From Multistage Information-Seeking Models to Multistage Search Systems

Hugo C. Huurdeman
University of Amsterdam
The Netherlands
h.c.huurdeman@uva.nl

Jaap Kamps
University of Amsterdam
The Netherlands
kamps@uva.nl

ABSTRACT

The ever expanding digital information universe makes us rely on search systems to sift through immense amounts of data to satisfy our information needs. Our searches using these systems range from simple lookups to complex and multifaceted explorations. A multitude of models of the information seeking process, for example Kuhlthau's ISP model, divide the information seeking process for complex search tasks into multiple stages. Current search systems, in contrast, still predominantly use a "one-size-fits-all" approach: one interface is used for all stages of a search, even for complex search endeavors. The main aim of this paper is to bridge the gap between multistage information seeking models, documenting the search process on a general level, and search systems and interfaces, serving as the concrete tools to perform searches. To find ways to reduce the gap, we look at existing models of the information seeking process, at search interfaces supporting complex search tasks, and at the use of interface features over time. Our main contribution is that we conceptually bring together macro level information seeking stages and micro level search system features. We highlight the impact of search stages on the flow of interaction with user interface features, providing new handles for the design of multistage search systems.

Categories and Subject Descriptors

H.3.3 [**Information Storage and Retrieval**]: Information Search and Retrieval—*Search process*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Theory and methods*

General Terms

Design, Experimentation, Human Factors

1. INTRODUCTION

In the current, information-abundant age, search plays a pivotal role in our daily lives: we encounter, explore and acquire information via online search systems. The range of activities performed via search systems is steadily increasing, and performed interactions range from simple lookups to multifaceted and complex searches, during sessions spanning minutes, seconds, hours, or even days. The more complex interactions might include different phases, and involve learning and construction.

Models of the information seeking process, such as Kuhlthau's ISP model [28], divide the search process for complex search tasks into multiple 'stages,' which occur over a period of time. However, current search systems are mainly using a "one-size-fits-all" approach: one interface is used in all stages of the search process. Therefore, the search process of the user might not be adequately supported in the context of complex search tasks [9, 22, 25, 26, 64, 68]. However, so far, information seeking literature has not been very specific in discussing concrete support for search stages, and few systems explicitly supporting multiple search stages are in existence (discussed below). Hence, the main aim of this paper is to bridge the gap between multistage information seeking models and multistage search systems and user interfaces.

In this paper, we look conceptually at different ways to divide the information seeking process in the context of complex tasks into multiple stages and at how these stages could be supported by systems. We summarize literature from different fields related to search stages and user interfaces for complex search, and discuss their implications for multistage search systems. To gain further insights on possible stage influence on search features, we look at the temporal use of interface features in search user interfaces (SUIs). Finally, we discuss potential ways to support stages in a system: an open question is whether these should be supported in elementary interfaces, single stage feature-rich interfaces, or in multistage interfaces providing search stage-specific support for complex search tasks.

This paper investigates the following research questions:

RQ1 What are the conceptual implications of multistage information seeking models for the design of search systems?

Using available literature, we introduce different types of information seeking models characterizing the search process over time, and discuss the implications of distinguishing information seeking stages for search systems.

RQ2 How do current search user interfaces support the information seeking process in the context of complex tasks?

We discuss user interface frameworks, various search user interface paradigms and concrete interfaces in the context of cognitively complex tasks. This will provide insights into currently employed strategies in search interfaces to support users' complex search interactions, and their broader information seeking behavior.

RQ3 To what extent does the search stage influence the flow of interaction at the interface level?

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

IIiX '14, August 26 - 29 2014, Regensburg, Germany

Copyright is held by the owner/author(s). Publication rights licensed to ACM.

ACM 978-1-4503-2976-7/14/08 ...$15.00
http://dx.doi.org/10.1145/2637002.2637020 .

To investigate whether concrete search features are used differently over information seeking stages, we study existing literature and analyze the use of SUI features using eye tracking and log data collected in a previous user study, and subsequently discuss the implications for search systems.

The remainder of the paper is organized as follows: first, we look at models of the information search process, which divide the search process in different stages (Section 2). In Section 3, we look at frameworks of search user interface features and existing SUI paradigms. Section 4 discusses previous research that provides indications of the use of features in different stages, and newly analyzed data from a user study using a 'digital bookstore.' Section 5 contains the discussion and conclusions of this paper.

2. MULTISTAGE INFORMATION SEEKING MODELS

In this section, we study RQ1: What are the conceptual implications of multistage information seeking models for the design of search systems? A very large body of work captures research on users and their search process. Here, we look at models documenting the multistage search process, mainly from the fields of Library and Information Science and (Interactive) Information Retrieval. We discuss the models' consequences for search stages, and potential implications for multistage user interfaces.

2.1 Information Seeking Models

Information behavior is a broad concept, defined by Wilson [69] as "the totality of human behavior in relation to sources and channels of information, including both active and passive information seeking, and information use." For the purposes of this paper, we focus on information seeking, a subset of information behavior in Wilson's nested model of research areas [69]. It is defined by Ingwersen and Järvelin [25] as "human information behavior dealing with searching or seeking information by means of information sources and (interactive) information retrieval systems." Information searching, in it's turn, is a subfield of information seeking in Wilson's nested model, and specifically focuses on the interaction between information user and information system [69].

The process of information seeking can be modeled in a large number of ways, depending on the used perspective, and therefore has been described in a multitude of models, "frameworks for thinking about a problem" [69]. In the context of information seeking, examples of models are Kuhlthau [28]'s Information Search Process model,[1] Ellis [17]'s behavioral model, Foster [19]'s nonlinear model of information seeking, and Wilson [69]'s Problem Solving Model. These models shed light on different aspects of information seeking, using different approaches. For example, Ellis' behavioral model consists of information seeking patterns, that are "not meant to indicate a fixed sequence of events," but which interact in various ways [17], while Kuhlthau's process model uses a more sequential approach, consisting of search stages. In this paper, we have chosen to focus on the latter, temporally-based model [7], so we use Kuhlthau's Information Search Process model and Vakkari's adaptation of this model [60] as our framework.

In this paper, our focal point is on cognitively complex tasks, which can be carried out in work settings, but also in educational or daily life settings. In complex tasks, as Bystrom and Järvelin [10] indicate, "understanding, sense-making, and problem formulation are essential, and require different types and more complex types of information." Tasks can be categorized in different ways, for example based on complexity, but also based on their specificity or nature, e.g. *exploratory* versus *lookup* tasks [66]. Employed tasks can have a considerable effect on information seeking behavior [59], and can be viewed on different levels: *search tasks* are usually contained in larger *work tasks*,[2] which in their turn are contained in a particular *environment* [54]. In this paper, we look at search tasks and overarching work tasks. Both Kuhlthau's and Vakkari's models, discussed next, have mainly been constructed based on longitudinal examinations of particular "information-intensive, constraint-based" work tasks [54]: the preparation of papers and research proposals by students.

[1]Despite the name, this is an information *seeking* model, as is also pointed out by Cole [12].

