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THE COMPARISON OF THREE TOPOLOGICAL STRUCTURES USED IN USER INTERFACE DESIGN FOR SMART LIGHTING

Chien-Hsiung Chen[1] and Wen-Te Chang[2]
[1]Graduate School of Design, National Taiwan University of Science and Technology, Taipei, Taiwan
cchen@mail.ntust.edu.tw
[2]Department of Product Design, Ming Chuan University, Tao Yuan, Taiwan
wtchang@mcu.edu.tw

ABSTRACT:

The purpose of this study is to apply topological concepts in user interface design for smart lighting. A total of three topological structures, i.e., linear, network, and mixed types, were constructed for experimental purpose. The results generated from this study revealed that: (1) Depending on the complexity of the task, each type of topological structure may have its own unique design features that can facilitate user interaction task. The linear type of topological structure can support less complex tasks well. The mixed and network types of topological structure should be able to facilitate performance of tasks of greater complexity. (2) Users thought that the network type of topological structure was easier to understand than the mixed type. It is hoped that the research findings can be a good reference for interaction designers working on similar user interfaces in the future.

Keywords: Topology, Interaction design, Smart lighting

1. INTRODUCTION

With the progress of advance computing technology, intelligent consumer products have been much popularized and widely accepted by all types of users. Interaction designers working on these products are paying more attention to user interface design issues, such as interface usability, subjective satisfaction, and etc. It is very important, and perhaps even fundamental, to have a user interface design method that can help solve the complex problems regarding interface functions and user interaction styles through an optimal interaction design process. Topological concepts have been applied to web page design to facilitate users' wayfinding process and to prevent potential disorientations. These concepts have proven to be very useful. Ideally, topological concepts can also be adopted in user interface design to prevent user disorientations caused by complex interface functions and to reduce possible memory load. The purpose of this study is to apply topological concepts in user interface design for smart lighting. In this study, the task scenarios of the user interface design were first defined and simulated. After that, topological concepts were applied to help design the user interface. A total of three topological structures, i.e., linear, network, and mixed types, were constructed for experimental purpose. An experiment was conducted to evaluate the usability of these three types of user interfaces. The participants' psychological evaluation pertaining to the criteria of understandability, learnability, enjoyability, layout, fluency, and convenience were also investigated by means of a questionnaire and a post-event interview.

Generally speaking, most of the commonly used topological frameworks for user interface design are based on the hierarchical and network types of structure (Shin, Schallert, & Savenye, 1994). That is, the hierarchical type of structure adopts a linear connection style which is very similar to the route knowledge existing in the user's mental map. The hierarchical type of structure provides simplified function or layout on the user interface. Therefore, less information can be presented on the same user interface without causing users information overload. Nonetheless, this type of structure may result in heavier memory load when a function or a task can be completed in several steps. On the other hand, the network type of structure provides users with all the functions and layouts on the same user interface, and so the users can visualize them all at one time. This hypertext connection style is similar to the survey knowledge existing in the user's mental map. Users are able to "jump" to different functions or units by making use of its hypertext features. However, this type of structure may cause cognitive overload as users can access various types of information within the shortest possible time.

2. EVALUATION OF INTERFACE USABILITY

A user interface determines how a computer application appears to its potential users (Bodker, 1991). Generally speaking, the term "interface" can be defined as a concrete or an abstract medium which facilitates the communication between a user and an artifact, such as a computer system. A concrete interface promotes tangible interaction with ergonomically designed physical devices (e.g., a keyboard, a mouse, or any other type of input and output device). An abstract interface facilitates intangible interaction with a user-friendly design that incorporates users' psychological considerations (e.g., users' mental models) in the design process. McDonald and Schvaneveldt (1988) define interface design as the process in which an interaction designer plans and specifies the usability requirements of an interface. They also emphasize that the interaction designer's primary objective is to make the interface easier and more enjoyable to use, and to make it possible for users to perform computer tasks which they might not otherwise be able to handle. Hooper (1986) also contends that the primary consideration in the design of an interface to a computer system is that it works to fulfill the proposed usability requirements. Therefore, by means of an appropriate user interface design, the users will be able to explore the functions of the computer system efficiently and adequately and perform the computer work intended.

