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MEASURING WEBSITE USERS' MENTAL MODEL IN NFORMATION SEEKING WITH THE PATHFINDER NETWORK APPROACH

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Abstract: Website users' mental models can greatly affect their behaviors when looking for information. If their mental models closely resemble the interface designer's representation model, the users will have an easier time to accomplish their search task. So it is beneficial to quantify the similarity and differences between users' mental models and the representation model of website designers using the pathfinder network approach. With data gathered from undergraduate seniors (as users) and designers of the website at www.amazon.cn, this research presents the measurement and visualization method of website users' mental models based on pathfinder network in their information seeking process, followed by a discussion on similarity calculation between the users' mental models and the designers' mental model, and corresponding system that implements pathfinder network methods also developed.

Keywords: Pathfinder Network; Information seeking; Mental model; Classification system

1. INTRODUCTION

How to make website users feel the website interface can be understood and discovered ,how to describe website user's mental model by measureable data ,and deal with these data automatically, these becomes important questions. Most of information seeking behavior studies has investigated how mental models influence users' performance and searching behavior. Little attention was paid to measure, compare and visualize the website users' mental models automatically. This study bring forward a mental model measurement algorithm and corresponding software based on Pathfinder Network(PFNET), which not only describe the website users' metal model by PFNET automatically, but also can direct the website interface design by the comparison result with the website designers' mental model. An empirical study with the list of categories of e-business website www.amazon.cn directory to validate our mental model measurement algorithm and corresponding software.

Information seeking is an important human activity for gathering information and building knowledge. In its process, ''information seekers develop and use mental models for a variety of mental and physical objects, including information objects and different domains of knowledge [1].''In cognitive psychology, mental model is an important factor influencing human behaviors. Fodor [2] claimed that mental express is a language for thinking. If we know users' opinions on the essential affinities of a good website, we should be able to help users form correct mental models and consequently develop a site with good usability. Mental models help people understand a system, navigate through the system, and predict the system's behavior in future instances [3]. Norman [4] also applied the concept of mental models to the design of ''everyday things''. Users develop models of a device by ''interpreting its perceived actions and its visible structure''.

In the information seeking fields, research about mental models is expected to inform the design of information systems that are easy to use, intelligent in helping users to form an appropriate understanding of the system, and effective in reducing unnecessary human error [5].Past research about Information seeking mental

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models has mainly focused on a few areas: (a) the characteristics of mental models, such as accuracy and completeness [6][7][8], (b) transfer of mental models between systems [9] and (c) the impact of mental models on individuals' information searching behavior and performance [10][11][12][13]. These studies greatly improved researchers' understanding of the concept of the mental model. However, they produced few readily usable tools for system and user interface (UI) designers, which directly lead to the uncertainty about this concept's theoretical and practical meaning in the application oriented information seeking fields [5].

Mental models have been assessed using various methods including think-aloud and verbal protocols, online protocols, and performance data [14]. Yet Sasse [14] comments that the results of such methods are often problematic because of the restrictive and artificial experimental scenarios, an insufficient range of information collected, and small samples often focused on novice users. As an alternative method, Jonassen [15] suggests that structural knowledge methods can be used to develop representations of mental models. Structural knowledge is understood as “the knowledge of the structure of concepts in a knowledge domain”. Using these methods, concepts, as well as their relations with the others, are represented as a network, which depicts the mental model of the subject concerned. So, how can we measure the structural knowledge?

