Multi-window System and the Working Memory

Ayako Hashizume[1], Masaaki Kurosu[2], and Takao Kaneko[3]

[1] Graduate School of Human Sciences, Waseda University, Japan
[2] National Institute of Multimedia Education (NIME), Research and Development Division, Japan
[3] School of Human Sciences, Waseda University, Japan
hashi-aya@toki.waseda.jp

Abstract. This paper deals with the issue of the working memory load in relation to the multi-window system and explains the reason why multi-window and multi-monitor systems are better for the window operation in accordance to the structure and the function of the working memory. In the last part of this paper, a model revised from Card, Moran and Newell is proposed to explain the working memory load.

Keywords: working memory, multi-window system, user interface, dual display, memory model.

1 Introduction

Multi-window system is now widely used where multiple windows can be displayed at the same time and the currently active window will be positioned at the top. By using this system, the user can do multiple jobs on just one screen. But sometimes the window containing the necessary information will be hidden behind another one. The user will have to change the position and the size of the window accordingly so that the window containing the necessary information can be displayed better. This operation of changing window parameters requires certain time and reduces the efficiency of the operation of the user [1].

It is usually said that the overload on the working memory reduces the task efficiency. This paper will investigate the relationship between the window operation and the working memory load. Further, the paper will deal with the possible structure of the working memory and its load.

2 Window Display Patterns in the Multi-window System

Users open many windows at the same time, especially in the multi-window system so that users can use many application programs at the same time. Sometimes users leave the window where they have finished the job.

There are three patterns of window display in the multi-window system, namely, the overlapping windows, the cascade windows, and the tile view (Fig. 1).

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2007, LNAI 4562, pp. 297–305, 2007.

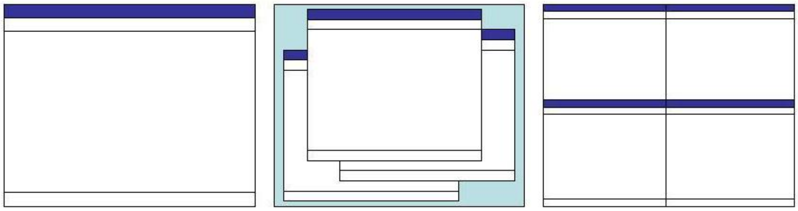

Fig. 1. Three patterns of window display: overlapping window, cascade, tile view

The overlapping windows is to display multiple windows one on the other. The cascade windows is to display windows one on the other with a slight displacement. The tile view is to juxtapose windows. This pattern was adopted in early operating systems such as Windows 1 or 3.1. At that time, the graphic power of the PC was not high so that the overlapping and the cascade patters were avoided in order to limit the use of CPU resource.

Current multi-window system frequently adopts the overlapping window. But this pattern sometimes hide the window that contains the necessary information, hence the user will have to change the location and the size of the window frequently. This operation is time absorbing and inefficient, so that the user will feel the mental stress [2].

The tile view requires less operation than the overlapping windows. So the application software sometimes adopts this pattern in order to reduce the menu operation. An example of the tile view in an application program is shown in Fig. 2.

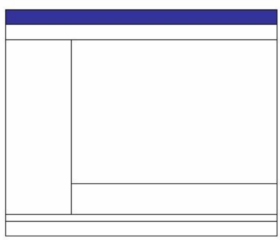

Fig. 2. Example of the tile view in an application program

Although the tile view has the merit of reducing the amount of operation, it has the deficiency of limiting the area size for an application program to display the information. This is the reason why the overlapping windows are now more prevalent than the tile view.

There are many systems proposed to solve this problem, but they tend to focus just on how to deal with the hidden windows. The optimal display arrangement depends upon the kind of applications, the task and the user preference. Thus, it is generally difficult to determine the optimal window arrangement uniquely.

Based on these considerations, it could be said that the dual monitor system will have both merits of the overlapping windows and the tile view (Fig. 3).

Fig. 3. Dual monitor system

In the dual monitor system, the user can use the same keyboard and the mouse for both monitor so that there will be less chances of doing inefficient window operations. This system is said to keep the mental workload at a certain low level and thus increases the task efficiency. In the next chapter, the relationship of this system and the efficiency of operation will be discussed in accordance to the human information processing, especially the working memory load.

