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Chang Liu
Department of Information Management
Peking University
China
imliuc@pku.edu.cn

Ying-Hsang Liu
Department of Archivistics, Library and Information Science
Oslo Metropolitan University
Norway
Ying-Hsang.Liu@oslomet.no

Jingjing Liu
M.D. Anderson Cancer Center
University of Texas
USA
jliujingjing@gmail.com

Ralf Bierig
Department of Computer Science, Hamilton Institute
Maynooth University
Ireland
ralf.bierig@mu.ie

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Search Interface Design and Evaluation

Chang Liu[1], Ying-Hsang Liu[2], Jingjing Liu[3] and Ralf Bierig[4]

[1] *Peking University; imliuc@pku.edu.cn*
[2] *Oslo Metropolitan University; Ying-Hsang.Liu@oslomet.no*
[3] *University of Texas; jliujingjing@gmail.com*
[4] *Maynooth University; ralf.bierig@mu.ie*

ABSTRACT

This monograph reviews research on the design and evaluation of search user interfaces that has been published within the past 10 years. Our primary goal is to integrate state-of-the-art research in the areas of information seeking behavior, information retrieval, and human-computer interaction on the topic of search interface. Specifically, this monograph (1) describes the history and background of the development of the search interface; (2) introduces information search behavior models that help conceptualize users' information needs, and how people seek, select, and use information; (3) characterizes the major components of search interfaces that support different subprocesses based on Marchonini's information seeking process model; (4) reviews the design of search interfaces for different user groups, especially that of vulnerable people, as well as personalized and adaptive search interfaces; (5) identifies evaluation methods of search interfaces and how they were implemented in research having different evaluation purposes. We also provide an outlook on the future trends of search interfaces including

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conversational search interfaces, search interfaces supporting serendipity and creativity, and searching in immersive and virtual reality environments.

1

Introduction and Historical Background

Information seeking and use is now routine in people's everyday lives. Searching through various information retrieval (IR) systems such as web search engines or search functions within information systems allows users to gain access to information on the Internet. Whereas most research in this area has focused on the algorithms behind the search engines from technical perspectives, an aspect vital to system development, in this monograph, we focus on the search interface, the place where searchers interact with the search system. In some books and research papers, 'search user interface' is the term used to highlight the human users of search systems and to emphasize how the search interface should be designed to be appealing to a wide variety of people (Hearst, 2009). In the current monograph, the terms 'search user interface' and 'search interface' are used interchangeably.

The design of search interfaces has had a long history. According to Hearst (2009, p. 1), the search interface supports the four main tasks users carry out, 'expression of their information needs', 'formulation of their queries', 'understanding of their search results', and 'keeping track of the progress of their information seeking efforts.' The development of search interfaces and the mode of interaction between the user and

the search interface have changed with increasing velocity along a spectrum of trajectories. The interfaces of search systems have evolved dramatically with the development of human-computer interaction (HCI) technologies. Search systems have become ubiquitous with both oral and visual communication channels and capable of being conversational and intelligent (White, 2018). Search activities are often considered easy tasks for users, but increase in difficulty with more demanding types of search tasks. That is, fact-finding and navigational tasks are easier to accomplish than complex learning or exploratory tasks. The search interfaces ideally should be able to help users resolve a wide range of information problems in both their working and living environments, and support users in finishing the entire work task or achieve their information goals, not only support the search aspect. The design of search interfaces needs to consider users' complete search process, be informed by the theories and practices of user search behavior, and apply appropriate technologies to accommodate different groups of users in various contexts.

This monograph aims to present a comprehensive review of the design and evaluation of search user interfaces in the last decade. Since there are several comprehensive reviews of search user interfaces from 2009-2012, (*e.g.*, Hearst, 2009; Wilson, 2011; Russell-Rose and Tate, 2013), there is no need to go back further. In the past 10 years, studies in information science, IR, and HCI have had a better understanding of users' search interactions, including cognitive and behavioral mechanisms in the search process and the implementation of new technologies, such as automatic speech recognition, virtual reality (VR), and artificial intelligence (AI), to support informational activities and sensemaking. Through our review of recent contributions in related disciplines for the design of search interfaces, we hope to shed light on how to better apply the newly developed technologies to solve users' information problems in the workplace and in their everyday lives.