Table 1: Kuhlthau's search stages, adapted from [33]

Stage	*Description*
1. Initiation	becoming aware of a lack of knowledge or understanding, often causing uncertainty
2. Selection	identifying & selecting general area, topic or problem, sense of optimism replaces uncertainty
3. Exploration	exploring & seeking information on the general topic, inconsistent info can cause uncertainty
4. Formulation	focused perspective is formed, uncertainty is reducing, while confidence increases
5. Collection	gathering pertinent information to focused topic, less uncertainty, more interest/involvement
6. Presentation	completing the search, reporting and using results

2.2 Kuhlthau's & Vakkari's Models

Information Search Process Based on several longitudinal studies (e.g. [29, 30]), Carol Kuhlthau developed a multistage model of the Information Search Process (ISP) [28], which "depicts information seeking as a process of construction". Kuhlthau's model is descriptive, documenting "common patterns in users' experience in the process of information seeking" for complex tasks requiring construction and learning, with a discrete beginning and ending [33]. So far, as Case [11] indicates, the model has been predominantly applied in the context of education. In this setting, the students participating in the studies generally have a lower domain knowledge than in work tasks carried out by domain experts, potentially influencing the initial (exploration) stages of the tasks. However, similar stages were observed in studies with a securities analyst and lawyers performing complex work tasks "that require extensive construction of new knowledge" [32, 34].

The ISP model consists of six stages: *initiation*, *selection*, *exploration*, *formulation*, *collection* and *presentation* (see Table 1 for details). Upon introduction, a novel aspect of this model was the inclusion of affective aspects, together with the cognitive and physical aspects (the interplay of thoughts, feelings and actions) [33]. Uncertainty is one of the key concepts in this process, often initiating the information seeking process, and fluctuating as a person moves through different stages of their search process, encountering different kinds of information. This concept of uncertainty has been further operationalized and tested by Wilson et al. [70].

Task-based IR Process In 2001, Vakkari refined Kuhlthau's model in the context of Information Retrieval (IR) into a tentative theory of the task-based IR process [60], based on a longitudinal study with twelve students ([57, 58, 61]). Here, he refined concepts used by Kuhlthau in the context of task performance, and summarized Kuhlthau's six stages into three categories: *pre-focus* (Kuhlthau's

[2]Here, we use Ingwersen and Järvelin [25]'s definition of work task, which includes includes both professional (e.g. job-related) and daily life tasks.

stage 1, 2 and 3), *focus formulation* (stage 4), and *post-focus* (stage 5 and 6). Vakkari emphasizes the crucial role of finding a focus in the search process. In the pre-focus phase, thoughts are "general, fragmented and vague", and it is hard for a searcher to express concretely what information is needed. After forming a focus, the search is more directed, leading to more relevant information being sought for. Finally, in the post-focus phase, searches are more specific; this phase might also include rechecking for additional information [61]. There is a high degree of similarity between Kuhlthau's and Vakkari's findings. Subsequent testing of Vakkari's theory confirmed its validity, but also indicated that the experience of searchers should be included in the theory's scope [62].

2.3 Consequences of Search Stages

Given the large amount of empirical support for the models discussed in the previous section, clear indications exist that there are different stages in the search process of users in the context of complex tasks. A key question is whether there are also differences in the interaction with (interactive) information retrieval systems in these stages. While Kuhlthau looked less at the implications of the search stages on IR systems, Vakkari studied some of these effects of task stages. He demonstrated that the *information sought* for, the *relevance* and the *search tactics, terms and operators* varied during different stages.

Information sought In Kuhlthau's model, information sought, in the context of a term paper assignment, converges from *general* (background) information in the first stages, to *specific* (relevant) information in the middle and to *pertinent* information (related to the focused topic) in the final stages [32]. A user encounters high uniqueness (new information) and low redundancy (familiar information) of found documents in the beginning, while the final stages are characterized by the opposite: low uniqueness and high redundancy.

Vakkari provides a more precise, and slightly altered conception of information looked for in different stages: in the beginning (pre-focus stage) users mostly search for *general background information*, including models and conceptualizations of the topic. In the focus formation stage, the information sought is mostly *faceted background information* (broad sub-fields of the topic), and texts with methodological advice and examples about cases. Finally, in the post-focus stage participants in the study were searching mainly for *specific information* [60]. Hence, as previously observed by Kuhlthau, the information sought for evolves during different stages.

Relevance Relevance is a key aspect in the context of IR and IR research. There are many factors influencing the relevance of a certain document to a user, and many relevance criteria can be distinguished (see e.g. [48]).

One of the factors influencing relevance judgements by users is their stage of search. As Vakkari indicates [58], in the beginning of the search process, the ability of the study's participants to differentiate between relevant and irrelevant material is low, due to unstructured mental representations of the topic. As evidenced by other studies as well [42, 52, 61, 62], if users know less of the topic, they are uncertain if a source is relevant or not, and they judge more documents as partially relevant.

Other research has looked at the categories of relevance criteria used in different stages of the search process. Vakkari studied the relevance criteria in different search stages, of which 'topicality' and 'interest' evolved considerably [61]. In a larger study, Arthur Taylor et al. did not find significant differences for 'interest', but 'specificity' and 'source novelty' did vary significantly during different stages [53]. Hence, the categories of relevance criteria are dynamic, and evolving through the various stages. The studies also show that the notion of relevance is quite complex, and the different settings of the studies make them hard to compare.

Search tactics, terms and operators In both models, an assessment is made of the search terms, operators and tactics used by searchers. Kuhlthau indicates that the "searcher's ability to express precisely what information is needed grows", while the "degree of efficient and effective interaction between the system and the user increases", without going into specific details. More concretely, Vakkari [60] observes that the number of search terms used increases, and the number of synonyms, narrower terms and related terms increases, while the number of broader terms decreases. In this study, he concludes that the searchers are using a "larger and more specific vocabulary" in successive searches, coupled with an increased usage of operators.

A search tactic, as defined by Bates [4], is a "move made to further a search." In Kuhlthau's model, search tactics could be classified as browsing and querying [60], while Vakkari, in his theory, makes use of a much larger classification, consisting of 12 tactics; in the study sample of eleven students in Information Studies, evidence was found that the used tactics evolved during the different stages. Another study by Vakkari et al. [62], in the context of psychology students, however, did not show all of these tendencies (which might also be caused by other experimental factors and the participants' search experience).

2.4 Implications for Multistage Interfaces

In this section, we have looked at the conceptual implications of multistage information seeking models for search systems. In terms of impact, Kuhlthau [31] puts forward that her ISP research and model has had "considerable impact" on library and information services, but "little impact" on IR systems' design. Without providing clear guidelines on how to implement them, she mentions that different concepts could be used in the design of IR systems, like the *process* concept, the *uncertainty* principle, the relation between *uniqueness* and *redundancy*, the *mood* or stance of an individual in the process, user's evolving *interest*, *complexity* and the concept of *enough* in solving a problem. Further guidance in Kuhlthau's work [32] includes the advice for information systems to not "overwhelm the users" in the beginning: new tools provide access to a large number of sources and therefore intensified users' confusion and uncertainty. A few "well-chosen introductory pieces" might be better in the first (orientation) search stages.

