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The Efficiency, Usability and Preference of User Interface with Regards to Topological Structure and Task Type

[1]Chien-Hsiung Chen, [1]Wen-Chih Chang and [2]Wen-Te Chang
[1]National Taiwan University of Science and Technology, Taiwan
[2]Ming Chuan University, Taiwan

Abstract: This study investigates user interface task performance in terms of 3 design proposals (linear, hierarchical and network types), 3 task difficulties (easy, medium and hard), 6 usability self-report criteria (enjoyability, layout, understandability, learnability, fluency and convenience), as well as participants' subjective evaluation. The participants were 36 college students. As the study result indicated, different degrees of task difficulty were interrelated with the topological structure of user interfaces. When task difficulty was very high, both network and hierarchical types of structure resulted in better user performance. In contrast, when task difficulty was low, the linear type of structure performed better. The network type of structure had the highest rating in a self-report usability questionnaire and user preference. Our results integrate the evaluation of user performance, usability and preference and provide an example of the use of topological structures to evaluate interfaces.

Key words: Topology, task difficulty, usability, user interface design

INTRODUCTION

Interface technology is developing rapidly. Using the I-phone (Apple Inc, 2008) as an example, the traditional keypad has been replaced with a touch panel. Using powerful virtual digital functions, users can jump to different functions or units using the function modes of virtual interfaces. However, this type of interface representation may result in cognitive overload as a user attempts to find a specific single function within it and does not know where to go for various types of information.

The research and development of new interfaces requires pilot tests or evaluations of user experience to better understand how users learn to use the interface based on either previous experience (i.e., from traditional interfaces) or trial and error. Based on the results of such tests, the interface can be modified or approved. One of the most difficult tasks in this process is to select the best design from among several proposals, each of which has different interface topological structure. One way to evaluate different design proposals is to compare topological complexities, a method that is based on the theory of spatial metaphor and inspired from hypertext design (Lin, 2003; Kim, 1999; Kim and Hirtle, 1995), user behavior in hypertext perusal may be similar to spatial processing in a physical environment.

Two common topological structures in hyperlink use are hierarchical and network structures (Locatis *et al.*, 1989; Shin *et al.*, 1994). A hierarchical topology is essentially characterized by its parent-child links where the user can be well guided under such a rigid structure on one hand (i.e., less disorientation), but has to be taxed by the tedious back/forward and backtracking moves on the other. In contrast, a network structure provides users with all the functions and layouts on the same user interface, enabling users to visualize them all at one time. However, this type of structure may result in cognitive overload as users attempt to find a specific single hypertext within, do not know where to go, various types of information. Previous studies (Lin, 2003, 2004; McDonald and Stevenson, 1998) had attempted to find the best hypertext topology by comparing and integrating the merits of the original two topologies (i.e., hybrid topology). However, they have been divided as to which topological structure is easier to use and best enhances navigation. Kim and Hirtle (1995) argued that task difficulty is one of the major reasons for this uncertainty.

Task characteristics are the main factors affecting the comparison of topologies. The successful design of specific task factors and their interactions with cognitive aspects are key factors in reducing disorientation (Bosco *et al.*, 2004; Kim and Hirtle, 1995). We found during the development of the design of a topological

Corresponding Author: Wen-Chih Chang, 4F, 186-1, Sec. 1, Chung-San Road, Shu-Lin, Taipei, Taiwan

interface that a multi-layer task requiring cross-referencing information from more than one single function similar to a network topology took hypothetically less search time and required opening fewer function layers than hierarchical topology. In a single-layer task requiring information only from a single function similar to a hierarchical topology, the user may spend less memory load on unrelated information than the network topology; better efficiency can be predicted. Thus, we assumed that the interaction between task type and topological structure would affect the comparison of topological structures.

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 tests will allow an interaction designer to know if the goals are truly achieved. In fact, to an interaction designer, the goal of conducting usability tests is to improve interface usability by ensuring that it is not only easy to learn and use, but is also highly functional.

