

Towards a theoretical framework for information retrieval in an information seeking context

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INTRODUCTION

This paper presents the initial stages of the development of a three-dimensional model as a theoretical framework for conceptualizing and exploring interactive information retrieval (IR) with an information seeking context. The model, displayed in Figure 1, includes a Plane of Judgment within a Plane of Interaction within a Plane of Time. The Plane of Judgment includes levels and regions of relevance judgments, and other user judgments during interactive IR, e.g., magnitude or strategy feedback, tactics, search strategies, or search terms. The Plane of Judgment exists within a Plane of Interaction. The Plane of Interaction consists of interactive IR models, including Ingwersen (1992, 1996), Belkin, Cool, Stein and Theil (1995), and Saracevic (1996b, 1997). The Plane of Interaction includes movement or shifts within interactions or search episodes, e.g., tactics, information problem, strategies, terms, feedback, goal states, or uncertainty. IR interactions that occur within a Plane of Interaction exist within a Plane of Time. The Plane of Time includes users' information seeking stages, represented in the model by Kuhlthau's Information Search Process Model (1993) and users' successive searches over time related to the same or evolving information problem (Spink, 1996).

The three-dimensional model is a framework for the development of theoretical and empirical research to: 1. Integrate interactive IR research within information-seeking context 2. Explore users' interactive IR episodes within their changing information-seeking contexts 3. Examine relevance judgments within users' information seeking processes 4. Broaden relevance research to include the concurrent exploration of relevance judgment level, region and time

Each Plane of the three-dimensional model is presented and discussed to develop an integrated view of users' interactive IR processes within their

changing information-seeking contexts. The next section of the paper explores the first dimension of the three-dimensional model - the Plane of Judgment.

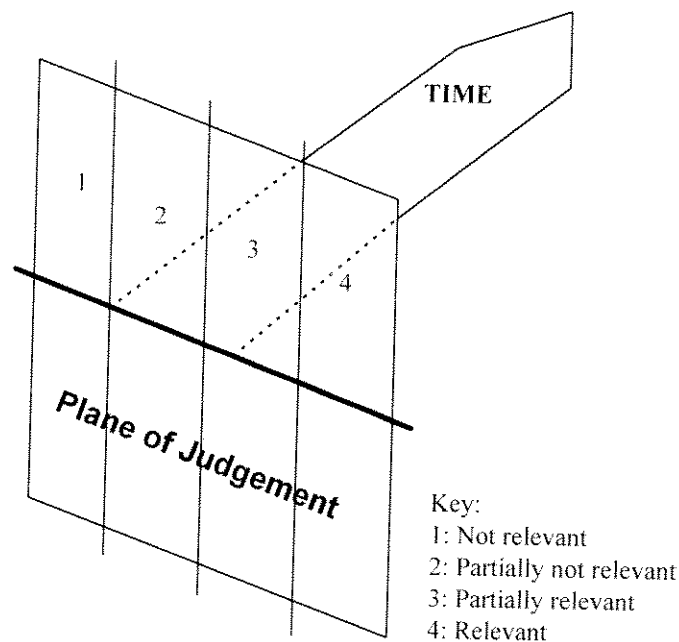


Figure 1: Three dimensional model

PLANE OF JUDGMENT

The Plane of Judgment is presented first, as it served as a beginning for the development of the three-dimensional model. A Plane of Judgment arose from research exploring levels and regions of users' relevance judgments (Spink & Greisdorf, 1997a,b; Spink, Greisdorf & Bateman, 1998, in press). The Plane of Judgment, displayed in Figure 1, consists of Levels of Relevance and Regions of Relevance.

Relevance level

The first dimension of the Plane of Judgment, or relevance level, developed from Saracevic (1996b), who suggested that "as a cognitive notion relevance involves an interactive, dynamic establishment of a relation by inference, with intentions toward a context." Within the cognitive level of IR interaction, Saracevic

(1996b) proposed an interdependent system of relevances based on five manifestations or levels of relevance:

Systems or algorithmic relevance: relation between a query and information objects (texts) in the file of a system as retrieved, or as failed to be retrieved, by a given procedure or algorithm. Each system represents, organizes and matches to a query using specific methods and algorithms. These methods and algorithms encompass an assumption of relevance, in that the intent is to retrieve a set of texts that the system inferred as relevant to the query. Comparative effectiveness in inferring relevance is the criterion for system relevance.