This section first presents a brief history of search interfaces; it then reviews previous review books and important review papers on search interfaces. The section closes with a description of the scope of this review and the structure of the following sections.

1.1 The History of the Search Interfaces

Search interfaces are the place where users interact with search systems. However, the first large-scale operational IR systems were non-interactive (Cool and Belkin, 2011). For example, the Medical Literature Analysis and Retrieval System (MEDLARS), which was launched in 1964, only allowed the submission of requests to be queued at the National Library of Medicine for groups of searches against tapes. Thus, there was no interaction between end-users and the retrieval system at this stage. Real interaction did not happen until some sort of terminals were provided and users were connected to search systems online. For example, Medline replaced MEDLARS and began to provide search services to end-users in 1972. Later, there was a worldwide movement in libraries to replace card catalogs with online public access catalogs (OPACs). The retrieval systems and search interfaces were rooted in the field of Library and Information Science. The retrieval systems were designed to help users to retrieve documents from document collections or libraries, a task typically done by librarians. Many researchers agree that OPACs were the first type of end-user IIR systems (Savage-Knepshield and Belkin, 1999; Borlund, 2013). Therefore, the review of the early stage of search interfaces included both retrieval systems and OPACs.

This section reviews several interaction styles of search interfaces as they appeared chronologically in the early years before the modern search interfaces for web search engines had appeared. These four interaction styles are command-language interaction style, form fill-in interaction style, menu-driven interaction style, and direct manipulation interaction style (Borlund, 2013; Shneiderman *et al.*, 1997). For a list of the interactions they supported, see Table 1.1. The development of these four interaction styles demonstrated that end-users were being given more functions and options to interact with the search interfaces throughout the history of the design of search interfaces (Kelly, 2015).

1.1.1 Command–Language Interaction Style

At the beginning of the design of search systems, roughly from the mid-1960s to the mid-1970s, command–language interaction was the sole

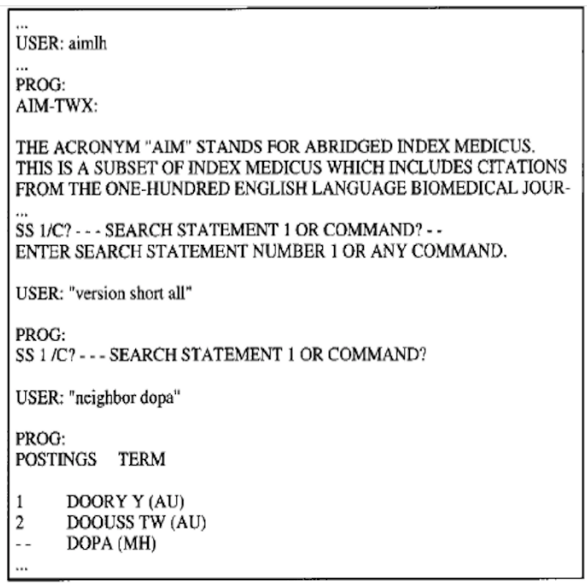
Table 1.1: Four interaction styles of search systems

Interaction style	Example search systems	New techniques to support users' interactions
Command-language interaction style	AIM/TWX, DIALOG, MEDLARS, NASA/RECON, the SMART system, The Biomedical Communication Network	• Display of online thesauri to help with query formulation; • Choice of novice or experienced searcher interface mode; • Ability to save search queries to rerun at a later time or on a different database; • Relevance feedback • System prompts for further information from user about his/her information need.
Form fill-in interaction style	THOMAS system	Adopted a cognitive viewpoint; engage users directly with texts; base user-system interaction around feedback
Menu-driven interaction style	RABBIT system	Provide selections from multiple commands
Direct manipulation interaction style	TileBars, book house fiction retrieval system	Provide visual representation

style of search interfaces due to the constraints of information technology. Command-language interfaces required searchers to construct search formulation phrases or sentences to search within an explicit framework of system files and commands. During this period, several operational IR systems were designed and developed, for example, AIM/TWX, DIALOG, MEDLARS, NASA/RECON, the SMART system, and the State University of New York (SUNY) Biomedical Communication Network (Walker, 1971).

