AN INTERACTIVE INFORMATION SEEKING INTERFACE FOR EXPLORATORY SEARCH

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Abstract: As the Web has become a commodity, it is used for a variety of purposes and tasks that may require a great deal of cognitive efforts. However, most search engines developed for the Web provide users with only searching and browsing capabilities, leaving all the burdens of manipulating information objects to the users. In this paper, we focus on an exploratory search task and propose a framework for human-Web interactions. Based on the framework, we designed and implemented a new information seeking interface that helps users reduce cognitive burdens. The new human-Web interface provides a personal workspace that can be created and manipulated cooperatively with the system, which helps users conceptualize their information seeking tasks and record their trails for future uses. This interaction tool has been tested for its efficacy as an aid for an exploratory search.

1 INTRODUCTION

For a traditional Web search engine, the process of querying and viewing the search result is usually regarded as a single isolated session that ends in itself. As the Web has become a commodity, however, it is used for a variety of tasks in many different ways, encouraging new paradigms in information seeking (e.g. berrypicking (Bates, 1989), information foraging (Pirolli and Card 1995), and sense-making (Russel et al., 1993)). However, most popular commercial search engines have taken a conservative position and adhered to the traditional model, leaving all the rest of the information seeking and related tasks to users. More specifically, a user would have all the burdens of manipulating the information objects that have come to his attention in a series of search activities.

An area in which this type of cognitive burden affects significantly is exploratory search. An exploratory search task (Marchionini, 2006; White and Drucker, 2007) is to investigate on the background information of a topic or gather information sufficient to make an informed decision. For example, assume that a user is considering purchasing a DMB (digital multimedia broadcasting) receiver. The user would want to learn more about the DMB technology and the manufacturers of various products related to it, so that he can select the vendor and the product that best suit the needs. We argue that most existing search engines and their interfaces are not satisfactory for exploratory search tasks because of the following.

1. Cognitive burdens: Compared to the task of searching for a specific or known item, an exploratory search task usually requires users to send a series of queries during a search session, visit new domains, and revisit previously visited sites (especially branch pages) (White and Drucker, 2007). These activities together mean a significant amount of information and workload to be handled by the user, which traditional search engines have rarely attempted to reduce. The workload is associated with representing information needs (Taylor, 1968), determining informativeness (Teevan et al., 2004), and memorizing previously explored information (Cockburn, 2001). Without explicit support from a search engine, the difficulties resulting from the workload are left as a cognitive burden to the user.
2. Narrow interaction channel for incorporating user interests: In an exploratory search, a user needs to build up background information on a topic gradually until she feels that a sufficient amount of information has been gathered for the given task. As such, it is important to remember which information items have drawn the user's

attention as the system processes the current query. However, current search systems rarely support the notion of "session" and interactions explicitly. While the one-time query/result model is simple and natural with HTTP, it ignores what has been done by the user in an attempt to change her anomalous state of knowledge (Belkin, 1980). Although there have been some attempts to infer user interests explicitly (George et al., 2002; Martin and Jose, 2004; Harper and Kelly, 2006), implicitly (Shen et al., 2005), or both (Zigoris and Zhang, 2006), the problem remains challenging, especially within the context of user-system interactions.

Given the limitations of traditional search engines for an open-ended, exploratory search task, we propose a new interaction tool that can provide an interface between a user and a search engine, called *sketchBrain*. Our aim is to provide an effective interaction environment that facilitates the series of activities in an exploratory search of the Web.

There are several noble features in this interaction environment. First of all, *sketchBrain* keeps track of query trails and post-query navigation trails (based on the click streams following the issued queries) and allows the users to conceptualize them. For an information seeking activity, a trail is sketched on the user's workspace of *sketchBrain*. Over the trail, the user can associate user-defined topics and system-provided semantic associations between topics using the annotation facility in *sketchBrain*. These annotations together with the information items and queries are key objects in the underlying model. In essence, the workspace serves as a rich memory for the past and current search efforts, which can be accessed later.

