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Age Differences and the Depth - Breadth Tradeoff in Hierarchical Online Information Systems

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ABSTRACT

This paper examines previous research on the topic of depth versus breath in hierarchical menu structures, and explains why searching for information on the world wide web follows a similar model. It also proposes age related enhancements to available mathematical models, design guidelines where possible and future research topics in the area.

1. Introduction

The World Wide Web (WWW) is exponentially increasing, both in terms of user population, as well as the amount of available information. In the beginning, people tended to concentrate more on aesthetics; how to make pages "look nice" by overloading them with images, java applets and other gadgets. Currently we are seeing a shift towards web usability, where the topic of information architecture is gaining momentum. People are using the WWW more and more in searching for specific information (eg. medical, travel) than for random browsing. Taking into account the user needs for fast and accurate access to information, big commercial search engines are evolving into a hierarchical collection of links and data (eg. Yahoo, Lycos, Altavista, Google). It is not surprising that all of the popular search engines now include hierarchical indexes/organizations of "important" links.

Both the exponential increase of use and information available on the web makes it necessary for information system designers to allow for a more diverse user population. Research has shown that older people, the fastest growing segment of the population (Charness and Bosman, 1990), are willing and able to learn to use computers, but that they have more difficulty than younger adults in doing so (Czaja, 1996). More and more older adults today use the WWW for information retrieval (especially health related), communication with family members and for keeping up with daily news. There is little existing research on the older adults' Web use, particularly on their ability to navigate complex sites (Mead, 1997). But it is expected that older adults' limitations in working memory and motor skills effects their performance when browsing the world wide web.

This paper examines previous research on the topic of depth versus breath in hierarchical menu structures, and explain why searching for information on the world wide web follows a similar model.

2. Depth versus Breath in Menu Selection

The topic of menu selection and especially depth versus breath tradeoffs has been extensively examined, both empirically and analytically. Menu panels usually consist of a list of options. These options may consist of words or icons. The word or icon, conveys some information about the consequences of selecting that option. Sometimes the options are elaborated with verbal descriptors. When one of the options is selected and executed a system action occurs that usually results in a visual change on the system. The total set of options is usually distributed over many different menu panels. This allows the system to prompt the user with options that are unlikely or illegal.

Web indexes are organized in a similar structure. Links (very often 2-3 words, sometimes elaborated with verbal descriptors) are arranged in various levels of homepages. These links convey information about the page (with information or further sub-categories) that will be displayed if that specific link is selected. It has been shown experimentally (Zaphiris (2000), Larson, K. & Czerwinski, M. (1998)) that hierarchical menu design experiments can be replicated when applied to hierarchies of web links.

Hierarchical decomposition of the user's selection of action is often necessary to facilitate fast and accurate completion of search tasks, especially when there is insufficient screen space to display all possible courses of action to the user. Hierarchical structures also help the novice user who lacks sufficient memory capacity to learn and recall all of the commands necessary to execute the desired actions.

On the other hand, the navigation problem (i.e. getting lost or using an inefficient pathway to the goal) becomes more and more treacherous as the depth of the hierarchy increases. Research has shown (Snowberry, Parkinson, and Sisson (1983)) that error rates increased from 4.0% to 34.0% as depth increased from a single level to six levels.

The challenge, therefore, is to enable the user to select the desired course of action using a clear, well defined sequence of steps to complete a given task (Wallace, Anderson, & Shneiderman, 1987).

2.1 Empirical Results

The trade-off between menu depth and breadth is considered by some researchers as the most important aspects that must be considered in the design of hierarchical menu systems (Jacko & Salvendy, 1996). Miller (1981) found that short-term memory is a limitation of the increased depth of the hierarchy. His experiment examined four structures (64^1, 2^6, 4^3, and 8^2) with a fixed number of target items (64). As depth increased so did response time to select the desired item.

Snowberry, Parkinson & Sisson (1983) replicated Miller's study by examining the same structures but this time including an initial screening session during which subjects took memory span and visual scanning tests. They found that instead of memory span, visual scanning was predictive of performance, especially in the deepest hierarchies.

Kiger (1984) extended Miller's research by doing an experiment that provided users with five modes of varying menu designs of 64 end nodes (2^6, 4^3, 8^2, and 16x4, 4x16). Performance and preference data were collected. The results of the experiment showed that the time and number of errors increased with the depth of the menu structure. The 4x16 structure had the fastest response times and the fewest errors. The participants ranked the menus with least depth as the most favorable (The 8^2 structure was favored).

