Designing Multistage Search Systems to Support the Information Seeking Process

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Abstract Due to the advances in information retrieval in the past decades, search engines have become extremely efficient at acquiring useful sources in response to a user's query. However, for more prolonged and complex information seeking tasks, these search engines are not as well suited. During complex information seeking tasks, various *stages* may occur, which imply varying support needs for users. However, the implications of theoretical information seeking models for concrete search user interfaces (SUI) design are unclear, both at the level of the individual features and of the whole interface. Guidelines and design patterns for concrete SUIs, on the other hand, provide recommendations for feature design, but these are separated from their role in the information seeking process. This chapter addresses the question of how to design SUIs with enhanced support for the macro-level process, first by reviewing previous research. Subsequently, we outline a framework for complex task support, which explicitly connects the temporal development of complex tasks with different levels of support by SUI features. This is followed by a discussion of concrete system examples which include elements of the three dimensions of our framework in an exploratory search and sensemaking context. Moreover, we discuss the connection of navigation with the search-oriented framework. In our final discussion and conclusion we provide recommendations for designing more holistic SUIs which potentially evolve along with a user's information seeking process.

1 Introduction

Revolutionary advances in information retrieval technology have occurred during the past decades. We have arrived at the point where systems may actually *solve*

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problems for users. For instance, search engines on the web provides us with 'instant answers' for factual questions ranging from the weather in the next week-end to the birthdate of the current prime minister. Information seeking in the context of more complex tasks, however, is still not as straightforward, because such tasks cannot be fully articulated with a single query, nor directly answered by a succinct snippet of information. For instance, gaining novel ideas for research, or finding the appropriate sources for writing an essay requires intensive interaction with search engines as well as information sources. These types of complex tasks typically involve "sustained interaction and engagement with information" (Kelly et al., 2013), thus involving more lengthy information interactions. Associated search episodes can include multiple subtasks (Wildemuth et al., 2014), and these types of tasks feature learning and construction, understanding and problem formulation (Byström and Järvelin, 1995). During the process of information seeking and use, as occurring in complex research-based tasks, the needs and understanding of a user may evolve, moving from broad conceptualizations to a focused perspective (Kuhlthau, 2004). Therefore, to create supportive systems for complex tasks featuring sustained information interaction, current *ad-hoc* approaches to search-based interaction should be rethought. Instead of optimizing the results display of singular queries, there is a need for a fundamentally different approach that would provide dynamic support for a user's information seeking ***process***.

The non-trivial question which follows is how to concretely achieve this enhanced process support. This chapter focuses on the presentation of results from search engines via their constituent search user interface (SUI) features, representing the key information interaction components of the system. Creating compositions of interface features with high *usability* is no easy task. Thus, as Oddy already argued in 1977, the "art" of information system design is to "find the form and timing of information presentation which will best aid the system user" in whichever task at hand. In this chapter, we focus on the timing and form of SUI features, assessing how they fit in different stages of the information seeking process, and how they can potentially be recombined in dynamic ways. This book chapter truly stands on the shoulders of giants, incorporating findings from decades of research in library and information science and interactive information retrieval (e.g., Bennett, 1972; Bates, 1990; Ingwersen, 1992; Marchionini, 1995; Golovchinsky and Belkin, 1999; Ruthven, 2008; Hearst, 2009; Wilson et al., 2010). It also builds on our own earlier work in recent years (e.g., Kamps, 2011; Huurdeman and Kamps, 2014; Huurdeman et al., 2016), and extends Huurdeman (2017, 2018). Earlier findings are further integrated into a framework for complex task support in search systems.

To this end, we first present background literature related to process support for complex tasks (Section 2). Based on previous research, we then outline our framework for complex task support and its relation to SUI features (Section 3). Then, we introduce examples in relation to the proposed framework (Section 4). In Section 5, we discuss the relationship between navigation and search. Finally, we provide a discussion of our findings and our conclusions (Section 6).

2 Background

This section reviews relevant concepts and literature on search and work tasks, information seeking models, and user interface components of information search systems.

2.1 Conceptualizations of Tasks

This chapter focuses on information seeking models, search user interfaces and the underlying information retrieval systems. The "*raison-d'être* of information retrieval systems is to deliver task-specific information that leads to problem resolution," as Toms (2011) has suggested. This also points to the importance of the *task* itself, which is pivotal in relation to this chapter. A variety of conceptualizations of task exists, but we take the general view as "an activity to be performed in order to accomplish a goal." (Vakkari, 2003). In particular, we focus on cognitively complex tasks. Unlike simple lookup tasks, complex tasks (Wildemuth et al., 2014) may involve learning and construction, understanding and problem formulation (Byström and Järvelin, 1995). They might be performed by topic novices, but also by more experienced actors. For instance, a student may perform a task involving a topic she knows little about, but this knowledge advances over time, or a researcher may start with a loose research question, which becomes more focused after interaction with a set of information. Besides their obvious occurrence in work and study contexts, complex tasks are also performed in leisure settings, for instance shopping for products which are inherently complex.

In this chapter, we look at *work tasks*, which might consist of various *search tasks*, within a particular *environment* (Toms, 2011). Work task has been defined as a "job-related task or non-job associated daily-life task or interest to be fulfilled by cognitive actor(s)". These tasks can be "natural, real-life tasks", assigned requests or assigned simulated work task situations (Ingwersen and Järvelin, 2005, p.20). Work tasks, in their turn, may lead to one or more search tasks, defined as "the task to be carried out by a cognitive seeking actor(s) as a means to obtain information associated with fulfilling a work task" (Ingwersen and Järvelin, 2005, p.20). The complexity of information seeking and searching has been captured in a wide variety of models, discussed in the next section.

2.2 Information Behavior, Seeking and Searching

We now describe the concept of information behavior, and the macro-level, cognitive models of information seeking and search.

Table 1: Kuhlthau's search stages, adapted from Kuhlthau (2005)

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

Information behavior has been defined by Wilson (1999) as "the totality of human behavior in relation to sources and channels of information, including both active and passive information seeking, and information use." In Wilson (1999)'s nested model of information seeking and searching, a subset of information behavior is *information seeking*, which is "human information behavior dealing with searching or seeking information by means of information sources and (interactive) information retrieval systems" (Ingwersen and Järvelin, 2005, p.21). Finally, the *information searching* subset in Wilson (1999)'s nested model focuses specifically on the interaction between information user and information system.