Figure 1.1 is a sample dialogue from the AIM/TWX system, which shows the representation of the command-language interface during that period (Katter and McCARN, 1971). In this system, searchers could enter either a search statement or a command. In this example, the user first typed the command "aimlh", which invoked the display of an explanation of AIM. The user then entered another command "version

short all" to which the system responded by showing the abbreviations of all routine system messages. Next, the searcher entered "neighbor dopa", and the system responded with a list of the neighboring terms of the term "dopa" retrieved from the index.



```
...
USER: aimlh
...
PROG:
AIM-TWX:

THE ACRONYM "AIM" STANDS FOR ABRIDGED INDEX MEDICUS.
THIS IS A SUBSET OF INDEX MEDICUS WHICH INCLUDES CITATIONS
FROM THE ONE-HUNDRED ENGLISH LANGUAGE BIOMEDICAL JOUR-
...
SS 1/C? - - - SEARCH STATEMENT 1 OR COMMAND? - -
ENTER SEARCH STATEMENT NUMBER 1 OR ANY COMMAND.

USER: "version short all"

PROG:
SS 1 /C? - - - SEARCH STATEMENT 1 OR COMMAND?

USER: "neighbor dopa"

PROG:
POSTINGS    TERM

1       DOORY Y (AU)
2       DOOUSS TW (AU)
- -     DOPA (MH)
...
```

Figure 1.1: Sample dialogue from AIM/TWX

The search interface for the DIALOG system was a question-answer negotiation process. It provided a command input function for well-defined information needs and also provided a browsing function (the so-called "expand" function on the interface). After clicking this function, the interface showed terms that were alphabetically near to the search term in the query with the intent to help searchers better understand their information needs. The NASA/RECON system also provided an "expand" function for searchers and showed the thesaurus structure of related terms in the query.

During that time, Boolean operators were adopted in the retrieval algorithms, but some search interfaces, like the SUNY system, concealed the use of the underlying Boolean expressions by asking in a prompt window, "Do you want to add another subject to this group?" This was

the first implementation of this kind in search interface design that did not force searchers to formulate a command as a query.

Even though the IR was only able to support searchers with the specific information they wanted, researchers realized searchers' queries, especially the original queries, were often inadequate. Researchers desired to know more of users' interactions with the IR systems, but in the meantime, suggested librarians "show searchers a few books in an attempt to pinpoint searchers' needs" (Ide, 1967; Ide, 1969).

By the middle of the 1960s, several interface techniques had been introduced to assist end-users (Kelly, 2015), including:

- Displaying online thesauri to help with query formulation (*e.g.*, the DIALOG system and the NASA/RECON system);
- Providing a choice of novice or experienced searcher interface mode (*e.g.*, the DIALOG system);
- Concealing the use of Boolean expressions (*i.e.*, AND, OR, NOT) during query formulation by prompting users with questions, such as "Do you want to add another subject to this group?";
- Enabling the saving of search queries to be rerun at a later time or on a different database (*e.g.*, the SMART system);
- Providing relevance feedback (*e.g.*, the SMART system);
- Adding system prompts for further information from the user about his/her information needs (*e.g.*, the SUNY Biomedical Communication Network).

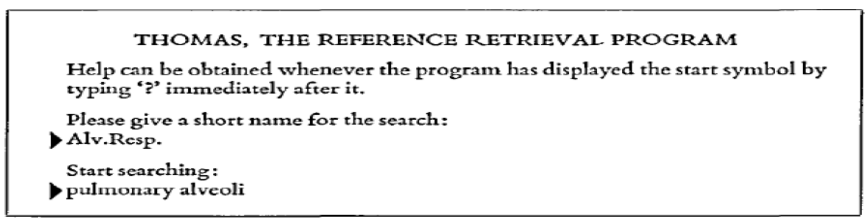
In 1971, the first workshop about interactive search interfaces was held (Bennett and Walker, 1971). In this workshop, Bennett presented his challenge paper, proposing questions on how to design search interfaces to support various levels of user expertise, the conceptual framework of the appropriate level of interactions that search interfaces should support, and how to evaluate search interfaces and IR systems from the users' perspective. Bennett's design challenges continue to guide and influence research and practice in user-system interaction to

this day, and have led to substantial progress in the development of search interface design.