An experiment by Jacko and Salvendy (1996) tested six structures (2^2, 2^3, 2^6, 8^2, 8^3, and 8^6) for reaction time, error rates, and subjective preference. They demonstrated that as depth of a computerized, hierarchical menu increased, perceived complexity of the menu increased significantly.

Wallace, Anderson and Shneiderman (1987) confirmed that broader, shallower trees (4x3 versus 2x6) produced superior performance, and showed that, when users were stressed, they made 96 percent more errors and took 16 percent longer. The stress stimulus was simply an instruction to work quickly ("It is imperative that you finish the task just as quickly as possible"). The control group received mild instructions to avoid rushing ("Take your time; there is no rush").

Zaphiris (2000) replicated Kiger's (1984) structures but this time on the WWW using hyperlinks. Overall, the results were in agreement with those of Kiger (1984). They found that of the structures tested (2^6, 4^3, 8^2, and 16x4, 4x16), the 8^2 structure was the fastest to search.

Larson & Czerwinski (1998) carried out an experiment using 512 bottom level nodes arranged in three different structures (8x8x8, 32x16, 16x32). Subjects on average completed search tasks faster in the 16x32 hierarchy, second fastest in the 32x16 hierarchy, and slowest in the 8x8x8 hierarchy. Also, on average, subjects tended to be lost least often in the 16x32 hierarchy.

2.2 Mathematical Modeling

Regarding the depth vs. breadth tradeoff in hierarchical information structures, researchers initially provided qualitative recommendations rather than theoretical or empirical predictions (Shneiderman, 1980; Norman, 1990). Starting in the mid-80's a stream of quantitative modeling in this area emerged.

Lee and MacGregor (1985), broke down the search time in hierarchical menu retrieval into two factors, the human factors and the machine factors. The human factors include search strategy, the strategy employed by a user in searching through the alternatives on an index page; reading speed, the rate at which users read or scan the alternatives; and key-press time, the time required to press the appropriate key(s) and/or make the necessary mouse move to select an alternative. With respect to scanning, people typically employ one of two basic strategies for searching through a list of alternatives: exhaustive search and self-terminating search (Norman, 1990).

Hierarchical menu structures of n items obey an inverse relationship between breadth b and the depth d:

$$d = \frac{\ln n}{\ln b} \qquad (1)$$

The total search time through the index, ST, is the product of the number of menus accessed and the average access time per menu:

$$ST = d(E(I)t + k + c \qquad (2)$$

where *E(I)* is the expected number of items examined by a user on one menu frame before making a decision, *t* is the time to process one option, *k* is human response time and *c* is computer response. For exhaustive search the number of alternatives per index page that minimizes search time can be computed using

$$b(\ln b - 1) = (k + c)/t \qquad (3)$$

Assuming random sequencing of the alternatives, a self-terminating search would require reading on average one-half of them before encountering the appropriated one.
Thus,

$$ST = \frac{((b+1)t/2 + k + c)}{(\ln b)} \ln n \qquad (4)$$

Taking the derivative of the above equation and setting it to zero, it can be shown that the optimum *b* assuming a self-terminating search is given by:

$$b(\ln b - 1) = 1 + 2\frac{k + c}{t} \qquad (5)$$

3. Age Related Differences

In a study by Mead (1997) age related differences and training on WWW navigation strategies were examined. They state that older and younger adults who report low levels of computer experience were more likely to employ high visual momentum navigation strategies when searching a hierarchical library database than were younger adults who reported high levels of computer experience. Low computer experience participants were more likely to move up to higher levels in the hierarchy (zooming out) than were participants with high computer experience. They also observed that novice searchers are more likely to "get lost" in a hierarchical structure than were more experienced searchers. In an experiment they conducted, where they asked their participants to complete nine search tasks on the WWW, they showed that seniors were significantly less like to complete all tasks than were younger adults. However seniors were as likely to complete the five tasks with short optimal path length (two moves or fewer) as younger adults. Seniors on the other hand, were significantly less likely to complete the tasks with long optimal path length (3 moves or more) than were younger adults. Error results showed seniors may experience considerable difficulty finding information on the WWW when path length is long. Finally seniors were reported to adopt less efficient search strategies and had more problems remembering which pages they had visited and what was on those pages than did younger adults.