Second, our interaction tool is equipped with operations on the objects created and manipulated in the workspace. In addition to the annotation facility, *sketchBrain* allows users to manipulate the objects for their information seeking tasks. Implicit operations such as *project*, *select*, *and classification* (to be described in Section 3.1) can be utilized for the activities necessary for an exploratory search.

Third, *sketchBrain* has an intelligent path recommendation algorithm that can help users choose the most promising page to be explored at the next step in navigation. It assists users in quickly determining informativeness of the pages that can be explored at the next step. Fig. 1 shows all the suggested pages whose colours are on the spectrum between yellow and red. The user is currently visiting the page regarding "Microsoft Windows," the blue node, and about to choose one from the available paths surrounding the node representing the current visit. The degree of relevance is determined by the algorithm and is shown in various colours (red indicates the most relevant one).

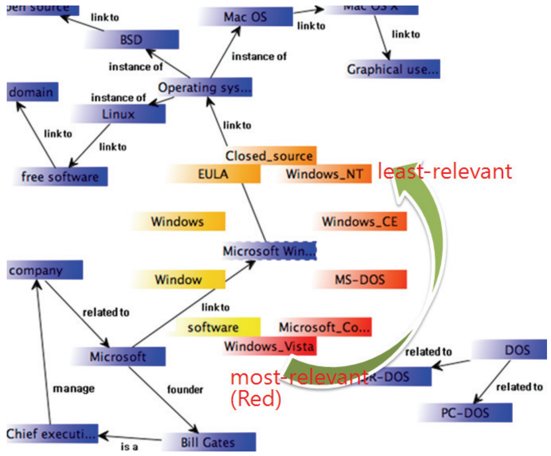


Figure 1: An example screen shot of *sketchBrain.*

This new interactive tool, *sketchBrain*, is based on an underlying interaction model, called two-level model. It is based on the recognition that two spaces are involved in human-Web interactions: information space and knowledge space. The information space is essentially the Web itself, containing the information objects (e.g. Web pages), whereas the knowledge space is superimposed on the information space to contain a user's conceptual understanding of information objects and their relations. Concepts in the user's mind, emerged by reading Web pages at the information level, are expressed as *topics* and their *associations* (or relationships) in the knowledge space. Topics are also connected to information objects (called *occurrences*) on the information space, which can be seen as a manifestation of the topics. For convenience, an occurrence can be of any granularity, such as a page, a figure, or a phrase. The connection between a topic and an occurrence provides a way to establish a link between the two spaces.

The three terms, topics, associations, and occurrences, are borrowed from the Topic Maps framework (ISO/IEC 13250). In our information seeking interface, implicit knowledge-level operations usually performed in user's mind can be explicated and automated to help reducing user's cognitive burdens. In essence, interactions between the user and the system enabled by the two-level model occur at the knowledge level and across the two levels, in addition to the searching and browsing operations of traditional search engines that occur at the information level.

In *sketchBrain*, our path recommendation algorithm supports a guided navigation for a successful completion of a certain information seeking task. Previous approaches to guided navigation (Joachims et al., 1997; Olston and Chi, 2003) keep track of and utilize previous users' browsing behaviours and queries. Although they propose good ways to suggest paths that match the inferred task on a specific point, they have utilized relatively noisy information such as all previous queries and pages visited. Our approach for supporting guided navigation utilizes both explicit and implicit feedback from the workspace in *sketchBrain*. All the supports are geared toward exploratory search tasks.

The remainder of this paper describes some related work (Section 2), the interaction framework for supporting an exploratory search task (Section 3), and empirical evaluations (Section 4)