Similarly, Vakkari [58] emphasizes that "more support is needed in the initial stages of a task," when users have an unstructured mental model. At this stage, users are building up their knowledge frame of a topic, which is needed before focus formulation can take place [12]. Sources containing background information, conceptualizations and frameworks about the topic might be useful at the early stages, in addition to links to sources of general information (e.g. textbooks, encyclopedias and reviews). Several studies, by Vakkari and others have also indicated that relevance changes during different search stages. It is hard for searchers to judge relevance in the first stages, and criteria of relevance evolve, i.e. important relevance criteria in the beginning might be less important at the end of the process. Finally, evidence exist that the search tactics, the search terms and operators used evolve over time, at least for experienced searchers.

In terms of our main aim to explore ways to bridge the gap between multistage information seeking models and search systems, we observe the following. From the perspective of information seeking, Kuhlthau and Vakkari have thoroughly described and validated the multistage nature of the search process, but they have provided less handles to actually implement system support for these stages and their temporal progression. As their models describe the information seeking process more on a *macro* level, it can be hard to implement specific system and interface features guided by the models' implications at the *micro* level [69]. Our main conclusion in this section is that there is a good general understanding of the information seeking stages at the macro level, but that the translation into system and user interface design choices at the micro level remains unsolved. In the next section, we look at search interfaces supporting complex search tasks, and whether they incorporated the multistage information seeking process.

3. USER INTERFACES SUPPORTING INFORMATION SEEKING

In this section, we study RQ2: How do current search user interfaces support the information seeking process in the context of complex tasks? After studying multistage information seeking from a conceptual angle in the previous section, we now focus on search user interfaces, and interface features that can provide support in various search stages. The following sections focus on SUI frameworks, SUI interface paradigms and features, from the fields of Interactive IR and Human-Computer Interaction (HCI).

3.1 User Interfaces

Evidently, user interfaces play a crucial role in the interaction with search systems. By interacting with the interface, users specify their needs, and via the interface, users retrieve the results of their queries. In Section 2, we have encountered the large body of theoretical work related to information seeking. For the design of concrete search user interfaces, however crucial they are in the search process, a smaller number of general frameworks and theories exist. In general, it is no straightforward task to design an interface with a high *usability*: as Shneiderman [50] argues, designing a user interface is "a complex and highly creative process that blends intuition, experience, and careful consideration of numerous technical issues". In the past, some authors even claimed that interface design is more an "art" than a "science" [51]. However, the field is evolving, and gradually more structured frameworks, guidelines and design pattern libraries for search user interfaces have emerged.[3]

The constituent elements of SUIs serve as the tools for users to specify their information needs. In this context, Wilson [67] has created a "starting framework for thinking about SUI designs". It divides search user interface features into the following groups: *input features*, *control features*, *informational features* and *personalizable features* (adapted in Table 2). Input features make it possible for users to express what they are looking for, control features allow modifying or restricting input, informational features provide results, or information about results, and personalizable features "tailor the search experience to the searcher, either by their action or by those of other searchers" [67]. Using these four groups, we can characterize SUIs on a basic level. The categorization of features is not always unambigious: as Wilson indicates, some features have characteristics that can belong to multiple groups, for example the search box is primarily used as an *input* feature to enter keywords, but also as an *informational* feature, since it additionally informs users which query they have previously entered. Related

[3]E.g. the Endeca User Interface Design Pattern Library `http://www.oracle.com/webfolder/ux/applications/uxd/endeca/content/library/en/home.html`.

Table 2: Framework SUI Features (adapted from [67])

Group	*Feature example*
Input	Search box, Categories, Clusters, Faceted metadata, Social metadata
Control	Related searches, Corrections, Sorting, Filters, Grouping
Informational	Results display, Text snippets, Deep links, Thumbnails, Immediate feedback, Visualizations
Personalizable	Recent searches, Item tray

Table 3: Exploratory search systems' features (adapt. [64])

Exploratory search feature	*Category*	*Example*
Rapid query refinement	input	FilmFinder [1]
Facets/metadata-based filtering	input, control	Flamenco [72]
Leveraging context	informational	WebWatcher [3]
Visualizations	informational	manyEyes [63]
Histories/workspaces/progress	personalizable	HunterGatherer [49]
Task management	personalizable	SearchBar [39]
Learning & understanding	–	SuperBook [16]
Collaboration	–	SearchTogether [40]

to this work, Wilson et al. [68] created a taxonomy of search result visualization techniques, divided by level of search support, evaluation depth and prevalence. The taxonomy showed that some search visualization methods were at the time (2010) heavily studied, but rarely used (e.g. facets), and others were heavily used, but rarely studied (e.g. tag clouds).

In the next sections we study how actual search interfaces offer search features in the context of complex search settings.

3.2 Traditional Search

Search user interfaces have evolved considerably since the early command-line dialogue systems in the 1970s [67]. Experiments with rich interface features in the 1980s and 1990s, supporting all stages of search performance [25], have been followed by more streamlined interfaces mainly focused on query formulation and result list examination. This tendency can be seen in current digital libraries, but also in the clean, general-purpose search engines like Google, Yahoo and Bing, even though novel contextualization and personalization features are increasingly utilized.

Some motivations behind the simple design are related to cognitive aspects: search tasks are usually part of larger work tasks, and the interface should distract as less as possible, i.e. have a low cognitive load [22]. In addition to that, naturally, general-purpose search engines need to be accessible and understandable to a large audience with varying levels of system knowledge and search experience, which is not always the case, as various studies indicate [24].

General search engines and their input, control and informational features are highly optimized for *lookup tasks*: retrieving a focused set of results for a specific query, but less suited to open-ended queries [38]. Therefore, many authors argue for a move beyond the *lookup* paradigm, as "general-purpose systems will no longer suffice for the complex search tasks in which users engage" [64]. This has lead to initiatives to provide explicit support for exploratory search.

3.3 Exploratory Search

Exploratory search is a form of information-seeking which is complex, multifaceted and open-ended, as White and Roth indicate [64]. They point out that exploratory search is motivated by complex information problems, poor understanding of terminology and information space structure, and often a 'desire to learn'. While traditional search usually consists mainly of *lookup* activities, exploratory search, according to Marchionini, also includes *learning*, and *investigation* activities [38]. Like in Kuhlthau's model, searchers experience various levels of uncertainty, and the uncertainty might subside when the process moves from exploratory browsing to focused searching [64].

Table 3 lists a set of features and examples proposed by White and Roth [64], which should be supported by exploratory search systems, composed in a series of expert discussions and workshops. We can categorize the features using Wilson's SUI framework: *input* and *control* features, like support for (dynamic) queries and facets, *informational* features like visualizations, and *personalizable* features such as histories and task management. Some of the features in Table 3, however, are not common in search systems and not included in Wilson's feature set, like explicit features for learning, understanding and collaboration.