Apart from the study mentioned above, there does not seem to be any other previous research on the effect of age in searching hierarchies of links and there has not been any previous research on the topic of depth versus breath in menu selection applications, as applied for people of age. In our analysis we will use the age sensitive components of the human processor model (Card, 1984) proposed by Charness and Bosman (1990). Since previous mathematical models take into account reading speed and motor speed these factors would need to be adjusted for aging in our new proposed mathematical model.

4. Analysis

In this paper a sensitivity analysis, taking into consideration age related differences, of the linear model (Lee & MacGregor, 1985) is presented.

Two age related sensitivity parameters were defined

1. a_1 - represents an age related parameter for human processing time, estimated using perceptual processor cycle time (McFerland, 1958) as

$$Y_i = 104.16 + 1.05 age_i \qquad (6)$$

2. a_2 - represents the age related parameter for human motor response time, estimated using the extended Fitts' Law (Fitts, 1954)

$$MT = IM \log_2(D/S + 0.5) \qquad (7)$$

where MT represents movement time, IM an age related variable (in ms/bit); IM = 60.68 + 1.68(age), D the distance of movement from start to target center and S the size of the target.

The following modified linear model is proposed

For exhaustive search

$$TEA_{b,d} = d(b * a_1 * t + a_2 * k + c) \qquad (8)$$

For self-terminating search

$$TSA_{b,d} = d\left[\frac{(b+1)*a_1*t}{2} + a_2*k + c\right] \qquad (9)$$

Where TEA and TSA represent the total search time through the index for exhaustive and self-terminating searches respectively. Contour plots of various combinations of breadth and depth were plotted for two age groups (25 and 70 years of age).

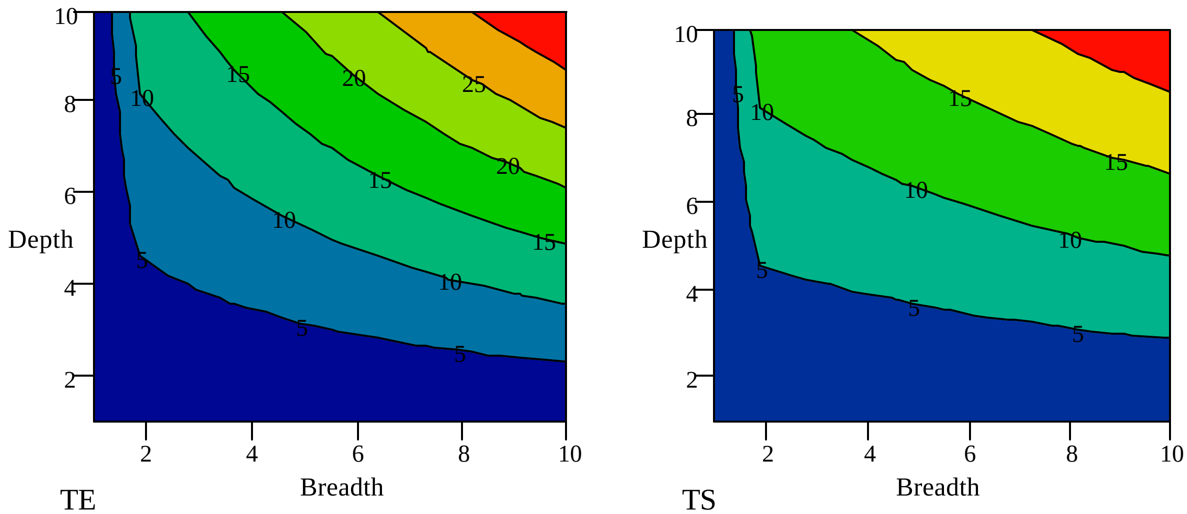

Figure 1: Contour plots for exhaustive and self-terminating search times for young (age = 25) users at t=0.25, k=0.5, c=0.5