2.2.1 Information Seeking

We first discuss information *seeking*: in the field of library and information science, a large variety of models has been conceived, describing information seeking from a macro perspective. These include temporally-based models, such as the Information Search Process model by Kuhlthau (1991, 2004); non-sequential models, such as Ellis (1989)' behavioral model, and non-linear models (e.g., Foster, 2005). Furthermore, some models focused on problem solving, such as Wilson (1999)'s problem solving model. In this chapter, our focal point is the temporally-based models defined by Kuhlthau (1991, 2004) and Vakkari (2001).[1]

Kuhlthau (1991, 2004)'s *Information Search Process* (ISP) model, which focuses on a temporal progression of stages based on several longitudinal studies, has been influential and is one of the most cited models in the library and information science field (Beheshti et al., 2014). A key aspect of the model is that it looks at information seeking as a process of knowledge construction across six broad stages (summarized in Table 1), during which a user's uncertainty fluctuates. These include early stages of *initiation* and *topic selection*, as well as *exploration*. At a certain point, a *focus* is formulated, after which information seeking in itself becomes more focused, and

[1] An extensive further overview of information seeking models can for instance be found in Case (2012); Fisher et al. (2005).

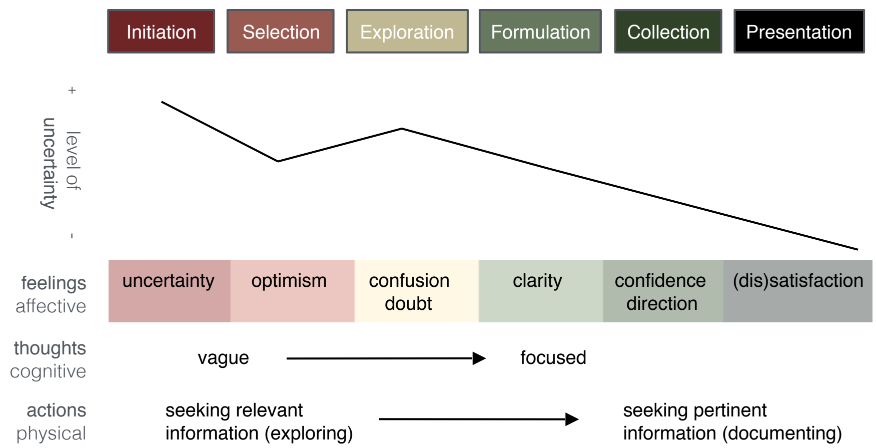

Fig. 1: ISP Model documenting stages in tasks involving construction; figure adapted from Kuhlthau (2004, p.206).

stages of *collection* and *presentation* follow. The ISP model focuses on the evolution of users' thoughts, feelings and actions (see Figure 1).

Based on other longitudinal studies, Vakkari (2001) introduced a theory of the task-based information retrieval process. He refined Kuhlthau's stages into three categories: *pre-focus*, *focus formulation* and *post-focus*. Vakkari focused in particular on the pivotal aspect of finding a focus within the search process. Within the initial pre-focus stage, fragmented, vague and general thoughts occur, and there is a difficulty for a searcher to specify the information needed. When a focus is formulated, more directed searches follow, and the final post-focus stage involves specific searches and potential rechecks for additional information. Whilst Kuhlthau (1991, 2004)'s ISP model does not focus on the effects of the stages on search system use directly, Vakkari (2001)'s theory "is more specific in the domain of information retrieval", and documents the effects of stages in the context of IR system use. He observed implications for information sought, assessed relevance and search tactics, terms and operators (see Figure 2). Information sought converges from general background information to specific information, while assessment of relevance becomes easier over time. The number of search terms increases, in particular narrower terms and synonyms, while broader terms gradually decrease over time.

2.2.2 Information Searching

As in the case of the information seeking models, a wide range of information *searching* models exists (Wilson, 1999), focusing on the direct interaction between user and system. For instance, Spink (1997)'s model of the IR interaction process describes

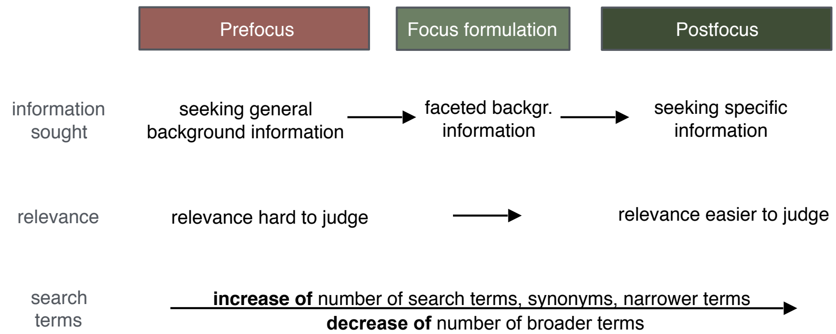

Fig. 2: Effects of search stages - diagram summarizes findings Vakkari (2001).

specific cycles of interaction with IR systems, including user judgments, search strategies, tactics and moves. Saracevic (1997)' Stratified model of Information Retrieval Interaction views IR interaction as a dialogue between user and computer, and includes different levels (strata) of interactions. Belkin et al. (1995) have modeled the behavior "people engage in while searching for information in some knowledge resource" as Information Seeking Strategies (ISS). These may be seen as interactions between user and IR system components, and an 'episode' may consist of a sequence of ISSs. ISSs can be described using four dimensions: *method of interaction* (scanning versus searching), *goal of interaction* (learning versus selecting), *mode of retrieval* (recognizing versus specifying) and *considered resources* (information versus meta-information). Finally, Marchionini's (1995) Information-seeking Process Model describes various specific sub-processes and their relationships (including 'define problem', 'select source', 'formulate query', 'execute query').

2.3 Search User Interfaces

We now describe the micro-level search system features and UI design considerations to actively support user search behavior in the context of complex tasks.