Most current systems only support few features of this list. For example, many library systems and online bookstores contain facets that can be used to select and filter results. Some prototypes, however, integrate more of the features mentioned above. An example of those is Golovchinsky et al's Querium [20], which includes queries, relevance feedback, facets and metadata-based result filtering, visualizations and task management. Bozzon et al. [8] developed an exploratory search framework, *SeCoQL*, that supports Kuhlthau's stages. They interpreted Kuhlthau's stages on a process level, and mapped these to concrete/operative actions represented as a finite-state automaton (FSA). The multi-domain system explicitly supports complex and multifaceted activities, like booking a trip to a foreign city, via interconnected sets of widgets for data exploration. Their evaluation shows that the most relevant Kuhlthau stages in their system were *Initiation*, *Selection* and *Exploration*.

While it is not necessarily an element of a larger overarching search process like in Kuhlthau's model [64], there is overlap between Kuhlthau's initial stages and exploratory search: searchers are unfocused and experience various levels of uncertainty. Therefore, we argue that the act of exploratory search is similar to the initial stages of Kuhlthau's model, in particular the *Exploration* phase, and we could thus place it in the early stage of search. In effect, various system features useful for exploratory search (as exemplified in Table 3), could be valuable for adaptive systems supporting the full search process as well.

3.4 Sensemaking and Analytics

The combined process of information seeking, analysis and synthesis in the context of HCI is often described as *sensemaking*, or "the iterative process of formulating a conceptual representation from a large volume of information" [22]. Hence, besides information search, the analysis and synthesis steps also play an important role [45].

Sensemaking is often associated with complex, information intensive tasks, for example carried out by intelligence analysts [43], but also applies to other complex tasks. Pirolli and Card distinguish two major loops in sensemaking based on research conducted among information analysts: an *information foraging* loop, involving "processes aimed at seeking information, searching and filtering it", and a *sensemaking* loop, involving "iterative development of a mental model that best fits the evidence" [44].

Like exploratory search, sensemaking can be supported in information search interfaces. Marti Hearst [22] discusses examples of sensemaking interfaces and their constituent elements, which include flexible arrangement and grouping of information, integrating notetaking and sketching, hypothesis formulation and collaborative search. Ideally, these elements work together and support *flow*, "a fluid and effortless move between operations such as querying, reading, saving, annotating, organizing and labeling" [23]

For example, *CoSen* is a system that allows for sensemaking, by organizing retrieved information in a tree structure, showing past queries and by providing clustering tools [46]. *Sandbox* is a 'thinking environment' which allows for organizing results visually and facilitates hypothesis generation, aimed at information analysts [71]. Finally, *CoSense* is a system to facilitate sensemaking for collaborative search tasks on the Web. Note the overlap here with exploratory search interfaces, for which collaboration features also are suggested (see Table 3). Other interfaces, not necessarily categorized as sensemaking interfaces, also support analytical tasks. An example is Dunne et al's *Action Science Explorer* (ASE) [15]. This tool, intended for researchers and analysts to rapidly understand scientific paper collections, integrates search, statistics, text analytics and visualizations.

The sensemaking and analytical interfaces discussed in this section potentially cover a wider range of search stages, as compared to exploratory search systems. Many interfaces offer, besides traditional query and results, additional features to 'make sense' of encountered materials, in order to analyze, organize, synthesize and collaborate, largely aimed at researchers and information analysts. This means that some of these systems conceptually support the intermediate and final stages of Kuhlthau's and Vakkari's models. Consider, for example, Kuhlthau's *Formulation*, *Collection* and *Presentation* stages which, according to Kuhlthau, involve processes similar to hypothesis generation, data collection, information organization and the preparation of a "personalized synthesis of the topic" [32]. Hence, there is overlap between the progression of Kuhlthau's search stages, and the "flow" of sensemaking systems.

3.5 Implications for Multistage Interfaces

After taking the broad perspective of information-seeking models and the implications of search stages at the *macro* level in section 2, we here took a different perspective and looked at the support for information seeking stages in actual search user user interfaces. While a large number of interfaces support information search using *micro*-level UI features, we encountered less examples of interfaces explicitly supporting the macro stages of the higher-level information seeking process. Conceptually, however, elements of exploratory search, could fit in the early stages of Kuhlthau's and Vakkari's model, including a move from exploratory browsing (pre-focus) to focused searching (formulation). The concept of sensemaking has a relationship with the intermediate and later stages of the models. So certain search features might be useful for initial exploratory stages of more cognitively demanding tasks, or could help "making sense" of data and information, even though we observed overlap between described sensemaking and exploratory search features.

Despite the large number of prospective features to aid users in their complex searches, popular search engines usually present a streamlined experience to users, providing only the most essential interface features. Other initiatives take a different approach by combining many features into one search interface (e.g. Querium [20], ASE [15]), often focused on experts and researchers. They provide users with advanced functionality, which can be integrated in their workflow and used as a *tool* [6], but might involve a steeper learning curve: a result of the multitude of on-screen features is that user interfaces become more complex. Possible drawbacks of this approach include large screen space needed, and increased perceptual and cognitive loads [15]. As Diriye et al. [13] indicate, excessive search features might even impede information seeking.

In terms of our main aim to bridge the gap between multistage information seeking models and search systems, we observe the following. From the perspective of user interface design, no matter how helpful features can be on an atomic level, it is no straightforward task to integrate advanced exploratory and sensemaking features into one interface, of which the design in itself is already complicated. This is related to the somewhat evasive concept of "flow" [6, 22, 50]. As Shneiderman [50] points out, "creating an environment in which tasks are carried out almost effortlessly and users are 'in the flow' requires a great deal of hard work by the designer." Our main conclusion in this section is that there is a good understanding of search user interface features at the *micro* level, but that our general understanding of behavior at the *macro* level is fragmented at best—a completely opposite conclusion from the previous section.

This immediately suggests ways of connecting and reconciling these two views: what if we use the understanding of information seeking models at the macro level as a guide for understanding the flow of interaction at the micro level? In the previous section, we saw that search stages in complex search tasks have effects on factors such as types of information sought, relevance and search tactics. Based on the occurrence of these effects, we hypothesize that also the flow of users' atomic actions in search user interfaces at the micro level is influenced by search stages at the macro level. To shed more light on this hypothesis, we now will investigate whether search features are actually used differently in distinct search stages in the next section.

4. INTERFACE FEATURES AND SEARCH STAGE

In this section, we combine the perspectives of information seeking models and search user interfaces explored in the previous two sections. We study RQ3: To what extent does the search stage influence the flow of interaction at the interface level? To do so, we explore SUI feature use over time. We look if we can find indications of a connection between the information seeking stages at the macro level, and the interaction flow of feature use at the micro level. Different usage patterns of search features might occur at different moments of a complex search task. We first look at existing literature that has tracked the use of search features over time, and secondly perform a small-scale analysis of data from a previous user study. Finally, we discuss the implications for multistage interfaces.

4.1 Interface Features & Search Stage

Some previous studies have focused on the use of search system features over time, usually based on analysis of system log and questionnaire data. Results from White et al. [65] indicate that implicit Relevance Feedback (RF) was used in the middle of search tasks, while explicit RF was used more towards the end of search tasks. Other potentially useful features are query suggestions. Experimental results discussed by Niu and Kelly [27, 41] indicate that query suggestions were used more for difficult topics, and in later search stages, potentially working in a similar vein as Bates [4] "idea tactics", i.e. helping users to generate new ideas or solutions.

