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Navigation Strategies in Case of Different Kind of User Interfaces

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1. Introduction

Information seeking is a very frequent task in our everyday computer usage. We often search not only one but also more information, more objects on web pages, on the user interface of different kind of software or multimedia program. In our study we sought the answer to the question how property of objects (etc. size, form) influence the time needed to find them, how object placement influence searching time, what kind of searching strategy users use to find the targets and whether we find everything we need.
We examined within-page navigation thus, all targets were placed on the same screen. Users had to search among 2- and 3-dimensional shapes and in pictures.

1.1 What do we (not) observe?

If we open our eyes, a huge amount of visual information streams to us, which changes for moment to moment as we move our head and eyes. It would be unnecessary to process all incoming information in the fullest detail. From these huge amount of information the brain should select and process in full detail only those information which is necessary. Which information will be processed in detail?
Visual information is projected on the retina. The region of sharp-sightedness is the central part of the retina, called fovea. Information projected on this area can be processed in the fullest detail. Information projected on the periphery can be processed in less detailed.
What happens if we search an object? In the first moment a "map" is formed about basic visual features of visual information in the brain. This is the pre-attentive stage. On the basis of this map, our visual attention guides what we should see in more detailed. In the attentive stage we concentrate only on a limited part of the visual field; the information processing is more detailed in this smaller field. We could perceive objects or reading texts only in this stage.

1.2 The visual attention

If we search something, our gaze is guided by the visual attention. It is hard to imagine how visual attention works; what kind of processes work in the brain when we decide where we look, and on which area we look after a few minutes.

Source: User Interfaces, Book edited by: Rita Mátrai,
ISBN 978-953-307-084-1, pp. 270, May 2010, INTECH, Croatia, downloaded from SCIYO.COM

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According to a famous philosopher, William James visual attention looks like a spotlight with which a small area of a dark stage is illuminated: perception is more precise or faster in the area to which we just pay attention (James, 1890). This is the area of attentional focus.

The size of this area is not state, it can be smaller or larger depending on the actual task (LaBerge, 1983). Efficiency of the processing in the attention area is not uniform; it decreases by moving off the central point (LaBerge and Brown, 1989). However, it was found in certain tasks, that the centre of the attention area can be "holed" as well, as if it were ring-shaped (Eimer, 1999). Moreover, some researches highlighted the discontinuity of the spatial attention. The attention area can be made up of more areas, which are not connected with each other (Kramer and Hahn, 1995).

Helmholz took note of an interesting phenomenon. We are able to fix on a given point but pay attention to another point of the field of view. This means that the attention area and the area around the fixation point is not definitely the same.

Consequently, an eye-tracking experiment do not give a definite answer to the question whether information on which the user fixated was increasingly realised in the user. Therefore in our experiments targets had to be clicked on, because if the user clicked them on, then it is sure that they perceived them.

2. From visual search to navigation structure

In visual search task one object has to be found. If more objects have to be found, what does the order of findings influence? Is the order of finding targets randomly or does it have a kind of structure?

A method was developed to analyse the order of finding objects. Targets were represented as nodes of a graph. Navigation routes of every user can be drawn as directed edges between the nodes, where the head of arrow shows the going direction. Navigation routes of all users can be drawn in the graph; in this case the directed edges are to be weighted. The weight of each edge shows the relative frequency of the sequence of selection. This graph was called as navigation graph.

Definition: A G(N,A) ($n=|N|$) navigation graph which contains n target objects is a weighted, directed graph in which the w(i,j) ($0 \leq w(i,j) \leq 1$) weight of the $(i,j) \in A$, $i,j \in N$ edge denotes, how many percent of subjects clicked on the object j directly after the object i.

If the order of clickings were random than in the navigation graph there were edges from one node to the other and the weight of each edge would be $1/(n\text{-}1)$ where n is the number of nodes.

In the navigation graph there may be some edges which weight is very small because users rarely choose that two objects after each other. If the weight of an edge is significantly smaller that $1/(n\text{-}1)$ then it can be deleted from the graph and we get the navigation structure.

Definition: In a G(N,A) ($n=|N|$) navigation graph an $(i,j) \in A$, $i,j \in N$ edge is significant, if the weight of the edge is significantly higher, than 1/(n-1). (Expected value calculated on the base of the equal distribution.) In the opposite case the edge is non-significant.