Topical or subject relevance: relation between the subject or topic expressed in a query, and the topic or subject covered by retrieved texts, or more broadly, by texts in the systems file, or even in existence. It is assumed that both queries and texts can be identified as about a topic or subject. Aboutness is the criterion by which topicality is inferred.

Cognitive relevance or pertinence: relation between the state of knowledge and cognitive information need of the user, and texts retrieved, or in the file of the system, or even in existence. Cognitive correspondence, informativeness, novelty, information quality, and the like are criteria by which cognitive relevance or pertinence is inferred.

Situational relevance or utility: relation between the situation, task, or problem at hand, and texts retrieved by a system or in the files of a system, or even in existence. Usefulness in decision making, appropriateness of the information in the resolution of the problem, reduction of uncertainty, and the like are criteria by which situational relevance is inferred.

Motivational or affective relevance: relation between the intents, goals, and motivations of a user and the texts retrieved by a system or in the files of a system, or even in existence. Satisfaction, success, accomplishment, and the like are criteria for inferring motivational relevance.

There also exists a cognitive notion of negativity within that same realm of relevance. Therefore, a cognitive notion of relevance also involves an interactive, dynamic establishment of no relation or a partial relation by inference, based on interactions toward a context. If this negative aspect is added to the manifestations of relevance as defined by Saracevic, we find an expansion of the cognitive plane of judgement to allow further manifestations as follows:

- Systematic/Algorithmic Inference: the relation or non-relation between query and information objects;
- Topical/Subject Inference: the relation or non-relation between the subject/topic expressed and the retrieved text(s);
- Cognitive Inference/Pertinence: the relation or non-relation between a user's state of knowledge and the informativeness of the retrieved text(s);

- Utility/Situational Inference: the relation or non-relation between the problem at hand and the retrieved text(s);
- Motivational/Affective Inference: the relation or non-relation between the user's goals/intents and the retrieved text(s).

Saracevic's five levels of relevance exist in Figure 1 within regions along the vertical axis. Their placement along the vertical axis does not imply a relationship between the levels. The manifestations of inferential relationships become levels of relevance is shown as the first dimension of a plane of relevance judgement. These levels of relevance imply no hierarchy or measure of strength. They merely exist as possible relational inferences at a specific point in time. Each level exists as a discrete category - not on an interval scale. Each user relevance criterion could also be situated within one or more of Saracevic's five levels of relevance along the vertical axis. Sometimes multiple criteria may be used. For example, the user may have several other criteria that represent several levels to judge high relevance - affective ("I like the author") or situational ("I can locate or access this easily").

Each user criterion for a relevance judgment could be identified within one of Saracevic's levels of relevance. Some relevance levels (e.g., cognitive relevance) may be hard to measure, and some levels may interact with each other (e.g., cognitive, situational and affective) and may be difficult to measure separately. Saracevic's approach follows previous research exploring users' relevance judgments that have produced many studies examining users' criteria for highly relevant items retrieved from IR systems. Users have been found to employ many criteria besides topicality when making high relevance judgments (Bateman, 1998). For example, quality criteria (accuracy, journal or author reputation) are important in a user's high relevance criteria. Bateman (1998) lists criteria that affect user high relevance judgments. These findings further imply that relevance is multifaceted and may not be measurable as a binary (relevant/not relevant) variable.

Relevance criteria research has generally focused on investigating users' criteria for highly relevant items with a limited focus on the criteria and role of users' partially relevant or not relevant judgments. This approach is based on the assumption that partially relevant judgments are similar or identical to highly relevant judgments and criteria. The "highly" relevant paradigm has also underpinned the design of ranked retrieval systems and automatic relevance feedback techniques. This model includes a Plane of Judgment with both negative and positive aspects of Saracevic's five levels of relevance on the vertical axis and regions of relevance on the horizontal axis.