3 Working Memory (WM)

The concept of working memory (WM) was originally proposed by Baddeley and Hitch (1974) in order to emphasize the functional aspect of the short term memory (STM) [3]. Until then, the STM was regarded not with the detailed processing function but just a box of simple buffering function. Baddeley and Hitch positioned the WM as to have both of the retaining function and the processing function.

It is still difficult to precisely define the WM, but it could be defined as "the memory function to process and retain the information necessary for conducting a certain task in accordance to the situational change and the progress of the task".

WM is frequently regarded as a "box" to retain the information for a short time in order to conduct a task. But it is not a structurally independent "box" [4]. Rather, it is a set of mental mechanisms.

The role of the WM is not limited to the memory function. It is strongly related to such higher and complex cognitive functions as thinking, inference, problem solving and decision making. It is active in a complex recognition process in everyday behavior. It is the mechanism or the process to control and adjust the information related to the task [4].

WM is important in the use of the computer. It retains the incoming information, and changes and renews the contents of information accordingly to the operation and the processing. WM is used as a memory tool for achieving the goal. This kind of mechanism is necessary for operating the computer.

3.1 Long-Term Working Memory (LT-WM)

However, the actual structure of the WM is not yet completely uncovered. When there emerges the new phenomenon that the conventional memory model cannot explain, a revision was added to the concept of WM. The concept of the long-term working memory (LT-WM) was thus proposed by Ericsson and Kintsch [5].

The reason why the concept of LT-WM was proposed was that there are some characteristics that cannot be explained by the traditional concept of WM, especially in the information processing of experts. Experts memorize information by activating abundant knowledge and skill that have accumulated in a long span of time. Ericsson and Kintsch thought that they keep the information in the long-term memory (LTM) so that it could be used instantly afterwards. According to this idea, the information that will have to be kept in the WM could only be the minimum information that can be used for the information retrieval. Thus the mass of information can be retained systematically with the minimum load on the WM itself. At the same time, such information can be accessed instantly just as the information kept in the WM in an active status. Ericsson and Kintsch called this kind of systematic retention of information as the LT-WM in order to differentiate the concept with the conventional WM or LTM.

Long term knowledge plays an important role in the use of information stored in the WM not for the experts but for various situations. Information stored in WM is just a set of fragments. The long term knowledge is necessary to actively use that information. Physiologically, it is said that the long term knowledge is stored in the hippocampus where the storage of information and the generation of retrieved information are conducted. In addition to that, the prefrontal cortex (PFC) is working for activating the retrieval key. The inter-relationship of the hippocampus and the PFC is the function of LT-WM.

3.2 Short-Term Working Memory（ST-WM）

The short term working memory (ST-WM) corresponds to the traditional concept of WM. But due to the advent of the concept of LT-WM, this term was invented for the purpose of differentiation.

Furthermore, ST-WM is conducting the encoding of information and the control of information retrieval. With these in mind, a new model of WM is proposed in Fig. 4.

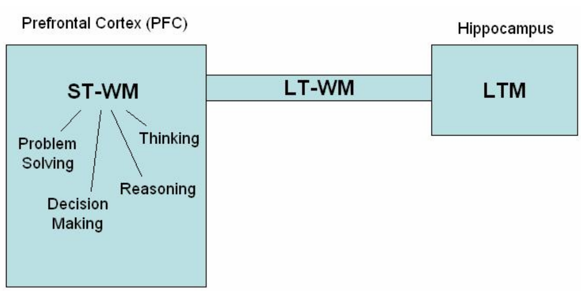

Fig. 4. A proposed model of memory including ST-WM, LT-WM and LTM

4 Load and Capacity of Working Memory

Working memory is thought to be limited in its capacity. The amount of workload varies in time depending on the task and it should be within the capacity. If it exceeds the capacity, the working memory will be overloaded and some information will be lost. And it is usually said that the task efficiently declines when too much load is given to WM. It is because there is a limitation of the processing capacity of WM. The amount of the limitation is traditionally said to be 7 plus or minus 2 chunks as Miller proposed [6]. According to this quantification of capacity limit, the amount of memory to which young people can remember is called the "chunk" and is about 7 whatever the contents to memorize is including number, letter and word. It differs for senior persons and children. Based on later researches, it was revealed that the capacity is dependent on the kinds of information, i.e. is 7 for numbers, 6 for letters, and 5 for words. Furthermore, short words requires less capacity than long words. Generally speaking, the memory capacity for information contents that can be represented as words (number, letter, and word) is related to the time to pronounce them, and is also dependent on the contextual aspects of the information content [7].

