Transitions in Search Tactics During the Web-Based Search Process

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Although many studies have identified search tactics, few studies have explored tactic transitions. This study investigated the transitions of search tactics during the Web-based search process. Bringing their own 60 search tasks, 31 participants, representing the general public with different demographic characteristics, participated in the study. Data collected from search logs and verbal protocols were analyzed by applying both qualitative and quantitative methods. The findings of this study show that participants exhibited some unique Web search tactics. They overwhelmingly employed accessing and evaluating tactics; they used fewer tactics related to modifying search statements, monitoring the search process, organizing search results, and learning system features. The contributing factors behind applying most and least frequently employed search tactics are in relation to users' efforts, trust in information retrieval (IR) systems, preference, experience, and knowledge as well as limitation of the system design. A matrix of search-tactic transitions was created to show the probabilities of transitions from one tactic to another. By applying fifth-order Markov chain, the results also presented the most common search strategies representing patterns of tactic transition occurring at the beginning, middle, and ending phases within one search session. The results of this study generated detailed and useful guidance for IR system design to support the most frequently applied tactics and transitions, to reduce unnecessary transitions, and support transitions at different phases.

Introduction

Search tactics and strategies have been important research topics in information searching since they are the essential components of the search process. "Move" is another term often used interchangeably with "tactic." Different definitions have been employed to represent moves, tactics, and strategies for different foci of research. Bates (1979, 1990, 1992) defined levels of search activities from move to strategy: (a) A move indicates an identifiable thought or action in information searching; (b) a tactic consists of a move or moves applied to advance the search process; (c) a stratagem is comprised of multiple tactics that exploit a specific information domain and associate a mode of searching; and (d) a strategy represents a plan that includes moves, tactics, and/or stratagems for the search process. By integrating a planned model and theory of situated actions, Xie (2008) concluded that information search strategies are the products of plans and situations. Marchionini (1995) defined moves, tactics, and strategies. According to him, moves are the low-level individual actions, tactics are a group of actions applied to advance information seeking, and strategies are approaches taken to solve problems, which consist of a series of ordered tactics. Incorporating Bates' (1979, 1990, 1992) and Marchionini's definitions, the authors defined search moves, search tactics, and search strategies for this study. Moves are basic thoughts or actions in the information search process. Search tactics refer to a move or moves, including search choices and actions, that users apply to advance their searches in the information search process. Search strategies represent patterns of sequential tactics that imply users' plans for the search process as well as changes occurring in the search process. In this study, the focus of search strategies is on patterns of sequential tactics.

Submitting query terms has been considered one of the fundamental interactions between users and information retrieval (IR) systems. Researchers have identified search tactics or moves that are mostly related to query formulation and reformulation (e.g., broadening, narrowing, keeping, or changing the meaning of queries, etc.) as well as tactics associated with file structure, search process monitoring, document analysis, and so on (Bates, 1979, 1990, 1992; Fidel, 1985; Shiri & Revie, 2003; Shute & Smith, 1993; Wildemuth 2004). At the same time, strategy study generates the same pattern. Studies of query formulation and reformulation account for the majority of the strategy research, which focuses on cognitive involvement and system features (Chen & Dhar, 1991; Markey & Atherton, 1978).

Received August 28, 2009; revised May 5, 2010; accepted May 13, 2010

The new Web environment offers more system features than does the traditional searching environment. It also leads to the emergence and use of new search tactics and strategies. In addition to query formulation and reformulation, users apply tactics and strategies such as going backward, going forward, opening multiple tabs, scanning Web sites, following links, searching known addresses, saving documents, and so on, in the Web environment (Aula, Jhaveri, & Kaki, 2005; Bhavnani, 2001; Hawk & Wang, 1999; Thatcher, 2006). However, Web IR systems do not effectively support users in their search process, the transitions of search tactics in particular. Compared with traditional IR systems, Web IR systems offer a simplified and easy environment for users that requires different types of cognitive involvement. "Web IR systems" here refers to any IR system that users can access and use on the Web including, but not limited to, Web search engines, online databases, online public access catalogs (OPACs), digital libraries, and so on.

The information search process is a complicated and dynamic process, one that consists of multiple types of search tactics. To understand the dynamic search process, it is not enough just to identify types of tactics or strategies. Rather, it is necessary to look into the transition of search tactics in the Web environment. In search-tactic analysis, a transition also can be a unit of analysis as well as a tactic itself. Tactics set up the most fundamental level of interactions. Transitions of tactics reveal a user's successive decision-making process to attain what she or he needs. In Web searching, users select many search tactics such as creating a query, clicking hyperlinks, and evaluating the relevance of an item. A chain of transitions of these multiple tactics constitutes the essence of the information search process. Unfortunately, less research has focused on the transitions in search tactics. Moreover, the existing research on transitions in foci, phases, stages, or tactics has been conducted either in a non-Web environment (Kuhlthau, 1991), in a mediated IR environment (Robins, 2000; Olah, 2005), by log analysis (Jansen, Zhang, & Spink, 2007), or on one type of work task (Vakkari, 2001).

To identify patterns of applied search tactics and their transitions in the search process, there is a need to explore users' search tactics and their transitions by investigating real general users' search behaviors in accomplishing real tasks in a Web-based search environment. By analyzing search tactics, we can have a better understanding of the nature of the information search process. The analysis of search tactics and their transitions offers an opportunity for IR system design to support not only users' search tactics but also their transitions. Therefore, the design of a Web IR system can be enhanced to support transitions in search tactics, which are the critical points of the search process.

Literature Review

Searching behaviors can be discussed on two levels based on their units of analysis because a search process consists of different levels of subprocesses. Literature on two levels (strategies and tactic/moves) of search behaviors in relation to this study are reviewed here. Search tactics/moves are the elements of search strategies.

Search tactics are essential components of search strategies. Search tactics are classified in different categories depending on the research emphasis. Even though search tactics and moves are defined differently, researchers have not followed the same definitions. These two terms are used interchangeably in the literature. In this review, literature in relation to search tactics and moves is included. Researchers' original terms were adopted when citing their works. Query formulation and reformulation is always at the center of search-tactic analysis. Fidel's (1985) operational moves and conceptual moves identified the moves that either keep or change the meaning of a query in the query-reformulation process. While operational moves are characterized by reducing or enlarging the size of search results, conceptual moves are exemplified by intersecting, narrowing, or expanding the meaning of queries. Shute and Smith's (1993) knowledge-based tactics also are associated with query reformulation, specifically topic refinement. Their 13 search tactics can be classified in relation to broadening, narrowing, and changing topics. Adapting Shute and Smith's tactics, Wildemuth (2004) added other moves such as error and repeat. In addition to different types of search-formulation tactics, Vakkari, Pennanen, and Serola (2003) also discovered several search-related tactics such as searching for an author, term checks, and so on. In their study, nine search formulation tactics were operationalized.

Research on search tactics is not limited to query reformulation. Bates' (1979) work is one of the initial identification of tactics that extends tactics to other components of the search process. She classified 29 tactics into monitoring, file structure, search formulation, and term tactics. Monitoring search process and exploring file structure also were considered important tactics for information searching. In a thesaurus-enhanced search environment, Shiri and Revie's (2003) cognitive moves added analysis of documents such as browsing retrieved titles. Their physical moves focused on system-feature uses such as scrolling up and down, scrolling back and forward, using citation-display and e-mail features, checking search history, and so on. The Web environment brought new search tactics for information searching. Bhavnani (2001) identified five tactics that can describe a user's search process, including finding Web sites, scanning Web sites, comparing, verifying, and ending task.

Search strategies consist of a series of search tactics and moves. Parallel to search-tactic research, most of the identified search strategies are in relation to query formulation and reformulation. Markey and Atherton's (1978) building-block, pearl-growing, successive-reactions, most-specific first, and lowest-postings-facet first are the most frequently cited strategies. While Markey and Atherton's strategies emphasize cognitive involvement, Chen and Dhar's (1991) strategies are more related to the options offered by online IR systems from the search-option heuristics strategy, the thesaurus-browsing strategy, the screen-browsing strategy, and the trial-and-error strategy. The known-item instantiation strategy is similar

DOI: 10.1002/asi

to the pearl-growing strategy. Marchionini (1995) summarized search strategies into two essential types: analytical and browsing. Analytic strategies are more goal-oriented and systematic while browsing strategies are more informal and interactive.

In the new Web environment, new strategies have emerged. For example, Hawk and Wang's (1999) problem-solving strategies highlight some characteristics in Web searching: surveying, double-checking, exploring, link-flowing, back-and-forward-going, shortcut-seeking, engine-using, loyal-engine-using, engine-seeking, and metasearching. While these problem strategies are related more to physical strategies, Thatcher (2006, 2008) identified 12 cognitive search strategies including safe player (broad first, search engine narrowing down, search engine player, and known address search domain), parallel player, link-dependent, to-the-point, known address, sequential player, deductive reasoning, and secondary search. He further investigated the impact of Web experience on the application of these cognitive strategies. Aula et al. (2005) presented the search and re-access strategies of experienced Web users. Their findings showed that the most frequently applied search strategy was opening multiple tabs while using a search engine to find information again, typing in the URL again, or saving documents that were the essential re-access strategies.