Because usability tests can be expensive, difficult and time consuming, Nielsen (1989, 1990) proposed 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. In general, having 5 experts involved in such tests is sufficient (Nielsen, 1995, 2003). Nevertheless, to include more participants to ensure the quality and validity of such tests, other measuring tools (e.g., self-reported questionnaires) can be used (Redish, 2005; Wickens *et al*., 2004).

The most credited usability questionnaires include the System Usability Scale (SUS) (Brooke, 1996), the NASA TaskLoad Index Standard Workload Test (NASA-TLX) (Hart and Stavel, 1988; Hart and Wickens, 1990) and the Questionnaire for User Interface Satisfaction (QUIS) (Chin *et al*., 1988). It would be a great challenge for an interaction designer to create a user interface with maximum usability for all interface functions. Shackel (1986, 1991) proposed 4 dimensions of usability: Effectiveness, learnability, flexibility and attitude. These dimensions can be included in a self-reported questionnaire and can be carried out before or after the user test.

We investigated user interface performance in terms of 3 topological structures (linear, hierarchical and network) and 3 task difficulties (easy, medium and hard) and included an assessment using a self-reported questionnaire. Our results have implications for interface design related to task type and topological structure and can be applied to user interface design and evaluation.

MATERIALS AND METHODS

A mixed-factor experimental design (i.e., 3×3) was adopted in this study. The independent variable was hyperlink topology (linear, hierarchical and network) and task type (easy, medium and hard). The dependent variables were the mean times of task operation (Shin *et al*., 1994). A between-subjects design was used for the variables of topology. Participants were randomly assigned to one of the experimental conditions. A within-subjects design was used for task type. Twelve participants were recruited for each of the three topological structures for a total of 36 randomly allocated participants.

Participants: Thirty-six participants (18 females and 18 males) were recruited for the experiment. All were college students from the design school of Ming Chuan University, Taiwan. Their ages ranged from 19-22 years old with the mean age of 20.17 (S.D. = 0.81). All participants were paid approximately US$6 per hour for their participation.

Research design

User interface design: The virtual user interface designs for classroom lighting control were implemented based on requirements and functional investigation. There were 5 major functions to be shown on the user interface, i.e., on/off switch, brightness, hue, lighting position and special modes. Based on the topological structures mentioned above, Fig. 1 displays 3 types of interface designs: linear, hierarchical and network.

There were 32 functional nodes. The features of each topological structure are summarized as:

- In the linear structure, four nodes were shown at each level and only one single function could be operated at a time (Fig. 1a). The user could shift to other functional modes by clicking on the back (down-arrow) or forward (upper-arrow) buttons.
- In the hierarchical structure, two levels with eight nodes were shown (Fig. 1b). In addition to the functions in the linear structure, four function layers were displayed (brightness, hue, position and special mode). The user could choose to operate the specific function under each function layer by clicking on the functional mode buttons.
- In the network structure, 4 levels with 32 nodes were shown (Fig. 1c). The user could jump to any function desired by interacting with all of the 32 functions displayed.

