Abstraction Hierarchy-Based Information Representation in Designing UI of DSS

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Abstract

This paper describes a framework for representing information in designing user interface (UI) of decision support system (DSS) for large-scale engineering systems. Abstraction hierarchy (AH) is introduced as the useful knowledge representation framework, which has been extensively studied in process control domain. Explaining several advantages of the AH, three experiments are reported, which were conducted to investigate the effectiveness of the AH-based information representation. The experimental results confirmed that the AH is a viable framework for identifying information that should be provided through UI and organizing the information to enhance the user's problem solving and decision–making performance. Finally, based on the experimental studies and the authors' experience of applying the AH to various engineering and management systems, this study proposes a procedure of the AH-based information analysis and representation in designing UI of DSS.

Keywords: Decision support, Abstraction hierarchy, Human-computer interaction, and User interface

I. Introduction

To support the human user's decision-making and problem solving in large-scale engineering systems such as nuclear power plants and C^{3}I (command, control, communication, and intelligence) system, several components consisting of decision support system (DSS) should be developed in an integrated design framework [8, 14]. Of those, user interface (UI) is considered as the most critical element determining the effectiveness of DSS [8, 10]. UI is a medium through which the human user receives the information about the systems' state and controls the state of the systems [10]. Physical aspects of UI, such as display and input devices, have been drastically improved with the advance of hardware technology. However, less research interest has been given to its logical aspects related to design of information content, dialog style, graphical format, and etc [2]. This study is concerned with designing proper information content and structure to enhance the user's performance, in association with information layout in UI.

The key problems that UI designers should systematically deal with are what information to provide through interface (correspondence problem) and how to present the information (coherence problem) [2]. The latter depend on the designer's degree of freedom more than the former that can be dealt with well through a systematical and comprehensive analysis of the systems, the user, and the user's tasks. Several studies pointed out that the design of information content and structure is more crucial to affect the quality of the UI, and that interface designers should identify and represent the intrinsic functional structure (invariant) of the systems that the user should interact with, to determine information content and structure of UI [1, 5, 9, 11]. In this regard, abstraction hierarchy (AH), developed by Rasmussen, is a worthwhile basis for developing information content of UI [7].

II. Abstraction Hierarchy

The AH is a multilevel information representation framework for describing the inherent functional structure of the systems [6-7]. AH is defined by goal-means relations between levels, with higher levels containing more of functional and the systems' purpose-related information and lower levels containing more of physical and means-oriented information. Typically, five abstraction levels are used to describe goal-means relations in the large-scale engineering systems. Rasmussen defined these levels as follows [6]. *Functional purpose (FP)*: the purpose for which the systems was designed; *Abstract function (AF)*: the causal structure of the systems in terms of mass, energy, information or value flows and the priority measures; *Generalized function (GF)*: the purpose-relevant basic functions that the systems was designed to achieve, regardless of their physical aspects; *Physical function (PF)*: the characteristics of the components physically consisting of the systems and their interconnections; *Physical form (F)*: the actual appearance and spatial location of those components.

Vicente described three advantages of the AH concept as an information representation tool [13]. The first is device independent property in that it can be used regardless of the internal characteristics and mechanisms of the systems. The second is event independent property because it makes the designer identify information to be provided through the interface, without consideration of some predictable or particular events. The last is that it is psychologically relevant, so that it enables the designer to develop information structure compatible with the user's information processing strategies. From the user's point of view, the primary benefit of the AH-based information representation is that it explicitly provides functionally abstracted information that the user should attempt to know by performing cognitively burdensome processing.

The AH has been extensively applied in mainly process control system, as a basis of EID (Ecological Interface Design) which is a new human-computer interface design framework developed by Vicente and Rasmussen [11]. Several studies have showed that multilevel information representation based on the AH of the systems would be advantageous for supporting the user's problem solving and decision–making [3-5, 12, 15]. However, to establish a practical methodology for applying the AH concept to designing information content of UI, it is necessary to examine the roles and effectiveness of functionally abstracted information at various levels of the AH in a more analytical manner. Another important requirement for validating the AH concept is that its effectiveness should be examined, minimizing the graphical effects of the user interface as much as possible.