Definition: A navigation graph is a navigation structure, if it does not contain any non-significant edges.

2.1 Searching strategies

Navigation structure representates significant going directions, but does not show which object was selected first, which for the second time etc. These values were signed by every node and we called it navigation map.

Definition: navigation map is a $G(N,A)$ ($n=|N|$) weighted, directed graph which contains n target objects, in which $w(i,j)$ ($0 \le w(i,j) \le 1$) weight of the $(i,j) \in A$, $i,j \in N$ edge denotes, how many percent of subjects clicked on the object j directly after the object i, as well as $(i{:}s_i{:}v(i))$ denotes that on an $i \in N$ object s_i-th clickings ($1 \le s_i \le n$) occured in $v(i)$ % ($0 \le v(i) \le 1$). ($\max(s_i)$ denotes the ordinal number of that click where the value of v(i) is the greatest.)

After that we could conclude the navigation strategy of the users.

If users can perceive all objects for the first glance then they might click on the targets so that the length of the route will be minimal. In this case they follow global strategy; in this case the route went round by the user is the shortest. If the task is more difficult the user might click the nearest object every time; this is the local strategy. On a more crowded and disordered screen navigation of users becomes random; in this case the strategy is ad-hoc.

We analysed which strategy occurs the most frequently by every worksheet, and that strategy was called the dominant searching strategy for that worksheet.

How can we establish which searching strategy is dominant for each worksheet?

2.2 Calculation of similarity and identity indexes

New metrics and indices had to be made which show the occurrence of each sequences. With these metrics and indices any number of sequences can be compared with each other. For this, several concepts had to be initiated.

Clicking orders are called clicking sequences. The sequence which contains two elements is an element sequence. Two sequences can be equivalent if their elements and their order are also the same; antagonistic, if their elements are the same but their orders are reversed; and indifferent in any other cases.

Definition: The clicking orders $s=\{o_1,o_2,\ldots,o_n\}$, where $o_1,..,o_n \in \mathbf{N}$ are called (clicking) sequences, where $o_1,..,o_n$ denote the serial number of the objects, and $o_1 \neq o_2 \neq .. \neq o_n$.

Definition: The s_2 sequence is the opposite of $s_1=\{o_1,o_2,\ldots,o_n\}$ if $s_2=\{o_n, o_{n-1},\ldots,o_1\}$, where $o_1,..,o_n \in \{1,..,n\}$. The reversed sequence is denoted as $s_2=-s_1$.

Definition: A sequence is an element sequence if the sequence contains two elements: $e=\{o_1,o_2\}$, where $o_1,o_2 \in N$

Definition: Two element sequences e_1, e_2 are

- equivalent, if their elements and order of elements are also the same: $e_1=\{o_1,o_2\}=\{p_1,p_2\}=e_2$, $o_1=p_1$, $o_2=p_2$, $o_1,o_2,p_1,p_2 \in N$;
- antagonistic, if their elements are the same, but their orders are reversed: $e_1=-e_2$
- indifferent, if there are neither equivalent nor antagonistic.

After that we introduced the similarity measure which express numerically how similar are the two sequences. The similarity measure of two sequences are 1 if they are equivalent; -1 if there are antagonistic; 0 if there are indifferent. Similarity measure of two longer sequences can be calculated as follows: sequences should be divided into element sequences, after that they could be compared pairwise. Values given by pairwise comparison should be summed and divided with n-1 where n is the number of elements (thus, the number of objects which had to be found). Consequently, the value of the similarity measure is between -1 and 1.

Definition: Similarity measure of two element sequences:

$$sim_e(e_1,e_2)=\begin{cases}1, if & e_1=e_2\\ -1, if & e_1=-e_2\\ 0, if & e_1\sim e_2\end{cases} \tag{1}$$

Definition: Similarity measure of two $s_o=\{o_1,o_2,\ldots,o_n\}$, $s_p=\{p_1,p_2,\ldots,p_n\}$, o_i, $p_j\in\{1,\ldots,n\}$, $\forall i$, $j\in\{1,\ldots,n\}$ sequences can be calculated as follows:

$$sim(s_o,s_p)=\frac{1}{n-1}\sum_{i=1}^{n-1}\sum_{j=1}^{n-1} sim_e(\{o_i,o_{i+1}\},\{p_j,p_{j+1}\}) \tag{2}$$

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In case of *m* experimental people each sequence should be compared with the others pairwise, the value of similarity measures should be summed and normalized between -1 and 1, and we get the similarity index.