2 RELATED WORK

Various information seeking interfaces have been proposed to support complex information seeking activities. Sketchtrieve (Hendry and Harper, 1997) employs Cognitive Dimension Framework to map out the design space and provides an unstructured canvas. In this canvas, searchers can freely represent queries and corresponding search results with an intuitive interface by using typographic and layout cues that lie outside of a formal notation. George et al. (2002) introduces information seeking workspace called Garnet. They exploit implicit knowledge that can be discovered from the contents in the workspace and try to find direct connections between the workspace and digital libraries. They utilize spatial parsing to extract profiles of documents and use them to learn a lexical classifier. This classifier is to identify newly searched documents that are relevant to each parsed cluster. Martin and Jose (2004) suggest a personal information retrieval tool that employs a folder-like structure, so that searchers can bundle search results into folders. In addition to the interface that searchers can freely organize results, it assists query formulation and recommends hot relevant documents to each folder. Harper and Kelly (2006) employ a topical structure for relevance feedback. Their interface allows users to save documents in user-defined piles for similar documents, which could be used for relevance feedback. These approaches suggest new information seeking environments with some assistance. However, their design goals are not to support exploratory search explicitly, and the systems were not tested as such. Our interface provides users with a cooperative workspace and a proactive assistance, explicitly aiming at exploratory searching tasks.

3 INTERACTION FRAMEWORK

We have designed an interaction framework for *sketchBrain* and implemented a prototype system that includes a search engine and the interaction tool, capturing the key ideas of the two-level model described below. *sketchBrain* is implemented with an open source graphics library (http://www.jgraph.com/) in Java, which we extended for our purposes.

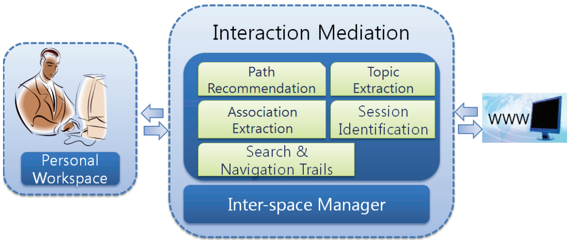


Figure 2: *sketchBrain* interaction framework.

As in Fig. 2, the framework connects users with the Web through Interaction Mediation. On the user's side is a virtual workspace, and the Web side is assumed to have a conventional search engine and browsing facilities. When the user searches/navigates the Web and attempts to make informed decisions based on the information found, Interaction Mediation provides a support with the goal of relieving his cognitive burden in the information seeking process. It consists of various tools that facilitate users' information seeking activities in terms of searching and browsing and work space creation/manipulation. Inter-space Manager associates trails and user's reification of them with raw information in the Web and provides facilities to manipulate them. A detailed description of the components for Interaction Mediation is given in Section 3.2.2.

3.1 The Underlying Model

Our interaction tool and user interface are based on our two-level model that explicates information and knowledge spaces where user information seeking activities take place. Fig. 3 depicts a conceptual view of the underlying model and the relationship between the information and knowledge spaces and the operations. We attempt to split users' conceptual work space into two levels and define operations on each space and inter-space operations (see Park et al. (2007) for details). The set of operations in Fig. 3 is by no means complete, and we intend to expand it as additional needs arise.

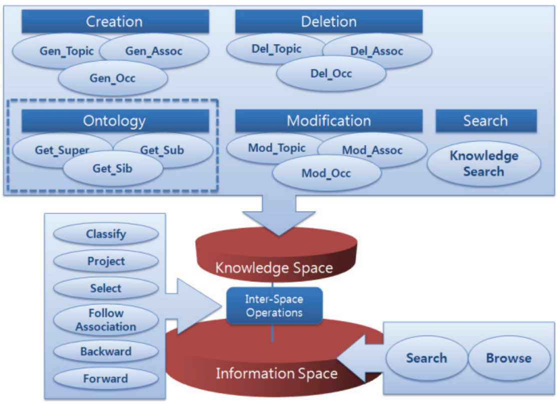


Figure 3: A conceptual view of the two-level model.

3.2 Interaction Framework Components

3.2.1 Personal Workspace

A screenshot for the user interface of *sketchBrain* is shown in Fig. 4. On the left is the user workspace where three workflows are sketched as indicated by (1).

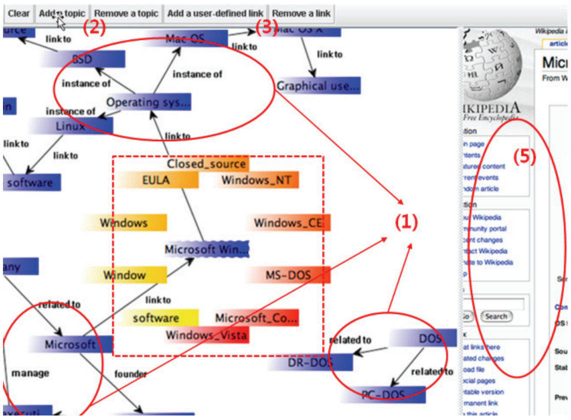


Figure 4: A snapshot of the *sketchBrain* user interface.

