Contribution of the Elements for Structuring Mental Models in User-Interfaces Operation

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Abstract: Users can accurately operate user interfaces by giving the design that support structuring a mental model. Then, grasping the elements for structuring mental models is important for friendly design. In our previous study, the elements for structuring mental models were proposed. Therefore, we aimed at examining the structuring process of mental models based on elements for structuring mental models in this study. We discussed the process by consideration of the role and the relationship among the elements which be observed by the operation experiment. As a result, we proposed the model of the structuring mental model process.

Key words: Mental model, User-interface, Mental model structuring process

1. Background

In recent times, due to rapid advances in technology related to information machines, which have become highly functionalized and "black box" like, users are becoming extremely troubled with machine operations. In order to conduct these operations through the operation screen, information is layered and operations are conducted from abstracted information. In this situation, in order to perform user-interface design, a recognizable approach, which unifies the mental models of the user and the designer, are necessary. Furthermore, by providing the user with a clearly defined mental model, system comprehension is promoted and operations of greater accuracy can be expected. From these points, understanding the mental models is extremely important for user friendly design.

2. Objective

In our previous study, the elements for structuring mental models were proposed. Therefore, we aimed at examining the structuring process of mental models based on elements for structuring mental models in this study. We discussed the process by consideration of the role and the relationship among the elements which be observed by the operation experiment.

3. Previous study which be proposed the elements for structuring mental models

In previous study for the mental model structuring elements, 3-points task analysis and user testing experiment is conducted to clarify the mental models structuring elements.

3.1 3-points task analysis [1]

Some tasks related to various products were investigated through the cognitive processes based on a 3-point task analysis method. 51 items needed for operating the interface were extracted for each step of the human

information processing in each task. The 3-point task analysis method, divided into three steps, is to analyze a task from the viewpoint of a human information processing. Next, the extracted items were considered with referring to previous studies of authors and the associated studies. As a result of this analysis, the components for constructing the mental model were grasped in three steps of the human information processing. We considered these elements are the hypothesis of the elements for structuring mental models.

3.2 User testing experiments to verify the hypothesis of the elements for structuring mental models [2]

(a) Summary of the experiment

User testing of 2 user-interfaces (digital camera and the fictitious remote control interface; Figure 1) is conducted to students and working people (each 19 peoples). In this experiment, (1) user-interfaces operation task and (2) mental model structuring level measurement task are conducted. First, the operation task is conducted that the participants construct the mental models. We got the utterance during the operation using the protocol analysis by the think aloud method. Then, the mental model structuring level measurement task is conducted to investigate the relationship between the utterance and the mental model structuring level. The mental model structuring tests are consisted from the task for Functional Model and the task for Structural Model. Functional model is the model regarding to understanding the contexts and the functions to understand "how to use it?" Structural model is the model regarding to understanding the structure and the principle to understand "how it works?" In this study, the test for the level of understanding the button function is conducted as the function model measurement. The test for the level of understanding the screen hierarchy structure is conducted as the structural model measurement.
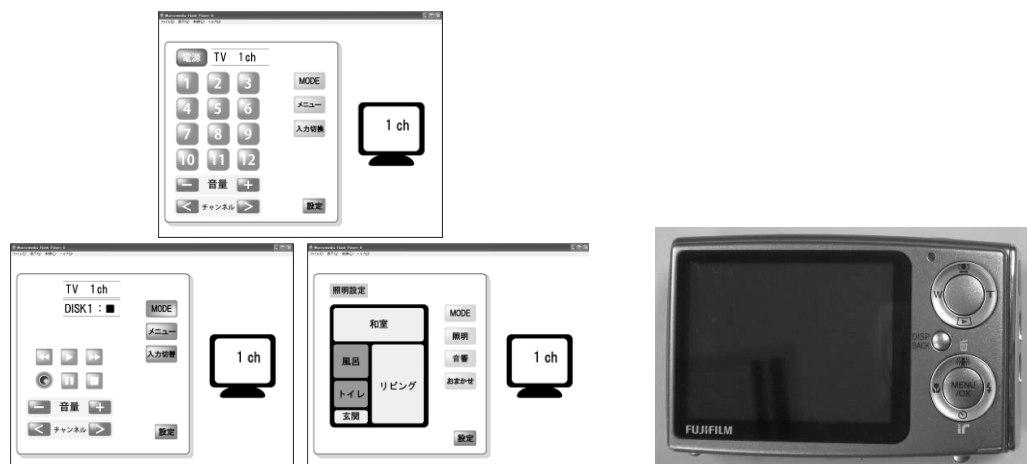

Figure.1 User-interfaces for the experiment

(b) Analysis methods

Firstly, we sorted the utterance to the 9 elements for structuring mental models and measure the quantity of the utterance for each elements. Then, the following analyses are conducted to verify the hypothetical elements.