However, it is difficult to represent the capacity limitation as numbers because of various factors that may affect the working memory capacity. It is often difficult to explain the complex cognitive task if the capacity were represented as a discrete number. It can be increased when the human being is conducting a complex cognitive task. In addition to that, it was revealed that the cerebral activity relating to the working memory increases its amount by the training [8], hence it is difficult to conceive the working memory as to have a limited capacity. Hence the notion of WM to have a certain limitation is too simple to explain various phenomena. There is an idea that the processing capacity is determined based on the characteristics of the multiple processes relating to the WM. In other words, WM itself does not have the limitation but instead there is a limitation of amount of total information processing capacity reflecting various factors. Although this aspect has not yet completely specified experimentally, the idea of capacity limit of WM will be one of the crucial issues in the cognitive psychology.

In the following section, a model is presented to explain how the WM is related to the task execution in the use of computer.

4.1 The Model Proposed by Card, Moran and Newell

Card, Moran and Newell (1983) proposed a model to explain the relationship between the task performance the working memory load [9]. Fig. 5 shows the idea of this model.

This figure shows the model describing the situation where the user is entering the text by looking at the manuscript. As the progress of the task, the user conducts detailed operations including the gaze at the screen, the character typing, and the shift of the pointer. Sometimes there is a duplication of the operation such as the shift of pointer while gazing at the screen. This kind of detailed duplicated operation will have to be stored in the stack (push) and then be taken out of the stack (pop). Such stack operations can be the load to the WM.

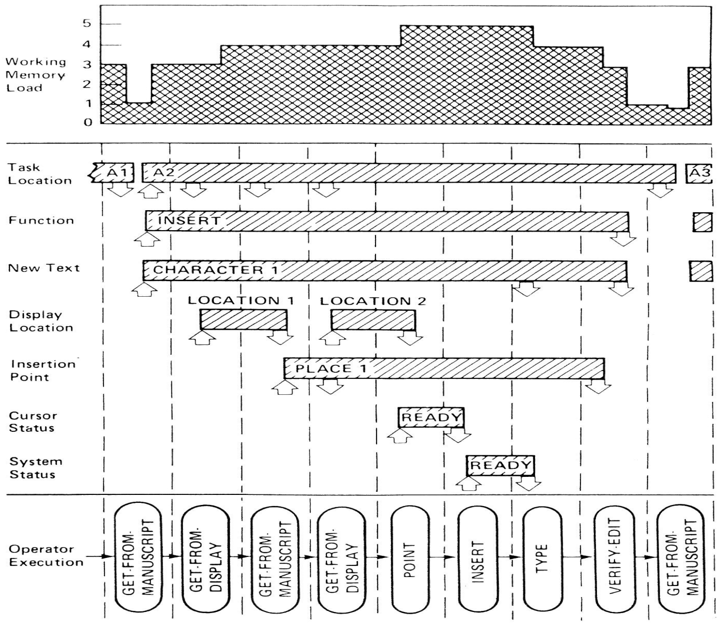

Fig. 5. The model proposed by Card, Moran and Newell to explain the working memory load during the execution of a task (Card, Moran and Newell, 1983)

This original model of Card, Moran and Newell shows how the memory load will change as the operation progresses. But it has a deficiency that should be reconsidered: the physical workload such as the gaze on the screen and the mouse operation are categorized as the working memory load. The load for the operator during some task is not only the working memory load as is shown in Fig. 5. It is better to treat the physical workload and the mental workload differently, considering the fact that the working memory load can be generated in various kinds of factors. Based on this consideration, a revised model will be proposed in the next section.

4.2 A Revised Model

The model mentioned above was originally proposed in 1983 and the situation of the computer use is somewhat different from that of today. Users today do not frequently use the paper-based manuscript to enter the text into the computer. Instead they tend to use the web site to get information while creating a new document or to use the data file stored in the disk. In other words, the degree of use of the display is much higher today than the time they proposed the model.