Compared to studies on tactics and strategies, fewer studies on transitions in search tactics or strategies have been conducted. Bhavnani's (2001) five tactics describe users' search processes from finding Web sites, scanning Web sites, comparing, and verifying to ending task. These tactics were the major components of the search behaviors. The transitions in these tactics formed different "search stages" labeled by Bhavnani (2001). Also in the mediated environment, Olah (2005) identified transitions between search stages in the information-seeking process. She found that the interaction process consists of a series of reiterative loops and linear moves. Database selection, review result set, and the physical delivery of result set were the three critical phases for multiple transitions. Interestingly, this research demonstrated that 63% of typical transitions that occur were not within the query-formulation/result set loop. Transition studies also have extended to transitions of foci. Robins (2000) explored the transitions of foci in mediated IR interaction via discourse analysis. Six foci were highlighted in relation to: documents, evaluation of search results, search strategies, IR system, topic of the search, and information about the user. Strategic and evaluation foci accounted for more than 60% of all foci occurrences. He concluded that there seems to be no pattern found among transitions in foci.

In the Web environment, there also are studies that have investigated the transitions of query modification, which, to some extent, examine strategy transitions in relation to query reformulation. Rieh and Xie (2006) identified eight types of query reformulation strategies based on transitions in search tactics/moves derived from log analysis: specified, generalized, parallel, building block, dynamic, multitasking, recurrent, and format reformulation. For example, a user applied the dynamic search strategy by adding specific terms, adding broad terms, adding parallel terms, and adding specific terms again in several modifications of the queries. Based on the log data, Jansen et al. (2007) calculated the occurrences of transitions of query modification within one Web session. Specialization was the most applied strategy after the initial queries, generalization was the preferred option after specialization, and system assistance was essential for content change.

Some researchers have associated transitions in search tactics with search stages, but less with search phases. Kuhlthau's (1991) information-seeking process model indicates that the stages in task performance determine how people search for information and what they search for. She associated the six stages with physical actions taken and appropriate tasks applied that are relevant to search tactics. While the actions taken range from seeking background information to seeking focused information, the search tasks applied range from recognize to identify to investigate to formulate to gather to complete. Vakkari (2001) and colleagues (Vakkari et al., 2003) combined Kuhlthau's six stages into three stages: pre-focus, formulation, and post-focus. They found that when users moved forward with the stages, they also changed their search tactics. This was characterized by increasing the use of certain search-formulation tactics such as intersect, vary, and parallel; increasing the application of conceptual search tactics; and decreasing the use of operational tactics. Spink (1996) explored the number of same or different search terms and strategies occurring in multiple search sessions. While previous research has focused on relating search tactics with different stages, the authors of the current article investigated strategies representing common patterns of sequential tactics at different phases. The difference between phases and stages lies with the fact that phases are associated with a single search session while stages are associated with multiple search sessions.

Xie (2000) investigated the transitions in dimensions of search strategies based on the analyses of library users. Incorporating other related studies, Xie (2008) further identified 12 types of intentions in relation to search tactics: identifying, learning, exploring, creating search statements, modifying search statements, monitoring, keeping records, accessing, organizing, evaluating, obtaining, and disseminating. These are the basis for the search tactics identified for this study.

A Markov chain has been applied in tactic- or strategy-transition studies as a technique to analyze sequential transitions and to predict a user's behavior. Using Markovian analyses, Chapman (1981) identified nine states of a search pattern and computed the probability of search-state transition. Chen and Cooper (2002) used probabilistic models to analyze the patterns of use in a Web-based library catalog. In their research, a Markov chain was applied to analyze patterns of state transitions in relation to search tactics for different usage groups, consisting of index access, search with retrievals, search without retrievals, modify search, screen display, record display, change display format, record processing, error, help, profile, and miscellaneous. In her

DOI: 10.1002/asi

dissertation, Santon (2003) analyzed transitions in search stages and looked for common patterns in the transitions. Based on a Markov model, she proposed a model representing a nonlinear process of multiple reiterative cycles that constitute the overall flow of communication within the information system, such as search intention, selecting database, formulating queries, and evaluating results. Muresan (2006) applied Markov models to model interactive user behaviors based on state transitions revealed from log data.

Previous research has studied different levels of moves, tactics, and strategies, and has examined transitions in tactics and strategies. In addition, previous works have identified changes in search foci, stages, intentions, and tactics during the search process. These studies have greatly helped researchers understand the dynamic information search process; however, the existing research also has several limitations. First, most research has focused on the identification of types of tactics and strategies; few studies have investigated transitions in search tactics and, in particular, during users' information search processes. Second, transition studies have been limited to mediated environments and log analysis. Some of the transition studies were conducted in mediated environments based on interactions between users and intermediaries or based solely on log analysis of tactic transitions in query formulation or reformulations. Third, fewer studies have further explored the patterns of transitions at different phases. Fourth, many of the studies were conducted based on convenience samples and assigned tasks as opposed to real users with their real problems. The limitations of previous research call for the need to investigate the patterns of search-tactic transitions involving real users with their real problems.

Research Questions

While some previous research has identified a variety of search tactics, less research has explored transitions in search tactics within the Web search process, and in particular, patterns of search-tactic transitions.

This study addresses the following three research questions:

RQ1: What are the most and least frequently applied search tactics in the Web-based search process?

RQ2: What are the frequency and probability of tactic transitions in the Web-based search process?

RQ3: What are the most frequently applied search strategies representing the common patterns of search-tactic transitions observed at different phases in the Web-based search process?

Methodology

To address these questions, the authors designed a user study, and systematically collected and analyzed the data. Multiple methods were used to collect data; accordingly, both quantitative and qualitative methods were applied to analyze the data. In data collection and analysis, data sources and methods of analysis were discussed for each research question.

TABLE 1. Characteristics of participants ($n = 31$).

Demographic characteristics	*N*	%
Gender		
Male	10	32.3
Female	21	67.7
Age (years)		
18–20	1	3.2
21–30	13	41.9
31–40	5	16.1
41–50	7	22.6
51–60	5	16.1
61+	0	0.0
Native language		
English	29	93.5
Non-English	2	6.5
Ethnicity		
Caucasian	29	93.5
Non-Caucasian	2	6.5
Computer skills		
Expert	3	9.7
Advanced	21	67.7
Intermediate	7	22.6
Beginner	0	0.0
Occupation	administrative assistant, marketing communications, librarian, student, programmer, tutor, school guidance secretary, social worker, portfolio specialist, trust associate, client relationship associate, software developer, self-employed, buyer, nurse, academic advisor, painter, unemployed, etc.	

Sampling

A total of 31 participants, responding to fliers posted at different community centers and public locations (e.g., local libraries, grocery stores, etc.), listserves (e.g., craigslist, etc.), and newspaper advertisement (*Milwaukee Journal Sentinel*, the main newspaper in Milwaukee), were recruited from the Greater Milwaukee area. They represented general users of information with different gender, race, ethnic backgrounds, education and literacy levels, computer skills, occupations, and other demographic characteristics. The flier and newspaper advertisement started with "Are you a user of the World Wide Web for business, pleasure or other reasons? Do you know anyone who is?" In the description, the requirements for potential participants were stated: (a) They had to be 18 years or older since this study focused on adult searchers, (b) they must live in the Milwaukee area, and (c) they needed to have some online searching experience. In addition, the instructions in relation to how to participate in the study and the incentive also were mentioned. Each participant was paid $75 for involvement in the study. Table 1 summarizes the characteristics of participants in this study.

Data Collection

Data were collected through several methods:

- *Prequestionnaire.* Participants were instructed to fill out a prequestionnaire requesting their demographic information and their experience in searching for information.

DOI: 10.1002/asi

- *Information interaction diary.* Participants were asked to keep an "information interaction diary" for 2 weeks to record how they achieved two search tasks, one work-related and another personal-related, at their own offices or homes. The diary consisted of information in relation to their tasks, source selections, search tactics, and reasons associated with why they applied or did not apply different types of search tactics.
- *Think aloud protocol and transaction logs.* Participants also were invited to come to the Information Intelligence & Architecture Research Lab to search for information for two additional work-related and personal-related search tasks. They were instructed to "think aloud" during their search process. Their information search processes were captured by Morae, a usability testing software that not only records users' movements but also captures their thinking aloud, including their feelings, thoughts, and intentions during the search process.
- *Postquestionnaire.* After the searches were done, participants were asked to fill in the postquestionnaire, which consisted of questions regarding their experience in the selection of information sources, their search tactics, their problems, and factors affecting their search tactics.

This study involved real users with their real problems. Tasks have been demonstrated as one of the leading factors that influences search tactics and strategies (Byström & Hansen, 2005; Byström & Järvelin, 1995; Li, 2009; Vakkari, 2003; Xie, 2009). To represent different types of work tasks that lead users to search for information, participants were instructed to select one search task in relation to their work-related tasks and another search task in relation to their personal-related tasks. The work-related tasks included a scholarly (e.g., a research project) or an occupational task (e.g., finding specific information for a client) while the personal-related tasks consisted of everyday popular tasks (e.g., shopping). Participants chose their own search tasks and selected the IR systems to search. Participants of this study searched four types of IR systems: (a) search engines (e.g., Google, Yahoo, etc.); (b) Web sites consisting of governmental, commercial, organizational, and individual sites; (c) OPACs (e.g., Milwaukee Public Library catalog, etc.); and (d) online databases (e.g., Pubmed, etc.). Participants' search sessions were recorded. In this study, a search session refers to a participant's whole search process, including using one or more IR systems in achieving his or her search task.

The recorded data were transcribed. A participant's every movement was transcribed, and his or her related verbal protocols also were included in the transcription. The coding scheme applied in this study is presented in next section. The coded dataset consisted of sequences of search tactics.