2. 1. WHAT IS INTERFACE USABILITY?

Interface usability describes and measures how useful and effective an interface is. Lindgaard (1994) claims that research on interface usability should focus on both ease of learning and ease of use pertaining to users' computer tasks. Therefore, the usability of a computer system can be measured in terms of how easily and effectively the system can be used by a specific set of users, given particular kinds of support to carry out a fixed set of tasks, in a defined set of environments (Chapanis, 1991). Dumas and Redish (1993) also argue that designing user interfaces with usability considerations will enable users to accomplish their computer tasks quickly and easily. For example, when two individual users with similar degrees of VCR knowledge were asked to set the clock on two different VCRs, and one could perform faster and more accurately than the other, we can infer that the VCR which allows the user to set the clock faster and more accurately than the other has higher interface usability in terms of clock setting.

It is a great challenge for an interaction designer to create a user interface which is equipped with maximum usability regarding all interface functions. Most of the time, compromises are made because of conflicts between users' performances and their preferences, which reduce the overall interface usability as well. Shackel (1986, 1991) proposes four dimensions of usability: effectiveness, learnability, flexibility, and attitude. All the dimensions can be integrated into distinct usability goals and criteria. In a discussion of Shackel's usability dimensions, Booth (1989) argues that flexibility is particularly difficult to specify, communicate, and test in a real interface (or product) development environment. Building usability in a user interface is termed usability engineering (Whiteside, Bennett, & Holtzzblatt, 1988). Usability engineering involves a series of design processes: identify potential users, analyze interactive tasks, define usability specifications, develop and test prototypes, and continue through iterative cycles of development and testing processes until the final design decisions are made.

In addition, Adler and Winograd (1992) emphasize the concept of usability challenge by arguing that the key challenge in designing new interfaces (or technologies) is to make the most of users' skills in creating the most effective and productive working environment. Rheinfrank, Hartman, and Wasserman (1992) also propose the idea of design for usability by emphasizing the shift in interface design perspective from "design as the post hoc application of form and appearance elements to functionality, with the intent of communicating that functionality" to "design as the conscious crafting of usability, through a skillful development of form and appearance elements, with the intent of providing people with the resources to perceive and construct usability themselves." Therefore, an interaction designer can turn innovative concepts into everyday operations through the design of better user interfaces. As a result, a product or a system which is designed with good usability will be utilized easily and effectively by all its users.

2. 2. USABILITY AND USABILITY TESTING

From previous discussions, it is known that the concept of interface usability is related to how easily and effectively a user can interact with an interface to accomplish his/her goals. Therefore, conducting usability testing will allow an interaction designer to know if the goals are really achieved. In fact, to an interaction designer, the goal of conducting usability testing is to improve an interface by ensuring that it is not only easy to learn and use, but that it also can provide a high level of functionality to its users at the same time. Dumas and Redish (1993) maintain that usability testing should incorporate five important considerations: 1) the primary goal is to improve interface usability, 2) the participants should represent real user groups, 3) the participants should perform real tasks, 4) what participants do and say should be observed and recorded, and 5) data should be analyzed to help diagnose and fix the real interface problems.

Instead of using the term "usability testing," Mack and Nielsen (1994) employ "usability inspection" to describe the evaluation of a user interface. They argue that usability inspection includes a set of methods which promotes the use of usability inspectors to examine the usability-related issues of a user interface. The usability inspectors can be either usability specialists, software development consultants with special expertise in user interface, end users with content or task knowledge, or other types of professionals. Mack and Nielsen also propose four basic ways to evaluate a user interface:

• Automatically: Usability measures of an interface are estimated with an evaluation software.

• Empirically: Usability is assessed by testing the interface with real users.