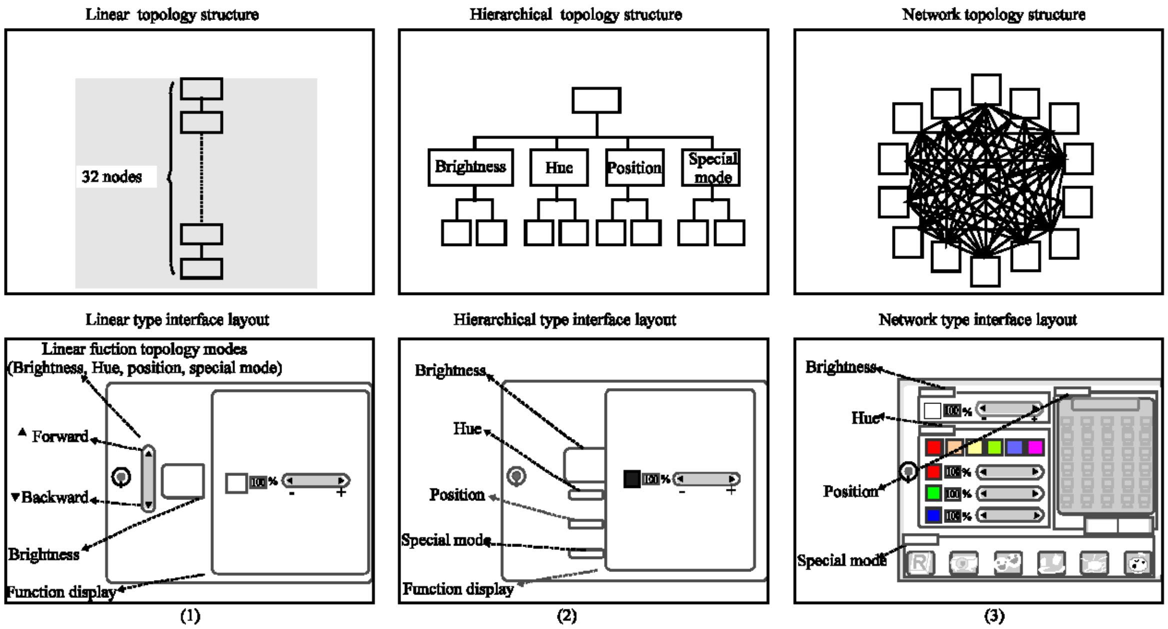

Fig. 1: The interface layouts were created based on three typological structures

Table 1: Usability self-report questionnaire

No.	Criterion	Question
1	Enjoyability	I felt very pleasant using the interface.
2	Layout	I felt that the organization of information on screen was very clear.
3	Understandability	I thought that the needs of experienced and inexperienced were taken into consideration.
4	Learnability	I felt that learning to operate the interface is very easy.
5	Fluency	I felt that tasks can be performed in a straight-forward manner.
6	Convenience	I found the system very cumbersome to use. #

The usability self-report questionnaire is seven point scale, from 'strongly disagree (1 point)' to 'strongly agree (7 point)'. Item with # is scored in reverse order

Questionnaire: The questionnaire was based on the SUS (Brooke, 1996) and QUIS (Chin *et al*., 1988) instruments. To investigate the relationship between the interfaces and existing questionnaires, 6 experts (2 each from the fields of psychology, human factors and interface design) were invited to discuss the construction and integration of the questionnaire. Each expert had more than 10 years of experience in his or her respective field. All participants were paid approximately US $50 per session for their participation. The factors regarding enjoyability, layout, understandability, learnability, fluency and convenience were identified according to the ISO (ISO DIS 92411-11) system related to usability principles. The restructured questionnaires were further modified using pilot test and second session of expert meeting. Table 1 shows the questions in terms of the six usability criteria.

Task design: To explore the relationship between interface hierarchy and the number of nodes shown on each screen, participants were asked to conduct interaction tasks pertinent to virtual lighting control. A total of 3 interaction tasks were planned based on the features of the task complexity with regards to the functional layers. The task specifications are listed in Table 2.

Equipment: A multimedia room was used as the experiment site to reduce the noise from the outside environment. A desktop PC together with a LCD minotor was used. The resolution was 1024×768 pixels at a frame rate of 85 Hz. The screen size of the projection area was about 200×160 cm. Participants were asked to sit 250-300 cm before the screen after several repeated measures.

Research procedures: Each participant was first briefly explained the nature of the experiment and task specifications. After the introduction, the participants were asked to learn to interact with the user interface by conducting some tasks for practice purpose. No time constraint was used during the warm up session. The sessions would stop when the participant had a basic understanding of the interface.