Verify the elements

- Correlation analysis between the level for structuring mental models and the utterance for each elements
- Comparison of the utterance quantity between the participants which can construct mental models or not

Examine the relationship among the elements

- Transition probability among the each elements

- Correlation among the each elements (Correlation analysis and network analysis)
- Keygraph: Relationship among the each elements in terms of the appearance frequency and the co-occurrence
- Formal concept analysis: Relationship among the each elements in terms of the existence or non-existence of appearance in each participants

4. The elements for structuring mental models and the consideration in each elements [1-4]

Each elements and the report in the previous study are shown as below. The previous study shows the characteristics and the relationship between each elements and the level of structuring mental models.

(1) Planning

Before problems are actually solved, objectives and the processes of reading the objectives are set, then the problem is solved.

"Planning" is the element which be needed to construct mental models. Besides, it is useful when the hierarchical structure is simple.

- "Planning" is not used for operation frequently
- Signature element
- "Planning" is used with "Predicting system behavior", "Concept formation" and "Metaphor"
- "Planning" is useful when it is easy to construct the low-level goal

(2) Understanding the situation

The operator grasps the situation which he presently is in.

"Understanding the situation" is the main element which be needed to construct mental models.

- "Understanding the situation" is useful if the user-interfaces' behavior depends on the situation that users is in now
- Most general and necessary element
- There is the relationship with functional model structuring

(3) Understanding the display

Obtaining and understanding necessary information from the interface regarding the qualities (color, shape, position etc.) of the operation target.

"Understanding the display" is the necessary elements for the operation. But, there is few contribution to the structuring mental models.

- "Understanding the display" is necessary for user-interface operation
- There is no difference among the mental model structuring level

(4) Concept formation

When interpreting the operation of the interface, creating images and knowledge of the operation target, renewing these should the situation change maintaining.

"Concept formation" is the main element which be needed to construct mental models.

- The participants which can construct the proper mental model quickly can construct the proper concept quickly
- If the user-interfaces is simple, it is easy that the concept is constructed by users

- General element

(5) Metaphor

Connecting the special qualities of the operation target based on similarities with the user's knowledge.

"Metaphor" is the main element which be needed to construct mental models.

- "Metaphor" is needed to understand icon and custom in user-interface

(6) Feedback consideration

Giving consideration to and being aware of movement and condition of the operation target following operation.

"Feedback consideration" is the stand-alone element which be needed to construct mental models.

- One of the most of general element
- Few relationship with other elements
- The participants need "Feedback consideration" frequently to modify the operation

(7) Predicting system behavior

Predicting the movement and condition of the operation target and understanding the function.

"Predicting system behavior" is the element which be needed to construct mental models.

- Few relationship with other elements
- "Predicting system behavior" is needed to construct both functional model and structural model

(8) Reciprocal action of system elements

Understanding the movement principles and structure of the elements of the operation target from their reciprocal relationships.

"Reciprocal action of system elements" is the element which be needed to construct mental models. Especially, it is needed when the hierarchical structure is complex.

- "Reciprocal action of system elements" is needed if the hierarchical structure is complex
- Few relationship with other elements
- Signature element

(9) Operation memory recall

Immediately recalling previous operations when doing the same or similar operations while operating the interface.

"Operation memory recall" is not element which be needed to construct mental models directly. But, this element is used for the operation as the basic elements.

- There is no correlation with the level of structuring mental model
- The appearance frequently is frequent
- There are the correlation with other main elements

5. Contribution of the each elements to the mental model structuring process

In this study, we considered the contribution of the each elements on the basis of the previous study results about the relationship among the each elements. In the figure and table of the following section, the elements are shown as below alphabet.

A: Planning

B: Understanding the situation

C: Understanding the display

D: Concept formation

E: Metaphor

F: Feedback consideration

G: Predicting system behavior

H: Reciprocal action of system elements

I: Operation memory recall

5.1 Results of the previous study [2]

(a) Transition probability among the each elements

Transition probability is calculated to examine the mental model structuring process in terms of anteroposterior relationship of timeline. Table 1 and 2 shows the result of the calculation. The transition to "Understanding the display", "Feedback consideration" and "Predicting system behavior" were frequent. Besides, the transition probability to "Feedback consideration" from "Understanding the situation", "Concept formation" and "Metaphor"was frequent. But, the transition probability to "Feedback consideration" from other elements was few.