Search User Interfaces (SUIs) play the role of intermediary between a user and information available in a system, and thus facilitate information searching. Hearst (2009) has characterized their role as aiding "users in the expression of their information needs, in the formulation of their queries, in the understanding of their search results, and in keeping track of the progress of their information seeking efforts." As this multifaceted role implies, designing effective and user-friendly SUIs can be a severe challenge, and "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" (Shneiderman and Pleasant, 2005). SUI design involves a variety of trade-offs, including the tension between simplicity and offered functionality.

The view of SUI design as a challenge is not necessarily new: already in the 1970s, researchers looked at challenges in designing interfaces for (bibliographic) search systems (Bennett, 1971, 1972). This includes the characteristics of searchers, the search environment and feedback to searchers. More recent research related to information retrieval and search interfaces has proposed a wide variety of potential features, including facets (Tunkelang, 2009), personal result spaces (Donato et al., 2010) and visual keyword suggestions (such as Google's discontinued 'Wonder Wheel'[2]). However, the majority of these types of features are not integrated in current general web search user interfaces.

Current IR systems, such as online search engines, are usually streamlined, and focus on query formulation and result inspection. As Hearst (2009) has suggested, reasons underlying the simple appearance of current general-purpose search engines might include that search engines need to be understandable and accessible for audiences with a wide variation of search and system experience. Other motivations behind the simple design are related to different cognitive aspects: search tasks are usually part of larger work tasks, and the interface should distract as little as possible (Hearst, 2009). This issue has also been illustrated by Diriye et al. (2010), who found that excessive SUI features with respect to the complexity of the task at hand might actually impede information searching. We can connect these cognitive aspects to *cognitive load theory*, which describes cognitive load as the load on working memory (Sweller et al., 1998). The working memory has a limited capacity for processing information, as opposed to to the 'effectively unlimited' long term memory, in which knowledge schemas can be stored. The act of processing and incorporating information in knowledge schemas that may be part of information-intensive work tasks is already demanding, i.e. has a high *intrinsic* cognitive load. Overly complex search interfaces may further increase *extraneous* cognitive load, and thus leave less cognitive resources available for the core task.

Notwithstanding the deceivingly simple appearance of current search interfaces, the "art" of designing them is still complex. Over the years, however, a number of frameworks, guidelines and design pattern libraries have been created (Shneiderman and Pleasant, 2005). Despite the immediate value of those frameworks for creating appropriate search user interfaces, they mainly focus on designing the functionality of SUI elements in the best way.[3] In that sense, it is unclear at which moments of complex tasks these features are most useful, and how they can be combined to support (and not impede) complex searches – thus, how these features fit in the macro-level information seeking process.

In the context of this chapter, we make use of two specific frameworks. First, with respect to the concrete features of SUIs, Wilson (2011) has proposed a taxonomy for

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[2] Google's Wonder Wheel provided "an interactive way of exploring related searches" (Wilson, 2011).

[3] For instance, how to design a 'pagination control' feature for a search engine, `http://web.archive.org/web/20150406100824/developer.yahoo.com/ypatterns/navigation/pagination/search.html` (accessed: 04/01/19).

Table 2: Wilson (2011) taxonomy of SUI features, with examples (adapted from Huurdeman and Kamps (2014))

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

thinking about SUI designs. It divides the features of SUIs into four main groups: *input features* allow searchers to express their input to the search engine, *control features* make it possible to modify or restrict input, *informational features* provide results or information about them, and *personalizable features* are tailored to the specific experience of a searcher (see Table 2). This framework can aid the creation and analysis of Search User Interfaces.

Second, a potentially helpful higher-level system perspective has been provided by Bates (1990). The "degree of user vs. system involvement in the search" encompasses a continuum, ranging from fully manual search activities to fully automated searches. Also, she distinguishes various levels of search activities. The lower level activities are *moves* and *tactics*. Moves are simple actions, for example entering a search term, and serve as the basic units of search activities. Tactics consist of one or more moves to further a search, and have strategic considerations. For instance, reformulating an entered search term to a broader (superordinate) term. Higher level activities include *stratagems*, and *strategies*. A stratagem is a complex set of tactics and moves, and generally includes a specific information domain, and a mode of tackling the file organization of that domain – for instance performing author searches in bibliographic databases to find other materials written on the same subject. Finally, a strategy is a plan for the entire information search, and may include all previous types of search activity.[4] Bates' search activities may provide inspiration for a better understanding of levels of system support across stages.

2.4 Search Interface Features for Different Information Seeking Stages

From the previous sections we can observe that there are issues in the translation from the rich stages described in information seeking literature to concrete support in terms of search system features, and vice versa. Information seeking models such as Kuhlthau (2004) and Vakkari (2001) thoroughly studied the *macro-level* multistage nature of the information seeking process, but do not provide immediate

[4] Although, as Bates (1990) notes, it is difficult to list a search strategy in advance "in any but the simplest searches, because most real-life searches are influenced by the information gathered along the way in the search."

handles for implementing search system and user interface features at the specific *micro-level*. Conversely, also the exact role of specific *micro-level* user interface features at different stages of the *macro-level* information seeking process is fuzzy (Huurdeman and Kamps, 2014). Only a limited number of studies have combined these perspectives.

Most of these studies have looked at feature use over time, often based on system log data. For instance, White et al. (2005) looked at implicit and explicit Relevance Feedback functionality, and concluded that implicit RF was used more in the beginning of search sessions, and explicit RF near the end. Query suggestions, according to Niu and Kelly (2014) were used for more difficult tasks and in later phases of search, suggesting their use as Bates (1979) "idea tactics". Some studies using eye tracking, including Kules et al. (2009), showed that users' main focus moved over time from looking at facets, query and results to looking mainly at results during the search sessions. According to Kules and Capra (2012), feature use varied over time, and they indicated that facets were especially used in cognitively demanding stages. Diriye et al. (2013) distinguish between search stage specific features (e.g. query box and 'starter pages' containing basic information) useful in the beginning of a search, and search stage agnostic features useful across stages (in their case, e.g. facets). Finally, Huurdeman and Kamps (2014) included a small-scale quantitative analysis of data from a user study involving eye tracking with 12 participants, and provided further indications that some types of search system features are search stage-sensitive, while other features are useful in all stages.