Pathfinder, which is easily implemented in an instructional setting to measure the development of users’ structural knowledge. Pathfinder is a self-contained set of computer programs that facilitate the elicitation of knowledge structure and provide several tools for assessing that structure. Pathfinder employs paired comparison to elicit judgments of similarity for all possible pairs of a list of concepts. Pathfinder networks are connected graphs where each node represents a concept and the edges represent the relation between the concepts. A weight associated with each edge represents the strength of the relation between the two concepts [16]. Pathfinder networks can be generated using proximity data (i.e., the similarity/dissimilarity, relatedness and psychological distances between concepts) to represent certain aspects of human semantic memory [17]. In the Pathfinder network shown, each node represents understanding of the concepts for the elements of a website interface (such as website category), and the link between two nodes represents a relation between those two concepts. The weight associated with each link represents a psychological distance based on similarity judgments of the users. The larger the distance between two nodes, the more dissimilar are the two concepts. A link weight of one means that the user thought that those two concepts were very closely related [18]. The property of a Pathfinder network to represent certain aspect of the human semantic memory as shown by network can be used to analyze, understand and categorize users’ knowledge structure in the information understanding phase [17]. The representation of knowledge structure as a network to generate the mental models of website developers and users, coupled with the ability of Pathfinder networks to cluster related concepts for categorization forms the basis of the research work reported in this article. In the experiments conducted, these properties of Pathfinder networks were used to categorize requirements, and also used to identify ambiguous, and misunderstood cognitions.

So, the purpose of this study was to design mental model measurement algorithm and tool based on pathfinder network. This study also did an empirical analysis to implement the mental model measurement algorithm and tool on an e-business website. In the remainder of the paper, Section 2 briefly presents Pathfinder based mental model measurement algorithm of website users in the process of information seeking. Section 4 describes the application of the techniques described in Section 3 for creating an online pathfinder network generating system for measuring website users’ mental model, and the application of the system on the e-business website www.amazon.cn, followed by a discussion on similarity calculation between the users’ mental models and the designers’ mental model. At last, the findings conclude with summaries and directions for future work will be shown.

2. PATHFINDER-BASED ALGORITHM FOR WEBSITE USERS' MENTAL MODEL

In website users' information seeking process, related data are needed to describe the mental model of website designers and website users. The generated PFNET is used to analysis the similarity and diversity of understanding the website interface of designers and users. We adopted the similarity of network chart is based on the path range, and the related coefficient is the similarity/dissimilarity measure of these two network charts.

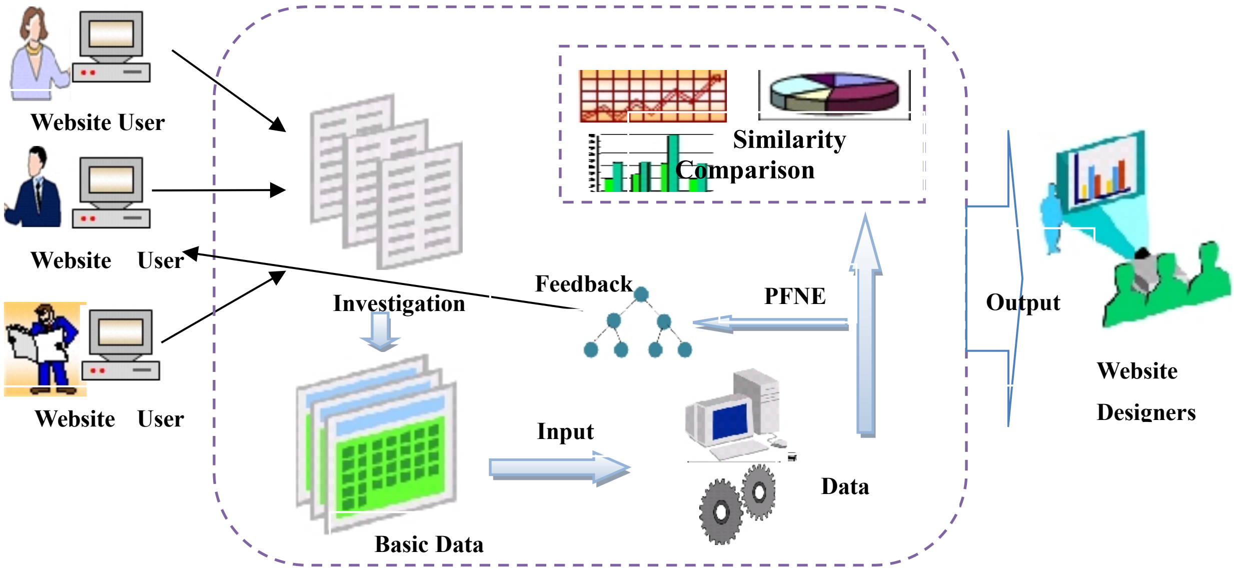

Figure 1. Process of the Pathfinder Network Chart Generalization and Similarity Comparison Tool of Website Users' Mental Model