Using this tool, a sequence of queries and search results and their relationships can be recorded as much as the user wishes to remember for future use. In effect, the network of topics and associations expresses her own conceptual understanding of the search results (e.g. creating a user-defined topic using (2) or associating topic nodes using a semantic association using (3)). In other words, our interactive workspace keeps track of previous interactions such as queries, browsed pages, and their relations to help users create own knowledge space. Using this knowledge space, the system can show what the user previously has seen and accessed and the reasons why she approached to them. In addition to this feature, our system can provide the relevant context of a specific page (like the one pointed by (5)) through time-variant multiple spreading activations, which can be used as a guidance for further navigation. The degree of relevance is determined by the algorithm and is shown in various colours (red indicates the most relevant one).

3.2.2 Interaction Mediation

Path Recommendation (Time-variant Multiple Spreading Action). Spreading Activation is a well-known information access technique in associative networks. In this paper, we utilize Time-variant Multiple Spreading Activation (TMSA) to recommend the best relevant path from a certain page. In order to analyze the current interest of an exploratory searcher, our algorithm introduces a new constraint and procedure.

Let us define

Target Network = *(N, E)*

where N is a set of nodes with $N \in \{N_{personal\_workspace} \cup N_{web\_topology}\}$ and E is a set of edges, $E \in \{E_{personal\_workspace} \cup E_{web\_topology}\}$

A target of TMSA is an integration of Web topology and personal workspace. Because our workspace refers to Web pages, the result from the integration can be regarded as a single network. Given the network, we define the iterative activation procedure as follows:

$$A_i^{(t+1)} = \frac{1}{\sum_i \sum_j w_{ji}} \cdot \sum_j \frac{\alpha \cdot w_{ji} \cdot S_j^{(t)}}{\sum_k w_{kj}} \qquad (1)$$

$$S_i^{(t+1)} = T_i \cdot A_i^{(1)} + A_i^{(t)} \qquad (2)$$

where $A_i^{(t)}$= activation level on node *i* at time *t*,
$S_i^{(t)}$= spreading energy on node *i* at time *t*,
α = decaying factor, and
w_{ji} = association strength between node *j* and node *i*

In our network, each node *i* has an activation level $A_i^{(t)}$ and a spreading energy $S_i^{(t)}$ at time *t*. Each activation level computed as in Equation (1) is determined by the spreading energy of adjacent nodes. When adjacent spreading energy is summed, the association strength between node *j* and node *i*, w_{ji} , is multiplied. This specifies how much adjacent spreading energy influences node *i*. The amount of spreading energy is determined by Equation (2) where $A_i^{(1)}$ represents the initial activation level on node *i,* and has a value when the user previously has interacted with the node. In other words, it has a value when it is from the personal workspace. T_i is a time decaying function and relieves its effects from the time when it first interacted. Other constraints will be described in the experimental settings (See sections 4.1.1.)

Search & Navigation Trails. Some past applications (e.g. Google Notebook, Yahoo Myweb, and Pathway) attempted to keep track of search or navigation trails and showed their usefulness. *sketchBrain* also keeps track of *query trails* and *post-query navigation trails*, which are based on click streams following issued queries. As in figures 5 and 6, search queries and post-navigations are sketched in the workspace of *sketchBrain*. Using the JDIC (JDesktop Integration Components) library, *sketchBrain* gets action events and shows them in our workspace.

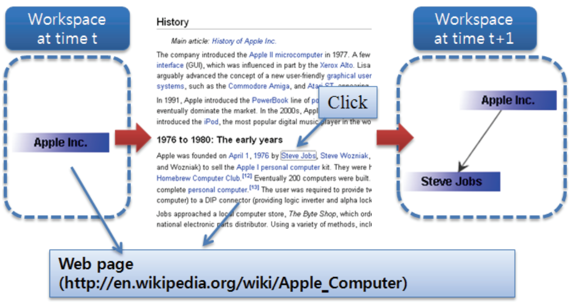


Figure 5: A snapshot of the navigation trails.