• Formally: Use exact models and formulas to calculate usability measures.

• Informally: Usability is estimated based on an evaluator's rules of thumb, such as his/her general skills, knowledge, and experience of the interface.

Because the process of usability testing can be expensive, difficult, and time consuming, Nielsen (1989, 1990) proposes the idea of "discount usability engineering" focusing on cheap, fast, and easy-to-use testing methods, such as user and task observations, scenarios, simplified thinking aloud, and heuristic evaluation. Among these methods, heuristic evaluation is the method used to help discover interface problems by using expert users. Heuristic evaluation involves having a small set of expert evaluators examine the interface and judge its compliance with recognized usability principles (i.e., the heuristics). Nielsen (1994) points out three basic components of heuristic evaluation:

• Have evaluators go through the interface twice. The first time is to focus on the task flow, and the second time is to focus on the individual dialogue elements.

• Ask the expert evaluators to inspect the interface with respect to whether or not it complies with a short list of basic usability heuristics and our general knowledge of usability principles.

• Combine the findings from about three to five expert evaluators and have them work independently of each other.

In addition, Rubin (1994) proposes four different types of usability tests: exploratory, assessment, validation, and comparison. The first three tests are conducted according to a specific purpose, and the last one, the comparison test, can be integrated with any of the first three tests to strengthen the test results. It is important for an interaction designer to understand that the process of usability testing is not just a single step. It is, in fact, a series of interrelated, iterative tests which can be planned and designed carefully to help generate a reliable result.

3. THE EXPERIMENT

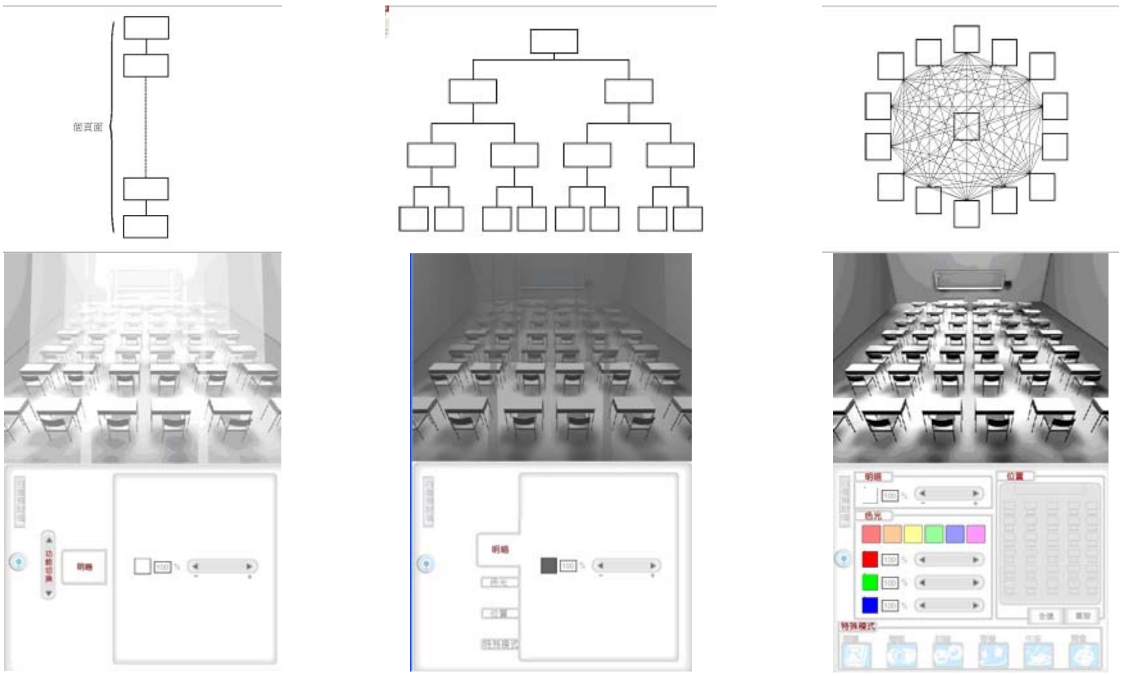
This research study was conducted in three phases: (1) review of the relevant literature; (2) development and modification of a questionnaire; (3) evaluation of a set of user interfaces by means of observation and experiment.

