

# Information-Seeking Behaviors of Computer Scientists: Challenges for Electronic Literature Search Tools

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## ABSTRACT

Since the recent emergence of electronic literature resources, researchers have begun to adopt new information-seeking practices. The purpose of this research is to investigate the information needs and searching behaviors of researchers, and their implications for electronic literature search tools. We conducted mixed-method case studies involving interviews, diary logs, and observations of computer scientists followed by a web-based survey to validate our findings. The results show that computer science researchers have the following main purposes for seeking information: keeping up to date, exploring new topics, reviewing literature, collaborating, preparing lectures, and recommending material for students. We found that keeping up to date with research is the most frequent purpose and exploring unfamiliar research areas is the most difficult. Furthermore, we found that literature searching is a collaborative process and, depending on the search purpose, different information sources and navigation strategies are used. On the basis of these findings we discuss six design challenges for literature search tools, which are: providing support for keeping up to date with research, exploring unfamiliar topics, browsing user history, collaborating and sharing, performing a federated search that goes beyond scholarly research, and sorting and navigating the results.

## Keywords

Information-seeking behavior, literature search tools

## INTRODUCTION

The introduction of electronic journals and databases led to drastic transformations in the literature search practices of scholars (Niu, *et al.*, 2010; Rowlands, *et al.*, 2008). Today, web-based electronic literature resources are the primary sources of scientific material in almost all fields of scientific

research (Niu & Hemminger, 2012). The main drivers for new information-seeking practices are the widespread adoption of web-based electronic journals and the ease of finding articles on the web via free search engines (Hemminger & Lu, 2007).

Since the 1990s, electronic dissemination of scientific information has improved immensely (Niu, *et al.*, 2010). Originally, the only electronic literature search tool available for academics was the search interface of their library homepage. Later, many different types of public scientific article databases with their own search interfaces emerged. They can be categorized as; (1) big multi-subject databases such as Web of Science, Google Scholar, and Microsoft Academic Search; (2) preprint databases such as arXiv.org; (3) publisher-specific databases such as IEEE Xplore, Science Direct, and ACM, and (4) subject-specific databases such as PubMed, and MathSciNet. In addition to search engines, there now exist other types of tools for managing and sharing scientific information such as Mendeley, Zotero, and Refworks, as well as networking and collaborating with the scientific community such as Research Gate, and Academia.edu. Since academics are increasingly deviating from physical libraries and embracing these electronic search tools (Hemminger, *et al.*, 2007), it is important to understand their current information-seeking behaviors in order to tune these tools to better support user needs.

Our current understanding of the literature search practices of researchers is mainly based on surveys, which explored factors that determine the use of digital libraries at a certain point in time (Vakkari, 2006). But there are several problems associated with them. First, the populations they studied are too general and vary in many respects such as discipline, university, and academic experience (Tenopir, 2003). Second, surveys help us in validating known concepts but do not reveal new behavioral patterns (Gable, 1994). Third, often their focus was limited to the behavioral changes of scholars when scientific articles became available via electronic media (Brown, 1999; Nicholas, *et al.*, 2007; Talja, *et al.*, 2007; King, *et al.*, 2003). Fourth, they do not investigate the use of resources other than electronic library sources such as peers and social support. For these reasons, a study focusing on specific groups of researchers and in-

volving observational methods is needed to understand scientific information-seeking behaviors.

The aim of this study is to investigate the information-seeking behavior of academics in the computer science discipline. We focused on computer scientists because scientists are the heaviest users of electronic literature (Hemminger, *et al.*, 2007), and computer scientists are known to be the early adopters of the latest search technologies (Tenopir, 2003). Hence, computer scientists help us to gain a better understanding of both the latest and old literature search tools, and their implications for scientific information-seeking. In order to gain a thorough understanding of these information-seeking behaviors, we need an in depth study that complements survey methods (Gable, 1994). Therefore we designed a mixed-method study which involves interviews, diary logs, and user observations followed by a web survey. Since one's academic position is the most important determinant of information-seeking behavior (Niu & Hemminger, 2012), we used representative samples of computer scientists from three academic levels; PhD, post-doctoral, and senior researchers. In order to validate the findings with a larger population, we conducted a web-survey with 76 computer scientists.

This paper will report the findings from the above mentioned user studies and present a discussion of the key challenges for literature search tools. From these challenges, we have extracted several guidelines that will help to inform the design of future literature search tools.

## RELATED WORK

As new practices of information-seeking emerged with the availability of electronic resources, researchers started investigating how scholarly information-seeking practices changed with the new technology (Brown, 1999; King, *et al.*, 2003; Hemminger, *et al.*, 2007; Nicholas, *et al.*, 2007; Talja, *et al.*, 2007). Early studies have found that the willingness to use electronic resources was dependent on the academic discipline (Tenopir, 2003). Today both empirical studies and anecdotal experience prove that almost all academic researchers primarily use electronic bibliographical tools for scientific literature searches (Niu, *et al.*, 2010; Hemminger, *et al.*, 2007; Liew, *et al.*, 2000). However, since there are many different tools in existence, it is important to understand how academics choose between them.

Hightower and Caldwell (2010) surveyed science researchers about their article database use and preferences. They found that the researchers preferred multidisciplinary databases over subject-specific databases and, Web of Science and Google Scholar were the most routinely used databases. The main reason for this is the increase in interdisciplinary research. Unfortunately, the paper does not address other possible factors such as the purpose of search. Dervin and Reinhard (2007) conducted an interview-based study involving 409, college, university faculty, and graduate

students to determine how their academic-related and everyday life problems affect the selection of the information source. Their analysis revealed that the purpose of search is the best predictor of a scholar's information-seeking and use practices. However, since this study involved the information needs in personal lives, their findings are too general to understand specific purposes of academic information-seeking. Niu and Haminger (2012) found that academic position was the most important determinant of information-seeking behavior.