III. Experimental Studies

To empirically investigate the effectiveness of providing functionally abstracted information to the user in large-scale engineering systems, this study conducted three experiments. The work domain in this study is the simplified secondary cooling system of nuclear power plant (figure 1). Though simplified, it has typical properties of large-scale engineering systems such as time lag, risky operation, high complexity, dynamic behavior, and etc. [14]. A systematic knowledge analysis of the work domain was conducted to identify information requirements to be provided on the user interface for the domain. This analysis included the systems' function analysis using the AH, the user's task analysis, and fault tree analysis. Table 1 shows an AH-based information representation of the work domain.

Based on such an information analysis, we developed six interface types that were used in three experiments. Figure 2 presents these interfaces. They are different in terms of information content and layout. All of these interfaces do not include sophisticated graphical formats that are designed to enhance the user's direct perception ability. Thus, the effectiveness of information at each level of the AH could be investigated in little conjunction with the graphical effects.

The first experiment compared three types of interface in the task of fault diagnosis: the first (P) representing only the physical properties of the process, the second (PG)

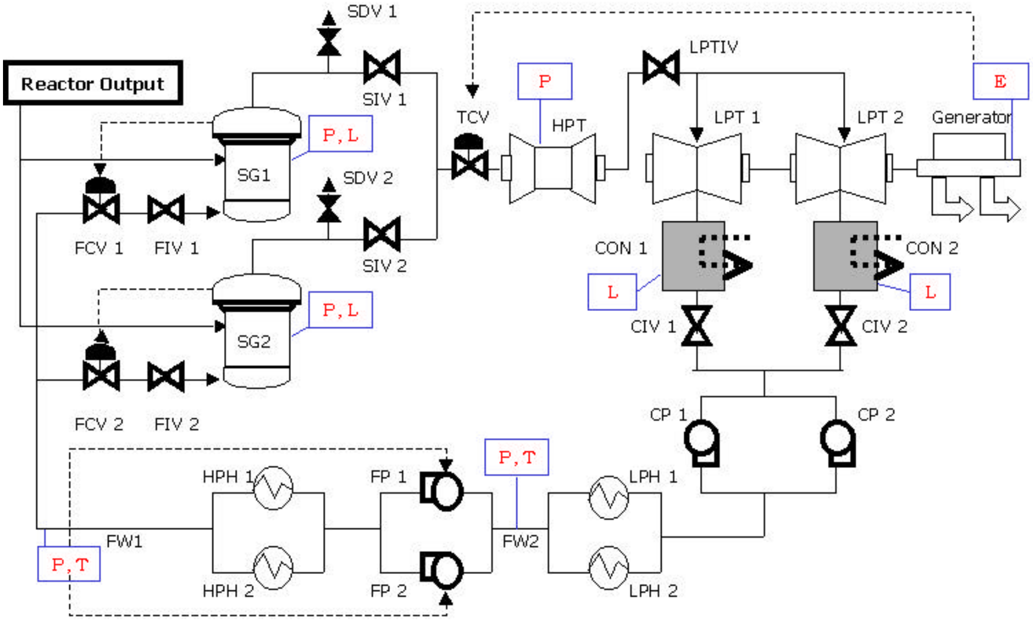
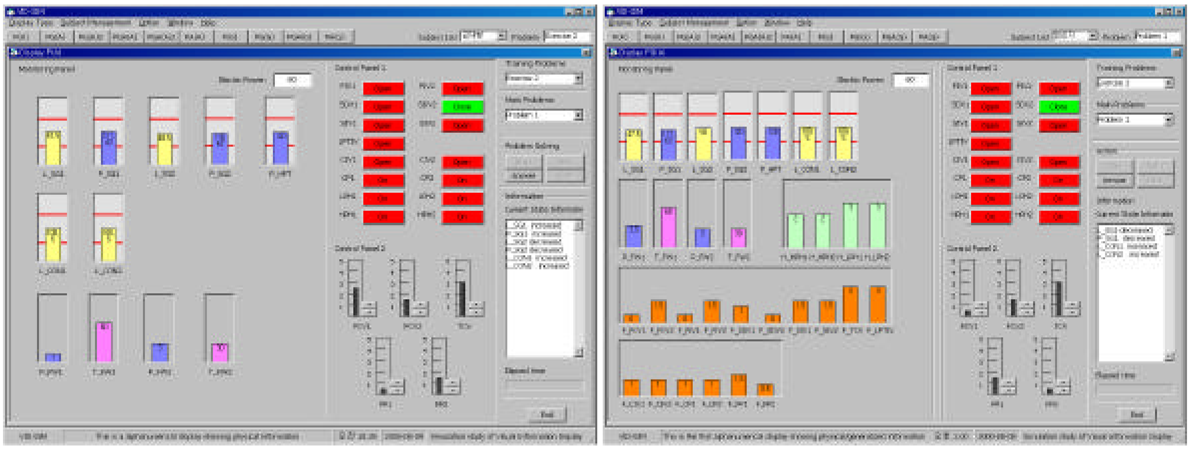