3. 1. PARTICIPANTS

A total of 36 participants (i.e., 18 males and 18 females) were recruited for the experiment. They were all college students who spent an average of 5.17 hours daily (Sd=2.22) using the computer. Their ages ranged from 19 to 22 years old, with the mean age being 20.17 (Sd=0.81).

3. 2. RESEARCH DESIGN

(1) User interface design: The user interface for smart lighting control was implemented based on requirement and functional investigation. There were five major functions to be shown on the user interface, i.e., on/off switch, brightness, color, lighting position, and special modes. Based on the topological structures mentioned above, three types of interface structure were created for experimental purpose, i.e., (a) linear type, (b) mixed type, and (c) network type. The number of functional nodes for connection was 27. Nonetheless, due to the difference among these three types of typological structure, the number of functional nodes shown on each hierarchical level was different. More specifically, only 4 nodes were shown on each level of the linear type of interface structure. Two levels each with 8 nodes were shown on the mixed type of interface structure. Four levels each with all 27 nodes were shown on the network type of interface structure (see Figure 1).



(a) Linear type of interface layout (b) Mixed type of interface layout (c) Network type of interface layout

Figure 1: The interface layouts were created based on three types of typological structure

(2) Questionnaire: The questionnaire used in the experiment was created based on the System Usability Scale (SUS) (Brooke, 1996) and the Questionnaire for User Interface Satisfaction (QUIS) (Chin, Diehl, & Norman, 1988). These two questionnaires were first translated into Chinese and further analyzed by means of factor analysis. The factors regarding understandability, learnability, enjoyability, layout, fluency, and convenience were identified in ISO terms related to usability principles. The seven-interval Likert scale was adopted in this new questionnaire.

(3) Task design: This research study was conducted to explore the relationship between interface hierarchy and the number of nodes shown on each screen. The participants were asked to conduct interaction tasks pertinent to smart lighting control. A total of five interaction tasks were planned based on the features of the topological structure. The task specifications are illustrated in Table 1.

(4) Experiment site and equipment: A multimedia room was used as the experiment site because it reduced the noise from the outside environment. A desktop PC together with a LCD projector was used. The screen size of the projection area was about 200*160 cm. Participants were asked to sit 250 to 300 cm from the screen.

Table 1: The summary of task specifications

	Task 1	Task 2	Task 3	Task 4	Task 5
	One layer Nodes: 3	Over 3 layers Nodes: 7	Over 3 layers Nodes: 9	One layer Nodes: 2	Over 2 layers Nodes: 6
Brightness	100%	50%	75%	50%	30%
Hue	Orange	Green	Mixed color R: 60%; G: 30%; B: 15%	Purple	--
Location	all	--		--	--
Mode	--	Presentation	--	--	Tea time

3. 3. RESEARCH PROCEDURES

(1) Warming up: A total of 36 participants were recruited to take part in the experiment. The experiment followed the between-subjects design. That is, each participant was required to interact with only one type of user interface. Therefore, 12 participants (6 males and 6 females) were assigned to interact with each topological structure. The nature of the experiment and the task specifications were briefly explained to the participants. After that, the participants were asked to learn to interact with the user interface by conducting some practice tasks. No time constraint was imposed during the warm up session. The practice ended when the participant had gained a basic understanding of the interface hierarchy and the relationship among the various nodes.

(2) Task observation: After the participant had become familiar with the user interface with which s/he was interacting, the experiment formally began. Each task was explained on a card and the participant randomly chose one card at a time. The participant was required to complete all the interaction tasks provided for the experiment.

(3) Usability questionnaire: After the experiment, the participant was required to fill out a questionnaire regarding the interface usability of the topological structure s/he had just interacted with.