Another potentially valuable approach is the use of eye tracking to detect passive use of search features and other implicit indicators (see e.g. [37]). In the remainder of this section, we focus on eye tracking studies in the context of search stages. Kules et al. [36] examined searchers' interaction with faceted library catalogs.

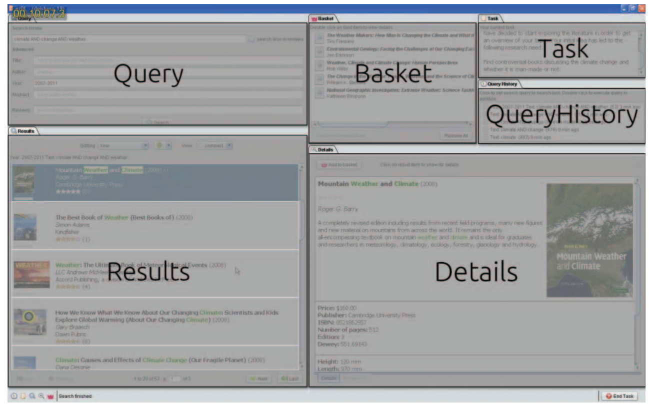

Figure 1: Screenshot ezDL interface with Areas of Interest

A significant difference was found in the searchers' average gaze durations of the facets, query and results *Area of Interests* (AOIs) over time: in the first results page viewed, the users looked at facets, query and results about equally, while in the second and third page viewed, users significantly looked more at the results; potentially related to users extracting information from search results. In a subsequent larger study, Kules and Capra [35] distinguished between *query terms*, *overview*, *extracting*, *deciding next* and *deciding topic* stages, based on elements of different information seeking models. In this research, again evidence was found that searchers utilize different elements of the interface at different stages of their searches. Here, the results indicate that facets play not only an important role in the initial search stages, but also in the decision making stages of the search process. According to Kules and Capra, this points to the usefulness of facets in cognitively demanding stages, similar to the use of query suggestions [27].

In an eye tracking study using an experimental interface with a rich feature set, Diriye et al. [14] confirmed the finding that certain search interface features are *search stage specific* and thus useful at certain points in the information seeking process. Examples of these features are the query box and 'starter pages' (pages containing basic information about the topic), which are mainly useful in the beginning of the process. They also indicate that other features are *search stage agnostic*, i.e. useful at any stage of the information seeking process, in this case search facets and search filters. Also the tasks had an influence on feature use: in more complex tasks the number of used search support features was higher.

4.2 Experiment

While the studies discussed in the previous section shed light on the use and usefulness of different *input*, *control* and *informational* features, we also would like to take a look at *personalizable* features used over time, and obtain a more in-depth overview of the usage patterns of SUI features. Therefore we take a tentative look at data from a user study featuring complex tasks carried out using a feature-rich search interface in the following section.

We use the dataset of a previous user study by Tran and Fuhr [56] which used the ezDL system, an advanced open-source IR frontend system supporting search and retrieval activities [5], developed at the University of Duisburg-Essen. The data indexed for the experiment consisted of a collection of 2.7 million book records from Amazon, in combination with LibraryThing data (see [56]). Twelve Computer Science students completed 3 tasks (2011), with a time limit of 15 minutes per task. The tasks consisted of narrow tasks, complex tasks, and a user-defined task. In this analysis, we

Table 4: ezDL tasks

You are at the early stage of working on an assignment, and have decided to start exploring the literature in order to get an overview of your topic. Your initial idea has led to the following research need:
1. Find trustworthy books discussing the conspiracy theories which developed after the 9/11 terrorist attacks in New York. 2. Find controversial books discussing the climate change and whether it is man-made or not. 3. Find highly acclaimed novels that treats issues related to racial discrimination.

Table 5: ezDL system features (using [67])

Category	*Feature*
Input	Search box, Social metadata
Control	Sorting, Filters
Informational	Results display, Text snippets, Images/thumbnails
Personizable	Recent searches, Item tray

focus on the complex tasks (specified in Table 4), one of which was self-selected by each participant. As can be seen in table 4, the simulated tasks in this experiment are information-intensive and constraint-based (i.e. the user is free to decide how to carry out the assigned task), like the paper and proposal writing tasks examined by Kuhlthau and Vakkari (see Section 2). In this analysis, we assume that searchers experience various 'mini' stages during completion of the complex search task (similar to [41]), even though we did not perform a longitudinal study like Kuhlthau and Vakkari (which focused on a higher-level work task).

The ezDL search system has an interface with a considerable number of features, which are described in Table 5). The use of these features can be tracked via the system log, and the corresponding Areas of Interests (AOIs) via eye tracking. The *AOILog* software [55, 56] allows for monitoring not only static AOIs, but also dynamic AOIs, for example each specific result list item, by keeping track of position, visibility and size of all user interface objects.

4.3 Findings

To detect changes in interface use in different stages of a search session, we divide the search session for the combined tasks 1, 2 and 3 (n=12) into three parts, based on a linear approximation of search stages: *beginning* (the first 33.3% of task time), *middle* (the second 33.3%) and *end* (the last third). For example, a 15-minute search session of a certain user is divided in three parts of 5 minutes. The results in Table 6 include the mean fixation counts[4], and fixation count percentages per stage. The results indicate a strong decline in the views of the query AOI after the initial stage, and a gradual increase in views of results and details (book details of a selected result). In the middle and end stage, the mean fixation counts for the basket rise. An ANOVA analysis shows that the changes in the fixation counts for the query AOI over time are significant at $p<0.01$. A pairwise comparison for the query AOI shows a significant difference for the *beginning* stage (compared to the *middle* and *end* stage). The other AOIs do not show significant differences over time.

To get a more detailed overview of the changes in SUI use over time, figure 2 shows a more detailed distribution of the use of interface features during task 1-3 over time[5], including an indication

Table 6: Mean fixation counts and percentage per phase

	Beginning	*Middle*	*End*
QueryView	68.8 (16.2%)	26.1 (5.0%)	18.9 (3.2%)
ResultView	167.3 (39.5%)	216.8 (41.4%)	253.1 (42.2%)
DetailView	178.3 (42.1%)	258.9 (49.4%)	302.1 (50.3%)
BasketView	9.2 (2.2%)	22.41 (4.3%)	26.3 (4.4%)

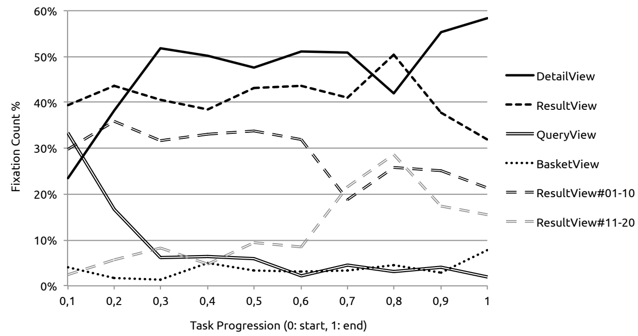

Figure 2: Eye tracking log complex Task 1-3 (n=12)