1.1.2 Form Fill-in Interaction Style

From the mid-1970s to the mid-1980s, designers of search interfaces believed that a reference retrieval system should aim to "help the user to make choices from among unseen documents" (Oddy, 1977). Most of these retrieval systems were designed to target novice searchers (Savage-Knepshield and Belkin, 1999). It was during this period that the form fill-in interaction type emerged, the THOMAS retrieval system being one such example. Users could interact with the system by inputting simple statements through dialogues. During this stage, IR was completed through a man-machine dialogue. An example retrieval process is shown in Figure 1.2 to Figure 1.5.

The THOMAS system was one of the first experimental IR systems that adopted a cognitive viewpoint in its design. Searchers could engage in a dialogue about their ill-defined information problem using this system. THOMAS is notable for being the first interactive IR system to engage users directly by way of texts and to base user–system interaction around feedback.


THOMAS, THE REFERENCE RETRIEVAL PROGRAM

Help can be obtained whenever the program has displayed the start symbol by typing '?' immediately after it.

Please give a short name for the search:
▶Alv.Resp.

Start searching:
▶pulmonary alveoli

Figure 1.2: THOMAS system Homepage and an example first query

1.1.3 Menu-Driven Interaction Style

Form fill-in interaction style required searchers to understand field labels and know the permissible values for the fields. Comparatively, another style, the menu-driven interaction style, was more appropriate for novice

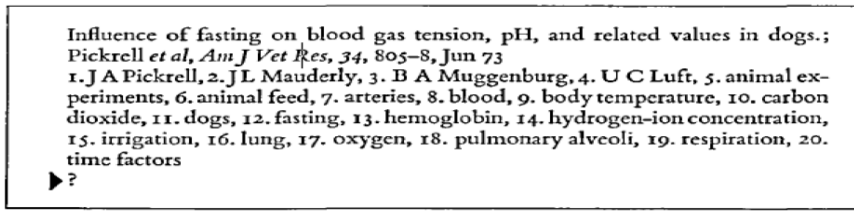
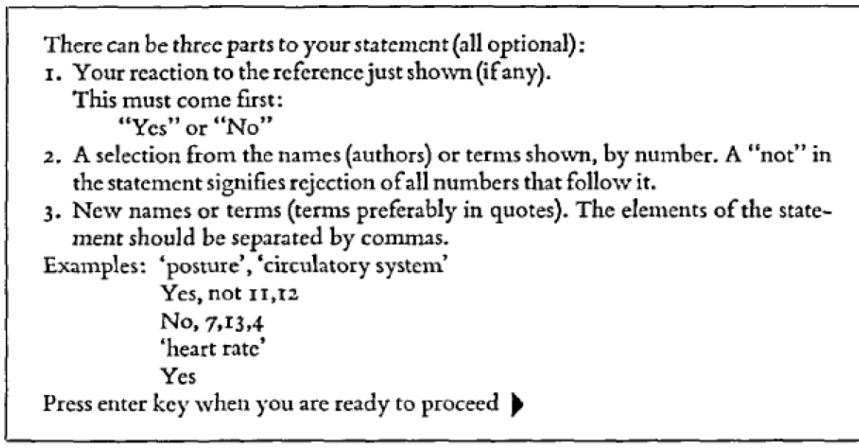

Influence of fasting on blood gas tension, pH, and related values in dogs.; Pickrell *et al*, *Am J Vet Res*, *34*, 805–8, Jun 73
1. J A Pickrell, 2. J L Mauderly, 3. B A Muggenburg, 4. U C Luft, 5. animal experiments, 6. animal feed, 7. arteries, 8. blood, 9. body temperature, 10. carbon dioxide, 11. dogs, 12. fasting, 13. hemoglobin, 14. hydrogen-ion concentration, 15. irrigation, 16. lung, 17. oxygen, 18. pulmonary alveoli, 19. respiration, 20. time factors
▶?

Figure 1.3: The reference presumed to be of the most interest to the searcher is shown, together with a series of associated terms or author names


There can be three parts to your statement (all optional):
1. Your reaction to the reference just shown (if any).
   This must come first:
   "Yes" or "No"
2. A selection from the names (authors) or terms shown, by number. A "not" in the statement signifies rejection of all numbers that follow it.
3. New names or terms (terms preferably in quotes). The elements of the statement should be separated by commas.