There are two main goals that the measurement and visualization tool for Website users' mental model needs to achieve (Fig.1). First, it should collect website users' online real-time basic data during their information seeking behavior, and can interact with the users while collecting data. Second, it should analyze the collected basic data and create a data analysis report, which can be a reference for website designers to improve the information structure of the website. The following is the explanation of the specific measuring process and related algorithm.

1) Data collection

The main task of this step is to form an initial weight matrix of users to related notion. In this step, W^{i}_{jk} is the shortest path from node j to node k in the certain i links, which uses matrix W^{i-1}_{jk} to calculate recursively. W^1 is the initial matrix.

2) Confirmation of parameter r and q

Parameter r is Minkowski r-metric, and is used to compute the weight of one path.

$$W(Path) = \left(\sum_{i=1}^{k} w_i^r \right)^{1/r}, r = 1,\dots,\infty. \quad W = \begin{pmatrix} w_{11} & \cdots & \cdots & w_{1n} \\ \cdots & \cdots & w_{ij} & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ w_{n1} & \cdots & \cdots & w_{nn} \end{pmatrix}_{n\times n}, 1 \le i, j \le n \quad \cdots\cdots(1)$$

In formula (1), w_i is the weight of edge i , $Path(e_1, e_2, ..., e_k)$ is a path ,（ w_1 , w_2 ,…, w_k ）are weights of the edges on the path. The legitimate value of the parameter r in the above formula can range from 1 to ∞ .The parameter r affects the path weight significantly. When r is equal to 1, the path weight is the sum of all edge weighs along the path; when r is equal to 2, the path weight is the Euclidean distance calculation of the path weight; and when r is equal to ∞ , the path weight is equal to the maximum edge weight among all involved edge weights.

Parameter q is the upper limit links of the certain path. The goal of this definition is to meet the rule of triangle inequality in the final PFNET, which the up limit of edges of each two indirect connecting nodes is q, all links of PFNET should meet the rule of triangle inequality, and meet Minkowski r-metric. The triangle inequality is:

In formula (1), the effective Value of q can range from 1 to n-1. The associated weights of e_{ab} , e_{bc} ,…, e_{fg} are w_{ab}, w_{bc} ,…, w_{fg} respectively. Parameter m is the path length.

3) Generation of pathfinder network chart

The task of this step is to calculate minimum weight matrix, and create pathfinder network chart. The detail method is to calculate the weights from node 1 to node k (choose the minimum among all valid numbers) which the path-length is i+1. The formula is following:

$$W^{i+1} = W^1 \otimes W^i$$

$$w_{jk}^{i+1} = MIN\left\{\left(\left(w_{j1}\right)^r + \left(w_{1k}^i\right)^r\right)^{1/r}, \ldots, \left(\left(w_{jm}\right)^r + \left(w_{mk}^i\right)^r\right)^{1/r}, \ldots, \left(\left(w_{jn}\right)^r + \left(w_{nk}^i\right)^r\right)^{1/r}\right\}$$

$$m \neq k, m \neq j, 1 \leq m \leq n, 1 \leq i \leq n-1$$

$$D^i = \begin{pmatrix} d_{11}^i & \cdots & \cdots & d_{1n}^i \\ \cdots & \cdots & d_{lk}^i & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ d_{1n}^i & \cdots & \cdots & d_{nn}^i \end{pmatrix}_{n \times n}, 1 \leq l, k \leq n, 1 \leq i \leq n-1 \quad d_{lk}^i = MIN(w_{lk}^1, w_{lk}^2, \ldots, w_{lk}^i), l \neq k \qquad \cdots\cdots(2)$$