Data Analysis

To log the participants' search process in real settings, and more important, to log multiple search sessions for one search task, diaries were used to record search tactics. However, data provided in the diaries were not as detailed as were the log data. Therefore, diary data were used only for offering explanation as to why participants applied or did not apply different types of search tactics while data recorded by Morae software in the lab were analyzed mainly for the research questions for this study.

The unit of analysis is each search tactic. As defined in the Introduction, search tactics refer to a move or moves, including search choices and actions, that users apply to advance their searches in information searching processes. The operational definition of transitions of tactics is discussed later. A coding scheme (Table 2) was developed mainly based on Xie's (2008) work in relation to interactive intentions and associated search tactics. Her classification scheme also was modified. "Accessing" was divided into two different tactics, "accessing forward" and "accessing backward," considering that the direction of accessing has different meanings in the search process. "Evaluating" was further divided into "evaluating search results" and "evaluating an individual item" because participants showed different evaluating behaviors under different circumstances. For instance, when participants looked at a list of search results, they were likely to assess quickly to select an item whereas when they faced each individual document, they usually spent more effort to judge its relevance. Thus, the authors created "evaluating search results" and "evaluating an individual item" categories to code quick judgments and thorough assessments, respectively. In the end, we came up with a coding scheme consisting of 13 types of search tactics. For simplicity, each tactic has been represented by an acronym.

To test the intercoder reliability of each search tactic, two researchers independently coded 20 tasks from 10 participants randomly selected from 60 tasks performed by 31 participants. The intercoder reliability for coding each search tactic was 0.97 according to Holsti's (1969) reliability formula. Reliability $= 2M/(N1 + N2)$, where M is the number of coding decisions on which two coders agree, and $N1$ and $N2$ refer to the total number of coding decisions by the first and second coder, respectively. Descriptive analysis was conducted to examine frequency of each type of tactic applied in the Web-based search process.

After coding each of the search tactics for all the searches, transitions of search tactics also were coded for all searches and saved in Excel spreadsheets. Repeated tactics were each coded separately, and they were included in the analysis of the transitions. The transitions between tactics were codetermined by log analysis and verbal protocol analysis. Each move was identified and associated with its previous and following moves to see whether a participant changed his or her search tactics based on the coding scheme. In addition, verbal protocols corresponding with each move were analyzed to assist the coding. When a change of search tactic was identified, the transition of search tactic was recorded. Descriptive analysis was conducted to examine frequency of each type of search tactic applied in the Web-based search process.

To investigate transitions in search tactics, a matrix of tactic transitions was produced to present an overall relationship among search tactics, and probabilities of transitions between all possible search-tactic pairs were calculated. A Markov

DOI: 10.1002/asi

TABLE 2. Coding scheme of types of search tactics.

Code	Types of search tactics	Definition	Example
Lead	Identifying search leads to get started	Discover information as search leads at the beginning of the search process	"Because my topic is very recent and it is business related, one of my first choices is cnn.com."
Creat	Creating search statement	Come up with a search statement for searching	[typing in] "I am going to search pea shoots;" [using a given form] "Fill fields with date and time to query what is available."
Mod	Modifying search statement	Change a previous search statement (e.g., narrow search results, broaden search results, etc.)	"[previous query] London city tour" → [modified query] London three-day tour"
EvalI	Evaluating an individual item	Assess relevance/usefulness of an item, or authority of an item	[examining references of an article] "This article has references so that might be reliable . . . this is new information so I think this is a good website." [examining a site] "The first site [this site] was useful it gave a lot of information about kennel cough the symptoms and how can we treat it." "This site was not useful at all; it did not provide much info about it."
EvalR	Evaluating search results	Quickly assess the relevance of search results	"I am still skimming my Google results and I am not finding any related results."
Rec	Keeping a record	Keep records of metadata of an item(s) before accessing it/them	[paper record] "so it is (the book) available at Central so I would write down the call number." [book marking] "I want to bookmark it."
AccF	Accessing forward	Go to a specific item or Web page that has not been accessed in the search by using direct location, tracking meta-information, or hyperlinks	"Type URL, frommers.com." "clicks link to Near Southside under heading Outreach communities"
AccB	Accessing backward	Go back to a previous page by using direct location, tracking meta-information, or hyperlinks	[typing in URL] "goes back to homepage through URL" "clicks library back button to results"
Lrn	Learning	Gain knowledge of system features, system structure, domain knowledge, and database content	"Learn how to use Google earth."
Xplor	Exploring	Survey information/items in a specific site	"[looking at LOC subjects] . . . ion exchange method, so I could see if that has anything to do with sugar, I could go back to Google and figure that out"
Org	Organizing	Sort out a list of items with common characteristics	"sorted results by length of antenna"
Mon	Monitoring	Keep track of the search process or check the current status	"I would like to check how I get here."
Use	Using/obtaining	Use relevant information to satisfy information needs or obtain information in physical or electronic formats	"Dynasty trust—this is kind of nice [PDF article]. I would print this and use it for my work files."

chain provides the estimation of probability of a user's movement from one state to another (Chen & Cooper, 2002). In this study, Markov chains were applied to examine the probability of a participant's search-tactic transitions. In general, a first-order Markov chain is a widely used technique for calculating the probabilities of transitions between two actions. In this study, a first-order Markov chain was employed to analyze the probabilities of transitions between two sequential tactics.

To determine the relationships among tactics and the tactics that play central roles in the search process, a social network analysis technique was applied to elaborate relationships among search tactics and to provide a visualization of relationships among search tactics. Social network analysis focuses on patterns of relationships between entities and examines the transitions between these entities (Haythornthwaite, 1996; Wasserman & Faust, 1994). In this study, the entities are different types of search tactics. To map the relationships among search tactics, social network analysis was employed to visualize the relationships among different types of search tactics in three ways: (a) presenting an integrated view of tactics and their transitions, (b) highlighting the tactics that play central connecting roles in the information search process, and (c) illustrating the close linkage among search tactics in the information search process. For this analysis, Netdraw (www.analytictech.com/Netdraw/netdraw.htm) software was used to analyze the data. Netdraw provides visualization of nodes and relationships in social network analysis. In this study, the tactics were regarded as nodes, and the transitions between the tactics were interpreted as links. In addition, betweenness centrality, which represents how a tactic is located in terms of its connection with other tactics, was computed for each search tactic to identify transitions of core tactics. Betweenness centrality serves as an indicator for the importance of a tactic as an intermediary in the IR process (Wasserman & Faust, 1994).

DOI: 10.1002/asi

Finally, the most frequently applied search strategies representing common transition patterns of search tactics were identified by employing fifth-order Markov chains. Initially, the transitions from the first-order to the sixth-order were investigated to find search strategies; however, the first- to fourth-order sequential transitions contained limited information to represent meaningful strategies that the authors attempted to analyze. In addition, sixth-order transition data were too large in scale to discover common search strategies. Thus, fifth-order sequence data were selected in the investigation of search patterns. Since the average number of tactics applied in one search session was about 60, six tactics (fifth-order sequence), which account for approximately 10% of tactics in a single session, are considered to be appropriate to identify common patterns in this study. Through the calculation of fifth-order Markov chains, the authors attempted to discover search strategies from the perspectives of sequences of tactics. In particular, most frequently applied strategies at the beginning, middle, and ending phases were explored. The first six tactics, applied at the beginning phases, and the last six tactics, applied at the ending phases, were examined, respectively. Middle phases, excluding the first and last six tactics, were analyzed separately. Then, based on the probability model, the most frequently applied search strategies that represent the most common patterns of tactic transitions in each phase were identified. Finally, a chi-square test was conducted to examine the associations between types of search tactics and types of phases.

Results

The findings of this study offer answers to the research questions proposed earlier, including the most and least frequently applied search tactics, the frequency and probability of tactic transitions, and the most frequently applied search strategies at different phases of the IR process. The results of the study can be represented at three levels of search tactics, depending on the number of search tactics analyzed. Each subsequent analysis is a step further from its preceding analysis. First, the most and least frequently applied search tactics were calculated by analyzing the frequency of each type of search tactic. Second, the frequency and the probability of tactic transitions were calculated by analyzing the transition of two search tactics. Third, the most frequently applied search strategies were identified by analyzing the transitions of multiple search tactics at different search phases. Figure 3 illustrates the key findings of the study and also presents suggestions for the system design according to results of the study; Figure 3 is in the Discussion because it also presents suggestions for the system design according to results of the study.

Most and Least Frequently Applied Search Tactics

A total of 3,756 tactics were observed in 60 search tasks from 31 participants. The number of search tactics varied by search sessions. A minimum value was 7, and a maximum value was 162. An overall average of search tactics per session was 62.60 ($SD = 36.72$). The frequency and proportion of each tactic are presented in Table 3.

TABLE 3. Frequency and proportion of applied search tactics.

Search tactic	Frequency	Proportion (%)
AccF	1,024	27.3
EvalI	837	22.3
EvalR	412	11.0
Xplor	385	10.3
AccB	383	10.2
Use	238	6.3
Creat	149	4.0
Lead	121	3.2
Mod	101	2.7
Org	44	1.2
Rec	41	1.1
Mon	14	0.4
Lrn	7	0.2
Total	3,756	100.0

The most frequently applied tactic was accessing forward (AccF), accounting for 27.3% of all the tactics. Accessing specific items using hyperlinks or typing URLs acted as one of the main tactics in the Web-based information search process. The second most frequently applied tactic was evaluating an individual item (EvalI), which represented about 22.3% of the tactics. Nearly half of the observed tactics were AccF or EvalI. Evaluating search results (EvalR; 11.0%), accessing backward (AccB; 10.2%), and exploring (Xplor; 10.3%) were third, fourth, and fifth, respectively.