Alternatively, a body of research has investigated the region of users' relevance judgments.

REGIONS OF RELEVANCE

The regions of relevance are situated within one of four relevance regions: highly relevant, partially relevant, partially not relevant, and not relevant. Therefore, a user's relevance judgment can be situated on the dimension of relevance level and the region within a relevance region. For example, a user may judge a retrieved item highly relevant based on the relevance level of topicality. The ability to plot these cognitive relations by inference is determined by the second dimension in the Plane of Judgment, the user's region of relevance attributed to these relations or non-relations. This second dimension also contains positive and negative aspects which can be labeled and depicted graphically.

In the model the second dimension is depicted within the four regions: (1) highly relevant, (2) partially relevant, (3) partially non relevant, and (4) not relevant. The distinction between the partially relevant quadrant and the partially not relevant quadrant in Figure 1 can be operationally defined as follows:

Partially relevant represents a judgement that confirms that some relation by inference exists as a manifestation of relevance, but the relation is weaker than a relevant relation at the time the judgement is made.

Partially not relevant represents a judgement that some non-relation exists by inference as a manifestation of relevance, but the inference is not strong enough to totally reject the relation as not relevant at the time the judgement is made.

Researchers within the region of relevance track investigate appropriate ways to measure the region of users' relevance judgments - from highly relevant to non-relevant. These judgments are often related to other factors such as the a priori definition of relevance or order of the citations. IR researchers often use triadic categorical scales for relevance judgments (e.g., relevant/partially relevant/not relevant), but collapsed users' relevance judgments into binary scales - relevant/not relevant - to simplify the calculation of precision and recall measures. This approach assumes that no information is lost in the process, and that partial relevance is the same as high relevance. Many studies have focused on binary (relevant/not relevant) relevance judgments and measures and collapsed users' relevant and partially relevant judgments together during their analysis to form the binary scale - relevant and not relevant (Spink, Greisdorf & Bateman, in press).

For a finer grain analysis, many more regions of relevance can be delineated as the granularity of relevance regions is sharpened. An overlay of the two dimensions (level and region) of a relevance judgment are represented on a plane of judgement. A user also makes a relevance decision at a specific point in time during or after the IR interaction, and a graphical representation of such decisions related to retrieved texts can also be plotted.

To extend the model, the Plane of Judgment is seen within a Plane of Interaction.

PLANE OF INTERACTION

Research based on interactive IR models evolved as IR systems developed from batch processing of user queries to interactive searching to increasingly focus on the human elements within the IR process using diverse methodologies. The Plane of Interaction related to the single search episode could be represented in the model by a combination of three different theoretical interactive IR models - Ingwersen's Cognitive Model of IR Interaction (1992,1996), Belkin, et al., 1995 Episodic Interaction Model, and Saracevic's Stratified Model of IR Interaction (1996a, 1997).

Interactive IR Models

Ingwersen's model. Ingwersen's (1992,1996) model is the most developed model that has been evolving over many years. The strength of his model is the cognitive and situational framework presented for IR interactions, and the elaboration and incorporation of what the user does, including other processes besides relevance judgments and query modification. However, user interactive process, such as feedback, are only implied processes within the model and not fully elaborated. The challenge for interactive IR models is to incorporate and elaborate feedback processes and user judgments related to a variety of situational and cognitive user states, including query reformulation, visualization, browsing and navigation.

Belkin's episodic model. Belkin, et.al., (1995) proposed an Episodic Interaction Model. This model assumes that the IR problem is based on the need to represent texts, users' Anomalous States of Knowledge (ASK), and the situational and cognitive aspects of the user's information seeking, as an approach to IR system design. The model is based on specific processes of users' information-seeking behavior, and considers user interaction with IR systems as sequences of different interactions in a series of episodes of information seeking. A central process of IR is considered to be the user's interaction with information. IR systems are depicted as needing to support users in different types of interactions and information seeking strategies. Saracevic (1997) notes that the strength of the model of Belkin, et al. is that it addresses directly the variety of processes found in IR, not only matching. He points out, however, that in common with all frame-based models, it has difficulty in identifying individual episodes and their effect on each other, as do all frame-based models.