Figure 6: A snapshot of the query trails.

Other Components. In the current implementation, there are four components that are not as fully developed as the other four introduced already. They are Topic Extractor, Association Agent, Session Identification, Interspace Manager. (1) Topic Extractor creates a topic from an information object when the user wants to record the information object as an occurrence for a future use. (2) Association Agent automatically generates and suggests an association between two topics the user is interested in. (3) Session Identification is to automatically discover different session boundaries (4) Inter-space Manager is responsible for the operations whose domains and ranges are across the two spaces. Although more complete development of these components would provide added functionality and make the interface more amenable for an exploratory search, the lack of the full functionality does not invalidate the main goal of reducing cognitive burden in an exploratory search task through Interaction Mediation, as proved by the experiments in Section 4. It simply means that users need to do some work manually or semi-automatically.

4 EXPERIMENTS

We tested our approach in three different ways. In Subsection 4.1, we report our evaluation of the guided navigation method as a component of the interaction tool. The next subsection describes our experiment on whether the proposed tool helps reducing users' workload (i.e. cognitive burdens) in exploratory search tasks, the primary motivation for devising the proposed method. In Subsection 6.3, we show how the proposed tool helps users in performing tasks that require organizing and remembering the results from searching and browsing. The second experiment in 4.2 was based on users' subjective opinions whereas the third one in 4.3 attempts to use objective measures.

Wikipedia was selected as a test environment for the second experiment where exploratory searching was the main task. We chose Wikipedia instead of the entire Web because it provided us with a somewhat controlled environment for topic and association generations. It contains a reasonably large number of encyclopedia articles and covers a very wide range of subject areas, providing a suitable environment where exploratory searches can take place.

4.1 Guided Navigation

This experiment was to find out whether our automatic guided navigation method would help users' information seeking tasks in general. It was targeted at our guided navigation's utility in terms of effectiveness by measuring recommendation relevance. The participants manually evaluated relevance of paths ranked among the top 10.

4.1.1 Constraints

For reasonable performance, we set constraints of TMSA to best suit the characteristics of Wikipedia. We defined the association strength, w_{ji} as:

$$w_{ji} = \tau_i \cdot \varepsilon_i \cdot p_{(j\to i)} \qquad (3)$$

where ε_i = user-participation constraint
τ_i = fan-out constraint
$p_{(j\to i)}$ = path constraint from node j to node i

These three constraints are dependent on the characteristics of the network. The detailed descriptions for the constraints are given below.

Fan-out Constraint. Nodes with a large branching factor, which are connected to many others, may be bypassed or have a penalty in the activation process. Since Wikipedia we used as the testing environment has the properties of a scale-free network, the nodes follow power-law degree distribution, $p(k)\sim k^{-\gamma}$ like other scale-free networks. We employ this distribution as a fan-out constraint.

Path Constraint. There may exist several different kinds of links in a network that spread activations. This constraint discriminates preferred paths from others. In a semantic network, it gives preference to meaningful links. In our algorithm, user-defined paths are deemed more important.

User Participation Constraint. An online social network like Wikipedia collectively facilitates the spread of ideas. As a result, it is critical to record how the network has evolved over time and which users have participated in the spread of ideas. As a way to be sensitive to this nature of Wikipedia and take advantage of it for our tool, we decided to utilize user participation as a constraint to be considered for spreading activation, with two variables, 'fad' and 'stickiness'. *Fad* refers to a fashion that become popular in a culture relatively quickly but loses popularity dramatically.

$$v_i = (stickiness_i, fad_i) \qquad (4)$$

where

$$stickiness = \frac{1}{N_{user}} \cdot \sum_{N_{user}} \frac{t_{last-edited} - t_{first-edited}}{t_{current} - t_{first-edited}},$$

fad = the number of in-links,
N_{user} is the number of users,
$t_{current}$ is current time,
$t_{first-edited}$ is time when it was first edited,
$t_{last-edited}$ is time when it was last edited

The value for the user-participation constraint on node i, ε_i, is computed by summation of cosine similarity values between recently visited articles' vector v_j and itself.

$$\varepsilon_i = \textstyle\sum_j cosine.similarity(v_i\, v_j) \qquad (5)$$

Each vector v has two dimensions with the two components, *stickiness* and *fad*.