Definition: Similarity index of *m* sequences:

$$I_S=\frac{1}{m(m-1)}\sum_{i=1}^{m}\sum_{\substack{j=1\\ i\neq j}}^{m} sim(s_i,s_j)=\frac{2}{m(m-1)}\sum_{i=1}^{m-1}\sum_{j=i+1}^{m} sim(s_i,s_j) \tag{3}$$

The value of similarity index is also between -1 and 1. This value is 1 if each sequence is the same; -1 if each sequence is antagonistic. But this is only possible if we compare 2 sequences. 3 sequences can not be pairwise antagonistic. Therefore the so-called identity measure and identity index were applied instead of similarity measure and similarity index.

Definition: Identity measure of two element sequences:

$$con_e(e_1,e_2)=\begin{cases}1, & \text{if} \quad e_1=e_2\\ 0, & \text{otherwise}\end{cases} \tag{4}$$

Definition: Identity measure of two $s_o=\{o_1,o_2,\ldots,o_n\}$, $s_p=\{p_1,p_2,\ldots,p_n\}$ o_i, $p_j\in\{1,\ldots,n\}$, $\forall i$, $j\in\{1,\ldots,n\}$ sequences can be calculated as follows:

$$con(s_o,s_p)=\frac{1}{n-1}\sum_{i=1}^{n-1}\sum_{j=1}^{n-1} con_e(\{o_i,o_{i+1}\},\{p_j,p_{j+1}\}) \tag{5}$$

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Identity measure of two element seqences is 1 if they are the same, otherwise this value is 0. Identity measure of two longer sequences can be calculated as follows: sequences should be divided into element sequences, compared pairwise the calculated identity measures should be summed and divided with *n*-1 where *n* is the number of elements in the sequence. The value of the identity measure is between 0 and 1.

Identity index can be calculated for *m* sequences. If its value is near 1, this means that users found the targets in similar order.

Definition: Identity index of *m* sequences:

$$I_C=\frac{1}{m(m-1)}\sum_{i=1}^{m}\sum_{\substack{j=1\\ i\neq j}}^{m} con(s_i,s_j)=\frac{2}{m(m-1)}\sum_{i=1}^{m-1}\sum_{j=i+1}^{m} con(s_i,s_j) \tag{6}$$

The value of the identity index is between 0 and 1. If the value is near 0, this means that clicking orders of users differ from each other in a great extent. If the value is high (if it is near 1), this means not only that users found the targets in similar order, but also that there are sequences which occur often thus, which appear more concentrated.

For every worksheet navigation route according to the global strategy and also to the local strategy was determined after users' navigation routes was compared pairwise to these predetermined routes. Identity indexes were calculated in every case. If identity index was smaller than 0.5 in case of both strategies, then we reconed the navigation strategy of the user ad-hoc. In any other cases the strategy was reconed dominant which gave higher value for the identity index.

3. Analysing searching strategies on different kind of user interfaces

3.1 Introducing test programs

In the worksheets of "Geometrical shapes" geometrical shapes (circles, squares and triangles) were placed on the screen. The task was to find all occurrences of a particular shape. (Mátrai, 2006; Mátrai, Kosztyán, Sik-Lányi, 2008a). There were 3 easier worksheets which contained fewer (8-9) objects with 4 targets, and all objects were regular and same hight. In the 4 complicated worksheets each form occurred 7-times, and all forms had different size. Squares were rotated, trianges were rotated and stretched. Worksheets were mirror image or rotated image of each other, but only the positions were mirrored or rotated, the objects were not. Similar worksheets were made with 3-dimensional shapes (sphere, cube, pyramid, torus, and column). Here not only the positions but also the objects were mirrored or rotated. Clicking orders and reaction times were measured (Sik-Lányi, Mátrai, Tarjányi, 2006).