Saracevic's stratified ir model. Recently, Saracevic (1996a, 1997) proposed a Stratified IR Interaction Model, depicting IR interaction as the interplay between

user levels: cognitive, affective and situational, and computer levels: engineering, processing and content, through an interface level at a surface level.

This model assumes that: (1) Human use of information is underpinned by cognitive and situational factors, and (2) Users interact with IR systems to use information. Saracevic's model draws on the work on Storrs (1996) in depicting IR interaction as "a dialogue between the participants - user and computer - through an interface, with the main purpose to affect the cognitive state of the user for effective use of information in connection with an application at hand" (p. 313). Interaction is understood as a "sequence of processes occurring in the several connected levels or strata" (p.316). Attributes of each IR model described, with some level of adaption, may be integrated into a Plane of Interaction within the three-dimensional model.

To extend the theoretical framework for our examination of the characteristics of judgments and search episodes, the Plane of Interaction is situated in a Plane of Time.

PLANE OF TIME

The Plane of Judgment exists within an interaction along a Plane of Time. For example, users' make judgments during an evolving information-seeking process or during successive searches. Each user judgements and searches may be plotted within three dimensions: (1) manifestations of inferential relationships (levels of relevance) and regions of relevance, (2) information-seeking, and (3) interactional time. Time may be plotted from the initiation of a user's information need, including the measures associated with the attributes of searches and judgments, in a 3D visual model. The Plane of Time, displayed in Figure 3, consists of two dimensions: (1) Information-seeking Time and (2) Interaction Time.

Information-seeking time

Information-Seeking Time is conceptualized by the inclusion of theoretical models of human information-seeking within the Plane of Time.

Information seeking models. Information-Seeking time is represented in the model by the Kuhlthau Search Process Model (1993) as the most developed model of the information seeking process. Other information-seeking or behavior models (Ellis, 1989; Wilson, 1997) of users in different contexts and related tasks could also be adapted and integrated for inclusion in the Plane of Time dimension of the model.

Results from information seeking studies show that humans progress through a series of stages, adopt different strategies and exhibit different information behaviors at different stages of their information-seeking process (Ellis, 1989;

Kuhlthau, 1993). Wilson and Streatfield (1980) found that social workers and their managers work tasks involved their seeking and exchanging information iteratively over time, suggesting that this behavior is characteristic of human communication in relation to specific issues of any kind, whether social or research-based. Kuhlthau (1993) found that the information search process of library patrons occurred in six clearly defined stages related to the cognitive, affective states and search activities of the users, including task initiation, topic selection, prefocus exploration, focus formulation, information collection, and search closure. Although Kuhlthau did not investigate the use of IR systems by library patrons, her findings suggest that IR system users continue to collect and seek information throughout their information-seeking process using or requiring different types of information, conducting different types of searches, and using different search terms and strategies at different stages of an information seeking process (Kuhlthau, Spink & Cool, 1992).

Therefore, the second dimension included in the Plane of Time is Interaction Time.

Interaction time

Interaction Time has two dimensions: (1) Time space within a search episode and (2) Number of successive searches over time.

Search Episode. A single search episode in consists of interactional time in which a series of information-seeking strategies (Belkin, et. al., 1995) takes place. A search episode is a user interaction with either a single or multiple digital information systems, i.e., CD-ROM databases, online databases, digital libraries, Web search engine, or OPAC. The individual search episode or interaction is therefore part of the Plane of Interaction within the Plane of Time and related to the Plane of Judgment, as many judgments occur during a search interaction. Therefore, the Plane of Interaction consists of all the activities, shifts, changes and judgments that occur during a single search episode. Modeling the single search episode, or even the single user query, has been a central feature of IR research. However, related or successive search episodes also occur during a user's information-seeking process.