Although using/obtaining (Use) was the ultimate goal for IR, the proportion (6.3%) of Use was relatively smaller than that of AccF, EvalI, or EvalR. This finding indicates that participants usually went through considerable effort and engaged in many tactics such as AccF, EvalI, EvalR, AccB, or Xplor before reaching Use. The tactics in relation to query statement creation and modification accounted for 4.0 and 2.7%, respectively, of total tactics. Although creating or modifying query statements was observed in most search sessions, those proportions were much smaller than those of AccF, EvalI, EvalR, and Xplor. Accessing forward or backward, evaluating, and exploring occurred more frequently than did query-related tactics. Relatively small portions were observed for other tactics such as monitoring (Mon), organizing (Org), learning (Lrn), and keeping a record (Rec).

The reasons behind the most and least applied search tactics are explored based on the verbal protocol and diary data in the Discussion.

Frequency and Probability of Tactic Transitions

To investigate transitions between tactics, a directed matrix of search-tactic transitions was created. Total transitions from one tactic to another for all participants were tabulated in the transition matrix presented in Table 4. The matrix includes 3,696 transitions of tactics from 60 sessions for

DOI: 10.1002/asi

TABLE 4. A frequency matrix of search-tactic transitions.

	To													
	Lead	Creat	Mod	EvalI	EvalR	Rec	AccF	AccB	Lrn	Xplor	Org	Mon	Use	Total
From														
Lead		24	3		1		88	2		3				121
Creat	1			4	113		28		2	1				149
Mod	1			2	86		9			1	2			101
EvalI	22	13	1	6	13	13	94	266	2	168	13	3	211	825
EvalR	4	1	26	4	2		342	17	2	5	5	1	2	411
Rec	3	1	1	2			12	12		5	1		3	40
AccF	7	92	17	762	20	3	21	4	1	69	14	1	13	1,024
AccB	16	10	46	23	161	4	27	7		74	2	6		376
Lrn		2	1		1	1	1						1	7
Xplor		3	4	12	1	2	354	4		2	1		2	385
Org	2			19	6		9	1			2		5	44
Mon	1		1		1		2	1					1	7
Use	11	2	1	3	7	18	31	69		57	4	3		206
Total	68	148	101	837	412	41	1,018	383	7	385	44	14	238	3,696

TABLE 5. A probability matrix of search-tactic transitions.

	To												
	Lead	Creat	Mod	EvalI	EvalR	Rec	AccF	AccB	Lrn	Xplor	Org	Mon	Use
From													
Lead		19.8	2.5		0.8		72.7	1.7		2.5			
Creat	0.7			2.7	75.8		18.8		1.3	0.7			
Mod	1.0			2.0	85.1		8.9			1.0	2.0		
EvalI	2.7	1.6	0.1	0.7	1.6	1.6	11.4	32.2	0.2	20.4	1.6	0.4	25.6
EvalR	1.0	0.2	6.3	1.0	0.5		83.2	4.1	0.5	1.2	1.2	0.2	0.5
Rec	7.5	2.5	2.5	5.0			30.0	30.0		12.5	2.5		7.5
AccF	0.7	9.0	1.7	74.4	2.0	0.3	2.1	0.4	0.1	6.7	1.4	0.1	1.3
AccB	4.3	2.7	12.2	6.1	42.8	1.1	7.2	1.9		19.7	0.5	1.6	
Lrn		28.6	14.3		14.3	14.3	14.3	0.0		0.0			14.3
Xplor		0.8	1.0	3.1	0.3	0.5	91.9	1.0		0.5	0.3		0.5
Org	4.5			43.2	13.6		20.5	2.3			4.5		11.4
Mon	14.3		14.3		14.		28.6	14.3					14.3
Use	5.3	1.0	0.5	1.5	3.4	8.7	15.0	33.5		27.7	1.9	1.5	

31 participants. The value in each cell represents the frequency of transitions from row tactic to column tactic. Of 169 pairs of tactics (the same as the number of total cells), 116 pairs had at least one transition whereas 53 cells showed no transition between two tactics. An average transition between two tactics was 31.86 ($SD = 90.88$). The most frequent transition ($N = 762$) was from AccF to EvalI. The transition from AccF to EvalI indicates that a participant accessed an item and then evaluated its relevance. The second most frequent transition was from EvalR to AccF, accounting for 342 cases, which suggests that a participant quickly evaluated search results and then accessed a specific item based on the quick evaluation. Transitions of "Xplor → AccF," "EvalI → AccB," and "EvalI → Use" also were frequently observed and ranked third, fourth, and fifth, respectively.

To scrutinize the probabilities of transition from one tactic to another, a first-order Markov chain was applied. Table 5 presents the probabilities of tactic transitions. Probability does not correspond with frequency of transitions mainly because probability also is affected by the number of options available after applying a specific search tactic. Participants' most probable transition from the Lead tactic was accessing forward (AccF) to a specific information item (72.7%). The most likely transition from creating or modifying search statements (Creat or Mod) was EvalR. In those situations, the most probable transition from EvalR was to AccF. The EvalI tactic led to the application of AccB (32.2%), Use (25.6%), or Xplor (20.4%). From EvalI, the probability of going to AccB was higher than that for Use. Since AccB from EvalI implies the result of finding nonrelevant items and Use from EvalI indicates the result of finding relevant items, the authors could infer that the participants encountered more nonrelevant items than relevant ones. For EvalR, more than 83% of the next tactic was connected to AccF. The AccF tactic most frequently led to EvalI, showing 74.4 % of probability. The AccBs were followed by EvalR (42.8%), Xplor (19.7%), and Mod (12.2%), respectively.

DOI: 10.1002/asi

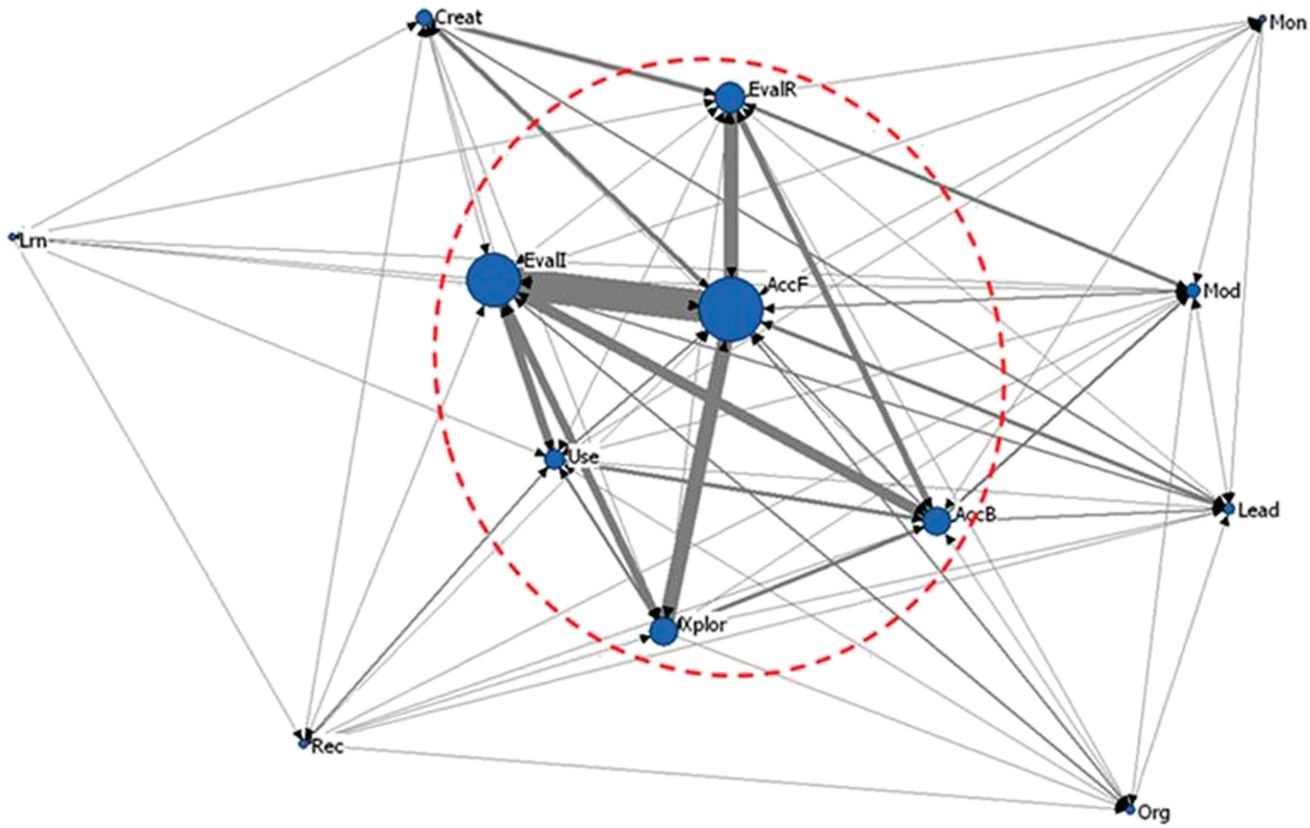

FIG. 1. Diagram of the search tactic network.

When encountering nonrelevant items, participants most probably chose the AccB tactic. They then proceeded to evaluate search results again (EvalR), to explore again (Xplor), or to modify queries (Mod). The tactics of Xplor usually led to access forward (AccF). The probability of AccF occurrence next to Xplor was 91.9%. Finally, after the Use tactic, the AccB tactic was more likely to be selected. About 33% of the Use tactics led to participants applying the AccB tactics to the previous page; otherwise, they chose the Xplor (27.7%) or AccF (15.0%) tactics, which means they explored more or accessed another page to search for more information.