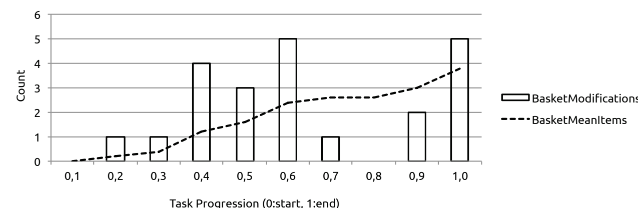

Figure 3: Basket modifications (bars) and mean number of items (dotted line) - Complex task 1 (n=5)

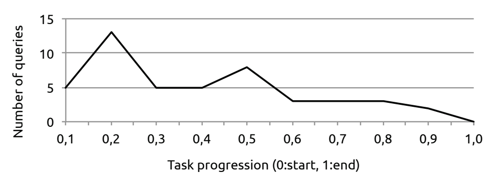

Figure 4: Total number of issued queries during task progression - Complex task 1 (n=5)

of the depth of result list items inspected. The horizontal axis represents task progression, 0 being the start of the task, and 1 the end of the task (mean task time: 11.4 minutes). The initial stages of the task are characterized by a predominant focus on the query (*QueryView*), while this quickly transforms into increased results list (*ResultView*) and subsequent item detail inspections (*DetailView*). We can also observe a change in the inspection of results items: while in the beginning, predominantly the top items are inspected, in the intermediate and later phases of the task also the lower items in the results lists are viewed. Finally, in the last 20% of the task, the main focus lies on the item details again, with a rise in fixations on the basket (*BasketView*) as well.

The ezDL interface contains a *basket*, where encountered books are stored (analogous to a *shopping basket* in e-commerce sites). This *basket* plays an essential role to gather materials relevant to the task goals. Figure 3 visualizes the role of the basket during

[4]In our study, we used a minimum fixation length of 80ms.

[5]An analysis using mean fixation time yielded similar results, but is not included here for brevity.

task completion (based on the systems logs). Here, we focus on complex task 1, performed by the highest number of participants (n=5). If we focus on basket modifications and item count as an indicator of task progress, we see that it is mainly utilized after the initial stages of a task, in various gradations, which include a 'dip' at 70% of task time, followed by a spike of usage at the end of the task. This provides indications for differences in the final (post-focus) stages of the surveyed task.

Finally, figure 4 shows the total number of queries over time for task 1, and shows akin to Figure 2 that users issue a decreasing number of queries over time, and seem to be less focused on the query in later task phases.

4.4 Implications for Multistage Interfaces

In this section, we looked at the influence of search stage on the flow of interaction with SUI features. While there are limits to the number of previous studies, and to the size of the dataset analyzed here, patterns in the use of search user interface features for the three complex tasks involved could be observed. In our analysis, we found differences in the interaction flow with SUI features at an early (pre-focus) and late stage (post-focus) of search. The initial stage is characterized by a significant focus on the query (a *control* feature), followed by increased results and detail inspections (*informational* features). The final stage features slight changes in the focus on results and details features, also in terms of the depth of inspected result list items. While most of these findings are in line with previous literature [14, 35, 36], we also found variations in the use of *personalizable* features (features relating to previous interactions). The basket is not used immediately, but starts to be used after the initial phase of the task. While this tendency might be a straightforward observation (a user first has to formulate a query and obtain a decent result set before gathering elements relevant to the task), glimpses of variations of use in the intermediate stage of the task, and a spike of increased usage near the end of the task could be observed: possible evidence of users inspecting and reviewing the collected basket items in the final stage of their search. Focusing on the basket modifications as indicator of task progress, we see support in our data for a final, post-focus stage.

In terms of our main aim to investigate the gap between multistage information seeking models and search systems, we observe the following. There is no clear dichotomy between the stages: feature use changes only gradually over time, especially the use of essential *informational* features like results lists. Hence, features might be useful at different stages, meaning that some features cannot easily be left out in a multistage interface. However, the results also indicate that some *input* and *personalizable* features are, indeed, search stage sensitive and could be offered at the moment they are needed, or gradually adapt themselves to different search stages (e.g. show different amounts of details), thus assisting the user and potentially reducing cognitive load. Our main conclusion in this section is that we see differences in the flow of interaction between the information seeking stages for some of the user interface features, supporting our hypothesis that the flow of users' atomic actions in search user interfaces at the micro level is influenced by search stages at the macro level.

5. DISCUSSION AND CONCLUSIONS

In this paper, we focused on moving beyond the "one-size-fits-all" approach in search systems for complex tasks involving learning and construction of new knowledge. We conceptually bridged multistage information seeking models and the design of search systems and user interfaces, and highlighted differences in the use of search user interface features over time, detecting variations in the the use of these features, especially in in the initial (or pre-focus) and final (post-focus) stages of a search episode.

Section 2 focused on temporally-based information seeking models, which differentiate various search stages over time, based on empirical evidence. During these stages, the information sought, the relevance, and the search tactics and strategies evolve. Authors like Kuhlthau and Vakkari have accurately pinpointed the issue of stage-specific search support, but provide less concrete pointers to implementation in search systems and interfaces. As Tom Wilson has indicated, many information seeking models focus on the *macro* level of the search process, while information system designers focus more on the *micro* level of search [69]. However, indications for the provision of search stage support in search systems can be determined from the theory, not only at the interface level (providing specific features supporting stages), but also at the system level (for example providing search stage adaptive ranking). Our main conclusion was that there is a good general understanding of the information seeking stages at the macro level, but that the translation into system and user interface design choices at the micro level remains unsolved.

To get more insights into the SUI features that could support complex, information-intensive search tasks, we have looked in Section 3 at concrete SUI features in the context of Wilson's framework for interface features [67]. We argued that there is an abundance of interfaces which support information *search*, but few systems provide explicit support for the higher-level information *seeking* process in the context of complex tasks. However, overarching interface paradigms have similarities with temporal search stages. We showed that exploratory search, though slightly different in nature due to the open-endedness of the tasks, could fit in Kuhlthau's and Vakkari's models, in particular in the early pre-focus stages. In addition to that, elements of search paradigms like sensemaking, could fit in the more advanced stages of search of Kuhlthau and Vakkari. There is, however, no integrated system, and many authors point at the complexity to understand the impact of design choices on the overall usability, and the complexity of creating a seamless and effortless flow of interaction [6, 22, 50]. Our main conclusion was that there is a good understanding of search user interface features at the micro level, but that our general understanding of behavior at the macro level is fragmented at best. This immediately suggested ways of connecting and reconciling these two views: what if we use the understanding of information seeking models at the macro level as a model to understand the flow of interaction at the micro level?