Many of these studies use a temporal division of search sessions to derive search stages, which could be better characterized as "phases of search" according to Niu and Kelly (2014) – since they might not include the same level of learning and construction as indicated in information seeking models such as Kuhlthau (2004)'s and Vakkari (2001)'s. Therefore, Huurdeman et al. (2016) looked further into exactly how the usefulness of specific types of search functionality evolves, via a user study with 26 participants with a novel multistage simulated task approach.[5] Participants used the experimental search engine *SearchAssist* to perform three distinct tasks, representing Vakkari (2001)'s *pre-focus*, *focus* and *post-focus* stages. Using extensive logging and tracking, insights were gained into the active and passive use of features, grouped via Wilson (2011)'s taxonomy of interface features. Questionnaires and interviews provided indications of how useful the users perceived the features to be over time, allowing for triangulation of findings. The main finding was that within a multistage task involving knowledge construction, the active, passive and perceived usefulness of SUI features differ per information seeking stage. *Informational features* were naturally useful in all information seeking stages. *Input* and *control features*, to express needs and modify input, could be categorized as search stage sensitive features. The value of these features was highest in the initial pre-focus stage, and decreased over time. This reflects a user's increasing understanding of a topic, during which the value of features to help formulating a query and delimiting a resultset may decrease. Contrary to input and control features, *personalizable fea-*

[5] The task approach has been further described in Huurdeman et al. (2019).

tures became more useful over time, as they may “grow” hand-in-hand with a user’s understanding during the information journey.

2.5 Summary

In this section, we started with an overview of tasks and information behavior, and gradually zoomed in to information seeking, information searching, as well as concrete search user interfaces and concluded that the ways in which they support the inherent cognitive aspects of macro-level information seeking stages is rather opaque. Therefore, in the next section, we introduce a framework which aims to provide more direct connections between macro-level stage and (categories) of micro-level SUI features.

3 Toward a Framework for Complex Task Support

This section outlines a framework for complex task support and its relation to user interface features of information search systems.

The information seeking models discussed in the previous section have illustrated that a searcher’s conceptual framework about a topic may evolve over time during cognitively complex tasks. For instance, during a novice user’s information journey, knowledge structures evolve, just as during a scholars’ research process, conceptualizations of a topic may undergo changes.

Keeping this evolution in mind, the system should constitute a “helpful framework within which the user can make problem-solving decisions” (Oddy, 1977). However, current search interfaces typically do not evolve with a user’s knowledge – to become truly ‘helpful’, a system should ideally support the information seeking *process* of a user, moving from exploratory *pre-focus*, to *focus formulation* and final *post-focus* stages. As indicated in the previous section, existing information seeking models, such as Vakkari (2001); Kuhlthau (2004), do not contain explicit references to actual search system and search user interface design.

Therefore, we introduce our framework for supporting complex tasks involving learning and construction, which explicitly connect the temporal development of complex tasks with different levels of support by SUI features. The framework combines the temporal stages proposed by Vakkari (2001), the findings from Huurdeman and Kamps (2014); Huurdeman et al. (2016), and Bates (1990)’ notion of search activities – in particular moves, tactics, strategems, and strategies.

Our proposed framework is visualized by Figure 3. The framework consists of three dimensions. As context, we use SUI features listed in Wilson (2011)’s taxonomy of SUI features, augmented with more recently introduced features. The dimensions are distinguished based on associated features’ level of support for the process, and the relative importance in different stages of a complex task.

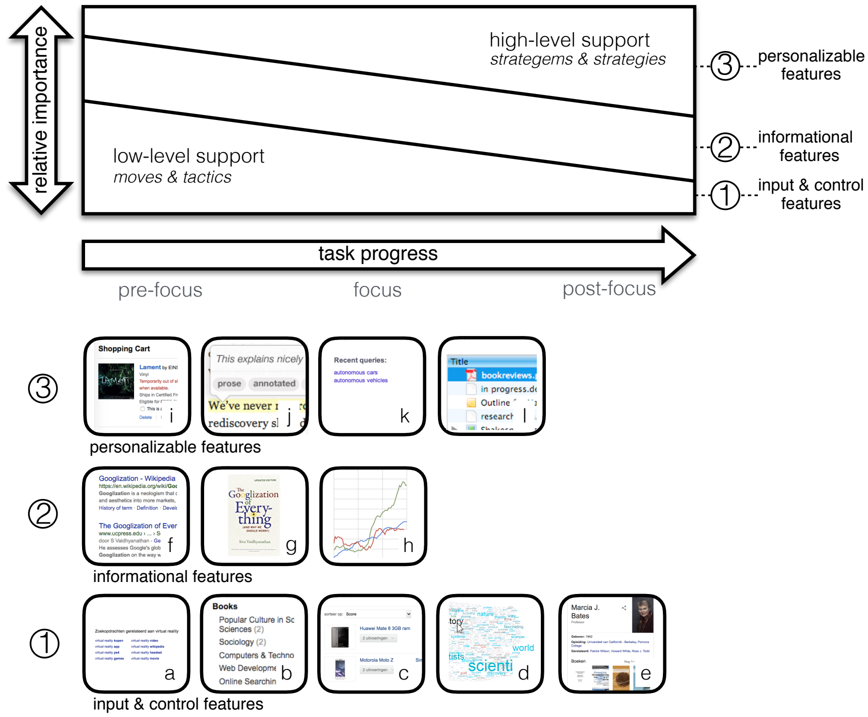

Fig. 3: Schematic overview our framework for complex task support: low-level support for moves and tactics gradually gives way to higher level support for stratagems and strategies.

The *first dimension* of the framework focuses on low-level support (Section 3.1). The *second dimension* consists of the general seeking support offered by informational features, i.e. the actual search results and information about those results (Section 3.2). These features might provide low and high-level support. The focal point of the *third dimension* is on specific high-level support (Section 3.3). During complex information seeking tasks, the relative importance of low-level support gradually decreases, while conversely the relative importance for high-level support is gradually increasing. The mid-point is formed by informational features, which have the same level of relative importance over time. Next, we will discuss each of the three dimensions in more detail.