Similar to general web searches, there exist classifications of search purposes and how they affect the search behavior. For example, Jansen, *et al.* (2008) classified the purposes informing web queries into informational, navigational, and transactional and Navarro-Prieto, *et al.* (1999) classified them as fact finding and exploration. Unfortunately, these general categorizations of web search purposes are insufficient to understand the purposes that inform a literature search. This leads to the need for a more specific study that focuses only on academics in order to gain a better understanding of what factors actually determine their information-seeking behaviors.

In some academic fields, such as software engineering and medical science, it is common practice to follow systematic literature review (SLR) methods recommended in that field (Kitchenham & Charters, 2007). One well-known SLR method is snowballing or citation chaining in which the researcher uses an article found in the search and follows either the articles that have cited it (forward) or the articles in its reference list (backward). There have been studies evaluating the efficiency of these methods (Jalali & Wohlin, 2012). Talja *et al.* (2007) found through a survey based study that citation chaining is an important search method used by academics. Other well-known methods include browsing a core journal, using colleagues as information sources, and using bibliographical tools (Vakkari & Talja, 2006). But there is very little known about how other factors, such as the purpose of search or level of knowledge, influence the selection of the search method.

On the basis of related work mentioned above, it is clear that an investigation of purposes of scholarly information-seeking would be beneficial. Our goal is to understand the purposes, the search behaviors, and the required tool support for the academic information-seeking. The major research questions are:

- What are the most common reasons or purposes for conducting a literature search?
- How do these different purposes affect the user's search behavior?
- How can literature search tools support these different purposes and search behaviors?

## METHODS

We designed a two-phase study to gain an in-depth understanding of the information-seeking behaviors of computer scientists. In the first phase we conducted case studies involving mixed data collection methods. In the second phase, we conducted a web survey to generalize the findings of the case studies.

### Case Studies

The purpose of the case studies was to gain a broader understanding of the characteristics of literature searches in the computer science domain. Since our goal is to understand behavioral patterns in the process of literature searching, naturalistic methods were selected as the best way to gather data which would include not only researchers' literature search practices, but also the contexts of their literature searches (Gable, 1994). We gathered data for the case studies through three methods; (1) interviews, (2) user observations, and (3) diary logs.

#### Participants

We recruited the participants from the Computer Science department at the University of Helsinki. The participants were recruited according to their academic experience level, which could be PhD researcher (with at least 1 year of research experience and with one or more publications), post-doctoral researcher (with at least five years of research experience and with one or more publications as the lead author) or senior research level (with at least seven years of research experience, leading a group or supervising more than one student).

We selected six participants (two participants from each academic level). Participants #1 and #2 were PhD-level researchers who had been researching for seven years and two years respectively and had around 20 publications and two publications respectively. Participants #3 and #4 were senior researchers who had been researching for 12 years and 18 years respectively and had around 15 publications and 70 publications respectively. Participants #5 and #6 were post-doctoral researchers and they had been researching for eight years and had around 35 publications and 50 publications respectively. We balanced the gender by hiring three female participants (Participants #1, #3, and #5).

#### Data Collection

First we conducted interviews with each participant to find the answers to three questions: (1) what the purposes behind scientific information-seeking are; (2) what search methods and tools do they use, and (3) what factors influence their search strategy. We first asked the participants to recall and list all their reasons for searching for scientific information. Then we tried to situate them in their most recent literature search task by asking them to think of the last time they had searched for literature and guide us through all the steps they remembered following. We mainly focused on the purpose that motivated the search task, the entry point of the search, the tools used, how they navi-

gated through the results, and other factors that influenced the search process. We also tried to capture what other procedures they follow and how different purposes affect their search strategy. This was a semi-structured interview. We let the participants describe all the tools and methods they had used in the past and at the present and how their search practices had evolved over time. Here we did not expect the participants to remember precisely every step they follow, but rather we expected to gain a rough understanding of their information-seeking behaviors. The interviews lasted for approximately 30-45 minutes. We voice-recorded all the interviews and transcribed them before the analysis.

After the interviews we conducted one observation session per participant to gain a more thorough understanding of their information-seeking behaviors. We asked each participant to inform us when they were searching for scientific information for a real purpose and then we visited them and observed their search process. The participants thought aloud while performing each step, so that we could understand the reasons behind the steps they took. We video-recorded all the sessions.

The third method involved longitudinal diary studies completed with the same participants. Here we prepared a set of guidelines for the diary entries. The main content expected in the diary logs was; (1) the purpose of the search, (2) the steps followed and tools used in the search process, and (3) user satisfaction with the findings. Participants were required to make entries at the end of every scientific information-seeking task. However, if this proved to be too demanding, the participants were permitted to make one entry per day. The participants continued making diary entries for a period of three weeks starting from the day of the interview.

### Web Survey

#### Survey Questionnaire

The questionnaire was constructed after the analysis of the data collected through case studies. Through the case studies we identified six purposes that motivate literature searches. Table 1 contains these purposes. The survey questionnaire<sup>1</sup> comprised one section per search purpose and under each section we asked the participants to rate the frequency and difficulty of searching for information for that purpose and the importance of different navigation and sorting methods, and to select the tools they used. The questionnaire also had sections about collaborations and background information. For all the questions that involved ratings, we provided a 7-point Likert scale (where 1 is the lowest rating and 7 is the highest). To reach large and diverse numbers of participants, a web-based survey design was used.

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<sup>1</sup>A copy of the final survey questionnaire is available at <http://goo.gl/dEPoN>

### Sampling

Our target was to involve a diverse population of computer scientists from different countries and universities. We sent emails to the department mailing list of our home university, and posted links on social media sites such as Twitter and Facebook and to different user groups in LinkedIn. As an incentive for participation, those who participated were entered into a raffle for one of three \$25 Amazon.com gift vouchers. The survey was opened for 14 days starting from 18<sup>th</sup> March 2013.

