Mathematical Modeling of Age Differences in Hierarchical Navigation Systems

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ABSTRACT
This poster presents a modification to an existing mathematical model for depth-breath tradeoff of menu-selection to account for age related differences.

Keywords
Menu-selection, navigation, aging, cognitive modeling.

INTRODUCTION
Much of the early research on menu selection was performed in the context of analyzing text menus [6, 7]. In particular, the depth vs. breath tradeoff has been extensively examined, both empirically and analytically. Recent empirical work has demonstrated that hierarchical menu design experiments can be replicated when applied to hierarchies of web links [10 ,2]. The navigation problem (i.e. getting lost or using an inefficient path) becomes more and more treacherous as the depth of the hierarchy increases [10].

MODEL FORMULATION
Regarding the depth vs. breadth tradeoff in hierarchical information structures, researchers initially provided qualitative recommendations rather than theoretical or empirical predictions [7, 9]. Starting in the mid-80's a stream of quantitative modeling in this area emerged.

The Linear Model (Lee & MacGregor, 1985)
Lee and MacGregor [3], 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 [7].

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

$$d = \frac{\ln n}{\ln b}$$

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

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

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

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

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,

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

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:

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

Age Related Differences in Navigation
In general the empirical work points out that older adults are at a disadvantage in information retrieval tasks. Mead et al. [5] found that both 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 database than were younger adults who reported high levels of computer experience. Nygren [8] found that estimated scanning rate was dependent on subject's age. In addition to studies that directly examined the effect of age, there are several studies that report task performance differences as a

function of other individual-differences factors such as cognitive ability and experience.

ANALYSIS

In this poster a sensitivity analysis, taking into consideration age related differences, of the linear model [3] is presented.

Two age related sensitivity parameters were defined:

- a1 - represents an age related parameter for human processing time, estimated using perceptual processor cycle time [4]

$$Y_i := 104.16 + 1.05 \cdot age_i$$

- a2 - represents the age related parameter for human motor response time, estimated using the extended Fitts' Law [1]

$$MT_i = IM \log_2(D/S + 0.5)$$

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

$$TEA_{b,d} := d \cdot (b \cdot a1 \cdot t + a2 \cdot k + c)$$

For self-terminating search

$$TSA_{b,d} := d \cdot \left[\frac{(b+1) \cdot a1 \cdot t}{2} + a2 \cdot k + c \right]$$

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).

CONCLUSIONS

The contour plots [11] show a stronger effect/sensitivity of depth to navigation/search time for older users when compared to the plots for younger users.

Suggestions to Practitioners

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.

Suggestions to Researchers

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.

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