To better view these directional relations between tactics, a visualization technique was applied by using Netdraw (Figure 1). Netdraw visualizes tactics and their relationships. In this figure, a circle represents one type of tactic, and the size of a circle suggests the frequency of applied search tactics. A line with an arrow indicates the relation and its direction, and the width of a line reflects the frequency of transitions between two tactics. Notably, Figure 1 also shows that the tactics at the center play central roles in the transitions, and the tactics adjacent to each other have close relationships. For the layout of tactics, the spring embedding algorithm, which provides an easily legible layout based on the node repulsion concept, was applied based on squared geodesic distance.

According to Figure 1, AccF, EvalI, EvalR, AccB, Use, and Xplor are located at the center of overall relationships, and they also are located in close proximity to each another. Particularly, the Use tactic is adjacent to AccF and EvalI, and this suggests that information using/obtaining (Use), which is considered to be an ultimate goal of IR, is closely related to activities in relation to AccF and EvalI. Moreover, a considerable proportion of EvalIs leads to Use directly in tactic transitions. The Creat tactic is a little far from the core tactic group in the network relations, but it is closely located to EvalR. The volumes of AccF, EvalI, AccB, EvalR, and Xplor were relatively higher than others, and those were the main tactics that participants applied in the information search process. The IR process in the Web environment consists primarily of the iterative sequential combinations of AccF, EvalI, AccB, EvalR, and Xplor, and these combinations finally lead to the achievement of Use. At the same time, the tactics that occurred less frequently, such as Mod, Lrn, Rec, Org, or Mon, are at the peripheral area of the diagram.

Using UCINET 6 (http:// www.analytictech.com/ucinet) to further analyze search tactics and their relationships, the authors calculated a betweenness centrality, representing how a tactic is located at a between position in the geodesics connections with other tactics. Table 6 shows the betweenness centrality of each tactic. Similar to the aforementioned analysis, AccF, EvalR, EvalI, Use, AccB, and Xplor show relatively higher centralities than do the others. Among all tactics, AccF shows the highest betweenness centrality. This indicates that AccF is the most important connector among tactics during the IR process. One interesting finding is that

DOI: 10.1002/asi

TABLE 6. Betweenness centralities of search tactics.

Rank	Search tactic	Betweenness centrality
1	AccF	10.898
2	EvalR	8.537
3	EvalI	6.315
4	Use	4.172
5	AccB	3.922
6	Xplor	3.421
7	Creat	2.306
8	Mod	1.856
9	Lead	1.711
10	Rec	1.204
11	Org	0.783
12	Lrn	0.732
13	Mon	0.143

EvalR shows higher betweenness centrality than does EvalI, although EvalR was employed less frequently. This is due to the fact that EvalR has more diverse connections to other types of tactics, including both query-related tactics and exploration tactics, even though the number of EvalR tactics was lower than that of EvalI.

Most Frequently Applied Search Strategies at Different Phases

To identify the most common patterns of tactic transitions, the authors applied a fifth-order Markov chain (explained earlier) to analyze the fifth-order sequences that occurred more than 20 times (Table 7). Overall, the number of observed sequences in the fifth order was 3,456. Since the average number of tactics applied in one session was about 60, six tactics (fifth-order sequence), accounting for approximately 10% of the tactics in one session, were considered to be appropriate in identifying common patterns in this study. These fifth-order sequences represented the most frequently applied strategies in the analysis. Frequently observed sequences that consist of six tactics revealed three types of search strategies: (a) iterative result-evaluation strategy, (b) iterative exploration strategy, and (c) query-initiation strategy.

Iterative result-evaluation strategy refers to a search strategy that is characterized by evaluating search results. It mainly consists of EvalR, AccF, EvalI, and AccB. The iterative pattern of "EvalR → AccF → EvalI → AccB → EvalR → AccF → EvalI → AccB → . . ." was observed from fifth-order chain analysis. As Table 7 shows, of 17 frequently observed fifth-order sequences, 5 were related to the iterative result-evaluation strategy.

Iterative exploration strategy refers to a browsing strategy that is exemplified by exploring and evaluating information in a site or related sites. It mainly consists of Xplor, AccF, EvalI, and AccB. Therefore, this strategy could be generalized as an iteration of "Xplor → AccF → EvalI → AccB → Xplor → AccF → EvalI → AccB → . . .." Of 17 frequently observed fifth-order sequences, 11 could be viewed as part of the iterative exploration strategy.

These two search strategies echo Catledge and Pitkow's (1995) early findings on browsing strategies. Catledge and Pitkow identified one navigation strategy: the looping back strategy that is related to the Hub and Spoke structure. While the looping back strategy refers to users' return to the original point of entry, this study's iterative strategies characterize the iterative tactics applied in relation to exploration and evaluation. This study's findings indicated that the Hub and Spoke design contributed to the application of these strategies, and suggestions for how to improve the design are discussed later.

A query-initiation strategy refers to a strategy in which the search process starts with creating search statements. This strategy occurred 24 times, forming the pattern "Lead → AccF → Creat → EvalR → AccF → EvalI" in fifth-order analysis. An iterative result-evaluation strategy

TABLE 7. Most frequently applied search strategies with examples.

Strategy type	Tactic sequence (fifth-order)						Frequency
Iterative result-evaluation strategy	AccF	EvalI	AccB	EvalR	AccF	EvalI	89
	EvalR	AccF	EvalI	AccB	EvalR	AccF	75
	EvalI	AccB	EvalR	AccF	EvalI	AccB	52
	AccB	EvalR	AccF	EvalI	AccB	EvalR	50
	EvalR	AccF	EvalI	Xplor	AccF	EvalI	32
Iterative exploration strategy	Xplor	AccF	EvalI	Xplor	AccF	EvalI	79
	AccF	EvalI	Xplor	AccF	EvalI	Xplor	51
	EvalI	Xplor	AccF	EvalI	Xplor	AccF	51
	AccF	EvalI	AccB	Xplor	AccF	EvalI	40
	Xplor	AccF	EvalI	AccB	Xplor	AccF	40
	AccF	EvalI	Use	Xplor	AccF	EvalI	36
	Xplor	AccF	EvalI	Use	Xplor	AccF	34
	AccF	EvalI	Xplor	AccF	EvalI	AccB	30
	AccF	EvalI	Xplor	AccF	EvalI	Use	26
	EvalI	Use	Xplor	AccF	EvalI	Use	24
	EvalI	AccB	Xplor	AccF	EvalI	AccB	21
Query-initiation strategy	Lead	AccF	Creat	EvalR	AccF	EvalI	24

DOI: 10.1002/asi

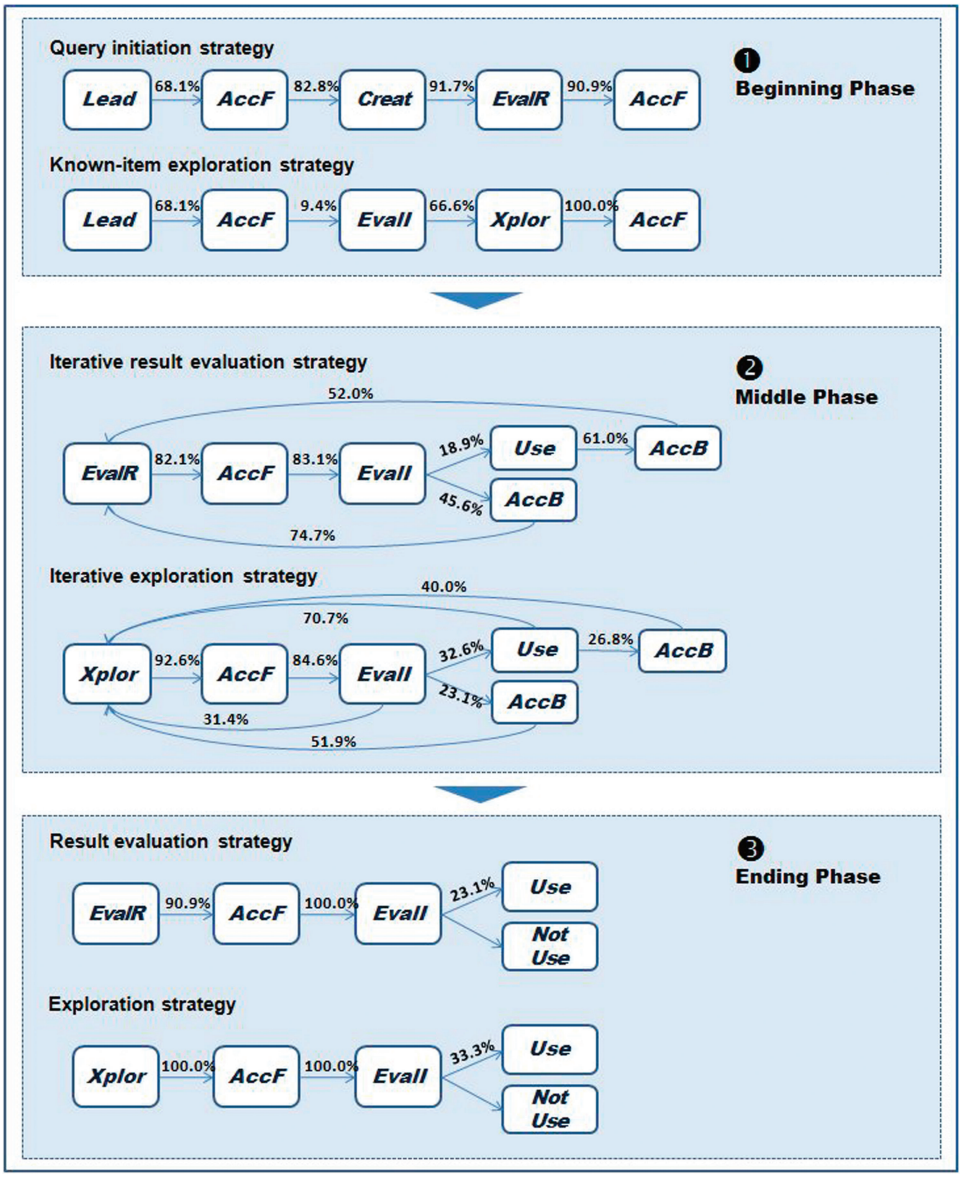

FIG. 2. Most frequently applied search strategies at three phases in the Web-based search process.

and an iterative exploration strategy occurred mostly in the middle of or at the end of the search process. Only a query-initiation strategy was applied at the beginning phase (discussed later).