The second dimension of the Plane of Time is **successive searching time**. Successive searching is represented within the Plane of Time as the number of searches conducted by a user during their information seeking process related to the same or evolving information problem (Spink, 1996). Successive searches are related user interactions with either a single or multiple digital information systems, i.e., CD-ROM databases, online databases, digital libraries, Web search engine, or OPAC which are separated by a time period (hours, days, weeks, months) of evaluation of the previous search episode before embarking upon a new search episode. Recent research shows that users with a broader problem-at-

hand often seek information in stages over extended periods and use a variety of information resources. As the time progresses, IR users tend to search the same or different systems for answers to the same or evolving problem-at-hand. As they learn or progress in their work, or as they clarify a problem and/or question, or as their situational context changes, users come back to IR systems of various kinds for more searches. The process of repeated, successive search sessions over time in relation to a given, possibly evolving, information problem (including changes or shifts in beliefs, and cognitive, affective, and situational states), is called a successive search phenomenon.

Data from several recent studies highlights users' successive search behavior. Recent studies show users conduct successive IR searches when seeking information related to a particular information problem.

- In one recent study 18 (45%) of academic users were found to have previous mediated online searches on the same topic, frequently with the same search intermediary (Saracevic, Mokros, Su & Spink, 1991; Spink, 1993).
- Huang (1992) studied 44 end-users conducting online searches and found 19 end-users conducted successive searches.
- Robertson and Hancock-Beaulieu (1992) also identified successive searches by users of the OKAPI online catalog. They found a continuity of search topics and relevance judgments by the same users over successive searches as some users explored a topic over an extended period and interacted at intervals with the online catalog, using identical or closely related search strategies. This research highlights the need for longitudinal research at a problem-level of analysis as opposed to a single search level of analysis of searching behavior.
- A recent study of 200 academic CD-ROM and Online Public Access Catalog (OPAC) end-users by Spink (1996) shows that successive IR searches are a fundamental aspect of users' behavior when seeking information related to an information problem. End-users' working on a research project or paper were asked to estimate how many search sessions they had conducted on a particular information problem. Some 113 (56.5%) end-users reported conducting more than one IR search and 43 (21.5%) end-users reported five or more IR search sessions.
- Bateman (1998) investigated the search sessions over time conducted by 35 end-users and found that 33 (94%) end-users conducted more than one search session during their information seeking process related to a particular information problem. Table 3 shows the number of successive search sessions conducted by end-users during their information seeking process.

- A recent survey conducted by Spink, Bateman and Jansen (1998) found that EXCITE Web search engine users reported conducting successive search sessions over time related to a particular information problem.
- Spink, Greisdorf and Bateman (1998) studied 18 mediated online searches and identified the reasons, frequency and characteristics of successive mediated searches.

These studies show that users of IR systems and the Web, perform successive searches related to the same or evolving information problem over time. Spink & Greisdorf (1997a,b; Spink, Greisdorf & Bateman, 1998, in press) also found a relationship between partially relevance documents and changes in users' information-seeking processes. However, the nature of successive searches and related partially relevant documents during a user's longitudinal information search process, is in the early stages of development. This research has important implications for the design of effective IR systems to support effective user searching.

Successive search episodes then become units for observation and analysis. The modeling of users in successive searches is then successive user modeling. A key dimension is time, the key variable changes or shifts in successive search episodes over time, and the key constant is the same or evolving information problem. The evolution, if any, of a problem and other cognitive, affective and situational variables can be mapped, and the history of successive search episodes can be researched.

However, users' successive searching currently receives little, if any, support from present IR interfaces and procedures, or from Web search engines. IR systems generally follow a single search paradigm, i.e., they are designed and operate on the assumption that every search is an end in itself. Neither the commercial systems (such as Dialog or Lexis/Nexis), nor the TREC (Text Retrieval Conference) (Sparck Jones, 1995) experimental IR systems, nor the search engines on the Web, nor the 'intelligent' agents in knowledge base applications, address or support, successive searching. Research in this area is in its formative stage.