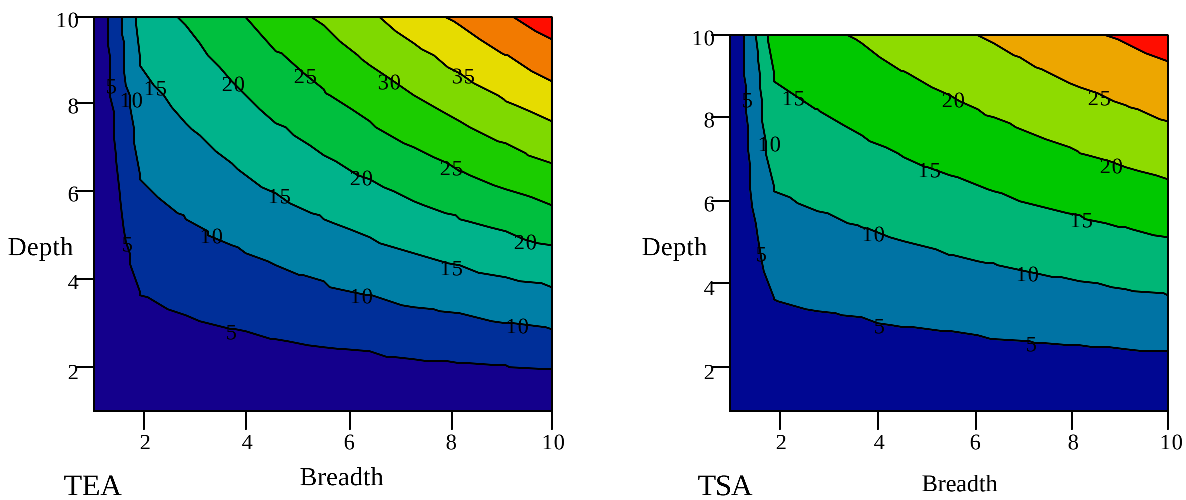

Figure 2: Contour plots for exhaustive and self-terminating search times for senior (age = 70) users at t=0.25, k=0.5, c=0.5

Finally an optimization analysis (using Newtons Method) was carried out in order to obtain optimum value for breadth that will minimize the total search time. Table 1 shows the results of this analysis.

5. Conclusion

The contour plots of the various search completion times show that seniors are expected to be slower, than their younger counterparts, in completing search tasks in hierarchical information structures associated with the decline in perceptual and motor abilities as we age.

Seniors also tend to have limitations in spatial abilities, which is a key issue in menu/link hierarchies. It is predicted that older users will tend to get more easily “lost” in very deep and very broad hierarchies thus resulting in a lower performance (the a_2 factor in the proposed model).

Also seniors are expected to have limitations in motor abilities. Since menu/link driven hierarchical user-interfaces are mainly mouse driven, it is predicted that older users will have a harder time selecting the appropriate choice among the ones presented to them (the a_1 factor in the proposed model).

All these factors combined result in slower completion times for seniors both for exhaustive and self-terminating designs.

Finally, only minor differences of optimum breadth were found for the two age groups (optimum breadth ranges in value from 3 to 18 depending on expertise.) It should be pointed out that even though the mathematical model predicts that performance of both age groups results in optimum performance for the same values of breadth this does not imply that their completion times will be equal. Also it is expected that designs with larger than optimum breadth will result in high age related differences in performance.

5.1. Suggestions to Practitioners and Researchers

Overall, difficult tasks, over-crowded interfaces, very deep hierarchies on slow computer networks, result in big age related differences in performance. Shallow hierarchies designed with optimum breadth will result in optimum performance with smaller age related differences among users.

Further research is needed on the topic. Experimental data needs to be collected and the proposed model tested against those data. Also experience and skill related parameters need to be calculated and incorporated into the proposed model.

k	t	c=0.5				c=1.0			
		E	EA	S	SA	E	EA	S	SA
0.5	0.25	6	6	8	8	7	6	10	10
0.5	.5	4	4	6	6	5	5	7	7
0.5	1	4	4	5	5	4	4	6	6
0.5	2	3	3	4	4	3	3	5	5
1	.25	7	7	10	10	8	8	12	12
1	.5	5	5	7	7	6	6	8	8
1	1	4	4	6	6	4	4	6	6
1	2	3	3	5	5	4	4	5	5

Table 1: Optimization results for optimum value of breadth that minimizes total search time (where results represent the optimum number of items per screen E = Exhaustive, S = Self terminating, EA = Exhaustive aging, SA = Self terminating aging.)

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