We accepted respondents from the computer science discipline, who were master's thesis writers, PhD researchers, post-doctoral researchers, or senior researchers. A total of 76 survey responses were received from all the categories: master's students 10% (8), PhD researchers 50% (38), post-doctoral researchers 24% (18), and senior researchers 16% (12). We received responses from 11 different countries. 42% of our respondents were female.

### FINDINGS

In this section we outline the statistical analyses of the survey responses in validation of the case study findings. Since the population of the case studies was restricted to six participants the statistical analysis of the survey is needed to validate the case study findings.

#### Purpose of Literature Search

Through the case studies we learned that a literature search is a process initiated for different purposes. Table 1 provides an overview of these purposes.

The senior and post-doctoral researchers explained that they perform literature searches for two primary needs - teaching and researching: "The general categorization I see is searching for research and searching for teaching" [Participant #4], "I mainly search for my research. I also search for information for teaching" [Participant #3]. By further analyzing the interviews and diary logs we found four purposes that underlay research (*stay up to date with research, explore unfamiliar research areas, collaborate, and review literature*) and two purposes related to teaching (*preparing lectures, recommending material for student reading*). Our aim is not to be exhaustive but rather to identify how different purposes affect the search strategies of computer scientists.

#### Frequency of Search Purposes

We found from the case studies that the frequency of occurrence of different search purposes varies. Therefore, in the survey we asked the participants to rate how often they search for literature for each purpose. Statistical analysis revealed that *staying up to date with research* is the most frequent purpose. Table 1 contains the mean and standard deviation of frequencies of the purposes in the descending order of frequency.

A Friedman test was conducted to evaluate the differences in medians. The test was significant  $\chi^2(5, N = 76) = 77.20$ ,

$p < .001$ , and the Kendall's coefficient of concordance of .27 indicated fairly strong differences among the six purposes.

Follow-up pairwise comparisons were conducted using a Wilcoxon test and controlling for the Type I errors across these comparisons at the .05 level using the Bonferroni procedure. The median ( $m$ ) frequency of searching for *staying up to date with research* ( $m = 6$ ) was significantly greater than the median frequency of searching for all the other purposes,  $p < .001$ . The median frequency of *exploring unfamiliar research areas* ( $m = 5$ ) was significantly greater than those of *preparing lectures* ( $m = 4$ ) and *recommending materials for students* ( $m = 4$ ),  $p < .05$ , but did not differ significantly from the median frequency of searching for *collaborations* ( $m = 5$ ),  $p = .269$  or *reviewing literature* ( $m = 5$ ),  $p = .156$ .

According to these results, we can conclude that computer scientists perform literature searches most frequently for the purpose of *staying up to date with research*. *Exploring unfamiliar research areas*, searching for *collaborations*, and *reviewing literature* are the second most frequent purposes. Searching to *prepare lectures* and *recommend material for students* are the least frequent purposes of searches.

#### Importance of Staying Up to Date

Since searching the literature in order to *stay up to date with research* is the most frequent purpose for searching, we further analyzed data related to this purpose.

During the interviews we found that the participants often browse authoritative information sources such as conference websites, proceedings listed on publishers' websites, and the web pages of well-known authors and research groups to stay up to date: "normally, I routinely scan conferences or publishers' pages to find about new developments" [Participant #4].

From the web-survey we tried to quantify whether researchers prefer getting alerts and automatic support through literature search tools to *stay up to date with research*. The sample as a whole prefer receiving alerts about the latest proceedings of reputed forums in their discipline ( $M = 5.34$ ,  $SD = 1.74$ ), and the latest publications of well-known authors ( $M = 5.42$ ,  $SD = 1.68$ ), other researchers they have worked with ( $M = 5.07$ ,  $SD = 1.64$ ), and colleagues ( $M = 4.60$ ,  $SD = 1.73$ ).

Correlation analysis revealed significant positive correlation between academic level and how often they search for new developments,  $r_\tau (N = 76) = .34$ ,  $p < .01$ . Further we found a positive correlation between how often researcher search for new developments and the statements "I have thorough knowledge of my research area"  $r_\tau (N = 76) = .34$ ,  $p < .05$ , "I have up to date knowledge of my research area"  $r_\tau (N = 76) = .40$ ,  $p < .01$ , and "I routinely scan conference proceedings"  $r_\tau (N = 76) = .496$ ,  $p < .001$ .

Purpose	Example excerpts from interviews and diary logs	Mean (M), Standard Deviation (sd)		
		Frequency	Difficulty	Known article search
Stay up to date with research	Participant #2, interview: "I search to learn about the progress and existing work in the field." Participant #2, diary log: "Check whether there are any new papers published on the subject I am working on."	M = 5.86 sd = 1.09	M = 3.05 sd = 1.51	M = 3.73 sd = 1.87
		M = 4.82 sd = 1.15	M = 4.04 sd = 1.49	M = 3.65 sd = 1.72
Explore unfamiliar research areas	Participant #1, interview: "I have to learn some new topic." Participant #3, diary log: "Today I searched for some articles on a new area."	M = 5.07 sd = 1.60	M = 2.26 sd = 1.27	M = 3.19 sd = 1.93
Collaborate	Participant #4, interview: "sometimes I search to find industrial collaborators or other researchers in some disciplines." Participant #6, diary log: "I searched about a researcher who visited our group and gave a talk recently"	M = 4.37 sd = 2.00	M = 3.17 sd = 1.31	M = 4.00 sd = 1.77
Review literature	Participant#2, interview : "you build your work on the previous work so you need to know the progress and existing work in the field" Participant #1, diary log: "I searched for literature to write the related works section in our paper."	M = 3.65 sd = 1.92	M = 3.20 sd = 1.07	M = 4.64 sd = 1.67
Prepare lectures	Participant #4, interview: "I search literature to plan courses." Participant #3, diary log: "I searched for literature to prepare slides for a course."	M = 3.56 sd = 1.94	M = 3.20 sd = 1.32	M = 5.27 sd = 1.59
Recommend materials for students	Participant #3, interview: "I search for something simple enough to recommend for students." Participant #5, diary log: "I searched for references to recommend for the masters students I'm now supervising"			

**Table 1. Literature search purposes (extracted from case studies) and their frequency, difficulty, and how often scholars search for known articles for each purpose (Based on survey data, ratings are from 7-point Likert Scale)**

We found a negative correlation between how up to date the knowledge is and how difficult it is to explore unfamiliar research areas  $r_t (N = 76) = -.273, p < .05$ , conduct literature reviews  $r_t (N = 76) = -.294, p < .05$ , and find collaborators or other researchers  $r_t (N = 76) = -.289, p < .05$ .