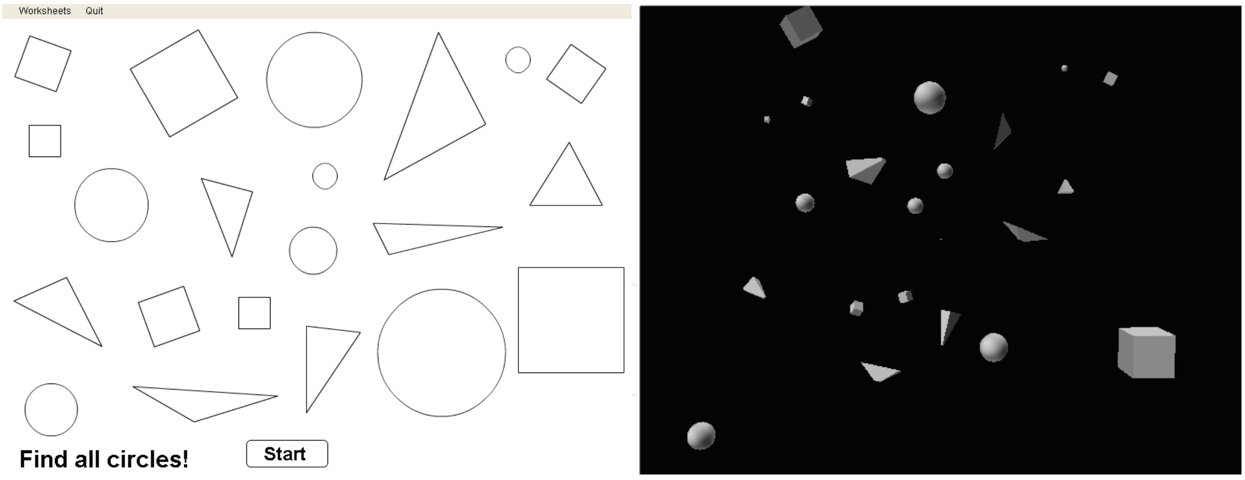

Fig. 1. Finding 2-dimensional and 3-dimensional geometrical shapes

Searching task can be made more interesting if targets are hidden in a picture. How can background image change searching routes and times? Does it help or disturb users in their searching task? Two worksheets were made to analyse this question. In the first one users had to discover 9 birds in a forest, in the other one 15 fish which were hidden not only in the water but also in a tree and in the cloud and behind the sun. Thus, targets were placed also in unusual environments. We wondered whether users search in "logical way" or not. Will they search targets in those places first where they think (according to their knowledge) they should be there or does background not influence their search? If we experiences that background promote search of users with mild intellectual disabilities, then this result can be used in home page or software design, because in this case proper design promote their navigation and decrease searching time (Mátrai, 2006).

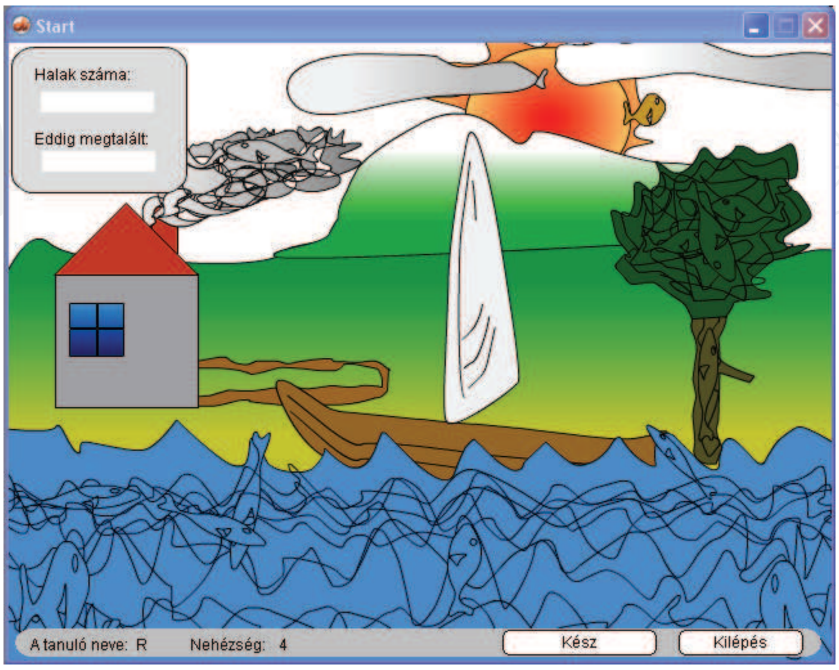

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Fig. 2. a. Finding fish in a picture.

Fig. 2. b. Finding birds in a picture.

The last task contained geometrical shapes: triangles, quadrangles and pentagons, where all occurrences of each particular shape had to be filled with different colours. Thus, not only a simple searching task had to be solved. Users also had to interpret the task. In our everyday information seeking tasks, information has to not only be found but also be interpreted.