(4) Interface preference: After the participant had answered the questions, s/he was shown, and asked to interact with, the other two types of topological structure. Finally, the participant was required to point out his/her most and less favorite user interface designs and to provide reasons.

4. RESEARCH RESULTS

4. 1. PARTICIPANT PERFORMANCE

The descriptive statistics of the participant's task performance on the three types of topological structure is illustrated in Table 2. Several one-way ANOVAs were conducted on all five interaction tasks to see if there existed any significant differences. The participant's task performance in task 1 and task 4 showed no significant difference (under α=0.05). On the other hand, the participant's task performance in task 2 ($F_{(2, 33)}$ = 4.56, p<0.05), task 3 ($F_{(2, 33)}$ =5.57, p<0.01), and task 5 ($F_{(2, 33)}$ = 5.19, p<0.05) all revealed significant differences. The results of post hoc comparisons using Tukey HSD are shown in Table 3.

Table 2: The descriptive statistics of participant's task performance on the three types of topological structure

Type of topology	Task	N	Mean (unit: s)	Std. Deviation	Maximum
Linear		12	19.3	9.0	39.0
Mixed	Task 1	12	27.3	9.3	48.0
Network		12	21.8	8.6	36.0
Linear		12	71.3	58.9	200.0
Mixed	Task 2	12	28.8	13.5	64.0
Network		12	38.8	15.3	75.0
Linear		12	129.8	51.8	129.8
Mixed	Task 3	12	88.2	31.0	88.2
Network		12	86.2	16.4	86.2
Linear		12	39.4	24.7	39.4
Mixed	Task 4	12	41.5	39.6	41.5
Network		12	48.3	22.9	48.3
Linear		12	29.5	9.9	29.5
Mixed	Task 5	12	58.3	33.8	58.3
Network		12	58.2	25.8	58.2

Table 3: The post hoc comparisons of interaction tasks by means of Tukey HSD

		Treatment	N	Subset for alpha = .05	
		Topological structure		1	2
		Mixed	12	28.8	
Task 2	Tukey B(a)	Network	12	38.8	38.8
		Linear	12		71.3
		Network	12	86.2	

Task 3	Tukey B(a)	Mixed	12	88.2	
		Linear	12		129.8
		Linear	12	29.5	
Task 5	Tukey B(a)	Network	12		58.2
		Mixed	12		58.3

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 12.000.
b Type 1/Type 2 Error Seriousness Ratio = 100.

As shown in Table 3, when conducting task 2, the participants' task performance on the mixed type (M=28.8, Sd=13.5) of topological structure was significantly better than that of the linear type (M=71.3, Sd=58.9) of structure. In task 3, the participants' task performance on the mixed type (M=88.2, Sd=31.0) and network type (M=86.2, Sd=16.4) of topological structure was significantly better than that on the linear type (M=129.8, Sd=51.8) of structure. No significant difference was found between the mixed and network types of topological structure. Finally, in task 5, the participants' task performance on the linear type (M=29.5, Sd=9.9) of topological structure was significantly better than that on the network (M=58.2, Sd=25.8) and mixed types (M=58.3, Sd=33.8) of topological structure. No significant difference was found between the network and mixed types of topological structure.

4. 2. PSYCHOLOGICAL EVALUATION BASED ON QUESTIONNAIRE

The descriptive statistics generated from the questionnaire to gauge the participants' psychological evaluations of these three topological structures are illustrated in Table 4. Several one-way ANOVAs were conducted. The participants' psychological evaluation pertaining to the criteria of enjoyability, layout, learnability, fluency, and convenience showed no significant difference (under α=0.05). However, the participants' psychological evaluation in understandability ($F_{(2, 33)} = 4.35$, $p<0.05$) revealed significant difference. The result of post hoc comparison using Tukey HSD is shown in Table 5. Table 5 indicates that the participants preferred the mixed and linear types of topological structure less while the network type earned the highest score among the three different types of topological structure.