3.1 First Dimension: Input and Control Features

The first dimension of our framework consists of features offering automatically generated suggestions to users. This support typically takes place at Bates (1990)'s search activity level of the 'move' (e.g. entering search terms), and 'tactic' (e.g. choosing a broader term). For instance, a word cloud feature may suggest keywords for a query, or a query suggestion feature may propose a broader formulation of a query. The need for this *low-level* support, embodied in various *input* and *control* features, generally decreases over time. When a user's conceptualization of a topic grows, she becomes increasingly able to express herself precisely in the context of that topic (Huurdeman et al., 2016; Kuhlthau, 2004), and support at the level of moves and tactics becomes more superfluous.

An SUI designer has a wide variety of features at her disposal to provide low-level support for searching. First of all, at the level of the query (see Figure 3, part ①), **Query Corrections**, **Query Autocomplete**, and **Query Suggestions (a)** can provide help in formulating the right query, and suggesting alternative queries. Especially in initial stages, **Facets and Filters (b)** can be useful to delineate resultsets, and adapting **Results Ordering (c)** may initially help to find the right items. **Word Clouds (d)**, even though their effectiveness in information searching has shown fluctuating results, may also provide inspiration. Finally, current search interfaces often contain **Entity cards (e)**, an information panel with brief information and related entities for an intended query target.

3.2 Second Dimension: Informational Features

The second dimension of our framework is formed by general information seeking support. This constitutes *informational* features, which provide the actual results, or information about encountered result items. For instance, a search system may show the title of a document, a short snippet and basic metadata. As evidenced in previous experiments (i.e., Huurdeman et al., 2016), these features may be useful throughout the process. They provide low-level support at the move and tactic level, for instance selecting and opening information sources, but also higher level support (e.g. offered by visualizations of result sets).

Informational features may provide both low and high-level support (see Figure 3, part ②). These features contain the **Search Results (f)** themselves, commonly shown by their title and a short textual snippet. Especially in e-commerce systems, also **Thumbnails (g)** might visually depict resultset items. **Visualizations (h)** can provide more insights into retrieved resultsets. These may initially be useful for a researcher to explore a set of data, but also to visualize a gathered set of focused results for analysis.

3.3 Third Dimension: Personalizable Features

The third dimension of a 'helpful framework' consists of features which can support seeking at a higher level. While these types of features may include automated functionality, the main aim is to provide insights into a user's process *through her actions*. As Kuhlthau's model has indicated, processes of hypothesis generation, data collection, information organization and the preparation of a personalized synthesis of a topic take place during processes of knowledge construction (Kuhlthau, 2004, p.194). This reflects the highly personalized nature of such complex activities, meaning that automated support may not suffice. Instead, the aim of *personalizable* features should be to aid users in performing their task. In different experiments, the usefulness of annotation, saving and organization features by both students and graduate researchers has been evidenced (e.g., Morris et al., 2008; Huurdeman et al., 2016; Hearst and Degler, 2013). As opposed to low-level features, these higher-level features may support Bates' 'stratagems' and 'strategies' (i.e. planning in the context of an entire search). On the one hand, through logging user's actions and potentially gathering data about the actors' domain knowledge or task at hand, they provide a trail of activities, which may (passively) aid users in locating where they are in the process. On the other hand, they also allow a user to 'work with results', and thus encourage reflection on encountered results. As such, they become increasingly useful throughout a task.

More high-level support throughout the process (see Figure 3, part ③) may be offered by **Results Saving (i)** features, alternatively embodied in e.g. shopping carts and wishlists. Interfaces may also offer **Personal Results Organization** opportunities. Furthermore, especially in a research context, **Annotations (j)** are used at different points in the process (Melgar et al., 2017). Other tools which may be useful, sometimes only in passive ways (Huurdeman et al., 2016) are **Query History (k)** features. Finally, **External tools (l)** may provide high-level support, such as word and data processing, as well as reference management.

3.4 Concrete Example: SearchAssist

In the previously described study by Huurdeman et al. (2016), the three dimensions of our framework for complex task support were included in an adaptable open-source search user system, using generally available search APIs and web frameworks. This interface shown in Figure 4 serves to illustrate the three dimensions of our framework. Its first dimension is reflected by the input and control features in the left-hand side panel, which make it possible to use low-level support in user's searches, with ① category filters, ② word clouds, ③ query suggestions, and ④ a query box, including query corrections. The framework's second dimension is reflected by ⑤, the search results feature displayed in the middle. Finally, the right-hand side panel originates from the third dimension of our framework: ⑥ recent queries and ⑦ categorizable saved results, and ⑧ a task bar. Besides its use in an experimental context, this

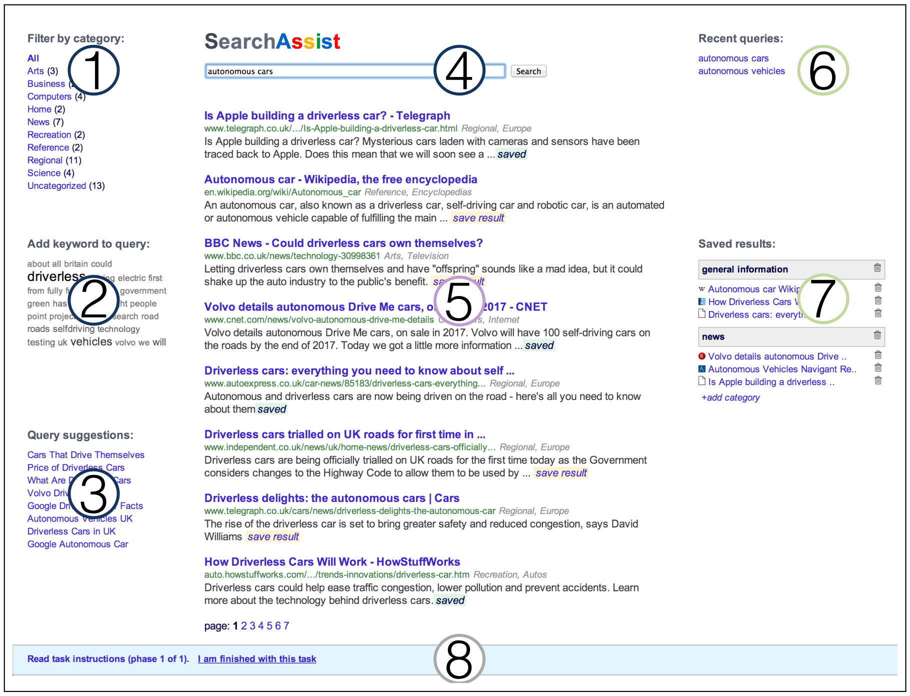

Fig. 4: Screenshot SearchAssist: *input and control features* (first dimension) in ①–④; *informational features* (second dimension) in ⑤; and *personalizable features* (third dimension) in ⑥–⑧.

interface was meant as a reusable component for information seeking studies, also reflected in the rich logging possibilities. Adaptive support for users can be catered for by gradually turning on and off features in this interface depending on the user's search stage. Further information on this search system and interface can be found in Huurdeman et al. (2019).