Examples: 'posture', 'circulatory system'
Yes, not 11,12
No, 7,13,4
'heart rate'
Yes

Press enter key when you are ready to proceed ▶

Figure 1.4: Assistance interface available upon searchers' request

searchers, providing searchers with a limited number of options to choose from during their search process. The RABBIT system (Tou *et al.*, 1982) is an example of this type. As shown in Figure 1.6, after entering a query, the searcher could enter attribute values. In response to the query, the system displayed one example instance from the database in detail along with a menu containing all other matches. To refine a query, the searcher would select an attribute to modify his query and then choose from five commands displayed in a pop-up menu in a context-sensitive manner as appropriate for that specific attribute. The provision of the labels on the menus of the search interface helped significantly in reducing the users' cognitive load by swapping recall memory tasks with recognition tasks from a list of options so that searchers could focus more on their

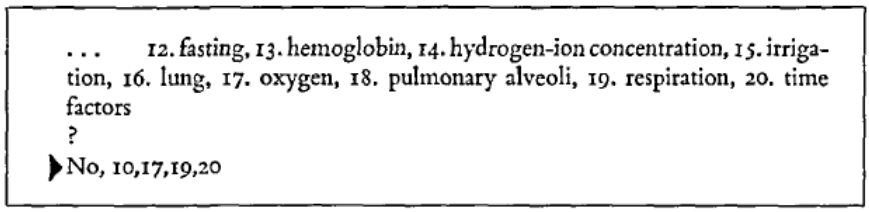


Figure 1.5: The searcher's sample reply to the dialog after he is done with the instruction

searching tasks (Shneiderman, 1983).

1.1.4 Direct Manipulation Interaction Style

The direct manipulation interaction style (Shneiderman, 1983) was implemented by a hypertext approach characteristic of the Berry-picking model (Bates, 1989; Bates, 1990). This, coupled with the advent of the graphical user interface (GUI), provided more flexibility and control for end-users during their search resulting in the use of retrieval systems by more and more untrained novices. A wealth of research examined the effects of the individual characteristics on users' search performance and search interactions in a quest to learn how to design IR systems that could better accommodate individual differences through interactions and search interfaces.

The appearance of the GUI near the end of the 1980s have made search interfaces more interactive since that time. The BookHouse fiction retrieval system designed by Pejtersen (1989) was an icon-based retrieval system designed to support casual novice users in their search for fiction books. On the homepage, the searcher was presented with a picture of a house built of books, a visualization of the public library environment (Figure 1.7). The left room had books for children, the right room had books for adults while the center room had books for both. The direct manipulation interaction features allowed the user to click directly on the figures executing different strategies as he/she usually did in a physical library. Novice searchers were able to self-explore the search system without extra training.