To have a better understanding of the entire search process, tactic sequences and probabilities of tactic transitions at beginning, middle, and ending phases were analyzed separately. Six tactics, approximately 10% of all the average employed tactics, were selected for analysis. Fifty-three of the 60 cases (representing 3,664 total search tactics) that contained at least 24 tactics were analyzed because the middle phases should contain more search tactics than the beginning and ending phases. Figure 2 shows the most frequently applied search strategies at three phases identified based on the analyses of probabilities of tactic transitions. Moreover, the probability of tactic transition also was presented at each phase. The Markov chain probability was calculated based on the number of tactics involved for each search strategy. The estimation of probabilities of tactic transitions was calculated based on different orders of Markov chains corresponding to the number of tactics involved. For example, the query-initiation strategy consists of five tactics, so fourth-order Markov probability was calculated for this strategy. In another example, the iterative result-evaluation strategy consists of six tactics including the recurrence of EvalR, so fifth-order Markov probability was computed for this strategy. These three phases highlight the typical search strategies applied within an information search session.

The relationships between search phase and tactic application were investigated by conducting a chi-square test. However, the observed counts of the three least frequently applied tactics, Rec, Lrn, and Mon, were too small to be

DOI: 10.1002/asi

TABLE 8. Frequency of and proportions of search tactics at the beginning, middle, and ending phases.

	Phase		
Search tactic	beginning	middle	ending
Lead			
Frequency	48	63	3
Proportion	15.1%	2.1%	0.9%
Creat			
Frequency	51	83	6
Proportion	16.0%	2.7%	1.9%
Mod			
Frequency	4	89	7
Proportion	1.3%	2.9%	2.2%
EvalI			
Frequency	41	695	86
Proportion	12.9%	23.0%	27.0%
EvalR			
Frequency	49	328	24
Proportion	15.4%	10.8%	7.5%
Rec			
Frequency	0	37	4
Proportion	0%	1.2%	1.3%
AccF			
Frequency	99	822	76
Proportion	31.1%	27.1%	23.9%
AccB			
Frequency	5	345	30
Proportion	1.6%	11.4%	9.4%
Lrn			
Frequency	0	7	0
Proportion	0%	0.2%	0%
Xplor			
Frequency	16	340	23
Proportion	5.0%	11.2%	7.2%
Org			
Frequency	1	34	6
Proportion	0.3%	1.1%	1.9%
Mon			
Frequency	0	5	9
Proportion	0%	0.2%	2.8%
Use			
Frequency	4	180	44
Proportion	1.3%	5.9%	13.8%
Total			
Frequency	318	3028	318
Proportion	100.0%	100.0%	100.0%

included in the test. Thus, these three tactics were excluded from the statistical test. The test revealed that there is a significant association between types of search tactics and three phases, $\chi^2(18, n = 3{,}602) = 412.655$, $p < 0.05$.

When examining the beginning six tactics, we found that the proportions of Lead, Creat, and EvalR were relatively higher at the beginning phase than they were at other phases (Table 8). Most of the beginning sequences included at least one Creat tactic. Of 53 beginning phase sequences, only 5 cases did not include Creat. In three cases, participants applied Creat twice at the beginning six tactics. To be more specific, in more than 90% of the search sessions, participants created a query or queries to get their search tasks started within their first six search tactics. The beginning phases that do not have a Creat tactic include Xplor. Approximately 90% of the beginning six tactics can be categorized into the following pattern, although some of them showed different minor variations. Next, a representation of the query-initiation strategy is shown:

$$\text{Lead} \rightarrow \text{AccF} \rightarrow \text{Creat} \rightarrow \text{EvalR} \rightarrow \text{AccF} \rightarrow \ldots$$

Simultaneously, when participants did not employ the query initiation strategy, the following sequence was an alternative typical starting pattern, which is a representation of known-item exploration strategy:

$$\text{Lead} \rightarrow \text{AccF} \rightarrow \text{EvalI} \rightarrow \text{Xplor} \rightarrow \text{AccF} \rightarrow \ldots.$$

At the middle phases, 3,028 search tactics were observed. AccF and EvalI account for nearly 50% of all the applied tactics. The proportions of EvalR and Xplor are approximately the same, comprising 10.8 and 11.2% of the tactics, respectively. Two typical types of search strategies, iterative result evaluation and iterative exploration, were mainly applied during the middle phase. For the iterative result-evaluation strategy, 82.1% of EvalR led to AccF, and sequentially, 83.1% of AccF led to EvalI. The possibility of shifting from EvalI to Use was 18.9% while 45.6% of EvalI led to AccB. Another typical search strategy was iterative exploration. More than 90% of Xplor tactics led to AccF, and then 84.6% of AccF led to EvalI. After evaluating an individual item (EvalI), the possibility of shifting to Xplor, Use and AccB were 31.4%, 32.6%, and 23.1% respectively. For the iterative result-evaluation strategy, the possibility of applying Use after EvalI was 18.9%. While 45.6% of the cases that did not include Use after EvalI moved to AccB, 74.7% of the AccB tactics led to EvalR. The iterative result-evaluation strategy can be characterized by repeating AccB and EvalR until finding satisfactory items. In iterative exploration strategy, the transition from AccB to Xplor with Use and without Use were 40% and 51.9%. The following are the representations of iterative result evaluation strategies and iterative exploration strategies, respectively:

$$\text{EvalR} \rightarrow \text{AccF} \rightarrow \text{EvalI} \rightarrow \text{AccB or Use} \rightarrow \text{“iteration.”}$$

$$\text{Xplor} \rightarrow \text{AccF} \rightarrow \text{EvalI} \rightarrow \text{AccB or Use} \rightarrow \text{“iteration.”}$$

The ending phase analysis involved the last six tactics applied in a search process. The analysis generated common patterns of tactic sequence with four tactics. At this phase, participants continued employing result-evaluation strategy or exploration strategy as they did at the middle phase. The ratio of Use is higher at the ending phases than it is at the other two phases. Of 53 cases, 20 showed at least one Use, accounting for 37.7% of all the cases. When not including the Use tactic at the ending phase, most of the ending sequences concluded with evaluating something (EvalI), but failed to find relevant items. In addition, the EvalI tactic (27.0%) was more often employed at the ending phases compared to the foregoing phases. The following tactic patterns are the representations of result evaluation and exploration strategies at

DOI: 10.1002/asi

the ending phase, which are similar to strategies applied in the middle phase; the only difference is that these strategies are iterative in the middle phrase.

$$\text{EvalR} \rightarrow \text{AccF} \rightarrow \text{EvalI} \begin{array}{l} \nearrow \text{Use} \\ \searrow \text{Not Use} \end{array}$$

$$\text{Xplor} \rightarrow \text{AccF} \rightarrow \text{EvalI} \begin{array}{l} \nearrow \text{Use} \\ \searrow \text{Not Use} \end{array}$$

At the end, the outcomes of these strategies could lead to use or not use the evaluated item.

$$\begin{array}{l} \text{EvalR} \searrow \\ \qquad\qquad \text{AccF} \rightarrow \text{EvalI} \rightarrow \text{Use} \\ \text{Xplor} \nearrow \end{array}$$

$$\begin{array}{l} \text{EvalR} \searrow \\ \qquad\qquad \text{AccF} \rightarrow \text{EvalI} \rightarrow \text{Not Use} \\ \text{Xplor} \nearrow \end{array}$$

Discussion

Unique Web Search Tactics and Search Strategies

This study did uncover some unique search tactics and contributing factors in Web environments from the most and least applied search tactics, most applied tactic transitions, and different types of search strategies by analyzing the common patterns of tactic transitions at the beginning, middle, and ending phases of the search process.