DISCUSSION

This paper presents work-in-progress. A three-dimensional model is being developed as a theoretical framework for conceptualizing and exploring interactive information retrieval (IR) with an information seeking context. The proposed model consists of a Plane of Judgment within a Plane of Interaction within a Plane of Time. The Plane of Judgment includes levels and regions of relevance judgments, and other user judgments during interactive IR, e.g., magnitude or strategy feedback, tactics, search strategies, or search terms. A Plane of Judgment exists within a Plane of Interaction. The Plane of Interaction

is represented by interactive IR models. The Plane of Interaction includes movement or shifts within interactions or search episodes, e.g., tactics, information problem, strategies, terms, feedback, goal states, or uncertainty. IR interactions that occur within a Plane of Interaction exist within a Plane of Time.

The Plane of Time consists of users' information seeking stages and successive searches over time related to the same or evolving information problem.

This research aims to develop of an integrated view of a user's interactive IR processes within their changing information-seeking context. The implication of this model is the potential ability to isolate a user's Plane of Judgment at a particular point in time based on an assessment of levels of relevance, regions of relevance, and time (information seeking stage and successive searches). This could lead to major implications for system design and design criteria. When a user's relevance judgments and search episodes are plotted on these three dimensions, the complex picture may be visually analyzed. This may be a useful and very practical method for users and researchers alike, particularly if the plotted searches can be automated and displayed to the user in a visual way.

This model could also be used to map the particular interests of relevance researchers, by locating each study on the three-dimensional model. We also suggest that most relevance research would probably cluster in the upper right relevant quadrant of the plane of judgment. The nature of relevance judgments during a users successive search process over an information seeking process, is an area for further discovery. There lies the future of relevance research.

The three-dimensional model is being developed to provide a framework for theoretical and empirical research to:

1. Explore shifts and changes in users' single or successive interactive IR episodes within their changing information-seeking contexts
2. Examine relevance judgments within IR interactions during users' information seeking processes
3. Broaden relevance research to include the concurrent exploration of relevance judgment level, region and time.
4. Integrate interactive information retrieval research within information-seeking research

The three-dimensional model has strengths and weaknesses. A key strength of the model is the focus on the big picture and the drawing together of major concepts - Judgment, Interaction and Time. Other concepts, such as feedback, representation, information problem, and situational context, may also be incorporated into the framework. The model's can also be used to integrate existing and future research and models from IR and information-seeking. A further strength is the framework provided for gathering, plotting and testing data from users. Strengths can also be weaknesses. The general framework of the model tends to focus on major dimensions and not specific differences in

information-seeking contexts. The model is also specifically related to the IR context, not information-seeking in general.

CONCLUSIONS & FURTHER RESEARCH

Research is currently being conducted to extend IR and information-seeking models by:

1. Exploring the shifts and changes in IR interactions during information seeking processes, including changes in uncertainty, relevance judgments and information problems.
2. Gathering and plotting user relevance judgment data, and other user judgment data, on the three-dimensional model for analysis.

This research includes two related projects (Spink, Wilson, Ellis & Ford, 1998). The first project is based in the School of Library and Information Sciences at the University of North Texas and is funded by a National Science Foundation POWRE Grant <http://www.nsf.gov/cgi-bin/show?award=9753277>. The second project focusing on uncertainty is based at the Department of Information Studies at the University of Sheffield (UK) and is funded by a grant from the British Library Research and Innovation Center.

The broad objectives of each project are to examine the nature and extent of successive search episodes in digital environments by real users over time. The project is seeking to: characterize progressive changes and shifts that occur in: user situational context; user information problem; uncertainty reduction; user cognitive styles; cognitive and affective states of the user, and consequently in their queries and characterize related changes over time in the type and use of information resources and search strategies particularly related to given capabilities of IR systems, and IR search engines, and examine changes in users' relevance judgments and criteria, and characterize their differences. Findings from this study, and additional studies currently being undertaken at the University of North Texas, will be used to extend the three-dimensional model.

ACKNOWLEDGMENT

This paper resulted from studies funded by a University of North Texas Research Initiation Grant 1993-94, UNT/SLIS Research Grant 1997-98, and a National Science Foundation POWRE Grant 1998-99. The author also acknowledges the valuable comments by Tefko Saracevic of Rutgers University, and Howard Greisdorf and Judy Bateman of the University of North Texas during the development of this research.

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