima et al. (1995, 1997, 2000) have expanded and adapted this model for the field of human-computer interaction, and have constructed computational models for the cognitive processes of how computer-literate users perform various office automation tasks by using graphical user interfaces. Tasks include word processing, spreadsheet, graphing, and web navigation. The models cover such aspects as action selection, error, learning, and search. In comparison with the modeling of the command-based interaction by routine operations, a graphical user interface requires the use of the adaptive knowledge shown in the previous example of the telephone.

Figure 4 depicts the outline of the model.

Comprehending Instruction: To begin with, once a task is assigned in the form of instruction or help, existing knowledge must be used to develop sub-goals. In this stage, such things as from which sub-goal should the process begin, and whether all of the sub-goals should be carried out are not known. The sub-goals which may have to be implemented are simply formulated.

Selecting a Goal: Next, information from the device is perceived. A sub-goal that matches the representation of the device is selected as the next goal to be accomplished.

Selecting Action: With the information from the device as a trigger, related information is extracted from existing knowledge stored in long-term memory. Evaluation of the importance of the knowledge for the task at hand is not undertaken at this moment, rather knowledge which may be of use for evaluating the selection of the next action is activated. In this way, the current sub-goal and the activated knowledge momentarily constitute an entire network. By integrating this and conducting a general evaluation, the selection of target of action and the action itself are carried out as discussed previously. Selected actions should be the most appropriate implementation on the information device evaluated to attain the sub-goal.

4. Conclusion

We discussed two kinds of operations, routine and adaptive, from the point of view of the cognitive processes in interaction between human and device. Both can be expressed in the processes outlined in Figure 1, however both the knowledge used and the method of its use varies. Figure 2 shows a model of the interaction process in routine operations, and expresses the certainty and speed of the interaction, while Figure 4 expresses the adaptability and flexibility of the interaction process in adaptive operations.

In order for the smooth implementation of routine and adaptive operations in the processes shown in Figure 1, the interface between human and device plays an important role. When considering errors, as the former is effected greatly by interruptions, interfaces must be made taking this into account. Despite interruptions having little effect on the latter, if the appropriate links for selecting the correct actions are not made from the interface information (label, button, indicator, webpage, etc.) to the necessary knowledge, it will not be activated at the time of selecting an action, and an incorrect action might be selected. In the case of routine operations, as the interpretation of interface information does not occur consecutively, this problem is not likely to eventuate.

When looking at human-device as a single system, the operation process in routine and adaptive operations appear identical. However the internal processes are entirely different. Therefore, the design of interfaces to assist in the everyday use of devices must be seen as being entirely separate from the design of interfaces to assist with operations conducted by professional operators. The clarification of the cognitive processes to adaptive use of knowledge in action selections is an important key to this end.

5. References

Kintsch, W. (1997). *Comprehension: A Paradigm for Cognition*, Cambridge University Press.

Kitajima, M. (1996). A Cognitive Model of Display-Based Human — Computer Interaction — Towards a Cognitive Model of Adaptive Expertise. *Journal of Japanese Society for Artificial Intelligence*, **11**, 2, pp. 321-329. (in Japanese).

Kitajima, M. & Polson, P.G. (1995). A comprehension-based model of correct performance and errors in skilled, display-based human–computer interaction. *International Journal of Human–Computer Systems*, **43**, 65-99.

Kitajima, M. & Polson, P.G. (1997). A comprehension-based model of exploration. *Human-Computer Interaction*, **12**, 4, 345-389.

Kitajima, M., Blackmon, M.H., & Polson, P.G. (2000). A Comprehension-based Model of Web Navigation and Its Application to Web Usability Analysis, in S. McDonald, Y. Waern & G. Cockton (eds.), People and Computers XIV - Usability or Else! (Proceedings of HCI 2000), Springer, pp.357-373.

Norman, D. A. (1986). Cognitive engineering, In Norman, D. A. and Draper, S. W., Eds., *User Centered System Design*, pp. 31-61, Lawrence Erlbaum Associates, Hillsdale, NJ.