First, the most and least frequently applied search tactics were identified, and factors behind the application of search tactics also were explored. Multiple factors contributed to these unique search behaviors. While some of them are in relation to participants themselves, including the law of least effort, lack of trust toward IR systems, their knowledge and skills, and preference, others are in relation to IR system design, consisting of the unavailability of features supporting certain search tactics, and poorly designed features or interface. Wildemuth's (2004) research results—that a few sequential combinations of moves are used most frequently—are reaffirmed by this study. Participants made greater effort in accessing and evaluating than they did in creating and modifying query statements. While much of the previous research has focused on query analysis, participants of this study employed about 70% of their tactics on accessing (including accessing forward and backward) and evaluating (including evaluating search results and evaluating individual items). Instead of modifying their queries, participants made greater effort to go through individual items from their search results to find useful information. Some participants did not want to make efforts in constructing queries. Participant 13 revealed her principle, "I don't usually search multiple times, and if I don't find it I usually give up." Some participants did not trust IR systems, and they did not think that IR systems could find relevant information for them. Instead, they would prefer to scan the results to find relevant documents themselves. Just as Participant 29 explained, "[The system] makes me uncomfortable because I feel like I go thru each one of these [results] and find which one I trust." The problem of IR system design also made a difference in their decisions. Participant 2 stated the reason for not reformulating queries, "Advanced search' tools vary from being user friendly to requiring know-how to enter data." Participant 16 complained, "The OPAC, I used (CountyCat), was very difficult to use. I couldn't do a subject search for 'Toulouse' and so I gave up [reformulating queries]."

At the same time, many participants did not put effort in actively monitoring their search process or effectively organizing their search results. These two search tactics only accounted for about 1.6% of all the applied tactics. This echoes some common characteristics of Web searching; for example, Aula et al. (2005) found that the history tool was not commonly used, and writing down queries was never used. It seems that accessing and evaluating items comprise the main part of the search process. The main contributing factors for the least applied search tactics are the law of least effort, participants' knowledge and skills, their past experience, unavailability of supporting features, and poorly designed features. Here are two typical examples of applying the law of least effort. Participant 11 confessed that "too much information to sort through, [but I] don't want to spend a lot of time." Participant 16 stressed, "I didn't want to take time to do this step [monitoring]."At the same time, some participants intended to apply some of the search tactics, such as modifying, organizing, and so on, but the IR systems did not support these tactics. According to Participant 4, "Limiting search by date published was not easy or even possible in some search engines. Did the best I could then. I limited to first 300 results." Participant 23 complained, "There was really no option for sorting." Interestingly, participants of this study did not deliberately seek help from IR systems when they encountered problems. Learning is one tactic where users actively gain knowledge on domain, system, and information retrieval skills—all of which are essential for effective IR. Trial and error was their preferred approach to overcoming problems. Most of the participants used the minimum features of IR systems; they were not willing to explore different system features. Participants' past experience in using help was the leading factor for minimum use of help features. Here is a typical statement, from Participant 10, "I am not very fond of these features [help-related features]. I don't usually find them [help-related features] helpful." Some participants could not find help. "I'm not even aware if MPL's website has a help feature," said Participant 16.

Second, unlike Robins' (2000) conclusion on the lack of patterns among transitions of foci based on mediated IR interaction, the analysis of transitions of search tactics shows that search-tactic transitions have their own patterns. The probability matrix of tactic transitions clearly highlights the high probability of transitions for each type of search tactic.

DOI: 10.1002/asi

It also identified the most frequently occurring tactic transitions. For example, creating and modifying search statements are most likely to lead to evaluating search results because these two search tactics normally generate a list of search results. While accessing forward is the preferred choice after evaluating search results, accessing backward, using obtained information, and exploring sites are all the possible selected tactics after evaluation. This analysis offers not only data for researchers to understand the nature of the information search process in the Web environment but also guidelines for Web IR system design.

Third, a key and interesting finding is that different types of search strategies were identified based on analysis of search-tactic sequences. This study validates Olah's (2005) findings that a series of reiterative loops constitutes the interaction process. Compared with previous research on search strategies, a significant contribution of this study lies in the findings that show corresponding typical patterns of tactics to account for participants' sequential movements in detail. This offers opportunities for researchers to understand the nature of search behaviors as well as to make concrete suggestions for IR system design to support these strategies.

Previous research (Kuhlthau, 1991; Vakkari et al., 2003) has examined the changes of search tactics at different stages, which are more related to multiple search sessions in achieving their tasks. This study reveals unique patterns of search-tactic transition at the beginning, middle, and ending phases within one single search session. At the beginning phase, after identifying an item to search, participants started with either creating search statements or exploring a known site. Even in the Web environment, participants in most cases had to create their own queries to search for relevant information; alternatively, participants explored related information in corresponding sites. At the same time, the analysis of the middle phase shows unique search patterns in the Web environment. The iterative result-evaluation strategy and the iterative exploration strategy were applied at the middle phase. Instead of modifying their search statements, participants either went forward and backward to access and evaluate search results or browsed related or higher or lower level pages. These constitute the crucial transitions of the search process.

The strategies presented in this study are the most frequent ones based on quantitative analyses; however, search strategies are not limited to those mentioned in this article. For instance, a participant kept changing search topics (modifying search statements) several times in achieving a search task. Quantitatively, the proportions of unreported strategies were too small, but these search strategies are still meaningful for generating implications for IR system design. We are working on identifying all search strategies employed in this dataset based on qualitative analysis. At the ending phase, evaluating, exploring, accessing, and using are the key components of tactic transitions. Note that for the ending phase in this study, more than 60% of the searches were ended without applying using tactics, although participants might previously have found and used some relevant information. This calls for the need to design IR systems to support users at different phases of their information search process.

Implications for IR System Design

The findings of this study provide useful information for IR system design from three aspects: (a) how to effectively support different types of applied tactics, (b) how to effectively support the most frequently occurring tactic transitions, and (c) how to effectively support tactic transitions at different phases of the information search process. Figure 3 highlights the key findings of this study and their relationships. It also presents design recommendations in relation to the study results.

To effectively support different types of tactics, we need to examine the top-two tactics that accounted for close to 50% of all the applied search tactics. While accessing forward could be done by just several clicks or typing a URL, evaluating individual item(s) requires considerable effort for participants to judge the relevance, usefulness, or credibility of an item. To make things worse, participants received less system support in evaluation. The typical support provided by an IR system is just highlighting the query terms, which is not enough for users to quickly judge each selected item. Evaluation features can be designed to support different types of search tasks. For example, for a known-item search, presenting and highlighting the meta-information of a document is essential. For a specific information search, presenting answers in relation to the specific information is more useful than is just a keyword in context. For items with a common characteristics search, it is important to present the best passage or generate an abstract if it is not available. In addition, it also is essential to highlight information that helps users judge the credibility of a document.

The next frequently applied search tactic is evaluating search results. The findings of this study call for the need to create better support for evaluating search results through the provision of concise summaries and informative surrogates for Web documents. Evaluating search results raises a question in relation to what information should be included in the list. Concise and informative is the requirement for the list. Since evaluating search results is the first step of evaluation, a short version of what is needed for evaluation can be incorporated into the search result list. Categorized overviews are useful in assisting users in assessing search results. Kules and Shneiderman (2008) conducted an experiment to examine users' use of categorized overviews of Web search results. The results showed that categorized overviews not only facilitated users' effective evaluation of results but also enabled users to change and adopt new search tactics. In addition, implicit help for evaluation, such as offering a feature to find documents like a specific part of the selected one, is very important in system design.

Learning and monitoring were the least applied search tactics. Lack of supporting features or poorly designed features for these search tactics are the contributing factors. Monitoring tactics were not chosen frequently mainly because most

DOI: 10.1002/asi

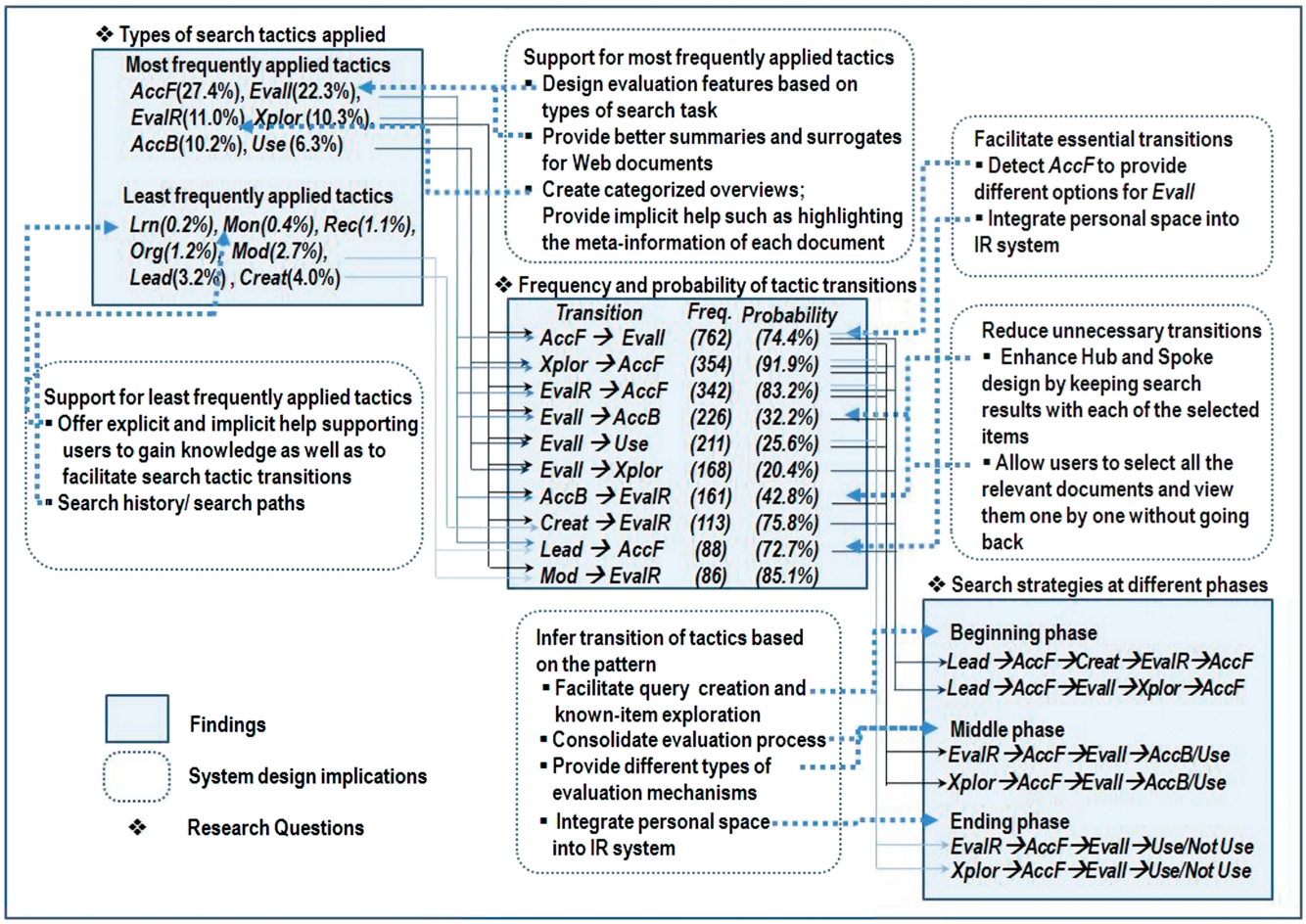

FIG. 3. Summary of findings and design implications.