Table 2: The summary of task specifications

	Task 1	Task 2	Task 3
Task difficulty	easy	medium	hard
Layers	One layer	Over 3 layers	Over 2 layers
Functions	Nodes: 3	Nodes: 9	Nodes: 6
Brightness	100%	75%	30%
Hue	Orange	Hierarchical color R: 60; G: 30; B: 15%	--
Location	all		--
Special mode	--	--	Tea time

The experiment would formally begin after the participant was familiar with the user interface with which s/he would interact. Each task was explained on a card and the participant would randomly choose one card for the task. The participant was required to complete all the 3 interaction tasks provided for the experiment.

After the experiment, the participant was required to fill out a usability self-report questionnaire regarding the interface usability of the assigned topological structure s/he had just interacted with. Once, the participant completed the questionnaires, s/he would be shown and asked to interact with the other 2 types of topological interface designs. In the end, the participant was required to point out his/her most and less favorite user interface design and explain the reasons. The full experiment lasted approximately 1 h for each of the participant.

Data analysis: One-way ANOVAs were conducted among all the three interaction tasks to see if there existed any significant differences. A mixed-design ANOVA (3×3) was conducted to analyze the interaction between the variables, with 3 topological structures as between-subject factors and 3 task types within-subject factor. Post hoc comparisons were processed to further identify the simple interactive effects among the factors. Because backtracking frequency and search time varied by task type, with backtracking frequency and search time higher on the multi-layer than the single-layer task, the authors did not analyze backtracking frequency.

RESULTS

Task performance: The descriptive statistics of the participant's task performance on the three types of topological structures is illustrated in Table 3. As the analysis result indicated, the participant's task performance in task 1 showed no significant difference (under $\alpha = 0.05$). However, the participant's task performance in task 2 ($F(2, 33) = 5.57$, $p<0.01$) and task 3 ($F(2, 33) = 5.19$, $p<0.05$) all revealed significant differences.

As mixed-design ANOVA further indicated, the interaction between task type and topological structure was significant ($F(2, 66) = 91.76$, $p<0.01$). The results of post hoc comparisons using Tukey HSD are shown in Table 4. It was noted from the post hoc comparison, in task 2, participants' task performance in the hierarchical type (M = 88.2, S.D. = 31.0) and network type (M = 86.2, S.D. = 16.4) of topological structure was significantly better than that of the linear type (M = 129.8, S.D. = 51.8) of structure. No significant difference was found between the hierarchical and network types of topological structures. Finally, in task 3, participants' task performance in the linear type (M = 29.5, S.D. = 9.9) of topological structure was significantly better than that of the network (M = 58.2, S.D. = 25.8) and hierarchical types (M = 58.3, S.D. = 33.8) of topological structures. No significant difference was found between the network and hierarchical types of topological structures.

Table 3: The means and standard deviations of the task performance

Type of topology	Task	N	Mean (unit: s)	S.D.
Linear		12	19.3	9.0
Hierarchical	Task 1	12	27.3	9.3
Network		12	21.8	8.6
Linear		12	129.8	51.8
Hierarchical	Task 2	12	88.2	31.0
Network		12	86.2	16.4
Linear		12	29.5	9.9
Hierarchical	Task 3	12	58.3	33.8
Network		12	58.2	25.8

Analysis of the usability self-report questionnaire: The descriptive statistics generated from the usability self-report questionnaire regarding participants' psychological evaluations on these three topological structures were shown in Table 5. As the collected data indicated that the usability self-report evaluation pertaining to the criteria of enjoyability, layout, learnability, fluency and convenience showed no significant difference (under $\alpha = 0.05$). However, the 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 6. It was noted that network type earned the highest score, while the hierarchical scored the lowest among the three topologies on the evaluation of understandability criterion.

Analysis of the preference on the topological structure: It was found from the interview session that network structure was the most favorite interface (by 29 participants), while the linear topology was the most un-favorite interface (by 34 participants). The participants thought that network topology was the most preferred topological structure because all of the interface information was displayed on the same screen, allowed them to accesses all of the wanted functions at 1 time.