Figure 1. The work domain: secondary cooling system of nuclear power plant

Table 1. AH representation of the work domain

Level	Properties
Functional purpose (FP)	Generate electricity as demanded Keep safety
Abstract Function (AF)	Conservation of mass (feedwater & steam) Conservation of energy
Generalized function (GF)	Heat transfer (heating, cooling) Mass flow Feedback control Power supply
Physical Function (PF)	Steam generation Condensation Feedwater heating Feedwater/steam stream Flow control Turbine operation
Physical Form (F)	Spatial layout Appearance



(a) P interface (experiment 1)

(b) PG interface (experiment 1, 2, and 3)

(c) PA interface (experiment 1)

(d) PGA interface (experiment 2,3)

(e) PGA2 interface (experiment 2)

(f) Revised PGA2 interface (experiment 3)

Figure 2. Interface types used in three experiments

representing purpose-related generalized functions in addition to the physical properties, and the third (PA) representing abstract functions governing the generalized functions in addition to the physical properties. The results showed that the diagnostic performance was improved by displaying functionally abstracted information at both levels. The effects of generalized functions were greater than those of abstract functions.

The second experiment evaluated the effects of information at abstract functions provided together with that of generalized functions and physical properties, and the effects of grouping of higher-level and lower-level information in terms of goal-means relations in the task of fault diagnosis. In this experiment, three types of interfaces were used: the first (PG) that was used in the first experiment, the second (PGA) representing abstract functions in addition to the contents of the PG, the third (PGA2) showing the goal-means relations by information grouping, with the same contents of the PGA. The results revealed that those effects were weak to enhance the user's performance. But the user using the abstracted functional information was found to show more stable operational performance.

The third experiment compared the same three interfaces as in the second experiment in more cognitively complex tasks including operation, fault diagnosis and compensation. The revised PGA2 interface was used in this experiment to exhibit the goal-means relations more explicitly. The results showed that the user's performance was improved with the abstract functional information, and the utility of functionally abstracted information became greater when the goal-means relations between information at different abstraction levels were exhibited by proper information grouping.

From the experimental results, we could draw three design principles of UI of DSS for large-scale engineering systems. First, the systems' information should be identified and displayed at multiple abstraction levels. Second, the goal-means relations among the abstraction levels should be explicitly presented, especially for cognitively burdensome tasks. Third, information layout should support information integration along decomposition structure within an abstraction level as well as across abstraction levels. Besides the above principles, the interface designer should consider what type of functionally abstracted information would be most useful under what type of task contexts.

As proved in these experimental studies, the AH concept is surely a viable information representation framework. However, it may be difficult for the interface designers to understand the AH concept and apply it practically. Thus, it is necessary to provide a way to use it systematically. This study proposes a procedure of the AH-based information analysis using five abstraction levels (figure 3). This procedure is based on the authors' experience of applying the AH to various engineering and management systems [4].

First, the purposes of the systems (FP) should be defined. It is important to note that the purposes do not include the aims the human user attempts to achieve in performing their activities [14]. Namely, a focus should be given on identifying the inherent and unchangeable objectives for which the systems is designed. Second, the designers should understand the purposes-relevant functions (GF) that are designed to achieve the functional purposes. These functions are directly connected to the functional purposes. Thus, it is rather easy to identify these functions. It should be noted that they do not have any connection with physical objects and processes. Third, physical object-based functions (PF) for achieving GFs should be defined. The difference between GF and PF is that PF has a connection with physical components. At this step, monitoring and control variables connected to components should be identified. Fourth, information related to GFs should be derived from the variables at PF-level. Fifth, real object (P) selected for accomplishing physical functions should be examined. Information about appearances, color, shape of an object and spatial location between objects is concerned with this level. Sixth, basic principles and priorities governing purpose-relevant functions (AF) should be identified taking consideration of FPs. For example, in process control, mass and energy balances in terms of causal relations are typical properties