These results indicate that those who *stay up to date with research* are from higher academic levels. Browsing through conference proceedings is the most commonly followed method to *stay up to date*. The negative correlations lead to the conclusion that *staying up to date* with developments in one's research makes it easier to conduct *exploratory searches* and *literature reviews* and find *collaborators*.

#### Difficulties

Qualitative data and survey statistics revealed that *exploring unfamiliar research areas* is the most difficult purpose for searching. Table 1 presents the mean and standard deviation of difficulty of searching for different purposes.

During the interviews we found that the level of difficulty of a literature search varies according to the purpose of the search. Some of the participants explained to us that *exploring an unfamiliar research area* is the most difficult task for them: "sometimes you don't even know the correct keywords you should search for; if you don't know the keyword, how can you start?" [Participant #2]. During the user observation session one of the senior researchers (Participant #4) was searching for material in preparation for

his lectures. After spending over fifteen minutes on this task he explained to us that he would contact someone who has better knowledge of this subject rather than spending any more time searching through the literature.

In the survey we quantified how difficult it is for computer scientists to find literature for these purposes by asking the participants to rate the difficulty (point 7 is the most difficult). A Friedman test was conducted to evaluate differences in medians. The test was significant  $\chi^2(5, N = 70) = 25.76, p < .001$ , and the Kendall's coefficient of concordance of .14 indicated fairly strong differences among the six purposes.

Follow-up pairwise comparisons were conducted using a Wilcoxon test and controlling for the Type I errors across these comparisons at the .05 level using the Bonferroni procedure. The median difficulty of *exploring unfamiliar research areas* ( $m = 4$ ) was significantly greater than the median difficulty of all the other purposes ( $p < .001$ ).

There was also a significant positive correlation between the frequency of *exploring unfamiliar research areas* and its difficulty,  $r_t (N = 76) = .23, p < .05$ . This indicates that even with more practice, researchers still find it difficult to explore unfamiliar research areas. We also found a significant negative correlation between the level of the research establishment and difficulty in *exploring unfamiliar research areas*,  $r_t (N = 76) = -.23, p < .05$ . This indicates that the researchers from less well-established research areas

find it even more difficult to explore unfamiliar research areas. With these results we can conclude that *exploring unfamiliar research areas* is the most difficult search purpose.

### Known Article Search

Qualitative data revealed that computer scientists frequently search for articles they have found before. Statistical analysis quantified that, for some purposes, they search for a known article more often than for the others. Table 1 provides mean and standard deviation of the frequency of computer scientists searching for known articles.

During the user observation sessions Participant #3 searched for literature to backup her current research and she mentioned that she was looking for a particular article she had come across before. She tried to recall how she found it before and tried similar queries in Google scholar. Then she skimmed through the result listing by checking only purple-colored links (which indicate the links she has clicked before). We also found from the diary logs that searching for a known article is an activity that computer scientists perform very often in order to accomplish different search purposes: “I remembered a paper I had read before. I just searched for bibtex to cite it” [diary log of Participant #1]. One post-doctoral researcher explained that he sometimes uses the internet as his personal archive and repeatedly comes back and searches for the same thing [Participant #6]. On the other hand, another post-doctoral researcher explained that since it is difficult to recall all the search queries and look for an article she has found before, she maintains a bibtex file and searches in that: “I have this 5000-10,000-line bibtex file which has everything that I’ve ever run into. If I’m looking for references for my students, I go to this file. I have keywords and my own notes there and I search through them. When I find something that is good enough for students, I take the author and title information to re-find it through Google or something” [Participant #5].

In order to quantify how often computer scientists perform search for a known article we asked them in the survey to rate how often they search for known articles. The sample as a whole often search for articles that they have found before ( $M = 6.11$ ,  $SD = 1.13$ ).

We also asked the participants to rate the importance of “known article search” for each search purpose. A Friedman test was conducted to evaluate differences in medians among how often they search for a known article for each search purpose. The test was significant  $\chi^2(5, N = 76) = 30.21$ ,  $p < .001$ , and the Kendall’s coefficient of concordance of .25 indicated fairly strong differences among the six purposes for searching.

Follow-up pairwise comparisons were conducted using a Wilcoxon test and controlling for the Type I errors across these comparisons at the .05 level using the Bonferroni procedure. The median frequency of a search for a known article for *recommending material for students* ( $m = 6$ ) was significantly greater than those of all the other purposes ( $p < .05$ ). The median frequency of a search for a known article for *literature review* ( $m = 4$ ) was significantly greater than that of *collaborate* ( $p < .01$ ) ( $m = 3.50$ ), *explore unfamiliar research areas* ( $p < .05$ ) ( $m = 4$ ), and *stay up to date with research* ( $p < .05$ ) ( $m = 4$ ), but did not differ significantly from that of *prepare lectures* ( $p = .316$ ) ( $m = 5$ ). These results indicate that computer scientists search for known articles most often when *recommending materials for students*. *Literature review* and *prepare lectures* were the second most frequent purposes that motivated a search for a known article.

### Collaboration and Sharing

Interviews and the survey statistics revealed that experienced researchers frequently search for collaboration purposes and they share their findings more often.