Table 4: The post hoc comparisons of interaction tasks by means of LSD

		Treatment topological structure	N	Subset for α = 0.05 1	2
		Network	12	86.2	
Task 2	Tukey B(a)	Hierarchical	12	88.2	
		Linear	12		129.8
		Linear	12	29.5	
Task 3	Tukey B(a)	Network	12		58.2
		Hierarchical	12		58.3

(a) Uses Harmonic Mean Sample Size = 12.000.; (b) Type 1/Type 2 Error Seriousness Ratio = 100

Table 5: The descriptive statistics of six evaluation criteria

Evaluation criteria	Topological structure	N	Mean	S.D.	Minimum	Maximum
	Linear	12.0	4.9	0.4	4.3	5.8
Enjoyability	Hierarchical	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	Hierarchical	12.0	5.1	1.0	3.7	6.2
	Network	12.0	5.3	0.5	4.7	6.5
	Linear	12.0	5.5	0.8	4.4	7.0
Understandability	Hierarchical	12.0	5.1	1.3	3.0	6.8
	Network	12.0	6.2	0.4	5.4	6.8
	Linear	12.0	6.0	0.4	5.4	6.8
Learnability	Hierarchical	12.0	5.3	1.3	3.8	6.8
	Network	12.0	6.0	0.5	5.2	7.0
	Linear	12.0	5.5	0.8	3.7	6.7
Fluency	Hierarchical	12.0	5.3	1.4	3.3	6.7
	Network	12.0	5.3	1.2	3.3	6.7
	Linear	12.0	4.9	0.6	4.0	6.0
Convenience	Hierarchical	12.0	5.4	0.9	4.3	6.7
	Network	12.0	5.0	0.9	3.3	6.3

Table 6: The post hoc comparisons of evaluation criteria by means of Tukey HSD

		Treatment Topological structure	N	Subset for α = 0.05 1	2
		Hierarchical	12	5.1	
Understandability	Tukey B(a)	Linear	12	5.5	5.5
		Network	12		6.2

(a) Uses Harmonic Mean Sample Size = 12.000; (b) Type 1/Type 2 Error Seriousness Ratio = 100

The linear topological structure did not show all of the information on the same screen, making it more difficult to browse through the interface hierarchy to complete the task.

DISCUSSION

Task complexity and user performance: Figure 2 displays the mean scores for task time of 3 topological structures on each of the task type conditions. The results of the task performance tests revealed no significant difference in task 1 among the 3 topological structures. This may be because the task could be conducted within one level with few nodes. Therefore, the complexity of the task was quite simple and participants could complete the task easily. In contrast, there were significant differences in tasks 2 and 3. Task 2 was the most difficult

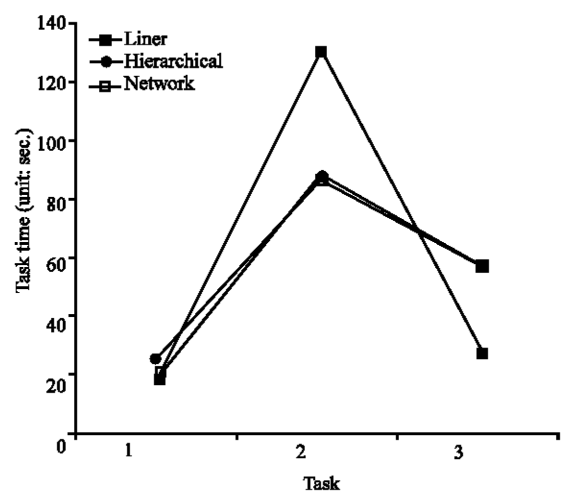

Fig. 2: Mean scores for task time of 3 topological structures on each of the task type conditions

and task 3 was somewhat easier. In task 2, participants performed better in both the network and hierarchical structures than in the linear structure. A possible reason for this is that task 2 was difficult and highly complex, requiring more time for participants to construct mental models. In contrast, task 3 was simple and participants could perform best when interacting via the linear structure.