In section 4, we looked at the influence of search stage on the flow of interaction, and we observed different use of features over time, based on previous literature and an analysis of eye tracking and system data from a small-scale user study. Some *informational* features (results lists and details) are generally used in all stages of the search, albeit in different depths, and therefore could be considered stage insensitive. However, the use of a subset of search features varied over time, like the gaze towards the query box (an *input* feature), and the use of the basket (a *personalizable* feature). Especially, we saw variations in the use of interface features in the beginning and end of a complex search task. This provides initial indications of different usage patterns of search user interface features in different search stages, which could be informative for the design of search systems. Our main conclusion was that we see differences in the flow of interaction between the information seeking stages for some of the user interface features, providing support for our hypothesis that the flow of users' atomic actions in search user interfaces at the micro level is influenced by search stages at the macro level.

The main aim of this paper was to bridge the gap between multistage information seeking models and multistage search systems and user interfaces. Our conceptual analysis clearly revealed differences in the levels of understanding of information seeking behavior at the macro level, and of systems and interface design at the micro level. Temporally-based information seeking models document complex tasks and search stages over time. These models describe information seeking behavior on a general, or macro level, and the high-level nature of these models makes it hard to directly implement their implications, even though they might be useful in supporting users' complex tasks. User interfaces supporting search, on the other hand, are often "one-size-fits-all" interfaces, containing a streamlined set of micro level features in traditional search systems, or a larger array of features in more analytical search systems. The SUI features of these interfaces can be used at different stages of a search, but the former approach might not be ideal for complex search tasks, while the latter approach might involve a steeper learning curve.

Based on our analysis of information seeking models, search user interfaces and search feature use over time, we hypothesize that there are differences in the interaction flow of SUI feature use at the micro level, depending on the current stage of search at the macro level. Taking Vakkari's stages as an example, when a user is in the pre-focus stage, patterns of interface use and system interaction are different than in the focus, or post-focus stage. This suggests interface elements which are search stage sensitive and we could customize the way search system features are shown during task progression. This customization could be performed in different ways: depending on the search stage, one could adaptively show SUI features, adjust the shown details of features, or change their prominence, position and size.

Future research still has to show whether this approach can be naturally integrated in the user's flow, for different complex tasks and contexts, without being confusing or intrusive. An essential aspect is that the user should remain in control and have the freedom to switch between interface units. Initial work has been carried out to create and evaluate a search stage sensitive system [21]. One could take this even further and build prescriptive systems that actively guide searchers in their search process, in particular targeting those with poor search literacy and stimulate their critical use of information, up to the point that it changes their information behavior [2].

Acknowledgments

We are very grateful to Vu Tran and the Information Engineering Group at the University of Duisburg-Essen for allowing us to analyze data collected with the ezDL interface. We also thank the anonymous reviewers for their useful feedback and suggestions.

This research is supported by the Netherlands Organization for Scientific Research (NWO project # 640.005.001).

REFERENCES

[1] C. Ahlberg and B. Shneiderman. Visual information seeking: Tight coupling of dynamic query filters with starfield displays. In *CHI*, pages 313–317. ACM, 1994.

[2] J. Allan, B. Croft, A. Moffat, and M. Sanderson. Frontiers, challenges, and opportunities for information retrieval: Report from SWIRL 2012 the second strategic workshop on information retrieval in lorne. *SIGIR Forum*, 46:2–32, June 2012.

[3] R. Armstrong, D. Freitag, T. Joachims, and T. Mitchell. Webwatcher: A learning apprentice for the world wide web. In *AAAI Spring symposium*, pages 6–12. AAAI, 1995.

[4] M. J. Bates. Information search tactics. *JASIS*, 30(4):205–214, 1979.

[5] T. Beckers, S. Dungs, N. Fuhr, M. Jordan, S. Kriewel, and V. T. Tran. ezdl: An interactive search and evaluation system. In *SIGIR 2012 workshop on open source information retrieval*, pages 9–16, 2012.

[6] B. B. Bederson. Interfaces for staying in the flow. *Ubiquity*, 2004.

[7] J. Beheshti, C. Cole, D. Abuhimed, and I. Lamoureux. Tracking middle school students' information behavior via Kuhlthau's ISP Model:Temporality. *JASIST*, 2014.

[8] A. Bozzon, M. Brambilla, S. Ceri, and D. Mazza. Exploratory search framework for web data sources. *The VLDB Journal*, 22(5):641–663, Oct. 2013.

[9] P. Brusilovsky and M. T. Maybury. From adaptive hypermedia to the adaptive web. *CACM*, 45(5):30–33, 2002.

[10] K. Bystrom and K. Järvelin. Task complexity affects information seeking and use. *IPM*, 31(2):191–213, 1995.

[11] D. O. Case. *Looking for Information : a Survey of Research on Information Seeking, Needs, and Behavior*. Emerald, 2012.

[12] C. Cole. A theory of information need for information retrieval that connects information to knowledge. *JASIST*, 62 (7):1216–1231, 2011.

[13] A. Diriye, A. Blandford, and A. Tombros. When is system support effective? In *IIiX*, pages 55–64. ACM, 2010.

[14] A. Diriye, A. Blandford, A. Tombros, and P. Vakkari. The role of search interface features during information seeking. In *TPDL*, volume 8092 of *LNCS*, pages 235–240. Springer, 2013.

[15] C. Dunne, B. Shneiderman, R. Gove, J. Klavans, and B. Dorr. Rapid understanding of scientific paper collections: Integrating statistics, text analytics, and visualization. *JASIST*, 63 (12):2351–2369, 2012.

[16] D. E. Egan, J. R. Remde, L. M. Gomez, T. K. Landauer, J. Eberhardt, and C. C. Lochbaum. Formative design evaluation of superbook. *TOIS*, 7:30–57, 1989.

[17] D. Ellis. A behavioural approach to information retrieval system design. *Journal of Documentation*, 45:171–212, 1989.

[18] K. E. Fisher, S. Erdelez, and L. McKechnie, editors. *Theories of information behavior*. Information Today, 2005.

[19] A. Foster. Nonlinear information seeking. In Fisher et al. [18].

[20] G. Golovchinsky, A. Diriye, and T. Dunnigan. The future is in the past: Designing for exploratory search. In *IIiX*, pages 52–61. ACM, 2012.

[21] M. Hall, H. Huurdeman, M. Koolen, M. Skov, and D. Walsh. Overview of the INEX 2014 interactive social book search track. In *CLEF 2014 Notebook Papers*, volume 1180 of *CEUR Workshop Proceedings*, 2014.

[22] M. A. Hearst. *Search user interfaces*. Cambridge University Press, 2009.

[23] M. A. Hearst and D. Degler. Sewing the seams of sensemaking: A practical interface for tagging and organizing saved search results. In *HCIR*. ACM, 2013.

[24] C. Hoelscher and G. Strube. Web search behavior of internet experts and newbies. *Computer Networks*, 33:337–346, 2000.

[25] P. Ingwersen and K. Järvelin. *The turn: Integration of information seeking and retrieval in context*. Springer, 2005.

[26] J. Kamps. Toward a model of interaction for complex search tasks. In *ESAIR*, pages 7–8. ACM, 2011.