During the interviews, senior researchers explained that they are constantly looking for a better tool for collaboration: “I still haven’t found a good tool for collaboration. I’m now doing a project with a couple of researchers from another country. We don’t have a good way of keeping track of what other people are reading. There’s a wiki and everybody was supposed to write this summary, but this never works, people forget. So having some kind of a system where we can search, read, make annotations, and share with others would be useful for all my collaborative projects” [Participant #4]. This suggests that it may be beneficial to integrate collaboration support with the literature search tool itself.

The results of the survey showed that computer scientists often follow articles recommended to them ( $M = 5.19$ ,  $SD = 1.14$ ) and would prefer to use literature search tools with integrated collaboration and sharing functionalities ( $M = 4.47$ ,  $SD = 1.16$ ). We also found a significant positive correlation between how often researchers collaborate, and their academic level,  $r_r(N = 76) = .321$ ,  $p < .05$  and the broadness of the research area,  $r_r(N = 76) = .389$ ,  $p < .01$ . These results indicate that experienced researchers and researchers from broader disciplines are more likely to conduct collaborative research. In conclusion collaboration and sharing are important activities that occur simultaneously with literature searching.

### Literature Search Tools

Interviews revealed that different tools are preferred for different purposes. The survey quantified this finding. Table 2 provides the tools preferred by the participants.

Purpose	Mean (M), Standard Deviation (sd)			Significance $\chi^2(2, N = 76)$ , Kendall's Co- efficient (K)	Most Significantly Preferred Naviga- tion Techniques	Preferred Tools
	Forward chaining	Backward chaining	Forum browsing			
Stay up to date with research	M = 5.72 sd = 1.39	M = 5.02 sd = 1.61	M = 5.54 sd = 1.43	8.97, $p < .05$ , K = .09	Forward Chaining, Forum Browsing	Google Schol- ar(36%),Conference pages (20%)
Explore unfamiliar research areas	M = 5.60 sd = 1.56	M = 6.23 sd = .951	M = 4.43 sd = 1.50	46.46, $p < .001$ , K = .505	Backward chaining	Google(45%),Wikiped ia(12%)
Collaborate	M = 5.05 sd = 1.79	M = 5.53 sd = 1.64	M = 3.95 sd = 1.97	24.14, $p < .001$ , K = .326	Forward/Backward Chaining	Google(53%)
Review literature	M = 5.48 sd = 1.77	M = 5.83 sd = 1.22	M = 4.00 sd = 1.77	25.21, $p < .001$ , K = .323	Forward/Backward Chaining	Google Scholar(42%)
Prepare lectures	M = 4.79 sd = 1.60	M = 5.44 sd = 1.41	M = 3.70 sd = 1.72	19.49, $p < .001$ , K = .300	Backward chaining	Google(39%)
Recommend ma- terials for stu- dents	M = 4.77 sd = 2.01	M = 5.63 sd = 1.35	M = 4.23 sd = 1.80	11.37, $p < .01$ , K = .190	Backward chaining	Google Schol- ar(41%), Google (37%)

**Table 2. Results of Friedman test on how often researchers use different navigation techniques and preferred tools for each search purpose**

During the interviews we asked our participants to explain what type of search tools they use for different literature search purposes. Something that was common to all the participants was the use of a generic search engine such as Google or a federated academic search tool such as Google Scholar as the entry point for a search: “I always start the search with Google Scholar, but sometimes I start with Google if I want to find industry solutions or explore a new topic, because then you need other sources of data in addition to scientific articles” [Participant #2].

In order to quantify this, in the web-survey we asked our participants to select the most frequent entry point for a literature search for each of the six purposes we identified. According to the survey results, a generic web search engine (Google) is preferred when *exploring an unfamiliar research area* (45%), *preparing lectures* (39%), and searching for *collaborations* (53%). A federated academic search tool (Google Scholar) is preferred when *staying up to date with research* (36%), *recommending materials for students* (29%), and *reviewing literature* (42%). For the purpose of *exploring an unfamiliar research* topic, a considerable percentage (12%) of the respondents selected encyclopedic sources such as Wikipedia as their starting point. But when *staying up to date with research* 20% of the respondents selected more specific sources, such as conference web pages, as their entry point.

### Systematic Literature Review (SLR) Techniques

Survey statistics quantified the importance of three most common SLR techniques in literature search. Table 2 contains the statistical data related to each technique.

From the case studies we found that computer scientists prefer different SLR techniques for different purposes. When conducting *literature reviews* they prefer to navigate by the name of an authoritative forum: “sometimes when I

am conducting research targeting a specific forum, I would like to see all the past work published there. Then I go to IEEE Xplore because they group papers by the name of forum” [Participant #2]. One senior researcher (Participant #3) explained that she goes directly to the web pages of reputed forums and browse through their proceedings if her target is to conduct a literature review. But for some purposes they prefer to navigate through citations or reference lists (snowballing): “I type the most recent article I know about the topic into Google Scholar and check who it has been cited by and that sort of tells me who’s aware of the problem and maybe if there’s progress I might check some papers it has been cited in” [Participant #6]; “I mostly use bibliographical tools for exploring new topics and in that case I chain through the reference list of an article” [Participant #4].

In the web-survey we tried to quantify the importance of these three common SLR techniques; browsing authoritative forums, chaining through articles citing a given article (forward citation chaining), and chaining through articles in the reference list of an article (backward citation chaining). We asked the participants to rate the importance of these navigation techniques for each of the six literature search purposes.

Friedman tests were conducted to evaluate differences in medians among the importance of the three SLR techniques for each of the six purposes. Table 2 provides the significances and the Kendall’s coefficients. The tests were significant. The Kendall’s coefficients of concordance indicated fairly strong differences among the importance of the techniques.