Therefore, we expected that important conclusions can be drawn by analysing reaction times and navigation structures, which can be use in textual searching tasks as well. Similarly to the "Geometrical shapes" task, 4 worksheets were made. We analysed whether reaction times and navigation structures between different layouts differ or not, and whether significant differences can be establish between the different groups (Mátrai, 2006).

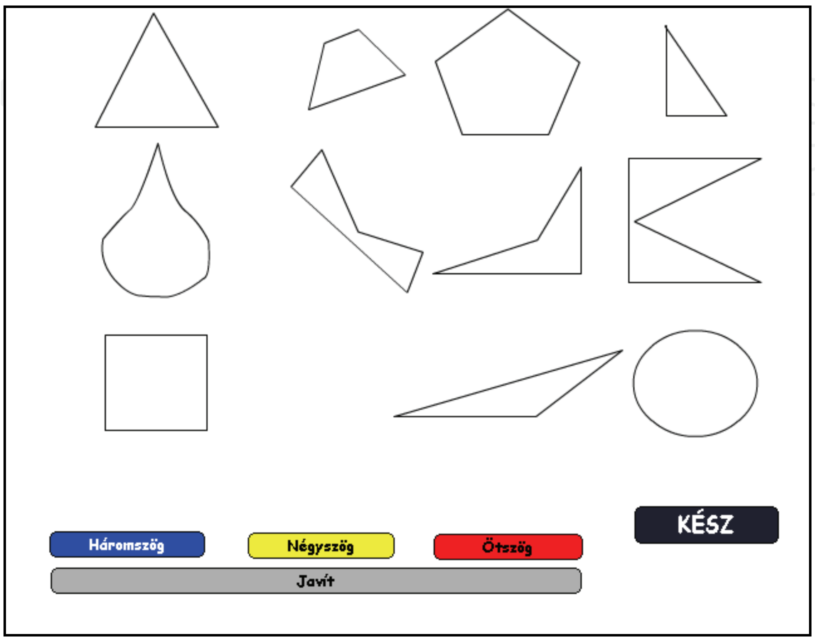

Fig. 3. Colourizing different shapes.

3.2 Participants, devices

In the experiments 120 university students (with age of 21-24), 55 secondary pupils (with age of 13-17), 45 children with mild intellectual disabilities (with age of 10-19) participated. Experiments were made in computer rooms with the control of the teachers during 45-minutes lessons. 17" cathode ray tube monitors were used, viewing distance was approximately 60 cm. Users who participated in the experiments could use the mouse without any difficulties.

4. Results

There were no signifant differences between results of universitiy students and secondary pupils, therefore their results were contracted.

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4.1 Finding geometrical shapes

In case of searching among 2-dimensional geometrical shapes, in a previous study it was established that for simple tasks – when a few (8-9) well-ordered objects were placed on the screen – the observed results closely mathed the global strategy, and searching routes from left to right also dominated. On more crowded and disordered screens search strategies were observed only by normal users (Mátrai, Kosztyán, Sik-Lányi, 2008a).
Position of objects had influential role on navigation by both groups, and strategy from going from left to right predominated even if the targets had to be clicked on. An object which influences the navigation (in our experiment it was the Start button) could guide the

attention to the bottom area temporarily. However, the most difficult objects to find are those in the bottom right section of the screen in that case as well.

In case of users with mild intellectual disabilities, reaction times could be approached with exponential trend best. In case of worksheets where users had to search among 3-dimensional objects, this nonlinear trend between the reaction time and number of targets were observed in a greater extent. In those worksheets, reaction times increased in greater extent by users with mild intellectual disabilities than in the control group. (Sik-Lányi, Mátrai, Tarjányi, 2006).

4.2 Searching figures in a picture

In the first worksheet users had to find all birds in a forest. Although there were birds which looked like a leaf for the first glance, significant differences in clicking orders were not found between the target groups. Both target groups followed local strategy. Navigation strategy of users with mild intellectual disabilities did not become ad-hoc. Moreover, analysing reaction times in function of number of found targets gave also interesting result. Reaction times could be approached with linear trend if the number of found target was not greater than 8 by both target groups. Consequently, the background promoted the searching task of the users with mild intellectual disabilities (Mátrai, 2006). Normal users solved the task in 30 sec, users with mild intellectual disabilities approximately in 90 sec.