4.1.2 Experimental Design and Result

We asked participants to evaluate how helpful it was to use our tool based on Time-variant Multiple Spreading Activation (TMSA). The participants were divided into three groups: the first with our time-variant spreading activation algorithm, the second with a method based on TF-IDF using the latest query, and the third with random recommendations. The participants formulated their own search queries and got engaged in browsing. Their tasks were to find relevant homepages given a broad question. The task is similar to Topic Distillation Task in TREC 2003 Web track. We allocated the need underlying the question like "Korean IT industry" to the participants who had to find a list of related homepages, not any pages about the questions, which provide credible information on the query topic.

In the course of finding relevant homepages, the participants often had to get engaged in navigation, at which time the system made recommendations. The participants were asked to evaluate the recommended paths within top 10 for their relevance. The average number of links (including internal links, external links, redirects, and binaries) in articles that participants had visited was 38.9. Each of the five participants performed six tasks, and the total number of browsing actions was 112. Table 1 shows the results that compares three different methods.

Table 1: The Result of the first experiment.

	TMSA	TF/IDF	Random
Accuracy for Relevance	72.78%	57 %	33.4%

It clearly shows that our method based on TMSA outperformed the other two methods. Moreover, the absolute value for accuracy is very promising.

4.2 Reducing Workload

Our second interest was to find out whether the system based on the two-level model would help reducing workload of users. Given the motivations of our work, workload is a reasonable measurement to test the tool's efficacy because it measures how much effort is required to complete an exploratory search task. In this experiment, we used a special instrument, subjective workload assessment technique (SWAT) (Reid and Nygren, 1988). This method has been utilized for evaluating three criteria: time, mental effort, and stress.

We asked the participants to perform a total of 10 exploratory search tasks in the Wikipedia environment where the articles contributed by experts around the world were judged to be sufficient for learning background and detailed information for exploratory search tasks. In this experiment, we utilized a simple English Wikipedia (http://simple.wikipedia.org/wiki/Wikipedia:Simple_English_Wikipedia), and evaluated the efficacy of our information seeking interface as an aid to exploratory searches. Each task has one topic selected from the topics of 10 different Wikipedia categories. This topic classification scheme uses nine shared categories for all Wikipedia articles (http://en.wikipedia.org/wiki/Wikipedia:Requested_articles#Other_classification_schemes.) During the experiments, each participant performed semantic annotation (Jijkoun and de Rijke, 2006) (e.g. "listing of important people" and "specifying categories of at least five important entities"), and summarizing the content of Wikipedia articles (e.g. answering non-factoid questions such as "writing a state of the art" and "writing important background information"). For a more realistic exploratory search environment, in semantic annotation, we provided blank forms that they had to fill out. To minimize potential biases like learning effects, the participants applied two methods, with and without the interface, in an alternating fashion.

Table 2: The result of SWAT.

	with interface (Average SD)	without interface (Average SD)
Time	1.6 (0.55)	1.8 (0.45)
Mental effort	1.2 (0.45)	2.4 (0.55)
Stress	1.8 (0.45)	2.2 (0.45)
Total	4.6 (0.89)	6.4 (0.89)

The participants' rates of SWAT range between 1 (the best) and 3, and the result of workload analysis are presented in Table 2. Our interface received a mean score of 4.6, which is a significant improvement over the case without the interface. In particular, the difference was the greatest for mental efforts as intended and expected for the interface. These observations showed that our new information seeking interface helped reducing workload in three different ways in the exploratory search tasks.