[27] D. Kelly. Query suggestions as idea tactics for information search. *HCIR 2009*, 2009.
[28] C. C. Kuhlthau. Inside the search process: Information seeking from the user's perspective. *JASIS*, 42:361–371, 1991.
[29] C. C. Kuhlthau. Perceptions of the information search process in libraries: a study of changes from high school through college. *IPM*, 24:419–427, 1988.
[30] C. C. Kuhlthau. Longitudinal case studies of the information search process of users in libraries. *Library & Information Science Research*, 10:257–304, 1988.
[31] C. C. Kuhlthau. Accommodating the user's information search process: challenges for information retrieval system designers. *Bulletin of the ASIST*, 25(3):12–16, 1999.
[32] C. C. Kuhlthau. *Seeking Meaning: A Process Approach to Library and Information Services*. Libraries Unlimited, 2004.
[33] C. C. Kuhlthau. Kuhlthau's information search process. In Fisher et al. [18].
[34] C. C. Kuhlthau and S. L. Tama. Information search process of lawyers: a call for 'just for me' information services. *Journal of documentation*, 57:25–43, 2001.
[35] B. Kules and R. Capra. Influence of training and stage of search on gaze behavior in a library catalog faceted search interface. *JASIST*, 63:114–138, 2012.
[36] B. Kules, R. Capra, M. Banta, and T. Sierra. What do exploratory searchers look at in a faceted search interface? In *JCDL*, pages 313–322. ACM, 2009.
[37] J. Liu, M. J. Cole, C. Liu, R. Bierig, J. Gwizdka, N. J. Belkin, J. Zhang, and X. Zhang. Search behaviors in different task types. In *JCDL*, pages 69–78. ACM, 2010.
[38] G. Marchionini. Exploratory search: from finding to understanding. *CACM*, 49(4):41–46, 2006.
[39] D. Morris, M. Ringel Morris, and G. Venolia. Searchbar: A search-centric web history for task resumption and information re-finding. In *CHI*, pages 1207–1216, 2008. ACM.
[40] M. R. Morris and E. Horvitz. Searchtogether: An interface for collaborative web search. In *UIST*, pages 3–12, 2007. ACM.
[41] X. Niu and D. Kelly. The use of query suggestions during information search. *IPM*, 50:218–234, 2014.
[42] N. Pharo and R. Nordlie. Examining the effect of task stage and topic knowledge on searcher interaction with a "digital bookstore". In *IIiX*, pages 4–11, 2012. ACM.
[43] P. Pirolli. Powers of 10: Modeling complex information-seeking systems at multiple scales. *IEEE Computer*, 42:33–40, 2009.
[44] P. Pirolli and S. Card. The sensemaking process and leverage points for analyst technology as identified through cognitive task analysis. In *Intelligence Analysis*, pages 2–4, 2005.
[45] P. Pirolli and D. M. Russell. Introduction to this special issue on sensemaking. *Human-Computer Interaction*, 26:1–8, 2011.
[46] Y. Qu and G. W. Furnas. Model-driven formative evaluation of exploratory search: A study under a sensemaking framework. *IPM*, 44:534–555, 2008.
[47] I. Ruthven and D. Kelly, editors. *Interactive Information Seeking, Behaviour and Retrieval*. Facet, 2011.
[48] T. Saracevic. Relevance reconsidered. In *CoLIS 2*, pages 201–218. ACM, 1996.
[49] M. C. schraefel, Y. Zhu, D. Modjeska, D. Wigdor, and S. Zhao. Hunter gatherer: Interaction support for the creation and management of within-web-page collections. In *WWW*, pages 172–181, 2002. ACM.
[50] B. Shneiderman and C. Pleasant. *Designing the user interface: strategies for effective human-computer interaction*. Pearson Education, 2005.
[51] S. L. Smith and J. N. Mosier. Guidelines for designing user interface software. Technical report, MITRE, 1986.
[52] A. Spink, H. Greisdorf, and J. Bateman. From highly relevant to not relevant: examining different regions of relevance. *IPM*, 34:599–621, 1998.
[53] A. R. Taylor, C. Cool, N. J. Belkin, and W. J. Amadio. Relationships between categories of relevance criteria and stage in task completion. *IPM*, 43:1071–1084, 2007.
[54] E. G. Toms. Task-based information searching and retrieval. In Ruthven and Kelly [47].
[55] V. T. Tran and N. Fuhr. Quantitative analysis of search sessions enhanced by gaze tracking with dynamic areas of interest. In *Theory and Practice of Digital Libraries*, volume 7489 of *LNCS*, pages 468–473. Springer, 2012.
[56] V. T. Tran and N. Fuhr. Using eye-tracking with dynamic areas of interest for analyzing interactive information retrieval. In *SIGIR*, pages 1165–1166. ACM, 2012.
[57] P. Vakkari. Cognition and changes of search terms and tactics during task performance: A longitudinal case study. In *RIAO*, pages 894–907. CID, 2000.
[58] P. Vakkari. Relevance and contributing information types of searched documents in task performance. In *SIGIR*, pages 2–9, 2000.
[59] P. Vakkari. Task-based information searching. *ARIST*, 37: 413–464, 2003.
[60] P. Vakkari. A theory of the task-based information retrieval process: a summary and generalisation of a longitudinal study. *Journal of Documentation*, 57:44–60, 2001.
[61] P. Vakkari and N. Hakala. Changes in relevance criteria and problem stages in task performance. *Journal of Documentation*, 56:540–562, 2000.
[62] P. Vakkari, M. Pennanen, and S. Serola. Changes of search terms and tactics while writing a research proposal: A longitudinal case study. *IPM*, 39:445–463, 2003.
[63] F. Viegas, M. Wattenberg, F. van Ham, J. Kriss, and M. McKeon. Manyeyes: a site for visualization at internet scale. *Visualization and Computer Graphics*, 13:1121–1128, Nov 2007.
[64] R. W. White and R. A. Roth. Exploratory search: Beyond the query-response paradigm. *Synthesis Lectures on Information Concepts, Retrieval, and Services*, 1:1–98, 2009.
[65] R. W. White, I. Ruthven, and J. M. Jose. A study of factors affecting the utility of implicit relevance feedback. In *SIGIR*, pages 35–42. ACM, 2005.
[66] B. M. Wildemuth and L. Freund. Search tasks and their role in studies of search behaviors. In *HCIR*, 2009.
[67] M. L. Wilson. Interfaces for information retrieval. In Ruthven and Kelly [47].
[68] M. L. Wilson, B. Kules, m. c. schraefel, and B. Shneiderman. From keyword search to exploration: Designing future search interfaces for the web. *Foundations and Trends in Web Science*, 2(1):1–97, 2010.
[69] T. D. Wilson. Models in information behaviour research. *Journal of Documentation*, 55:249–270, 1999.
[70] T. D. Wilson, N. J. Ford, D. Ellis, A. E. Foster, and A. Spink. Information seeking and mediated searching: Part 2. uncertainty and its correlates. *JASIST*, 53:704–715, 2002.
[71] W. Wright, D. Schroh, P. Proulx, A. Skaburskis, and B. Cort. The sandbox for analysis: Concepts and methods. In *CHI*, pages 801–810, 2006. ACM.
[72] K.-P. Yee, K. Swearingen, K. Li, and M. A. Hearst. Faceted metadata for image search and browsing. In *CHI*, pages 401–408, 2003. ACM.