Table.1 Transition probability in the fictitious remote control interface

	A	B	C	D	E	F	G	H	I
A	2.13	8.51	27.66	6.38	2.13	36.17	12.77	–	4.26
B	3.89	23.89	10.56	6.11	–	27.22	20.56	2.78	5.00
C	4.13	12.84	16.51	4.59	0.92	20.18	30.73	4.59	5.50
D	4.21	7.37	12.63	13.68	–	13.68	33.68	4.21	10.53
E	–	–	37.50	–	–	12.50	50.00	–	–
F	4.88	19.51	21.54	3.66	–	17.48	22.36	4.88	5.69
G	2.02	12.46	18.86	3.03	2.02	23.91	25.93	7.07	4.71
H	–	3.51	19.30	–	–	17.54	33.33	17.54	8.77
I	–	14.08	26.76	5.63	–	25.35	18.31	5.63	4.23

Table.2 Transition probability in the digital camera

	A	B	C	D	E	F	G	H	I
A	4.44	6.67	15.56	4.44	11.11	2.22	51.11	2.22	2.22
B	4.52	7.34	22.03	1.13	4.52	29.38	30.51	–	0.56
C	1.24	13.86	22.77	2.48	5.45	12.38	39.85	0.25	1.73
D	6.82	18.18	29.55	9.09	9.09	18.18	6.82	2.27	–
E	1.64	11.48	39.34	3.28	1.64	22.95	19.67	–	–
F	4.40	14.47	25.79	5.03	3.77	3.14	40.25	0.63	2.52
G	3.17	12.30	34.92	2.38	2.78	9.52	29.17	2.58	3.17
H	–	8.70	30.43	4.35	4.35	–	34.78	–	17.39
I	–	6.98	41.86	2.33	2.33	4.65	32.56	2.33	6.98

(b) Analysis by Keygraph

The utterance quantity is analyzed by Keygraph to examine the relationship among the each elements in terms of the appearance frequency and the co-occurrence. Key Graph means the method which is able to grasp the frequently appearing words and the characteristic words from documents and utterances [5]. Then, the method

shows the relationship among them for visualizing. In this study, Keygraph is used for the visualization of the relationship among the elements. Figure 2 shows the result of Keygraph in each interface.

"Concept formation", "Planning", "Reciprocal action of system elements" and "Metaphor" constructed the base of all elements. Besides, all elements were connected reciprocally.
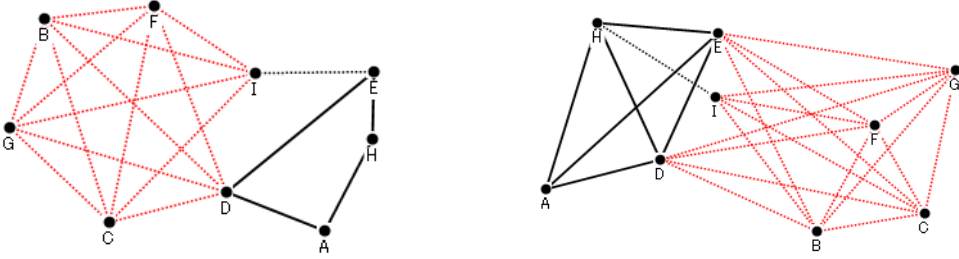

Figure.2 Keygraph result (left: fictitious remote control interface, right: digital camera)

(c) Analysis by Formal concept analysis

The concept structure based on the inclusive relationship is analyzed by FCA (Formal Concept Analysis) in terms of the existence or non-existence of appearance in each participant. FCA means the method which is able to grasp the structure and the inclusive relationship of words using a category matrix which consists of "Attribution" and "Object". In this case, the "Attribution" is characteristics of the "Object" [6-7]. In this study, the category matrix is made in terms of the existence or non-existence of appearance in each participant. Figure 3 shows the result of FCA in each interfaces.

In the fictitious remote control interface, "Predicting system behavior", "Feedback consideration", "Understanding the display" and "Understanding the situation" were shown in all participants' utterance and were the most general elements. Besides, "Metaphor" was the lowest concept. In the digital camera, "Predicting system behavior", "Feedback consideration", "Understanding the display" and "Understanding the situation" were shown in all participants' utterance and were the most general elements. Besides, "Reciprocal action of system elements" was lower concept than the fictitious remote control. "Metaphor" was higher concept than the fictitious remote control.
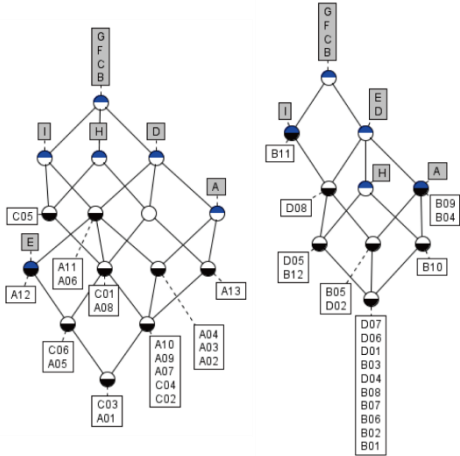

Figure.3 FCA result (left: fictitious remote control interface, right: digital camera)

5.2 Consideration

According to the transition probability among the each elements, the transition to "Understanding the display", "Feedback consideration" and "Predicting system behavior" is frequent. So, we considered that these 3 elements are main steam for structuring mental models. However, "Understanding the display" has few relationship to structuring mental models in the previous study. Therefore, we thought "Understanding the display" to get the necessary information for the operation is the first step as the basement of the structuring mental models.