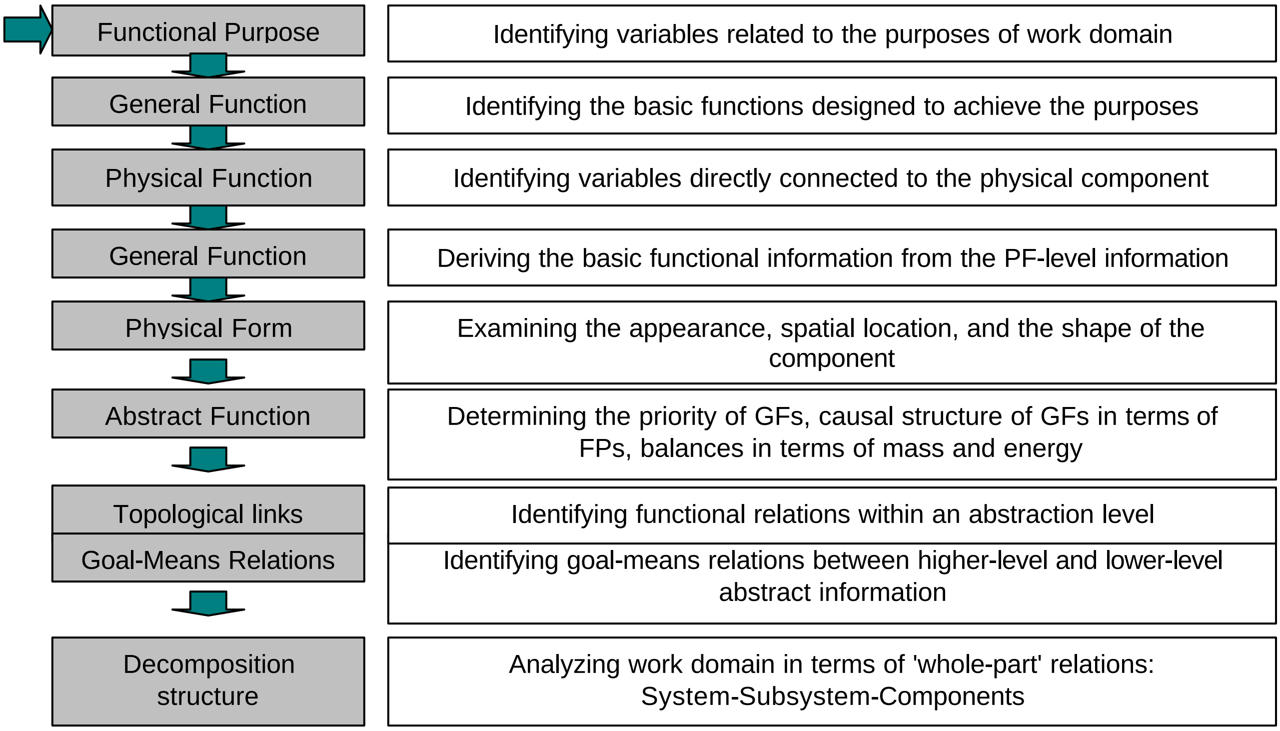


Figure 5. A procedure of goal-means work domain analysis using the AH concept

at this level. Seventh, topological links within an abstraction level and goal-means relations between higher and lower abstraction levels should be determined. Finally, physical structure of the systems in terms of 'whole-part' relations should be analyzed.

However, the UI designer does not have to make information analysis with five abstraction levels. What is important is that the designers have a mind to identify all kinds of information on the systems' functions affecting the possibilities of the user's activity in terms of goal-means relations, with the purposes at the top level and the physical objects at the bottom level. And the designers should always keep in mind that 'why-what-how' and 'many-to-many' relations characterizing goal-means hierarchy.

IV. Conclusion

To conclude, this study experimentally validates the effectiveness of the AH concept as a basis for designing information content provided through UI of DSS and proposes a procedure for developing the AH-based information representation. The greatest advantage of the concept is that it helps the UI designer to identify and organize functionally abstracted information in a systematic way, which has been found to be effective in supporting the user's cognitive tasks such as search, deep reasoning, and decision-making. Another important advantage is that it has a goal-means hierarchical structure compatible with the user's information processing mechanism in doing cognitively complex tasks, so that the AH-based interface can provide information in a way that the user effectively interact with the systems. However, to establish more comprehensive framework for making the most of the AH concept, more analytical evaluations should be conducted in various contexts to understand why and how the user's performance is increased by the use of the AH-based interface.

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V. References

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