This brief review of the history of search interfaces demonstrates

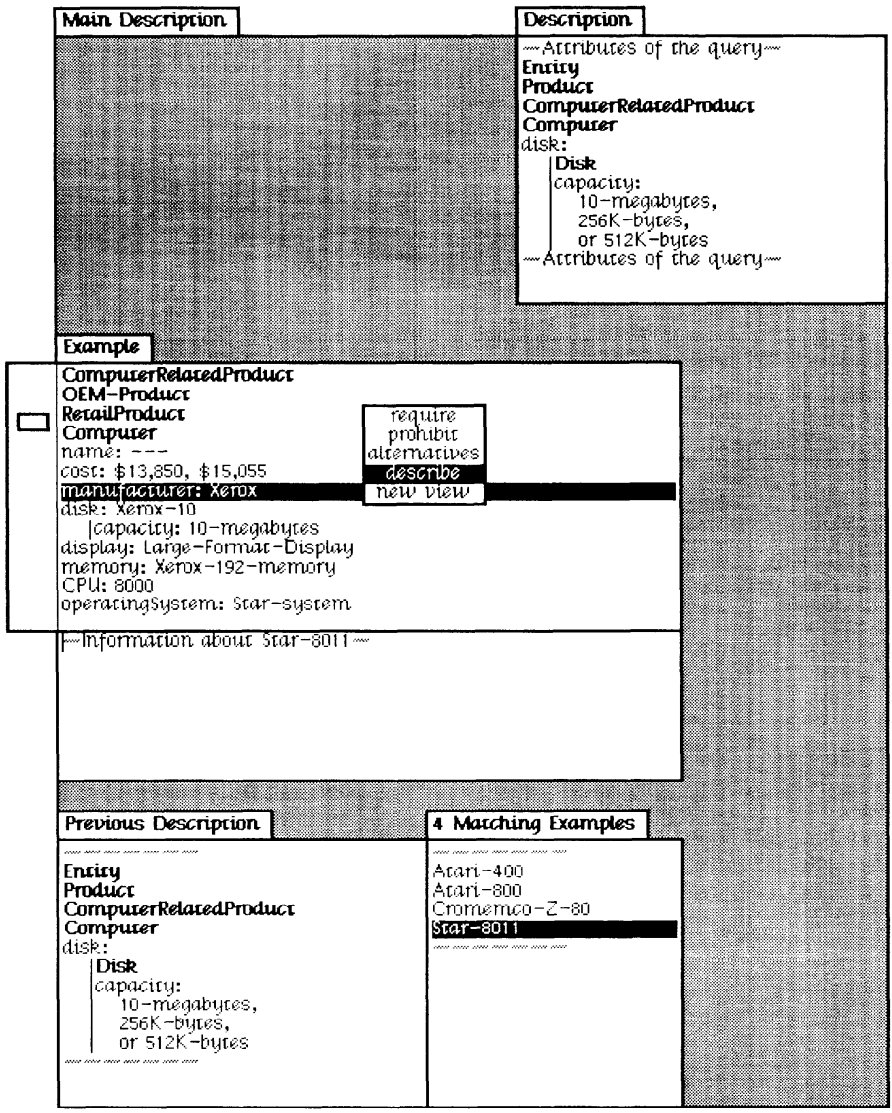


Figure 1. RABBIT Screen Display

Figure 1.6: A screenshot of the RABBIT system

that search systems have experienced a movement from a technology-dominated stage to a user interactive mode. The GUI and other display techniques in HCI have advanced the research and implementation of search interfaces of retrieval systems.

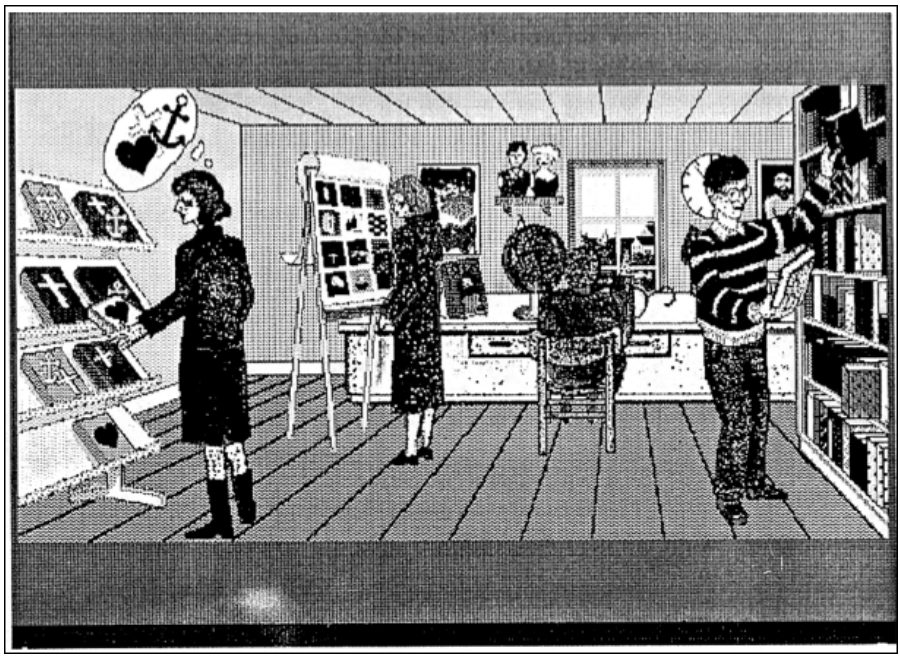


Figure 1.7: One of the search interfaces of the BookHouse fiction retrieval system

1.2 Previous Review on Search Interfaces

Ever since the first workshop on search interfaces was held in 1971, "The User Interface for Interactive Search of Bibliographic Data Bases" (Bennett and Walker, 1971), great progress has been made in the development of search interfaces resulting in them being more effective and efficient for end-users. In this workshop, Bennett and Walker (1971) were the earliest in paying serious attention to the interactive properties of IR and proposed a set of design challenges to researchers in the field. Of the several important review books and articles on search interfaces in the 1990s, the review written by Savage-Knepshield and Belkin (1999)

took the 'Bennett challenge' as a guiding framework and reviewed the historical development of search interfaces from the 1960s to the end of the 1990s.