In formula (2) W^1 is the original weight matrix W. Parameter n is the number of all nodes in a network. The above two equations are used to calculate the weight of a path when the path length increases by 1. If the path happens to grow in a network, it should consider all possibilities of path growths and select the most economical one. For instance, an existing path with path length i will increases by 1, that is means we need to convert w_i to w_{i+1} and the matrix w_i should to be referenced at first, so we can determine all possibilities for path growth. For weight w_{jk}^i , it be defined the minimum weight of a certain path, which start from point j to point k and the path length is i. We also consider the possible paths with path length i+1 are e_{j1}^1 and e_{1k}^i , e_{j2}^1 and e_{2k}^i, … , e_{jn}^1 and e_{nk}^i if the corresponding e_{jm}^1 exists with the path increasing, if this phenomenon occurred ,we can use the Minkowski r-metric to calculate new path weights for all newly generated paths with path length i+1. And the final step is to select the best (the lowest weight) path from the all newly calculated path weights.

The path-length-i minimum weight matrix w_i (1<=i<=n) is utilized to calculate the path-length-i complete minimum weight matrix D_i. In D_i, the element d_{lk}^i means the weight of a certain path, and the element d_{lk}^i comes from one of a group of paths whose path lengths is 1, 2, 3… i, respectively, and its weight is the lowest one of these paths.

4) Calculation of the similarity coefficient of users' and system designers' pathfinder network chart

In this step, we utilize the similarity comparison algorithm based on distance to calculate the similarity coefficient of website users' and designers' pathfinder network chart.

The basic idea of the similarity definition based on distance is that the possibility of similarity and clustering of adjacent data object are high. We often use Euclidean distance or Manhattan distance to define the similarity of data.

Assume $O = \{X_1, X_2, \ldots, X_n\}$ is a set of object, $X_i = (x_{i1}, x_{i2}, \ldots, x_{it})$,a similarity algorithm based on distance is called 'related coefficient method'. Its main function is to calculate the similarity between two objects in the set of objects. The detail algorithm as follows:

$$r_{ij} = \frac{\sum_{k=1}^{t}\left(x_{ik}-\overline{x_i}\right)\left(x_{jk}-\overline{x_j}\right)}{\sqrt{\sum_{k=1}^{t}\left(x_{ik}-\overline{x_i}\right)^2}\sqrt{\sum_{k=1}^{t}\left(x_{jk}-\overline{x_j}\right)^2}} \quad \cdots\cdots(3)$$

In formula (3), x_{ik} is the element of distance vector X_i, $\overline{x_i}$ is the mean value of all elements of distance vector X_i. In the same way, x_{jk} is the element of distance vector X_j, x_{jk} is the mean value of all elements of distance vector X_i. Related coefficient ranges from -1 to 1, -1 means that the two charts are entirely different. While 1 means it's entirely same of these two charts. Smaller the related coefficient is, lower the similarity between these two charts is. In order to avoid denominator changing to 0, when $\sum_{k=1}^{t}\left(x_{ik}-\overline{x_i}\right)^2$ or $\sum_{k=1}^{t}\left(x_{jk}-\overline{x_j}\right)^2$ equals to 0, related coefficient is set to be 0.

5) Judge the similarity between website users' mental model and website designers' mental model

According to pre-established rules to judge the similarity and diversity between website users' mental model and website designers' mental model. We define the following rules:

(1) If the value of related coefficient is between 0 and 0.4, there is no relationship or very low relationship between two network or nodes;

(2) If the value of related coefficient is between 0.4 and 0.7, there is moderate correlation between them;

(3) If the value of related coefficient is between 0.7 and 1, there is high correlation;

3. EMPIRICAL ANALYSIS

3.1 Participants and settings

We chose website directory of a list of categories as the study object in the empirical analysis, for it's a typical case on the research of website users' information acquisition. Website classification system is a web search tool that makes web information resource as objects, and is established based on the inter-relation of website content and characteristic. It's a high operating frequency tool that people utilized in their website information seeking. We chose closed card sorting method to record users' mental information, and adopted pathfinder network to quantitatively measure the record result.