4.3 Information Reuse

Since our two-level model and its manifestation as a tool were devised to help users reducing cognitive efforts in information seeking processes, typically consisting of searching and browsing activities, we decided to focus on information reuse activities in information seeking. In the Web environment, users often have to skim through an overwhelming amount of information, suffering from information overload, before their goals are achieved. Our experiment is an exploratory study designed to investigate whether our tool helps users in organizing, remembering, and reusing the information that has been encountered. Our tool was compared against two other systems designed for the same purpose: the Favorites tool in the Web browsers and the Stuff I've Seen (SIS) system (Dumais et al., 2003). The Favorites tool (or book mark tool) was found to be useful for PVR (Post-valued Recall) (Wen, 2003) and SIS was developed to search the information that has been seen in the past.

4.3.1 Experimental Design

The three methods, the Favorites tool, SIS, and our knowledge space tool, were compared in six different tasks by ten groups of users, each consisting of three undergraduate students. In total, 30 users were employed for six different tasks using three different methods. Each task consists of five questions and the six tasks are in six different domains like Medicine and Sports. The tasks were designed as follows. For a task, the participants (users) were first asked to read 30 pre-selected Web pages. One minute per page was given to simulate an information skimming situation. The participants were then asked to organize the pages using the given tool within one minute. After the preparation stage, they were given three information hunting questions elicited from the 30 pages they read, such as "Name the two new members to the Board of Directors of Good Samaritan Hospital in New York." The participants were timed for completion of each question answering. Since the maximum time given to each question was five minutes, the time taken for an unsolved question was assumed to be solved in five minutes, the maximum. In order to minimize user dependency and learning effects, the users were assigned to six tasks using three different methods in an alternating fashion (see Fig. 7). Each user evaluated each method twice for different tasks, and each task was given to the three users in an effort to minimize user dependency. Three users used the three methods in different sequences for different tasks so that there is little learning effect on average.

	T_1			T_2			T_3			T_4			T_5			T_6		
	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
U_1	O				O				O	O				O				O
U_2		O				O	O				O				O	O		
U_3			O	O				O				O	O				O	

T: Task, M: Method, U: User

Figure 7: Experimental design for each group.

To ensure that every participant has some familiarity with the three tools, we gave them a tutorial with 10 minutes of practice sessions in the same place with all the participants together. Following is a brief description of the other two methods compared against our knowledge space tool.

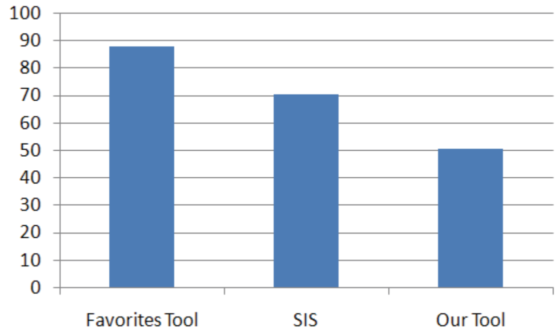
The Favorites tool is often used to save visited pages for future references. A user can create folders and put a page to be remembered into a folder. Folders are like topics in our tool and can be organized in a hierarchy. Most browsers are equipped with this tool.

SIS was developed to facilitate information reuse for various information resources. It provides the capabilities of fast unified indexing of various files in a desktop and of filtering files based on queries, file types, and time. It is now available on the Windows desktop.

4.3.2 Result and Analysis

The time measures collected for individual users for all the tasks were averaged to see the difference among the three methods. Since there were ten groups, each consisting of three participants, and six tasks performed with each tool, a total of 180 data was averaged for each tool. Each data point is for a task consisting of three questions solved by a participant using one of the tools.

The comparison result is shown in Fig. 8. It took about 50 seconds on average to solve the problems using our tool, but 88 (about 76% longer) and 70 seconds (about 40% longer) using the Favorites tool and SIS, respectively. Using SIS that has the extended search functions only, participants often produced no answer within the time limit because the pages were not pre-organized in their own ways. Although SIS didn't require any extra user efforts to organize the pages, the time spent on the organization was only one minute, once for all the tasks. If the initial investment for our tool had been spread across all the questions, the extra time spent would have been very small.



Unit: seconds

Figure 8: Comparison for task completion time.