Web search engines do not provide support for this type of tactic. Search history and search paths can be useful tools for users to quickly figure out how they arrived at where they are. Users in general prefer simple and intuitive system design in the Web environment, and they are not likely to put more effort into reorganizing information or reformulating queries. In that case, the design of help, including both explicit and implicit help, is the key to success. It seems that participants did not like the existing explicit help, as learning tactics were the least chosen tactics. To make things worse, few implicit help features were designed to facilitate users to effectively create search statements, monitor search process, organize search results, evaluate relevance and usefulness of documents, and so on. Based on one of the author's previous works on help, specifically, Xie and Cool's (2009) findings in relation to help-seeking situations and Xie's (2008) research on the design of help mechanisms, the authors suggest that both explicit and implicit help design should focus on supporting users to gain domain, system, and information searching knowledge as well as supporting users in search-tactic transitions. For example, since some of the participants did not have the skills to reformulate their search statements, explicit and implicit feedback mechanisms for knowledge support as well as interactive dialog protocols could be incorporated into the design. In addition, the help page should be integrated into the actual browsing and searching page. Search history and search path options should be created to help users deal with the situation of inability to monitor searches. To support evaluating tactics, different evaluation mechanisms should be available for different types of tasks, and context-sensitive knowledge assistance as well as frequently asked questions/examples dealing with unsatisfied interaction outcomes should be provided. Moreover, as part of the implicit help, this study identified a unique approach regarding how to reduce unnecessary transitions.

Support for the most frequently occurring tactic transitions can be discussed from two perspectives: how to facilitate the essential transitions and how to reduce the unnecessary transitions. Here, essential transitions refer to those transitions that are key to the search process and cannot be left out whereas unnecessary transitions refer to the transitions that can be skipped or merged together. Each type of search tactic has its own most frequently occurring tactic transitions. It is important for IR systems to more effectively and easily facilitate the transitions. These most frequently occurring transitions can help an IR system to predict the most likely occurring search tactic. For example, accessing to evaluating is the most frequently occurring transition.

DOI: 10.1002/asi

An IR system can detect the accessing tactics when users click a link or type a URL. Then the system should be ready to provide all the help for users to evaluate the item by offering different types of evaluation options discussed earlier. At the same time, the probabilities of tactic transitions also have implications for system design. For example, participants' most probable transitions from the Lead tactic were accessing forward (AccF) to a specific information item (72.7%). Participants in general found some search leads from their own resources, and most of the time, they would access the identified resource or URL. If IR systems can integrate users' personal resources into the system or enable users to export their materials to the IR systems, users could quickly and accurately use their own resources and retrieved resources.

It is not always "the more, the better" in terms of applying search tactics within a search process. Some of the transitions can be consolidated. The design of IR systems can be improved to reduce the unnecessary search tactics. For example, after evaluating an item, participants had to access backward several times to the search results and identify the next relevant items. The Hub and Spoke design can be enhanced by two approaches. One option is to keep the search results on the same page with each of the selected items for assessment, greatly reducing unneeded search steps. Another option is to enable users to select all the relevant documents together, allowing each of the items to be reviewed one by one, without going back. Another issue is that participants encountered many access problems such as dead links, system errors, and so on, which represent typical problems during Web searching. It is important for Web IR systems to guide users to an updated site, cached site, or related site instead of just showing the inaccessible error. Another option is to facilitate users transiting from an access problem to accessing backward more smoothly by leading them directly to their previous page or the next item of the previous page.

To support users at different phases of the search process, IR systems can infer transitions of tactics based on the transition patterns. Since different search strategies are applied at different phases, the first several tactic transitions of a search strategy enable IR systems to predict the follow-up tactics at different phases. Therefore, IR systems can be designed with different templates to guide users at different phases of the search process. At the beginning phase, IR systems can offer users two types of options: facilitating users to come up with their search statements or facilitating users to explore information based on the information leads that they identified initially. After detecting the query-initiation and known-item exploration strategies based on the identification of queries entered and pages scanned, respectively, from the initial tactics, the IR systems can introduce different types of evaluation mechanisms for search-result evaluation and visual tools for exploration (discussed later). At the middle phase, on one hand, for users who prefer searching by entering queries, system design should consolidate the evaluation process by reducing unnecessary transitions since much of the process involves quickly evaluating search results, accessing forward, evaluating individual items and accessing backward, or using obtained information. The design of IR systems should provide users different evaluation mechanisms such as a categorical view or an overview of the search results and enable users to select all the relevant items at once, as suggested earlier, to skip many times of accessing forward and backward. On the other hand, for users who prefer exploring, the design of IR systems needs to create a visual map for them to explore not only parallel pages but also higher or lower levels of pages. At the ending phase, for users who find what they need and use relevant items, it is important for IR systems to integrate users' personal spaces so that users can easily incorporate what they find to achieve their tasks, such as cite them in a paper or e-mail them to a colleague, and so on. For users who cannot find relevant items at the end, the IR systems should suggest possible tactics or strategies to modify their queries or explore further information within the system.

Strengths and Limitations of the Study

Many strengths of the study are evident. This is one of few studies that has collected data from real users with their self-generated search tasks. The realism gained by real users and real problems helps researchers understand the nature of the information searching process in the Web environment. Second, the employment of think-aloud protocols and log analysis offers in-depth and rich data that capture participants' cognitive aspects and behavioral aspects of the search. In particular, the captured data not only present how participants applied different search tactics and strategies but also reveal why they behaved as they did. Third, this study incorporated data collected from different settings. For example, log data offered a detailed search process with accompanied think-aloud protocols in the lab environment. The diary data provided more real-setting data, although the diary data were not as detailed as were the log data. Even though the diary data were not used to analyze transitions, they provide explanations for the reasons behind the applications of different types of search tactics.

This study also has limitations. First, the sample size could be enhanced to help generalize the results, even though this study investigated 31 participants' 3,788 applied search tactics in achieving their own 60 tasks. Second, think-aloud protocols could capture verbalization of participants' thoughts, but they could not capture all thoughts during their search process. Third, this study was based on the analysis of data generated from one search session. That might lead to the loss of realism since users might engage in multiple search sessions to accomplish their work and search tasks. Fourth, patterns of search-tactic transitions were derived from the most frequently occurring patterns, and they did not cover all the patterns presented in the search process.

Conclusion

This study examined real users' transitions in search tactics in achieving their real tasks. The results of this study highlight three main contributions. First, users do apply multiple search

DOI: 10.1002/asi

tactics in the search process, and call for the need for IR system design to support multiple search tactics instead of just query formulation. This study not only identifies the most and least frequently applied search tactics but also reveals the reasons behind the findings. It shows that users and IR systems co-determine the application of search tactics, which offers tangible design principles to support different types of search tactics. Second, the identification of the most frequent and most probable tactic transitions illustrates the key part of the Web search process. The results suggest that it is not enough to support each type of search tactic. Moreover, the design of IR systems needs to facilitate essential transitions and reduce unnecessary transitions. Third, the most important contribution of this study is the identification of search strategies that are different from those found in previous research. By analyzing the sequential transitions of search tactics, these search strategies represent the most common patterns of search-tactic transitions at different phases within a search session. The typical search-tactic strategies identified at the beginning, middle, and ending phase demonstrate that there are patterns in characterizing users' Web search behaviors. This finding sets up a foundation for offering design principles to support these patterns in the search process.

Next, we will qualitatively analyze all the transition patterns regardless of their frequency. Moreover, different types of factors, including tasks and their dimensions, affecting transitions of tactics will be further investigated. Further research will expand this study to more participants with a variety of tasks in real settings to best represent users' information search processes. Foremost, future research should not be limited to search tactics applied in users' interaction with Web-based IR systems. Instead, it should extend to the tactics applied in users' interactions with all types of resources, including human resources in the search process. This will enable researchers to design better IR systems to integrate different resources together.

Acknowledgments

We thank the University of Wisconsin–Milwaukee for its Research Growth Initiative program for generously funding the project, and Tim Blomquist and Marilyn Antkowiak for their assistance on data collection. We also appreciate the stimulating and constructive comments and suggestions offered by the anonymous reviewers.

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DOI: 10.1002/asi