Table 4: The descriptive statistics of six evaluation criteria on the three types of topological structure

Evaluation criteria	Topological structure	N	Mean	Std. Deviation	Minimum	Maximum
	Linear	12.0	4.9	0.4	4.3	5.8
Enjoyability	Mixed	12.0	4.9	1.0	3.5	6.3
	Network	12.0	5.1	1.0	3.3	6.3
	Linear	12.0	5.0	0.4	4.5	5.7
Layout	Mixed	12.0	5.1	1.0	3.7	6.2

	Network	12.0	5.3	0.5	4.7	6.5
Understandability	Linear	12.0	5.5	0.8	4.4	7.0
	Mixed	12.0	5.1	1.3	3.0	6.8
	Network	12.0	6.2	0.4	5.4	6.8
Learnability	Linear	12.0	6.0	0.4	5.4	6.8
	Mixed	12.0	5.3	1.3	3.8	6.8
	Network	12.0	6.0	0.5	5.2	7.0
Fluency	Linear	12.0	5.5	0.8	3.7	6.7
	Mixed	12.0	5.3	1.4	3.3	6.7
	Network	12.0	5.3	1.2	3.3	6.7
Convenience	Linear	12.0	4.9	0.6	4.0	6.0
	Mixed	12.0	5.4	0.9	4.3	6.7
	Network	12.0	5.0	0.9	3.3	6.3

Table 5: The post hoc comparisons of evaluation criteria by means of Tukey HSD

		treatment	N	Subset for alpha = .05	
		Topological structure		**1**	**2**
Understandability	Tukey B(a)	Mixed	12	5.1	
		Linear	12	5.5	5.5
		Network	12		6.2

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 12.000.
b Type 1/Type 2 Error Seriousness Ratio = 100.

5. DISCUSSIONS

5. 1. TASK COMPLEXITY AND USER PERFORMANCE

The results generated from the participants' task performances revealed that there existed no significant difference in task 1 and task 4 among these three types of topological structure. This can be due to the fact that these two tasks could both be conducted within one level with fewer nodes in the tasks. Therefore, the complexity of the task was quite low and the participants could complete the task easily. On the other hand, there existed significant differences in task 2, task 3, and task 5. In terms of the nature of the task, task 3 was the most difficult task of all, followed by task 2 and task 5. In task 2, the participants' performed best on the mixed type of topological structure. They performed worst on the linear type of structure. In task 3, the participants performed better on both the network and mixed types of topological structure. They again performed worst on the linear type of structure. The tasks planned in both task 2 and task 3 were difficult tasks of higher complexity. Therefore, the participants required more time to construct their mental models when conducting these two tasks. On the other hand, task 5 was a simple task and the participants performed best when interacting with the linear type of topological structure. They spent more time interacting with the mixed and network types of structure.

5. 2. USER PSYCHOLOGICAL PREFERENCE

The participant's psychological preferences pertaining to the criteria of enjoyability, layout, understandability, learnability, fluency, and convenience were investigated by using the questionnaire with a seven-interval Likert scale. The results showed that only the criterion of understandability revealed significant difference. Other criteria did not show any significant difference. This is because the participants thought that the network type of topological structure showed all the interface information on the same screen, which enabled them to understand all the information at one time. The other two types of topological structure did not reveal all the information on the same screen, and the participants had to browse through the interface hierarchy in order to complete the task.

6. CONCLUSION

This research study adopts the topological structure in the practice of user interface design for smart lighting. Both user psychological preference and task performance were explored. The research results indicate that depending on the complexity of the task, each of the three types of topological structure may have its own unique design features that can facilitate user interaction. More specifically, the linear type of topological structure can support tasks of less complexity well. The mixed and network types of topological structure should be able to facilitate task performance of higher complexity. In addition, users also thought that the network type of topological structure was easier to understand than the mixed type of structure. It is hoped that the research findings can be a good reference for interaction designers working on similar user interfaces in the future.

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