We selected a Chinese e-business website Amazon.com.cn as the target simulate website to construct simulate circumstance. We used computer technology type books as target classification system. Then we took some representative classes and its subclass goods from each hierarchy to form the classification trees of the standard path. In this experiment, we selected nine concepts (Table 1), and the standard website concept relation path of these 9 concepts (Figure.2), every concept has been labeled by the serial number (Table 1),for example ,the concept "Computer & Network "is labeled serial number 1,which could promote the legibility of pathfinder network. In the part of disposing similarity, we take the 'weight' among concepts as 'mental distance' between two concepts what the participants thought.

Table 1. Experiment concepts

1.Computer & Network	4.Algorithm and Data Structure	7.Database System	10.Distributer System
2.Database design and management	5.Operating system	8.Linux	
3.Data Warehouse	6.Program Language &Software Development	9.Search Engine	

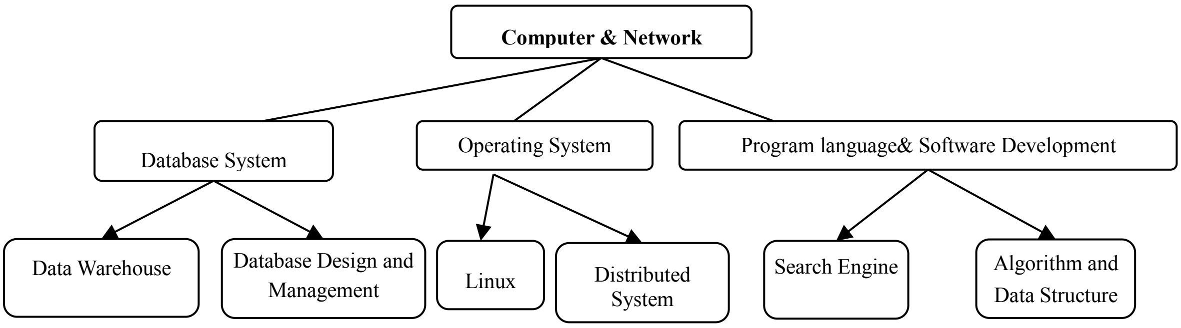

Figure 2. Standard website concept relation path

We create two experiment sample groups. The first group consisted of 147 senior students majored in Information Management, and the second group had 20 website designers. Both group of participants filled in an online questionnaire with computers, based on which we calculated the 'weight' among concepts to get the participants' 'mental distance' between two concepts ,and take the maximum probability data as the calculating data of pathfinder network software after obtaining the sample data.

3.2 Data Analysis

In the research， the weight of each edge is supposed as 1,which means r=1.The category of www.amazon.cn is taken as the standard path, which represents the mental model of website designers, table2 is the upper triangular matrix of website designers' mental model, and it's distance vector is A(2 2 4 1 1 1 2 2 2 2 4 3 3 1 4 4 4 4 3 3 1 4 4 4 3 1 3 4 2 42 2 1 3 1 2 3 1 3 3 3 3 4 2 4). The mean value of all of the elements in distance vector is $\overline{X} = 2.64$. The data of participants' mental models of website category can be resolved using the same method based on the questionnaire analysis. For example, distance vector of a website user's mental model is B：(2 2 1 1 1 1 2 1 2 2 2 3 3 1 4 3 4 3 3 3 1 4 3 4 2223 2 32 2 1 2 1 2 3 2 3 3 2 3 3 2 3).

So, the distance vector of designers' and a participant's mental model of website mental model can be resolved in formula.

$$\frac{\sum (X-\overline{X})(Y-\overline{Y})}{\sqrt{\sum (X-\overline{X})^2 \sum (Y-\overline{Y})^2}} \quad \cdots\cdots(4)$$

Correlation coefficient of each node between website designers and a participant can be calculated. Finally, the global correlation coefficient can be generated whose value is 0.814 (table4). Based this result, we can conclude that there is a great similarity between the understanding of category between the website users and designers. The next, experiment data of each participant can be resolved by this method, and maximum probability of all the participants is taken as the final data of website users, which is used to comparative analysis with that of website designers in the algorithm of pathfinder network.