Search User Interfaces (Hearst, 2009) was the first academic book to focus on the search user interface. It provided a comprehensive review of the human side of the information seeking process, described the methods for search interfaces design and evaluation, and discussed research results surrounding various components of search interfaces, (*i.e.*, query specification and query reformulation, the display of search results, grouping retrieval results, navigation of information collections, search personalization, and the broader tasks of sensemaking and text analysis). Max L. Wilson (2011) wrote a review shortly after that in 2011 highlighting the more complicated and exploratory scenarios that led people to search and to evaluate whether their search was successful. In this book, Wilson reviewed a large number of search user interface features and designs, and explored how they could support searchers with different kinds of intentions. The search features that Wilson reviewed were classified into four categories: input features, control features, informational features, and personalizable features. Russell-Rose and Tate (2013) published their book from the information architecture perspective, in which they reviewed theories in information seeking and wove that with the practice of search user interface design. They applied the principles of user-centered design not only to the search box and to the display of search results, but also extended it to faceted navigation, mobile interface, social search, and so on, and on multiple devices, such as desktop, tablet, mobile, and others.

In this decade, we have seen the widespread usage of search services by online searchers in more complicated and exploratory scenarios, accessing more diverse online resources and websites, and being initiated from various interactive devices. Besides the comprehensive review of search interfaces, there have also been several review books on specific topics of search, for example, faceted search by Tunkelang (2009). Faceted search has been prevalent in online information access systems, particularly for e-commerce and site search. Tunkelang (2009), in his review of its history, theory, and practice, states that faceted search is based on the faceted classification of information, which could also be a

fundamental theory of knowledge organization in all kinds of representation and discovery tools (Broughton, 2017). In addition, since working in collaboration to perform information-seeking tasks has become more and more common, Hansen *et al.* (2015) provided a collection of best practices and studies in the field of collaborative IR and search.

In 2017, Ryan White (2016) published his comprehensive review book, *Interactions With Search Systems*, which summarizes the current state of many empirical studies on search interactions, but is not particularly about search interfaces. He also cast an eye toward the future of search systems forecasting that the next generation search systems will go beyond the query-response paradigm and will provide more reactive, proactive, and iterative experiences to searchers given the advances in technologies such as speech recognition and computer vision, new interaction capabilities such as touch and gesture, the emergence of cloud computing, and the democratization of AI. As these technologies will also be sure to influence the future development of search interfaces, we think it is timely and necessary to provide an update on the subject of search interfaces, in particular, one that focuses on the recent developments and new applications of the past 10 years.

1.3 Scope

Since both Hearst (2009) and Wilson (2011) have provided extensive reviews on how users search and interact with search systems and the design of search systems before the year 2010, the current review will focus, in particular, on recent developments and new applications of search interfaces in the past decade. Search interface design is an interdisciplinary field which involves information-seeking behavior research in information science, IR in computer science, HCI, and human-centered computing. We will try to include the research from all of the above areas and other related areas as well that focus on how to implement search interfaces 1) for more complicated and exploratory searches, 2) in different domains and for different groups of users, and 3) with the help of the advances in new technologies, as well as 4) how to evaluate users' experience with search interfaces.

The structure of this review is as follows: Section 2 provides related theories and models in information seeking and search behaviors, and more importantly, it includes recent discussions on the application of work tasks and search tasks in search interface design. These theoretical developments help us build the framework on which to support users' search processes through search interfaces. Section 3 then explains how search interface features are designed to support different search processes, namely, the searching process, the browsing and selection process, and the process of working with the information. Section 4 begins to consider search interface design for different groups of people, for various domains, and on different devices, issues which have not been fully reviewed in previous review books since these advances have been recent, mainly occurring within the past 10 years. Section 5 details the methods for evaluating search interfaces including evaluation approaches, evaluation measures, and other concerns. The last section, Section 6, discusses the search interfaces of next-generation search systems which may incorporate and implement more advanced technologies, for example, physiological signal-based search interfaces, gaze-based search interfaces, gesture-based search interfaces, adaptive interfaces, conversational interfaces, and searching in immersive and VR environments.

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