For each purpose of search we conducted follow-up pairwise comparisons using a Wilcoxon test and controlling for the Type I errors across these comparisons at the .05 level

Purpose	Mean (M), Standard Deviation (sd)		
	Citation count	Forum rank	Year
Stay up to date with research	M = 4.27 sd = 2.13	M = 5.68 sd = 1.53	M = 5.88 sd = 1.42
Explore unfamiliar research areas	M = 5.39 sd = 1.65	M = 5.49 sd = 1.51	M = 5.56 sd = 1.29
Collaborate	M = 5.07 sd = 1.72	M = 5.37 sd = 1.88	M = 4.84 sd = 1.63
Review literature	M = 5.05 sd = 1.84	M = 5.38 sd = 1.60	M = 4.93 sd = 1.72
Prepare lectures	M = 4.55 sd = 1.82	M = 4.94 sd = 1.48	M = 4.91 sd = 1.57
Recommend materials for students	M = 5.03 sd = 1.89	M = 5.03 sd = 1.72	M = 5.07 sd = 1.31

**Table 3. Importance of search result sorting methods (Based on survey data, 7-point Likert scale)**

using the Least Significant Difference (LSD) procedure. According to them, for the purpose of *staying up to date with research*, the median importance of forward citation chaining ( $m = 6$ ) was significantly greater than that of backward citation chaining ( $p < .05$ ) ( $m = 5$ ) but there was no significant difference between the median importance of forward citation chaining and forum browsing ( $p = .344$ ) ( $m = 6$ ). On the other hand, for *exploring unfamiliar research areas*, the median importance of backward citation chaining ( $m = 6.50$ ) was significantly greater than those of other techniques ( $p < .01$ ) ( $m = 5.50$ ). For the purpose of *collaborating*, the median importance of forward citation chaining ( $m = 5$ ) was significantly greater than that of forum browsing ( $p < .001$ ) ( $m = 4$ ) but there was no significant difference between forward and backward citation chaining ( $p = .093$ ) ( $m = 6$ ). Similarly, for *reviewing literature*, the median importance of backward citation chaining ( $m = 6$ ) was significantly greater than that of forum scanning ( $p < .001$ ) ( $m = 4$ ) but did not differ significantly from that of forward citation chaining ( $p = .103$ ) ( $m = 6$ ). For *preparing lectures*, the median importance of backward citation chaining ( $m = 5$ ) was significantly greater than that of both forward citation chaining ( $p < .05$ ) ( $m = 5$ ) and forum browsing ( $p < .001$ ) ( $m = 4$ ). For *recommending materials for students* the median importance of backward citation chaining ( $m = 6$ ) was also significantly greater than that of the other two techniques ( $p < .05$ ) ( $m = 5$ ). A summary of these results is shown in Table 2.

On the basis of these results, we can conclude that backward citation chaining is an important SLR technique. But forward citation chaining and authoritative forum browsing are also preferred for some purposes.

### Search Result Sorting

The observational study suggested that researchers prefer to sort search results by year, citation count, and the rank of the published forum. Table 3 contains the statistical data

related to the user preferences for different sorting methods.

Interview data indicated that depending on the search purpose different information types become important: “If I am searching for new concepts, I would go for the citation information; if it’s highly cited it is an indicator of a good paper to learn about this topic.” [Participant #3]; “Publication year and venue are important indicators when looking for new developments in my research area.” [Participant #2].

In the web-survey we asked the respondents to rate the importance of the citation count, the rank of the published forum, and the year when judging the search results.

A Friedman test was conducted to evaluate differences in medians among the three sorting methods for each purpose. The tests were significant only for two purposes; *stay up to date with research*  $\chi^2(2, N = 76) = 18.27, p < .001$  and *collaborate*  $\chi^2(2, N = 76) = 9.64, p < .01$ , and Kendall’s coefficients of concordance of .19 and .12 respectively indicated fairly strong differences among the sorting methods. This indicates that for other purposes, all three sorting methods are equally important.

For the purposes *stay up to date with research* and *collaborate*, we conducted follow-up pairwise comparisons using a Wilcoxon test and controlling for the Type I errors across these comparisons at the .05 level using the LSD procedure. For the purpose of *staying up to date with research*, the median importance of year ( $m = 6$ ) was significantly greater than that of citation count ( $p < .001$ ) ( $m = 5$ ), but did not differ significantly from that of the forum rank, ( $p = .551$ ) ( $m = 6$ ). For the purpose of *collaborate*, the median preference of forum rank ( $m = 6$ ) was significantly greater than that of year ( $p < .05$ ) ( $m = 5$ ), but did not differ significantly from that of citation count ( $p = .259$ ) ( $m = 6$ ). On the basis of these results, we can conclude that the forum rank is an important parameter for sorting results.

### CHALLENGES

This section discusses some key challenges derived from the findings of the case studies and survey.

#### Challenge 1: Support Researchers in Keeping Up to Date

Both the qualitative and empirical evidence suggested that senior researchers routinely keep up to date with research. Furthermore, there is evidence suggesting that the most difficult literature search task (exploring unfamiliar topics) becomes less challenging if you keep up to date with research. This search behavior could be aided, in part, through the inclusion of an automatic alerting system. The results from our web survey indicated that computer scientists would like to use alert services to learn about new developments in their network of researchers. Even though alerting features are provided in many existing databases, our results showed that novice researchers have less up-to-



date knowledge and senior researchers browse manually through conference proceedings to learn about new developments. Hence, there is a need for a proper alerting mechanism to encourage novice researchers to gain up to date knowledge and make it easier for senior researchers to keep up with new developments. We propose that an effective method would be to simply let the user choose their own alerting mechanisms based on their preferred forums.

### **Challenge 2: Support Exploration of Unfamiliar Research Areas**

Defining what constitutes an exploratory search is challenging because almost all searches are in some way exploratory (White *et al.*, 2006). However, exploratory searching is known to be one of the most difficult information retrieval tasks (Marchionini, 2006). Our study further confirmed that, even in scientific information-seeking, this proves to be true. Many techniques have been proposed to provide better support for exploratory searches (Marchionini, 2006), such as dynamically updating the presentation of results (Nowell *et al.*, 1996), categorization of results, faceted searching (Firan *et al.*, 2011), and mixed-initiative interaction. However, empirical evidence from our web survey confirmed that this problem is not properly addressed at the moment. We propose that the literature search tools should include techniques to support exploratory search such as interactive visualizations.