By searching fish, ad-hoc strategy was observed in both target groups. Users usually started searching in the water, after that in other parts of the picture. Searching from left to right was observed by both groups but especially by normal users. Users with mild intellectual disabilities found fish outside the water much later than normal users. However, normal users found the fish on the bottom right corner later than the fish behind the cloud or in the smog. It is inferred that the background influence searching by users with mild intellectual disabilities in a greater extent. By normal users, reaction times could be approached with linear trend if the number of found targets were not greater than 8, as in the previous task. But, in case of users with mild intellectual disabilities, the trend is nonlinear. After they found all fish in the water, they needed usually more than 10 seconds to found out to continue searching outside the water – this value is only 2-3 seconds in case of normal users. Normal users solved the task in 42 seconds, users with mild intellectual disabilities in 124 seconds.

4.3 Colourizing different kind of shapes

We discerned "within-object-group" and "between-object-groups" navigation. We analysed navigation strategy in all "object-group" similarly as in the worksheets introduced previously. By analysing "between-object-group" navigation, we examined whether the user clicked the triangles first, after that the squares and for the last the pentagons, and whether they started clickings in the next object group with the object which was the nearest to the previously found object.

Users with mild intellectual disabilities solved the task significantly slower in this case as well. However, reaction times of normal users could be approached by linear trend. Normal users usually followed global strategy; they searched the triangles first, after that the squares and for the last the pentagons systematically. In case of users with mild intellectual disabilities, after they filled all occurrences of a particular shape with colour, they needed few seconds for noticing that they did not finished the task. They often made mistakes as well. They often got confused that they should search more kind of shapes as well.

5. Conclusion

A method was developed with which navigation structures of users can be determined.
With the similarity and identity coefficients two clicking sequences can be compared, with the similarity and identity indexes the concentration of clicking sequences can be determined. With the suggested clicking scale preference map it can be examined which objects were found sooner and which objects were preferred during clickings.
The concepts of navigation graph, navigation structure, navigation and preference map was defined. With the method these graphs, structures, maps can be determined if we know clicking orders. (Mátrai, Kosztyán, Sik-Lányi, 2008b).
The suggested (similarity, identity) coefficients and indexes can be used for characterizing clicking orders widely than rank correlation coefficients in case of comparing clicking orders. The method takes into consideration not only the clicking orders but also the occurrence of element sequences. Not only clicking sequences but also going directions can be determined and characterized. I used these methods for all tasks and compare navigation structures between average users and users with mild intellectual disabilities.
If the number of targets increases then searching strategies will be the followings in case of average users and those with mild intellectual disabilities as well: global, if the number of targets is not greater than 5, local in case of 6-9 targets, ad-hoc in case of 10 or more targets. Local and ad-hoc strategy can occur in case of fewer targets if target size and direction of rotation also change, and/or users have to search 3D-objects.
In case of users with mild intellectual disabilities, if more target properties change (eg. size, direction of rotation, form), then searching strategy became ad-hoc sooner in function of the number of targets than by average users.
Well-designed layout and logical background promote navigation especially of users with mild intellectual disabilities.

6. Future works

The authors continue examinations with tasks where users have to read as well. In this case more cognitive functions take role in the navigation. The effect of font type, font size, fore- and background colours on navigation strategies and searching times will be examined. Navigation on home pages with more column layouts will also be analysed.

7. Acknowledgement

The authors would like to thank the help of Edit Komlósi for correcting the English of this article.

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User Interfaces
Edited by Rita Matrai

ISBN 978-953-307-084-1
Hard cover, 270 pages
Publisher InTech
Published online 01, May, 2010
Published in print edition May, 2010

Designing user interfaces nowadays is indispensably important. A well-designed user interface promotes users to complete their everyday tasks in a great extent, particularly users with special needs. Numerous guidelines have already been developed for designing user interfaces but because of the technical development, new challenges appear continuously, various ways of information seeking, publication and transmit evolve. Computers and mobile devices have roles in all walks of life such as in a simple search of the web, or using professional applications or in distance communication between hearing impaired people. It is important that users can apply the interface easily and the technical parts do not distract their attention from their work. Proper design of user interface can prevent users from several inconveniences, for which this book is a great help.

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In order to correctly reference this scholarly work, feel free to copy and paste the following:

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