3.3 Findings

The result data (parameter r=∞, q=n-1, n=10 in this experiment) after the process of PFNET algorithm are shown in tables 3 and table4. The processed pathfinder network charts are shown in figure3 and figure4. According to the similarity judging rules, the PFNET network chart related coefficient between users group and website designers group is 0.31, which lies between the 'similarity and diversity' decision rule of 0 to 0.4 we have set. It belongs to the category of really low similarity, which means that the difference between designers' and users' mental model is really low. Meanwhile, it declares that the representation model of the website classification system does not match this kind users' mental model well. So it also means that we need to optimize the design of the website classification system.

Table 3. Website users' PFNET matrix

Column	Computer & Network	Database System	Database design and management	Data Warehouse	Program Language & Software Development	Algorithm and Data Structure	Search Engine	Operating System	Linux	Distributed System
Computer & Network	0	1	0	0	1	0	0	1	0	0
Database System	1	0	1	1	0	0	0	0	0	0
Database design and management	0	1	0	0	0	0	0	0	0	0
Data Warehouse	0	1	0	0	0	0	0	0	0	0
Program Language & Software Development	1	0	0	0	0	1	1	0	0	0
Algorithm and Data Structure	0	0	0	0	1	0	0	0	0	0
Search Engine	0	0	0	0	1	0	0	0	0	0
Operating System	1	0	0	0	0	0	0	0	1	1
Linux	0	0	0	0	0	0	0	1	0	0
Distributed System	0	0	0	0	0	0	0	1	0	0

Table 4. Website designers' PFNET matrix

Column	Computer & Network	Database System	Database design and management	Data Warehouse	Program Language & Software Development	Algorithm and Data Structure	Search Engine	Operating System	Linux	Distributed System
Computer & Network	0	2.2	0	0	0	1.6	0	0	0	0
Database System	2.2	0	0	1	2.2	0	2.2	0	0	0
Database design and management	0	0	0	0	1.3	0	0	0	0	0
Data Warehouse	0	1	0	0	0	0	0	0	0	0
Program Language & Software Development	0	2.2	1.3	0	0	0	1	0	0	0
Algorithm and Data Structure	1.6	0	0	0	0	0	0	0	0	0
Search Engine	0	2.2	0	0	1	0	0	0	2.1	0
Operating System	0	0	0	0	0	0	0	0	0	2.1
Linux	0	0	0	0	0	0	2.1	0	0	1.4
Distributed System	0	0	0	0	0	0	0	2.1	1.4	0