### **Challenge 3: User History Browsing**

Both the observational and survey results indicated the frequent use of search tools to find articles that users have read in the past. If the user remembers the title of the article then a search for a known article is a simple task. But according to the observational studies, on many occasions users do not remember the title, and yet remember the content. Therefore we propose that literature search tools should maintain a user history and allow the user to search within previously found results. Furthermore, the known article search process can also be improved by displaying previous search queries (Firan *et al.*, 2011) alongside previous search results.

### **Challenge 4: Support Collaborative Research**

Our results indicate that a literature search is not a solitary task but rather a process involving social collaborations. Furthermore, the survey confirmed that computer scientist prefer a literature search tool with integrated sharing and collaboration functionalities. The use of information recommended by colleagues is a well-known practice in the research community (Greenhalgh & Peacock, 2005). Even though separate tools exist for citation sharing and managing, such as Mendelay and Zotero, and systems such as BibSonomy<sup>2</sup>, where browser plug-ins are used to facilitate social bookmarking and publication sharing, we found that researchers would benefit more if citation sharing and

managing functionalities were integrated into literature search tools.

### **Challenge 5: Support Federated Searches Beyond Scholarly Research**

Both the observation studies and survey results suggested that computer scientists are not always looking for scientific articles; for some of their purposes they prefer more information in addition to articles. This was mainly due to the increased availability of resources that go beyond scholarly research material, such as encyclopedic sources, science blogs, and the web pages of top-notch researchers. Therefore generic web-search engines are equally important for scholarly information-seeking.

In order to provide better support to all the purposes that underlie literature searches, we need to allow federated searches that go beyond scholarly research, so that, depending on the purpose, researchers can receive information from different information sources. This could be implemented by going beyond scholarly databases and enabling users to selectively pick their preferred information source. One challenge that literature search tools can address is the intelligent detection of search purposes to allow dynamic selection of suitable information sources. Query intent classification is an active topic and several methods have been proposed to automatically classify queries in to the three types of user purposes identified for a generic web search: navigational, informational, and transactional (Brenes *et al.*, 2009). We identified a more specific classification for scholarly information-seeking. Therefore new information retrieval methods could be implemented to automatically detect the purposes of scholarly information-seeking.

### **Challenge 6: Navigation and Ranking Support**

Citation chaining (snowballing) and browsing through reputable forums are known to be the most common SLR techniques used by researchers (Greenhalgh & Peacock, 2005). Our results indicate that, for computer scientists, the most useful SLR technique is backward citation chaining.

At the moment some literature search tools, such as Google Scholar, provide support for forward citation chaining and the ACM digital library provides support for backward citation chaining. While these features are already supported, they are distributed across the services in such a way that users cannot use them jointly. Therefore we propose that literature search tools should provide support to both forward and backward citation chaining, as well as authoritative forum browsing. Authoritative forum browsing can be implemented by enabling the user to search by forum name and list all the articles published in the selected forum.

Our findings also indicate that sorting results based on the forum rank, year, and citation count is highly preferred by users and sorting by forum rank is the favorite. Sorting result lists by citation count and year is already supported in many search tools, but there is no support for sorting

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<sup>2</sup> <http://www.bibsonomy.org/>

results by the forum rank. We propose that literature search tools should provide an option to sort results by the ranking of the published forum. Therefore, if researchers are interested in navigating through top-ranked forums, then they can first use the option to sort results by forum ranking, select the top-ranked forum and navigate only through articles published there.

## SUMMARY AND DISCUSSION

Our study explored the main purposes of literature searches and their implications for the information-seeking behaviors of computer scientists. Our findings extend and deepen our knowledge about how to improve existing literature search tools to provide better support to users.

We found four purposes of research-based literature searches (keeping up to date, exploring new topics, reviewing literature, and collaborating) and two purposes of teaching-based literature searches (preparing lectures, recommending material for student reading) that characterize the information-seeking behaviors. Our objective was not to provide an exhaustive list of purposes but rather to identify the prominent ones that affect the information-seeking behavior of computer scientists. Since this study was focused only on computer scientists the findings should not be generalized. Further research is needed to comprehensively update the literature search purposes and related behaviors in ways that consider the differences in disciplines.

Our results show that staying up-to-date with research is the most frequently occurring search purpose. However, to stay up-to-date, researchers often browse conference/journal pages or the home pages of other researchers rather than using literature search tools. Vakkari (2006) reported that even though the proportion of frequent users of digital libraries has grown, it has not grown at the same pace as the use of digital resources. This may be explained by the fact that researchers are increasingly using material from other venues. We found that one of the reasons for using other channels is the lack of support provided by existing literature search tools to receive up-to-date information from diverse sources of scientific information. Therefore, if literature search tools provided better support for receiving up to date information, users would perhaps stick with them.

Tenopir (2003) found that academics follow other information in addition to scholarly publications. We found that the use of other information is dependent on the purpose of the search. For many purposes (exploring an unfamiliar topic, preparing lectures, and collaboration), researchers use generic web-search engines, reflecting the importance of diverse information channels that go beyond article databases. This further confirms that multidisciplinary article database support is no longer sufficient to satisfy interdisciplinary information needs. We proposed a useful future step for literature search tools; intelligent detection of the

search purpose and dynamic expansion of information sources.

Many of the findings of this research highlight the importance of extending our current understanding of literature search tools to include personalization and collaboration functions. Case study and survey findings indicate that computer scientists frequently search for information they have found before and they would like to receive updates from related forums, well-known and related authors, collaborators, and of fellow researchers. Through personalization literature search tools can support these functions (Sieg *et al.*, 2007). Many citation management tools already provide support for collaboration. Our results show that computer scientists are still in search of a literature search tool which provides integrated support for both collaboration and sharing tasks. Hence a single tool featuring a combination of functionalities, including searching, collaborating, and sharing information, would be preferable.