As such, it is more frequent that the users are using multiple windows at the same time. Fig. 6 shows such situation by applying a revised model of Card, Moran and Newell. This model splits the load to the "mental workload" and the "physical workload".

The basic idea of this revised model is to integrate the model of Fig.5 with the idea of Keystroke Level Model (KLM) that they also proposed. On the left hand side of Fig. 6, procedural steps of searching a word in a dictionary while browsing a web site are described at the level of keystroke. It often occurs that the users will have to check the dictionary for the word they encounter in the website, especially in foreign language.

The typical sequence will be as follows and KLM operators and the time estimates can be described for each of them. The dictionary search operation will be triggered while browsing the website (Get some information on the browser (nM) 1.35*M).

(1) The user finds a new word (M = 1.35 sec)
(2) The user will have to remember the word only if he is using the single monitor (M = 1.35 sec)
(3) The user opens or activates the dictionary window (H+P+K = 0.4+1.1+0.2 sec)
(4) The user types in the word with n letters (nK+M+K) 0.2*(n+1)+1.35 sec)
(5) The user get the meaning (M = 1.35 sec)
(6) The user will have to remember the meaning of the word only if he is using the single monitor (M = 1.35 sec)
(7) The user closes or inactivates the dictionary window (P+K = 1.1+0.2 sec)
(8) The user finally understands the information on the browser (M = 1.35 sec)

And the user will iterate this process while browsing through the website.

On the right hand of Fig. 6, accumulated physical workload and accumulated mental workload are shown. Physical workload is necessary only when the user moves their hand. But the mental workload is stacked with the consciousness that the user is browsing the website as the bottom level. Upon this fundamental level, the load for finding the word, remembering it, typing it, getting its meaning and remembering it, then finally understanding the meaning of information on the browser take certain amount of mental workload. What is important here is the mental workload for remembering the word and remembering its meaning are necessary processes only for the single monitor system as can be seen in Fig. 7-a,b,c.

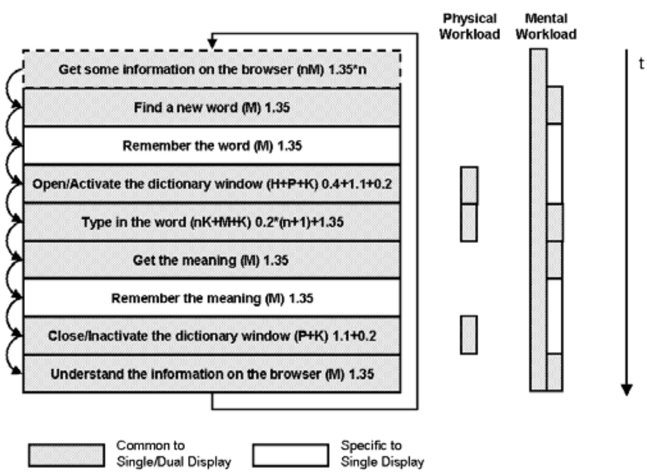

Fig. 6. Revised Model

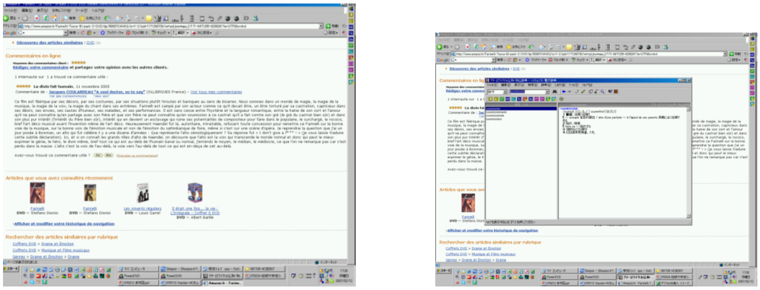

Fig. 7-a,b. Dictionary search while browsing the website on a single monitor system