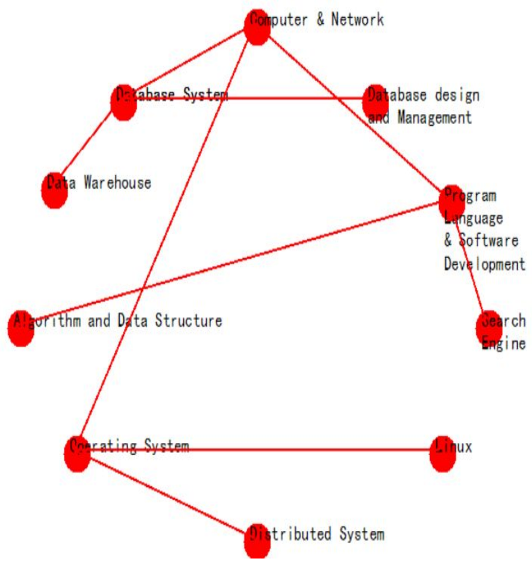

Figure 3. Website users' PFNET chart

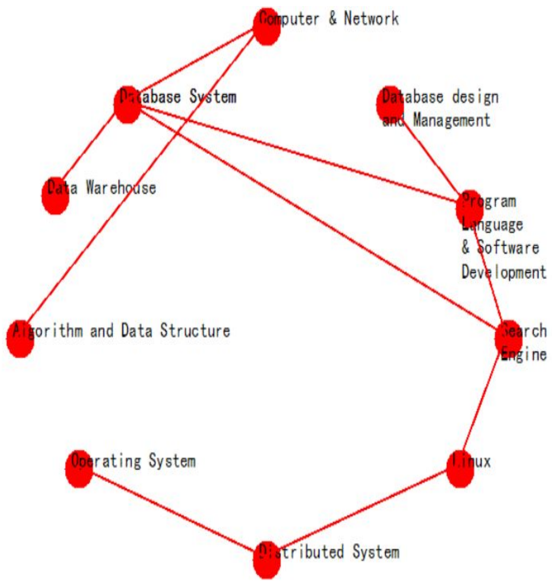

Figure 4. Website designers' PFNET network chart

4. DISCUSSION

At present, the contradiction between the improvement of website construction and the fall back of users' information seeking stands out. How to make users feel the website interface can be understood and discovered ,how to describe user's mental model by measureable data ,and deal with these data automatically, these becomes important questions. This is an urgent key issue that should be resolved during the construction of websites. Only after understanding the internal and cognitive model-mental model which decides users' information seeking behavior, can we understand users' cognition to the website interface and know clearly users' behavior decision-making inner emotions and principles. After that, we can provide theoretical foundations for website interface expression, online & off-line service design and improvement with a purpose. Furthermore, we can explore improving methods for users' information seeking from website interface design.

The statistically finding of this study is that website users' mental model during information seeking can be measured and compared with the website designers' mental model based the PFNET, and corresponding algorithm and software tools can be designed for the standpoint of mental model measurement and comparison.

This study consistent with and validate previous pathfinder research of effective study [15], similarity measurement study based on pathfinder[18], Knowledge Network Organizing Tool study based on pathfinder (KNOT), grades study to sustain the validity of pathfinder method[19][20], knowledge structure represent study[21].

This study also provides practical insights for those who design and develop the website interface based on website users' cognition. The website designers need to think about ways of optimization design for preventing users from getting lost in searching the website. A practical suggestion for the website designers is to make conceptual description clearly available on the interface, which mental model measurement algorithm and software can be designer based on PFNET, to get and deal with the behavior data that represents users' mental model online, and compare that of website designers automatically.

5. CONCLUSIONS AND FUTURE WORK

Mental model studies are increasingly common on the website users' information seeking. However, little measurement algorithm and software research has been done to systematically investigate user's mental models. Most of these studies investigate how mental models influence users' performance and searching behavior in interactive systems. Little attention was paid to measure, compare and visualize the website users' mental models automatically, and combine the measurement result with the website interface design, furthermore, a path that connect the research of users' behavior and website construct is especially want. We strongly believe it's not the end for website to gain user's mental model, but it's the start for the optimization design of website designers. In response to this need, this study bring forward the mental model measurement algorithm and corresponding software based on PFNET, which not only describe the website users' metal model by PFNET automatically, but also can direct the website interface design by the comparison result with the website designers' mental model.

In conclusion, as an exploratory study at the intersection of information seeking and mental model, this research bring forward the mental model measurement algorithm and corresponding system based on PFNET for website users. The research findings make a contribution to method and empirical knowledge on how to measure website users' mental model and compare with website designers' mental model automatically ,which can help the optimization design of website designers according users' experience. In future research, we will conduct the following topics:

(1) Validity examination of the algorithm. In the similarity comparison of PFNET, we use 'weight' to express 'mental distance' to compare similarity. How to check the validity of these measuring result, and is it reasonable about the set of 'similarity and diversity rules'?

(2) Dynamic measurement of website users' mental models. Users' mental models are tested, changed and developed with the interaction of external environment. How can we continue the measurement and simulation during the process of users' information seeking on the website and the 'relevance' and the 'spatiality' of users' cognitive concepts?

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