We showed that the frequency and difficulty of search purposes vary. Generally, we develop better skills in tasks that we perform frequently. But we found that researchers do not improve their skills in exploring new topics even with more practice. Our results further indicated that exploration is one of the most frequent purposes of literature search. Even though there is much research on supporting exploratory information retrieval, in scientific information retrieval this is still a big problem. This is a very important finding that literature search tools should take into consideration.

Our results show that backward citation chaining is the most frequently used literature review technique, while forward citation chaining and authoritative forum browsing are used for some specific purposes. Furthermore, computer scientists prefer sorting search results by the rank of the published forum. Since these features are scattered across different tools, there is still room for a tool which provides them jointly.

The findings presented in this paper will provide valuable cues for the improvement of existing literature search tools. There are some limitations to this work due to the small number of case study participants. We tried to compensate for this through 76 web-survey respondents, yet the overall number of participants is small and restricted to only computer scientists. However, these results could inform future work in this area and hopefully provide useful guidance for the design of literature search tools.

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## REFERENCES

- Brenes, D. J., Gayo-Avello, D., & Perez-Gonzalez, K. (2009). Survey and evaluation of query intent detection methods. *In Proc. of the workshop on Web Search Click Data*, 1-7.

- Brown, C. M. (1999). Information seeking behavior of scientists in the electronic information age: Astronomers, chemists, mathematicians, and physicists. *JASIST*, 50, 929-943.
- Dervin, B., & Reinhard, C. D. (2007). Predicting library, internet and other source use: A comparison of the predictive power of two user defined categorizations of information seeking situations—nature of situations versus situation “emotions” assessment. *Proc.of ASIST*, 44, 1-5.
- Firan, C. S., Georgescu, M., Nejdil, W., & Sun, X. (2011). FreeSearch-Literature Search in a Natural Way. *In Proc. of the Fifth Workshop on Human-Computer Interaction and Information Retrieval*.
- Gable, G. G. (1994). Integrating case study and survey research methods: an example in information systems. *European Journal of Information Systems* 3, 112-126.
- Greenhalgh, T., & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. *BMJ* 331, 1064-1065.
- Hemminger, B. M., Lu, D., Vaughan, K. T., & Adams, S. J. (2007). Information seeking behavior of academic scientists. *JASIST* 58, 2205-2225.
- Hightower, C., & Caldwell, C. (2010). Shifting sands: science researchers on Google Scholar, Web of Science, and PubMed, with implications for library collections budgets. *Issues in Science and Technology Librarianship* 63, 4.
- Jalali, S., & Wohlin, C. (2012). Systematic literature studies: Database searches vs. backward snowballing. *In Proc. of the ACM-IEEE international symposium on Empirical software engineering and measurement*, 29-38.
- Jansen, B. J., Booth, D. L., & Spink, A. (2008). Determining the informational, navigational, and transactional intent of Web queries. *Info. Proc. & Mang* 44, 1251-1266.
- King, W., Tenopir, C., Montgomery, C., & Aerni, S. (2003). Patterns of journal use by faculty at three diverse universities. *D-lib Magazine*, 9 (10). Retrieved January 20, 2013, from <http://www.dlib.org/dlib/october03/10contents.html>
- Kitchenham, B., Charters, S. (2007). Guidelines for performing Systematic Literature Reviews in Software Engineering. *Technical Report EBSE 2007-001, Keele University and Durham University Joint Report*, 1-57.
- Liew, C. L., Foo, S., & Chennupati, K. R. (2000). A study of graduate student end-users' use and perception of electronic journals. *Online Information Review* 24, 302-315.
- Marchionini, G. (2006). Exploratory search: from finding to understanding. *Communications of the ACM* 49, 41-46
- Navarro-Prieto, R., Scaife, M., & Rogers, Y. (1999). Cognitive strategies in web searching. *In Proc. of Conference on Human Factors & the Web* 5, 43-56.
- Nowell L., France R., Hix D., Heath L., & Fox E.(1996).Visualizing Search Results: Some Alternatives to Query-Document Similarity. *In Proc. of SIGIR* 19, 67-75.
- Nicholas, D., Huntington, P., & Jamali, H. R. (2007). Diversity in the information seeking behaviour of the virtual scholar: institutional comparisons. *The Journal of Academic Librarianship* 33, 629-638.
- Niu, X., & Hemminger, B. M. (2012). A study of factors that affect the information seeking behavior of academic scientists. *JASIST* 63, 336-353.
- Niu, X., Hemminger, B. M., Brown, C., Powers, A., & Cataldo, T. (2010). National Study of Information Seeking Behavior of Academic Researcher in the United States. *JASIST* 61, 869-890.
- Rowlands, I., Nicholas, D., Williams, P., Huntington, P., Fieldhouse, M., Gunter, B., *et al.* (2008). The Google generation: the information behaviour of the researcher of the future. *In Proc. of Aslib* 60, 290-310.
- Sieg, A., Mobasher, B., & Burke, R. (2007). Web search personalization with ontological user profiles. *In Proc. of ACM conference on Conference on information and knowledge management* 16, 525-534.
- Talja, S., Vakkari, P., Fry, J., & Wouters, P. (2007). Impact of research cultures on the use of digital library resources. *JASIST* 58, 1674-1685.
- Tenopir, C. (2003). Use and users of electronic library resources: An overview and analysis of recent research studies. Washington, D.C.: Council on Library and Information Resources. Retrieved January 20, 2013, from <http://web.utk.edu/~tenopir/eprints/index.html>
- Vakkari, P. (2006). Trends in the use of digital libraries by scientists in 2000-2005: A case study of finelib. *In Proc. of ASIST* 43, 1-17.
- Vakkari, P., & Talja, S. (2006). Searching for electronic journal articles to support academic tasks.A case study of the use of the Finnish National Electronic Library (FinELib). *Information Research* 12, 15.
- White, R. W., Kules, B., & Drucker, S. M. (2006). Supporting exploratory search, *Communications of the ACM*, 49(4), 36-39.