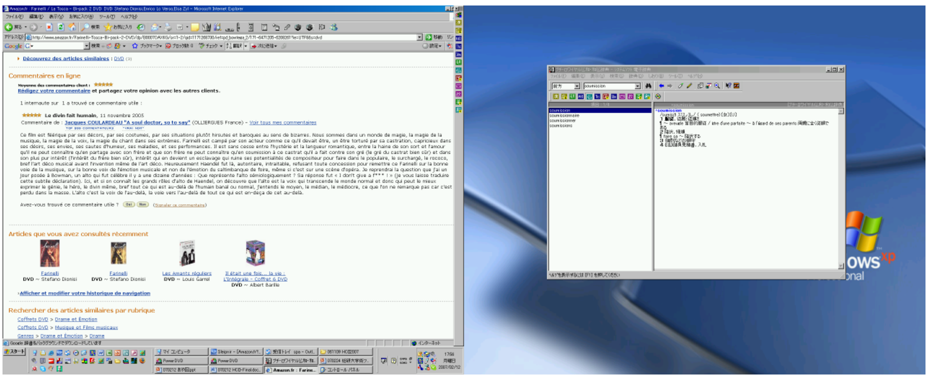

Fig. 7-c. Dictionary search while browsing the website on a dual monitor system

5 Conclusion

Based on the concept of working memory, the use of multi-window system was analyzed. A new use of the window system is now possible using dual monitors by putting each window on each side of monitors. Authors proposed a revised model based on the working memory model and the Keystroke Level Model originally proposed by Card et al. and analyzed the difference between them, thus put the prediction that less mental workload will be necessary for the dual monitor system.

Although our study revealed the difference of mental workload based on the concept of working memory, there are some points that require the further research.

(1) In Fig.5 and Fig. 6, it was avoided to decompose the load of each operation in detail. The load is represented as having the same amount at any time for any kind of operation, although the length of time to be loaded may vary. But in the real situation, the amount of the load must be different depending on the kind of operation. Furthermore, the mental workload is not the accumulation of simple loads but may be able to be decomposed more in detail because it is closely related to various factors including the working memory load. They may vary not only by the kinds of operation but also by the situation and contents of operation as well as the operators themselves. As Ericsson and Kintsch [5] proposed the concept of LT-WM, the amount of load may be

decreased in accordance with the expertise. Another possibility is that the training will make working memory more efficient as Klingberg et al. [8] proposed. In this sense, the working memory load should be considered in relation to the knowledge level of operator considering the practice and the expertise. This point should be considered further in the future research.

(2) Our approach was based on the hypothetical model and does not have the empirical evidence. The KLM is sometimes said to be less predictable due to the use of fixed parameters. This kind of model will be effective (only) when there is no real prototype. Because we already have the dual monitor system, it is necessary that we should conduct an empirical study although it is not easy to conduct the experiment in natural settings.

References

1. Tsuhara, S.: Automatic window rearrangement using fuzzy rules. In: Proceedings of ICUPC'95, pp. 682–686 (1995)
2. Arisawa, M.: Human Interface [In Japanese]. Jikkyo Shuppan Co, Tokyo Japan (1995)
3. Baddeley, A. D., Hitch, G. J.: Working memory. In: G.H. Bower (ed.), The Psychology of Learning and Motivation. Advances in Research and Theory, Vol. 8, Academic Press, 47-90 New York (1974)
4. Miyake, A., Shah, P.: Models of working memory. In: Miyake, A., Shah, P. (eds.) Toward Unified Theories of Working memory, pp. 442–481. Cambridge University Press, New York (1999)
5. Ericsson, K.A., Kintsch, W.: Long-term working memory. Psychological Review 102, 211–245 (1995)
6. Miller, G.A.: The magical number seven, plus or minus two – some limits on our capacity for processing information. Psychological Review 63(1), 81–97 (1956)
7. Hulme, C., Roodenrys, S., Brown, G., Mercer, R.: The role of long-term memory mechanisms in memory span. British Journal of Psychology 86, 527–536 (1995)
8. Klingberg, T., Forssberg, H., Westerberg, H.: Training of working memory in children with ADHD. Journal of Clinical & Experimental Neuropsychology 24, 781–791 (2002)
9. Card, S.K., Moran, T.P., Newell, A.: The Psychology of Human-Computer Interaction, pp. 392–397. Lawrence Erlbaum Associates, Hillsdale NJ (1974)