3.5 Summary

More dynamic support for complex research-based tasks may be achieved by differentiating SUI feature categories and their levels of support. In particular, functionality providing low-level support (i.e. *input* and *control features*), are useful in the initial stages of a complex research-based task. Searchers with low domain knowledge, but also researchers exploring a new topic and collection may utilize this functionality to bootstrap their searches. Features providing high-level support (in particular *personalizable* features), may invite searchers to explicitly reflect and interact with results, as well as seeing how these results fit in their process and strategy.

Our supportive framework for complex task support provides practical pointers to the use of features over time, and thus makes it possible to design SUIs pinpointed to the task at hand. On the one hand, this can be by customizing the interface on the basis of expected user activities, for instance low-level activities or more high-level activities. On the other hand, our framework might be useful for creating more adaptive, stage-aware interfaces. This adaptation can be done by the system by automatically adapting features, but could also be done by the user herself. A concrete example are the user-selectable interface panels as evaluated in Gäde et al. (2016), which include a *Browse view*, a *Search view*, and a *Book-bag* view, aiming to support pre-focus, focus formulation and post-focus stages.

These types of interfaces might contribute to creating more holistic systems for complex tasks where tasks can be carried out "in the flow." Our framework can also help understand and explain the design considerations of existing systems used in the context of complex tasks, which we discuss in the following section.

4 Systems Integrating Complex Task Support

This section connects the complex task support framework to examples of concrete systems within a research context, in particular emphasis on exploratory search and sensemaking systems.

4.1 Exploratory Search Systems and Features

As indicated by Marchionini (2006), traditional search is often focused on lookup searches, while *exploratory search* also includes learning and investigation. White and Roth (2009b) characterize it as a complex form of information seeking, which is multifaceted and open-ended – complex information problems are involved, as well as a poor understanding of terminology and information space structure. Also, exploratory searchers often exhibit a desire to learn.

As argued by Huurdeman and Kamps (2014), there are similarities between exploratory search and the initial parts of Kuhlthau's multistage model. White and Roth (2009a) indicate that searchers might initially experience uncertainty and this uncertainty might decrease when exploratory searching transitions to focused searching – this has similarities with Kuhlthau's model as depicted in Figure 1. As such, the concept of exploratory search fits well in the first dimension of our framework, since these SUI features are especially useful in the initial stages of a search.

A variety of exploratory search features has been presented in White and Roth (2009a) and summarized in Huurdeman and Kamps (2014). Many of the discussed features fit in the first dimension of our framework (Figure 3, part ①). FilmFinder (Ahlberg and Shneiderman, 1994) facilitated rapid query refinement in visual ways (thus representing an input and control feature). Flamenco (Yee et al., 2003) allowed for rich metadata-based filtering and facets and thus also allows users for input and control. Other features are characterized as supporting exploratory search, but more specifically can be classified as personalizable features which fit in the high-level support outlined by the framework (Figure 3, part ③). For instance, SearchBar allows for "search task management, a system for proactively and persistently storing query histories, browsing histories, and users' notes and ratings in an interrelated fashion" (Morris et al., 2008).

4.2 Sensemaking Systems and Features

In the context of Human-Computer Interaction, the combined process of information seeking, analysis and synthesis, has been described as *sensemaking*, which relates to the framework discussed in the previous section. Hearst (2009) has described sensemaking as "the iterative process of formulating a conceptual representation from a large volume of information".

The concept of sensemaking is commonly used in the context of complex and information-intensive tasks, comparable to Kuhlthau's and Vakkari's models, albeit sensemaking is more often described in a professional, as opposed to the more educational context of Kuhlthau (2004) and Vakkari (2001). For information analysts, (Pirolli and Card, 2005) describe two main loops in sensemaking: the information foraging loop ("processes aimed at seeking information, searching and filtering it"), and the sensemaking loop ("iterative development of a mental model that best fits the evidence"). There are explicit relations with Kuhlthau's model, as she indicates that the latter stages in her model (i.e. Formulation, Collection, Presentation) include processes related to hypothesis generation, data collection, information organization and personalized syntheses of topics (Kuhlthau, 2004).

As such, sensemaking has a relation with the third dimension of our framework (Figure 3, part ③), i.e. support at a higher-level, and features supporting sensemaking become increasingly important over the course of an information seeking process. Ample practical examples of sensemaking in previous literature exist. Hearst (2009) discusses the main elements which constitute sensemaking interfaces, including flexible grouping of information, notetaking and sketching, hypothesis formulation, as well as collaborative search. Some of these, mostly personalizable, features are included in CoSen, which organizes retrieved information in a tree structure (Qu and Furnas, 2008). Sandbox has been described as a "thinking environment". It allowed for visual organization of results and makes hypothesis generation possible (Wright et al., 2006). Hearst and Degler (2013) describes the process of designing and evaluating "a user interface at the seam between searching and saving and organizing search results". CoSense (Paul and Morris, 2009), on the other hand, focuses on sensemaking in the context of collaborative tasks.

4.3 Summary

The search systems and interfaces discussed in this section have outlined the relationship between on the one hand exploratory search and sensemaking features, and on the other hand our framework for complex task support. In particular, many features allow for organization of retrieved results and task management. However, most of these features do not take into account the support for navigating found websites and their structures, which we discuss in the following section.

5 Connecting Search and Navigation

This section discusses how the complex task support framework naturally integrates search and navigation features across search stages, and to what extent this both supports "search by navigation" and "search by query".