It was also identified that the interaction among topological structure and task type is significant. The performance of the linear topology was superior to the hierarchical and network topologies on single-layer task, but the network hierarchical was superior to the linear on multi-layer task. This study extended the findings of previous studies on hypertext navigational performance (Ainley *et al*., 2002; Conklin, 1987; Hidi, 2001; Lin, 2003, 2004; McDonald and Stevenson, 1998; Salmerón *et al*., 2006) by demonstrating that different topological structures and task types influence the navigational performance of users. This finding is consistent with the argument that task characteristic has a significant effect on navigational performance (Bosco *et al*., 2004).

The number of linking functional nodes was determined based on previous studies conducted by Conklin (1987), McDonald and Stevenson (1998) and Lin (2003, 2004). We compared different numbers of functions and links during the pilot stage and obtained fairly consistent results. Further studies should be conducted to determine whether using a larger number of hyperlinks would lead to similar results.

User psychological measurement: Participants' usability self-report questionnaire pertaining to enjoyability, layout, understandability, learnability, fluency and convenience were investigated using the questionnaire. Only the criterion of understandability differed significantly among the 3 topological structures. As the preference of the interface evaluation further indicated, participants reported that the network structure, which showed all of the interface information on the same screen, allowed them to understand the interface much efficiently and effectively. The 2 other structures did not show all of the information on the same screen, making it more difficult to operate through the interface hierarchy to complete the task.

Our results confirm that task type affects task performance. The user psychology measurements should help designers to make final decisions regarding the best topological structure. Users preferred the network topology, regardless of the task type, which is consistent with previous studies that showed that user choice might not be the same as the result obtained from task tests because of task difficulty. Future research should consider more variables such as age, gender, or environmental issues related to the context of user experience (Marcus, 2002; Norman, 2003; Pemberton, 2002).

We used three topological structures to test user interface designs for classroom virtual lighting control. The efficiency, usability and preference of user interface with regards to topological structure and task type were

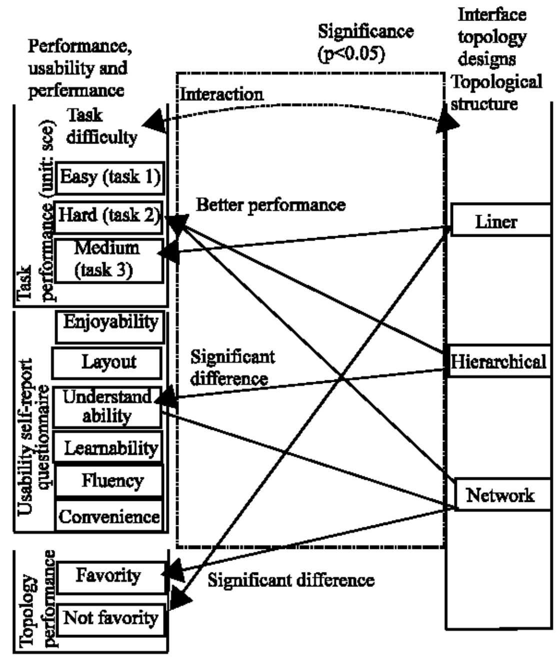

Fig. 3: The interface layouts were created based on three typological structures

explored. Figure 3 shows the correlation among the variables, namely, interface topological structure, task performance, usability self-report criterion and preference. Depending on the task complexity, each type of topological structure may have its own distinct design features that can facilitate users' interaction. More specifically, the linear structure sufficiently supports tasks that have little complexity, whereas the hierarchical and network structures best facilitate tasks that have great complexity. Users thought that the network structure was easier to understand than the other structures and was the most favorite interface topology among the three design proposals. These results should be a good reference for interaction designers when designing similar user interfaces in the future.

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