The comparison data for different tasks in Fig. 9 are even more encouraging in that our tool outperforms the Favorites tool for all the tasks and SIS for all but one case (task 1). Task 1 was easy for SIS because a search query with a proper noun can easily retrieve the relevant page but not so easy for our tool because the proper nouns were not used as topics.

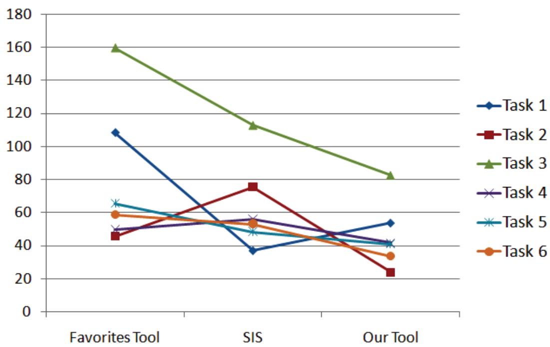


Figure 9: Comparison by different tasks.

Our further analysis of the experimental results revealed relative advantages and disadvantages of the three methods for the given tasks. The Favorites tool is easy and efficient to use in organizing pages in a hierarchical way, but makes it rather difficult to look for specific information. In a shallow hierarchy, the granularity level is usually too high to pinpoint a folder that may contain the information. When it is deep or skewed with a deep branch, it would be time-consuming to repeatedly go down the hierarchy to locate a folder that may contain the information. Besides it is impossible to express a semantic relationship between two pages.

In the case of SIS, an advantage is that users do not have to take an extra step for constructing a knowledge space and yet find information using various contextual cues. However, it suffers from all the problems associated with query-based search engines, such as inability to formulate a meaningful query or recall contextual cues. It still has to rely on searching information space without personalized knowledge space.

Our tool based on the two-level model has the best of the both worlds. With the knowledge level operations, the information that has been encountered in the past is semantically organized in a personal conceptual space. The “Sequence Guide” feature allows users to easily go back to a past query session and the corresponding topic map in the knowledge space to provide a simplified view. Although the time required for the construction of a knowledge space in the experiment was artificially limited to one minute, it was entirely possible for users to feel that the additional efforts necessary for knowledge space construction was an added burden.

In order to see statistical significance of the results, we employed ANOVA that is used for determining statistical significance of differences among different groups. Table 3 shows that the mean for our tool was better than those of Favorite and SIS.

Table 3: ANOVA result.

			95% Confidence Interval for Mean	
Methods	Mean	Std.Deviation	Lower Bound	Upper Bound
1: Favorites	87.69	98.82	62.16	113.22
2: SIS	70.09	67.67	52.61	87.57
3: Our Tool	50.33	43.78	39.02	61.64

ANOVA puts all the data into one number (F) and gives us *one P* for the null hypothesis. The value was equal to $F(2,177)=3.866$ ($p < 0.05$), and the difference was reliable at the 95% confidence level. It means that users are more likely to say that our tool has superior information reusability.

Table 4: Pairwise comparisons.

Used Method (I)	Used Method (J)	Sig
1: Favorites	2: SIS	0.39
	3: Our Tool	0.015
2: SIS	1: Favorites	0.39
	3: Our Tool	0.305
3: Our Tool	1: Favorites	0.015
	2: SIS	0.305

In addition, information reusability was different, depending on the methods. Table 4 shows the detailed analysis about statistical significance for pair-wise comparisons. In the result, the difference between our tool and Favorites was significant with a very high level of confidence. However, the significances of the differences between other pairs were less confident.

5 CONCLUSIONS

We have proposed a new tool based on a our own model for exploratory searches, which explicates operations at the knowledge level and across the information and knowledge spaces in addition to the typical information level operations, searching and browsing. The notion of knowledge space, in conjunction with that of information space, facilitates explication of knowledge level and inter-space operations so that users can reduce their cognitive burdens when the interactive tool is available.

Although the superiority is not strongly conclusive in some cases, due to the explorative nature of the current study and the confidence level in the significant tests, the result indicates that our novel approach to an interaction mediation for exploratory search based on the two level model and the associated operations is very promising and worth a further study.

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