5.1 Navigation Support and Informational Features

Thus far, this chapter has mainly focused on *information seeking*, concerning interaction with information sources, and *information searching*, specifically focusing on the interaction between information user and information system. In a search context, Jul and Furnas (1997) also have distinguished between "search by query" tasks, i.e., those tasks conducted within a search system, and "search by navigation" tasks. While we have covered the former type of task in detail, we have focused less on search by navigation: users might navigate beyond the actual search interface by clicking on result-set items, examine resources linked from the result list (e.g. webpages) and navigate further from the encountered resource (e.g. to other webpages in the found website). While visiting various pages, users might learn about their topic from contextual information encountered along the way (Karanam et al., 2016; Karanam and van Oostendorp, 2019; van Oostendorp and Karanam, 2019).

Our framework suggests a holistic approach, where further interaction with the search results (the second dimension with informational features, Figure 3, part ②) is conceptually regarded as part of the system. It is an open question how visible the system should be when interacting with results outside the system itself: it could be always present as a task bar, or minimized and available upon request, or remain hidden until the user navigates back to the search support system. Other than the search results themselves, including ways of deep linking, and aggregated results already mentioned in Section 3, there seem no additional informational features to support navigation. But there are further connections between navigation support and the search-based aspects of the first and third dimension of our framework.

5.2 Navigation and Input and Control Features

In the first dimension of our framework (Figure 3, part ①), we listed various input and control features which offer automatically generated suggestions to users at Bates (1990)' move and tactic level. In terms of navigation support, these types of features offer a continuum, ranging from a focus on navigating the search result space, to pure navigational support for found resources.

First, the discussed facets and filters make it possible to better judge the types of information retrieved so far, both by their grouping and by their labeling. These labels may provide a more analytical view on content, and can be considered as *suggestions* for navigation. Using facets and filters, it is possible to navigate the result space without reformulating a query, and get a basic idea of what is being found – even before visiting the actual pages. Other initial topical information and ideas for basic navigation might be given by the query suggestions, entity cards, as well as result space visualizations (e.g., Ruotsalo et al., 2014).

Second, we might combine search and navigation, inspired by additional features discussed in previous literature. Capra et al. (2015) describe search assistance in the form of a 'Search Guide', which allowed users to view previous search trails from three other users. Search trails "provide an interactive display with information about how another person searched, and may include the queries issued, results clicked, pages viewed, pages bookmarked, and annotations made by the original searcher." This way, a searcher might get more information on likely successful browsing paths, aiding in navigation, and these types of features might provide "information scents" to users (Pirolli and Card, 1999).

Third, an approach more specifically focused on navigation has been described by Dehghani et al. (2017), involving browsing path recommendation. Their approach includes a path recommendation engine, which based on a text query, "ranks different browsing paths in the hierarchy based on their likelyhood of covering relevant documents." An SUI feature which offers this approach might help users to more quickly understand the structure of important retrieved websites, especially in the context of complex information structures.

Thus, we may extend the featureset specified in the second dimension of our framework (Section 3) with additional features tailored to assisting navigation, for instance by showing search trails by other users, and by means of a browsing path recommendation feature.

5.3 Navigation and Personalizable Features

The third dimension of our framework (Figure 3, part ③) contains features which can support seeking at a higher level – the discussed personalizable features provide insights into a user's process through her actions. Examples of these kind of personalizable features included lists of recent queries and previously visited pages.

As indicated by users utilizing the SearchAssist system depicted in Figure 4, its previous searches feature became increasingly useful over the search episode, because it indicated what searchers did before, thus providing handles to monitor their process (Huurdeman et al., 2016). This notion of task management can be extended further. For instance, Jia and Niu (2014) present a "history preview" feature, meant to "assist searchers to review what they have done within a search session in order to help them define the next steps during the search process." The visualized 'search trajectory' includes previous queries, and per query, list actions such as clicked results, saved results and pagination use – thus showing the trail of activities and previous navigation done by a user. This provides similar functionality as the search trail feature by Capra et al. (2015), but focused on a user's own process and by nature personalized. An extensive search trajectory SUI feature could support Bates (1990)' notion of a search strategy, i.e. documenting a plan for the entire search, potentially consisting of moves, tactics and strategems. These types of features could also show conducted navigation steps beyond webpages directly found in the search system. Insights into the structure of found information could be for instance be visualized using tree structures (e.g., Qu and Furnas, 2008).

Thus, in the light of supporting navigation, the feature set mentioned in the third dimension of our framework (Section 3) can be extended with history features showing a user's own search trail, including previous queries and actions.

5.4 Summary

Our inquiry into supporting both "search by query" and "search by navigation" resulted in two new insights: the potential for integrating navigation-related features in our framework, as well as the potential for supporting users in their navigation steps outside of the search system within longer sessions.

First, our framework naturally supports the integration of novel navigation-oriented features within the discussed first and third dimension, and within the associated early and late stages of search. More specifically, the idea of search trails might aid users in both early (pre-focus) stages and late (post-focus) stages of the information seeking process. First, in early stages by recommending potentially viable search and navigation trails using input and control features. For these kinds of recommendations for instance previous user data, but also computational cognitive models of web navigation might be of value (Karanam et al., 2016), as well as further path recommendation techniques (Dehghani et al., 2017). Second, in late stages users might be able to view their *own* search trails using personalizable features. The concepts of search trails can be connected to both Bates (1989)' Berrypicking model and Pirolli and Card (1999)'s information foraging theory. By providing search as well as navigation support, these types of features might potentially further aid users in complex task performance.

Second, we touched upon the support for showing search and navigation trajectories including navigation steps beyond webpages directly found in the search system.

Such a feature could register navigation behavior outside of the search system, and show this in the SUI interface. For instance, this could be implemented by showing a “minimized” version of the SUI in further navigation ventures (for instance in a frame), or by including a browser extension capturing navigation steps across the overall search episode.