Next, the system behavior is predicted by some elements and users can operate user-interfaces. Then, users examine the feedback on the basis of the feedback from the interfaces to modify the mental models.

Besides, we could consider that "Understanding the situation", "Concept formation" and "Metaphor" are the main elements by the result of Keygraph and formal concept analysis. Users can predict the system behavior to use these necessary elements for structuring mental models.

Additionally, we considered about "Planning" and "Reciprocal action of system elements". These elements are signature elements depend on the function and the hierarchical structure. "Planning" is useful when user-interfaces have simple function and hierarchical structure (Users can construct the low-level goal to operate the interface). "Reciprocal action of system elements" is useful when user-interfaces have complex function and hierarchical structure. If the function and hierarchical structure is complex, users can be planning to understand the reciprocal action of system elements. These 2 elements have the relationship to construct mental models.

Moreover, we considered about these elements in terms of "Functional model" and "Structural model". "Predicting system behavior" by "Concept formation" and "Metaphor" after "Understanding the situation" is the construct of "Functional model". Understanding "Reciprocal action of system elements" is the construct of "Structural model". Furthermore, according to 3-hierarchy model of mental models, the mental models is constructed by the following 3 level; (1) Memory level, (2) Network structuring level, (3) Mental model structuring level. So, functional model and structural model relate to the 3-hierarchy model. Firstly, functional model is constructed. Then, structural model is constructed. Therefore, we can consider that users predict the system behavior firstly. Afterward, users understand the reciprocal action of system elements.

Finally, we visualized the summary of the mental model structuring process based on these considerations as figure 4. This model shows the contribution of the elements in the mental models structuring process. We propose this model as the hypothesis model of the mental model structuring process.
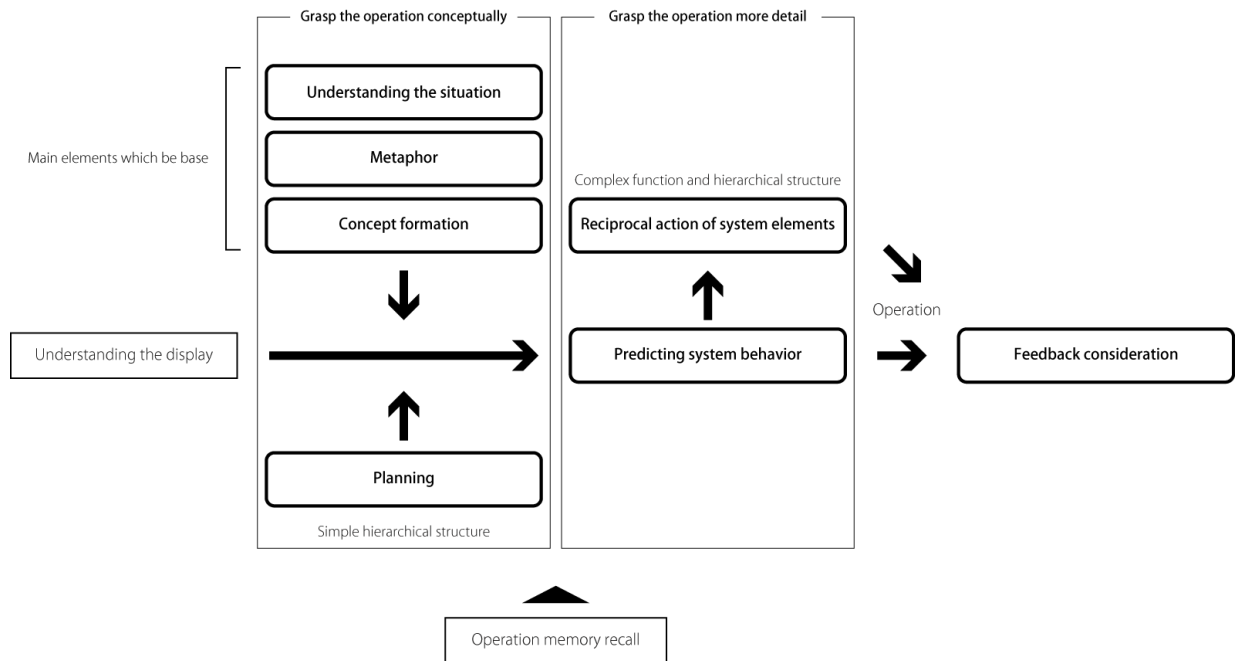
Figure.4 Mental models structuring process

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