6 Discussion and Conclusions

This chapter was inspired by a paradox: on the one hand, search engines on the web provide a world of information at our fingertips, and the answers to many of our common questions are just a simple click away. On the other hand, many of our tasks are complex and multifaceted, and involve a process of knowledge construction: various information seeking models describe a complex set of cognitive stages, influencing the interplay of users’ feelings, thoughts and actions (Kuhlthau, 2004; Vakkari, 2001). Despite the evidence of the models, the functionality of search engines, nowadays the prime intermediaries between information and user, has converged to a streamlined set. Even though the past years have embodied rapid advances in contextualization and personalization, our complex information environment is still reduced to a set of ten ‘relevant’ blue links. This may not be beneficial for supporting complex tasks involving ill-formulated or exploratory needs (White and Roth, 2009a), for tasks requiring sustained interaction with information, and for ventures involving the formulation of a deep understanding on a topic (Kelly et al., 2013; Smith and Rieh, 2019). This suggests that the currently dominating lookup search approach falls short of the rich interaction needed for task-sharing between user and system (Beaulieu, 2000).

The main reason for the current lack of complex task support is that designing optimal search user interfaces is highly non-trivial. Real world applications vary dramatically over use-cases, work tasks, available information and encoding, available systems, and searcher competencies—making every application highly unique. Properly supporting them requires significant advances in our general understanding of how generic search components support information interaction at a higher level of abstraction. Indeed, the design of SUIs can be seen as an “art” (Oddy, 1977; Smith and Mosier, 1986), involving numerous thorny issues and trade-offs in usability. For instance, combining excessive sets of features may overload the user, while a streamlined approach can be too limiting for supporting user needs in different stages of complex tasks. At each stage of a task, an optimal combination of features may exist. This paper provides handles to determine the **relative importance** of features when designing SUIs, thus connecting theoretical information seeking models and more concrete search user interface design.

At the level of the whole SUI, various approaches for the provision of dynamic support for information seeking stages can be suggested. First of all, a totally open approach is possible: searchers are free to choose a custom set of SUI features at any point of the process (“build your own SUI”). Second, predefined interface panels combining features can be offered to a user (e.g. for exploration and focused search). This way, a user can choose a panel she needs at any stage, or indicate their current information seeking stage (for instance, via a selector or slider). Third, a totally adaptive approach may be followed: using evidence from usage data, interface features are automatically offered or disabled. Hence, the potential adaptation of interfaces for complex tasks spans a continuum, ranging from fully manual to entirely automatic approaches. Albeit we focus on the SUI level, this is reminiscent of Bates (1990)' degree of user and system involvement in the search process.

In the CLEF Interactive Book Search Track, users were able to select interface panels for pre-focus, focus and post-focus search stages, and positive effects on user engagement were found (Gäde et al., 2015). It would be valuable to gain further insights into the influence of dynamic presentation of search stage-sensitive SUI features on user satisfaction, i.e. the features within the first and third dimension of the framework discussed in Section 3. Future studies should further look at the impact of dynamic and adaptive presentation of SUI elements, especially since this influences the consistency of an interface. This may be tested by adaptively enabling and disabling SUI features in experimental systems with rich functionality in a (simulated) complex work task setting. Multistage systems may provide new ways to reduce unnecessary *extraneous* cognitive load (as defined by Sweller et al. (1998)) by hiding superfluous interface elements, and increase *germane* cognitive load, focused on the stage of the learning task at hand. Furthermore, providing further navigation support for resources linked from search engines might provide value.

At the level of atomic SUI features, this paper briefly outlined feature utility during the information seeking process, based on Bates (1990) levels of search activities discussed in Section 2.3 (i.e. *moves*, *tactics*, *strategies* and *strategems*). Further research is needed to allow for making more conscious choices of which features to include in an interface, based on the purpose they serve in the process. For instance, we may use Bates' levels of search activities as a 'lens' for analyzing existing SUI features. Furthermore, as suggested in Huurdeman et al. (2016), individual features could be improved by taking previous user interactions as a basis and thus becoming more *personalizable*. For instance, query suggestions can lose their value over time due to a user's increased domain knowledge, but may provide more "intelligent" suggestions by taking into account previous user interactions.

Previous literature in the area of cognitive modeling, and devised computational cognitive models such as SNIF-ACT (Fu and Pirolli, 2007), CoLiDeS (Kitajima et al., 2005) and CoLiDeS+ (Karanam et al., 2016) can inspire further improvements of SUIs supporting a user's process, especially in early search stages. First of all, by utilizing the models we might derive the optimal formulation of category and link labels, for instance within the category filters feature of the SearchAssist interface described in Section 3.4, thus providing optimal information scents (Pirolli, 2009). Second, cognitive models might provide further browsing path recommendations in the context of search systems, as shown in e.g. Dehghani et al. (2017), and provide ongoing assistance in selecting useful links and paths. Third, we might use cognitive models and associated cognitive architectures as an inspiration to improve design. Further work is necessary, however, to utilize predictive models at broader, macro-level scales – potentially needing "layers of models at different bands" (Pirolli, 2009; see also Pirolli, 2019). Challenges might occur: such models should be able to capture the dynamics of the information seeking process documented by Kuhlthau (2004), and ought to be able to "handle the complexities in realistic environments", such as real websites (Karanam et al., 2016).

The other way around, our research can inspire future development of cognitive models in an SUI context. Multifaceted data was collected in the context of Huurdeman et al. (2016), including eye tracking, detailed usage logs, questionnaires and interviews, and these rich kinds of data might be used to build up computational cognitive models.

The presented framework is a first step towards a more holistic approach for SUI design. Further research on the utility of SUI features, as well as more high-level SUI functionality in search systems is needed (see also Umemoto et al., 2019). For instance, explicit support for Bates' strategems and strategies is still rare, almost 30 years after her seminal paper. However, the ubiquitous presence of search engines in diverse manifestations may allow for more inclusive views on user activities in consecutive stages of complex search processes. By adapting low and high-level support, thus creating dynamic SUI compositions, we may be able to arrive at a more "intellectual symbiosis" between user and system as envisioned by Bates (1990).

Our main general conclusion is that there are many relatively unexplored ways to better support the search process, in ways that empower users to control complex information search tasks. This holds the promise to lead to better and more transparent search results and work task outcomes. And all this with the system adapting to the user's needs, rather than have the user adapt their entire search process to the system's functionality and (in)abilities.

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